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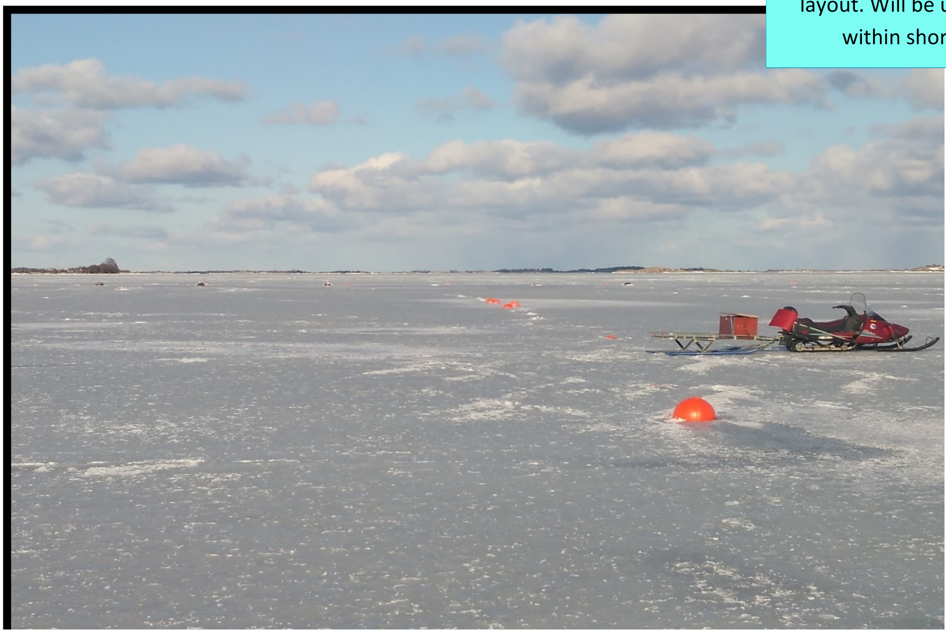

Results from Baltic Blue Growth project's mussel farms and way forward for mussel farming in the Baltic Sea

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Executive summary

The aim of this project has been to demonstrate good practice and provide guidelines on how to start up a Baltic mussel industry. The method here was to study 6 different sites in the Baltic Sea with project farms: The Musholm farm in the Great Belt (Musholm), Kieler Meersfarm in the Kiel bay (Kiel), a pilot farm belonging to Latvian institute of Aquatic Ecology outside Pavilosta coast (Pavilosta), a farm rent by Kalmar municipality in the Kalmar Sound (Byxelkrok), the East Sweden Aquaculture centre farm in St. Anna archipelago (St. Anna) and an associated farm established by Vormsi Agar OÜ outside Vormsi island (Vormsi). This report describes the activities and observations documented by our farm managers in the so-called "Mussel farmers Log" during a 2.5-year period. Farming and harvest techniques and results, no. of work hours and boat hours, technical problems, impact of ice and other site-specific conditions, conflicts with neighbors, fate of the mussels, predators and other observations are reported. We also describe the different technical setups of the farms, and impact of the environmental conditions that characterize each of our chosen mussel farm sites. We have analyzed the results in terms of harvest outcomes, differences in work effort spent on similar operations, investment costs and operational costs. Based on the limited number of farms we cannot conclude if one farm system is more efficient than the other, but it seems that anchoring, flexibility of the materials, buoys and logistics is very important, while specific substrates and mesh sizes are not key factors in the production of small mussels. At exposed sites, stronger (and thus more expensive) farm constructions and work-vessels were needed. Too strong current and wave-impact, as well as predators, had very negative effects on the production costs. The most successful sites for mussel farming in this project were found in the fjords in western Baltic and in archipelagos of the Baltic proper.

Methods

Over a period of 27 months, from May 2016 to Sept 2018 we have been collecting information from the project farms about:

- Status of the production system
- Occurrence of predators (Eider ducks, other birds, starfish…)
- Quality/quantity of mussels (size, meat content, biomass)
- Interactions with other users of the marine area/conflicts/complaints and solutions
- Test with different types of substrate
- Test of predator control
- Test of submerging production units

The methods used in the project to collect the combined summarized results have been:

- Data collection with a regular report called the "Mussel farmers Log" from the Musholm, Kiel, Kalmar Sound and St. Anna farms
- Regular Skype-meetings with the work team
- A study comparing results on recruitment, growth and biomass production from some standardized substrates (Smartfarm nets, trawl-nets, fuzzy ropes and Swedish bands) from the project farms

Results and conclusions were reviewed and commented by mussel farm experts John Bonardelli, Mads van Deurs and Jens Kjerulf Pedersen on a dialogue meeting with the mussel farm managers in Borgholm, Sweden 3-4 Oct 2018. Minutes from this meeting is referred to as “expert’s comments”.

The Operation Desicion System tool http://www.sea.ee/bbg-odss has been used to extract environmental and oceanographic information about the different farm-sites discussed in this report. In addition, interviews with the mussel farmers/farm managers Mats Emilsson, Tim Staufenberger, Per and Katrin Persson, Torben Wallach and Urmas Pau have been done to get more information related to investment costs, work-vessels, fuel costs, work methods, work hours needed for maintenance of the farms and harvest results. Due to great loss of mussels at two of the original farm sites, Byxelkrok and Mushom, we have added some data from mussel harvests in other projects from 3 nearby farm-sites in the Great Belt and Kalmar Sound. The Baltic Blue Growth project is henceforth referred to as “BBG”.

The project farms

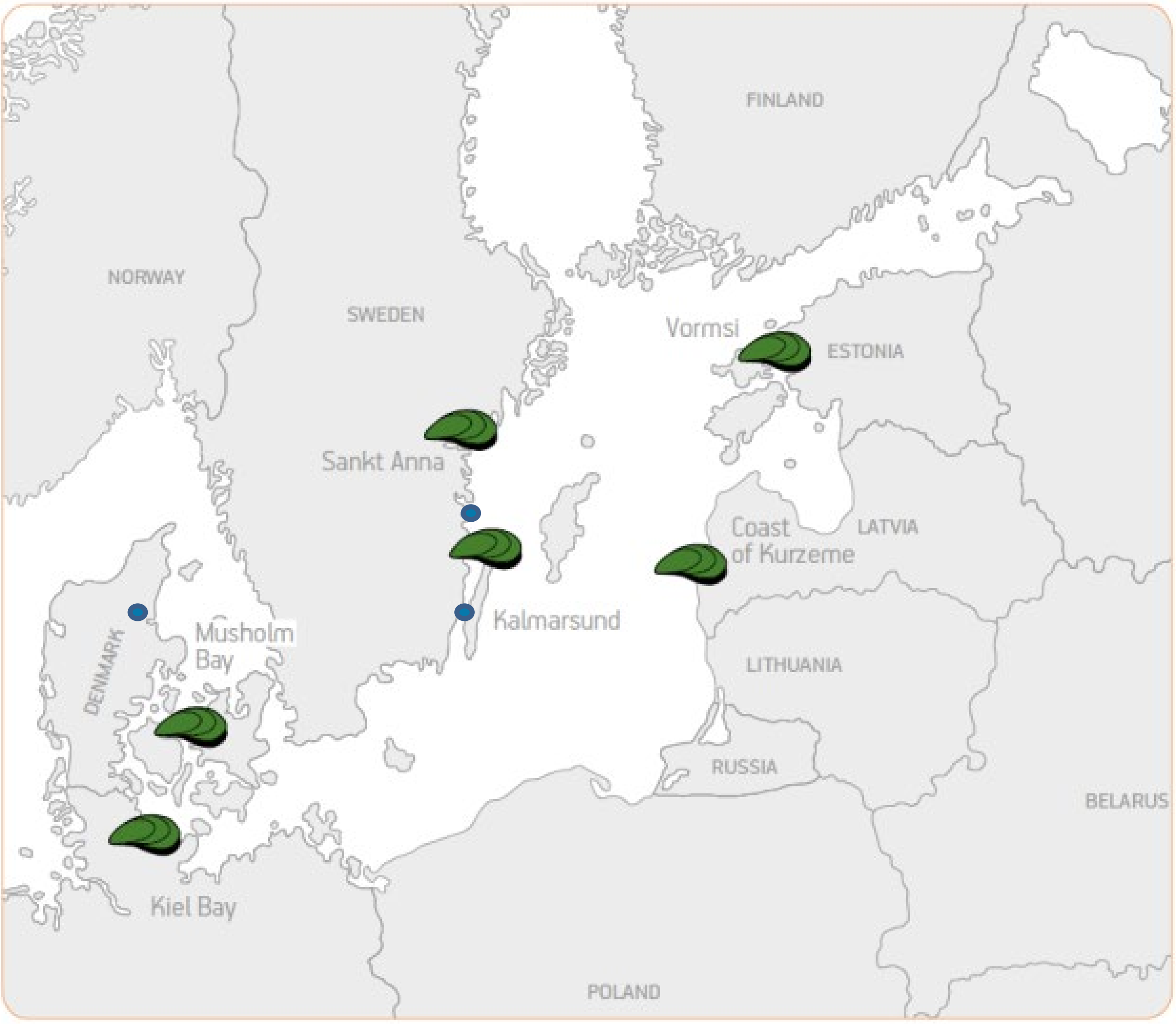


Figure 1. Farm-sites used in the project. Green mussels mark the farm sites for the project farms, from which most information summarized in this report origin. Blue dots mark the farm sites from which Musholm and Kalmar added some data gained from the parallell projects Blue Biomass and Nutritrade.

Original farm-sites, location	Size of farm	Mussels harvested	Estimated growth rate
Sankt Anna archipelago, Sweden (16.836,58.384)	Long line, 16*150 m lines. Total substrate length 24,000 m New Zeeland fuzzy rope Surface area 4 ha. Growth depth 1-10 m	79 tons from 16 units after 19-26 months. 24 000 m substrate. 3.3 kg/m	1-3 cm within 14 months

Byxelkrok, Sweden (57.303, 16.960)	Shelltech net 10*120m units, mesh size 200mm Total substrate 3600 m^2, 40000 m rope Surface area 1.2 ha Growth depth 3-6 m	n/a	O.5-1.5 cm in 1 year 1,5-3 cm in 2 years
Musholm, Denmark (55.475, 11.090)	Rope net 18-10*120m units mesh size 300 mm Total substrate 4200 m2 49000 m rope Surface area 8,2 ha Growth depth 0-3 m	13 tons from 4 units after 12 months. 1440 m^2 substrate, 9492 m rope	Around 2.5 cm within 1 year
Kiel Bay, Germany (10.420,54.552)	Longline, 3*100 m lines. Total substrate 1500 m fuzzy rope. Surface area 0,21 ha Growth depth 0,5-3 m	5[1] tons from 3 units after 11 months. 1500m substrate rope . 3.3 kg/m	Up to 10 cm in 12-14 months 3.3 kg per meter/year
Pavilosta Coast, Latvia (20.857,56.902)	5 parallel single submerged longlines, total substrate length 625 m sizal rope Growth depth 5-7 m	n/a	0.5 – 1.5 cm in one year 1-2 cm in two years

Table 1.The originally established BBG farms. Please note that several of the farms were altered or partially moved during the project. Work hours reported for "preparation and installation of farm units" refer to units that have been prepared during the BBG-project.

Associated farms and additional farm-sites, location	**Size of farm**	**Mussels harvested**	**Estimated growth rate**
Vormsi island, Estonia (23.032,59.057)	126 m unit with net-strings Growth depth 0-3,5 m	n/a	1-3 cm within 14 months
Västervik farm, Sweden (57.845, 16.757)	Double-knitted trawl net 2 units 120*4 m mesh size 150 mm Total substrate 960 m2 Growth depth 0-4 m	21 tons from 4 units 1920[2] m^2, or 25270m substrate	O.5-1.5 cm in 1 year 1-3 cm in 2 years
Hagby farm Sweden (56.560, 16.258)	Rope net 4 units 115*3,15 m Different mesh sizes Total substrate 1380 m2 Growth depth 1,5-5m	9 tons from 1449 m2, or 20459 m rope	O.5-1 cm in 1 year 1-3 cm in 2 years

[1] Weight estimated by Orbicon, as the harvest was discarded

[2] The same farm was harvested twice, in April 2016 and April 2018

Grankullavik Sweden (57.353, 17.105)	Winter harbour 2016/2017 for the 10 units from Byxelkrok/Kalmar Sound farm	n/a	
Kalundborg, Musholm farm (11.035,55.497)	6 net units, 90*3m different mesh sizes 1620 m2	n/a	Around 2.5 cm within 1 year
Limfjorden, Musholm farm towed in Sep 2018 from the Great Belt	18 “old” Smartfarm units towed from the Musholm farm during 2016	360 ton from 18 units, 5400 m2	

Table 2: Other farm-sites that have contributed data to the project. Either because the project-farms were moved/expanded to those sites, or because more farms were included in the network during the project.

Description of the farms, including a summary from mussel farmers’ logs

Musholm farm

Figure 2. The Musholm farm is launched close to a fish farm in the Great Belt for the catchment of nutrients from the farm.

The conditions for farming at the site of the Musholm fish farm are tough, with generally strong currents, shifting salinity and rough weather. The special interest for the Musholm farm is to maximize nutrient uptake to compensate for the nutrient discharge from their fish farm. Since it is more efficient to harvest the mussels at a smaller size when the aim is to gain a high biomass in a short time, the interest is also to grow small and thin-shelled mussels to be used in animal feed. The main (and original) farm site was situated at the fish farm. But during the course of the project, part of the farm units were moved around between 3 different farm-sites (listed in Table 1 and 2).

Originally the farm consisted of 18 rope-net units. These had grown out mussels already from start, and in May 2016, 4 of the units were harvested. In June 2016-Sep 2016, the farm consisted of 10 rope-net units each 120 m. Most of these were eventually moved to another project in Limfjorden, but within BBG, new test units equipped with substrate of different mesh sizes were used in an experiment to maximize the biomass production. The Musholm company together with Orbicon tested mesh sizes 50 mm, 80 mm and 150 mm and compared them to SmartFarm rope nets with mesh size 300*300. They also developed a system with stronger tubes to withstand the weather conditions in the Great Belt. Four such stronger tubes were launched at Musholm in April 2017. The mussel farm has been heavily predated by eider ducks who consumed 90 % of the mussels in 2017. Trials with drones, laser and a scare sound system were carried out, but these were not successful, so no permanent means to scare off the eider ducks were implemented in the project. Therefore it was decided in Sept 2017 to move the 4 extra strong units plus 2* 120 m Smartfarm units to Isefjorden, close to Kalundborg Port around 25 km north of Musholm. The move was done in Oct 2017, but the test units for the ongoing Musholm production test was left at the original farm-site at Musholm for the rest of 2017 until the test was finished. Based on the results from these tests, in May 10 new units of 100 m each were prepared and launched outside Musholm, again at the original site in the Great Belt. The new units are reinforced with thicker PP-pipes to better withstand the tough conditions of the Great Belt and have trawl-net as growth substrate. These units stayed in the Great Belt until September close to the fish farm for nutrient uptake and were then towed to the Limfjord for outgrowth, as part of the parallel project Blue Biomass. This seemed to work out very well.

Summary of observations and actions from the mussel farmers logs at Musholm/Kalundborg

2016	management	environmental	technical	biological
May	Harvest of 12,5 ton from 4 old 120 m Smartfarm units at Musholm		Test-units launched with nets of different mesh sizes	
June	Test nets placed inside empty fish-cage to protect from eiders ducks	Fair weather	10 Smartfarm units at the site	No biofouling
July				Mussel settled in red algae
Aug			Laser-device approaved	No starfish problem
Sept	Test of eider-laser Low impact	Eiders arrived	Laser-device up	5 mm mussels
Oct	Farm repaired. Most Smartfarm units moved to Limfjord.		One PP-pipe broken. Test units left at Musholm incl. 2 Smartfarm units	
Nov				500 eiders observed since Sept
Dec		Eiders are leaving		Mussels still very small

2017	management	environmental	technical	biological
Feb	The laser-device had low impact on eider ducks	Mussels out in the open are all very small	Laser trial evaluated	3,5 cm mussels and significanly more biomass inside the fish-cage
March		Eider ducks arrived		
April	Four additional 90 m pipes with extra strong PP-pipes and trawl net established at Musholm.		New test substrates deployed Farm consists of 6 full lenght units in total incl. 2 ”old” Smartfarm units	
June		Substrates covered in red macroalgae		Settling of mussels in the algae
July	Low impact	Eider ducks	A drone was tested as a predator control device	Mussels attached to the nets
Aug	Test to scare of eider duck with different sounds	Eider ducks	Visit by Mortalin sound system company	
Sept			Sound system not efficient	90% mussels lost
Oct	The 4 extra strong pipes + 2 Smartfarm units were towed to Kalundborg Fjord	No predation No conflicts	Ongoing production experiment 2017 with test nets continued at the Musholm site	Biomass lost when towing units
2018	**management**	**environmental**	**technical**	**biological**
March	6 tubes in Kalundborg Fjord.	No substrates left at original Musholm site	Test-tubes at Musholm got new nets with different mesh-sizes	
April		No predators in Kalundborg	Preparation of 10 new units at Musholm	
May	6 tubes in Kalundborg Fjord.	Mussel larvae observed in water	10 new 100 m extra strong units launched at original Musholm site	Sparce settling
Sep	6 tubes in Kalundborg Fjord		The 10 new units were moved from Musholm to Limfjord for outgrowth	

Full log-book can be acquired by request from the author of this report. For further details, please contact the Musholm fish farm (tv@musholm.com). For more information about the predator mitigation tests at Musholm, see the report ”Predators on mussel farms in the Baltic Sea – observations and experience from eider mitigation tool testing”[3] published on the project website https://www.submariner-network.eu/projects/balticbluegrowth

Kiel farm

Figure 3. Kieler Meeresfarm is placed in a densly populated area. Left: Photo by R. Lemke.

The Kiel farm is operated by the private company Kieler Meeresfarm, which is already running a small-scale commercial mussel cultivation in the Kiel Bay, selling its mussels to locals and restaurants for human consumption. During spring 2017 Kieler Meeresfarm has contracted operators for the Schleswig-Holstein Ministry of Energy, Agriculture, Environment and Rural Areas, that has deployed three new 100 m longlines within the approved farm area, each with 150 units of fuzzy rope substrate. The project mussel farming units at Kiel Bay were finalized in May 2017. In addition, test substrates consisting of trawl net mesh sizes 50 mm and 100 mm and Swedish bands were launched. Since then, the farm has not encountered any problems. In spring 2018, approximately 5 ton of small blue mussels were harvested, but most of the mussels were discarded since they were not needed for the project activities. All data, including environmental monitoring has been sent to the responsible project partners for further analysis. Mussel meat content was estimated visually in the field.

[3] Lyngsgaard M, Schriver A, Dolmer P, Lejbach A, and Wallach, T. 2019

Summary of observations and actions from the mussel farmers logs at Kiel

2017	**management**	**environmental**	**technical**	**biological**
Feb		2000 eider ducks	No ropes in water yet	
May		No eider ducks	3 longlines with fuzzy substrate rope and test substrates are launched	
Jun	Put out buoys to compensate for gain in biomass	Starfish present, but not on production units		Spat fall was little but sufficient
Jul	More buoys			Mussels started growing
Sept	Frequent adjustments of floating capacity	No eider ducks		Fast growth of mussels
Oct	Resque not successful Bad work conditions	Strong wind	Storm damage 1 line is sinking 1 line ripped out of anchoring	3 cm mussels containing up to 90 % meat.
Nov	Drifting line resqued Bad work conditions	Strong wind	All 3 lines sunken below surface	4 cm and containing up to 80 % meat
Dec	Managed to get the test lines up again	Strong wind 5 eider ducks		5 cm mussels containing up to 75 % meat.
2018	**management**	**environmental**	**technical**	**biological**
Jan	No immediate danger for the farm	Light drift ice 8 eider ducks		
Feb	Harvest method modified at the commercial farm	11 eider ducks	Mussels die at contact with ice-cold steel sorting machine	6 cm mussels containing up to 75 % meat.
Mar				7 cm mussels containing 70 % meat
Apr	Lines lowered to the bottoms for sea-stars to clean	15 eider ducks		Biomass estimated to 5 ton on 3 lines

May	Substrate ropes were taken up, cleaned, then back again	Nice weather Eider ducks left		Spawning started in mid-May
Jun	Working well	Very warm weather	All lines in surface	Low larval numbers, slow mussel growth
Jul		Water temperature up to 23 °C		2nd spatfall occurred. Low larval numbers
Aug		Water temperature up to 23 °C		Lines completely covered with spat, size of up to 8 mm
Sep		Water temperature dropped to 18 °C	All lines in surface	No spawning could be seen. Loss of large mussels probably due to warm temperatures. Small mussels stayed

Full log-book can be acquired by request from the author of this report. For further details, please contact Kieler Meeresfarm (info@Kieler-Meeresfarm.de).

St. Anna farm

Figure 4. The Sankt Anna mussel farm is the first full-scale farm with a long-line system on the Swedish East Coast. It is located in the sheltered archipelago of Östergötland, just east of the island Inre Kärrö.

This area in the middle archipelago of St. Anna was chosen based on physical, chemical and social conditions. It is part of a protected natural area and is therefore not affected by conflicts over land/water-ownership. The site has sufficient depth (~20 m), salinity and acceptable current and wind conditions. In addition, the area is not normally affected by ice movements during freezing or spring break-up. The farm was launched in the spring of 2016. The farm uses submerged long-line technology, 16 long-lines kept with 350 buoys and with 24 000 m Christmas tree seed collector ropes as substrate. Ropes that the mussels grow on go from 1.5-10 m depth. So far, the farm technology has worked fine. The mussels are allowed to grow out to full size on the collector ropes, no socking is planned. During the first summer it seemed like the settling of mussels had suffered some competition from cockles *Cerastoderma* sp, but the *Cerastoderma* sp. eventually fell off the ropes and after the first year the mussels totally dominated the biomass on the ropes. Submerging of the longlines for winters 2016/2017 and 2017/2018 was considered but not performed. The first winter had only very little ice, but during the second winter there was a thick and long-standing ice-cover over the farm from Jan-Apr. The farm did not suffer from ice damage, presumably due to the high tension of the long lines (Emilsson pers. comm). So far, the production on the farm has been very successful and it produced more than double the expected yield in mussel biomass. It was harvested in Dec 2017, May 2018 and Sep 2018, with the highest biomass measured in May 2018 after a 2 year growth period.

Summary of observations and actions from the mussel farmers logs at St. Anna

2016	**management**	**environmental**	**technical**	**biological**
June	Whole system launched	No eider ducks		Settling started in mid June
Aug	Regular control of the ropes	Heavy biofouling by cockles	No conflict with tourism and fishing	Mussels settled
Sept		The withefish *Coregonus lavaretus* could be a problem		
Oct				Mussel size 1-5 mm
Dec	Buoys are sinked down half under the surface	No predators	Preparing for ice	
2017	**management**	**environmental**	**technical**	**biological**
Jan		2 storms No ice	A few buoys came loose	
April			Farm survived winter	
May			Test fuzzy ropes from Kiel has been launched	

Jun	Adjustment of flotation to approx 500 buoys	No predators	Some floats came loose	Mussels biomass has increased notably
Dec	2 persons working 5h/day for 4 days		Barge taken up for winter	15.5 ton harvested from 3.5 longline
2018	**management**	**environmental**	**technical**	**biological**
March		12 cm ice-cover		Ice-cover at the farm is 12 cm.
April		Ice broke up in NW wind, 15-20 m/s	Not too much damage to the farm	
May	3 persons working 8h/day for 7 days			50.5 tons of harvested from 10 lines
Jun			Test with SLU	Harvested 360 kg from approx. 100 m substate.
Jul		Water temp. up to 25 ^{o}C		
Aug		Mussels died from high temperature?	We could observe that mussels had begun to fall off the ropes	empty shells seen among the mussels
Sep	3 persons working 6h/day for 2 days.		Lower biomass now than in the spring	Harvested 12.5 ton from 3 long-lines

Full log-book can be acquired by request from the author of this report. For further details, please contact the St. Anna mussel farm manager (emilsson.mats@telia.com).

Byxelkrok and other mussel farms in Kalmar Sound

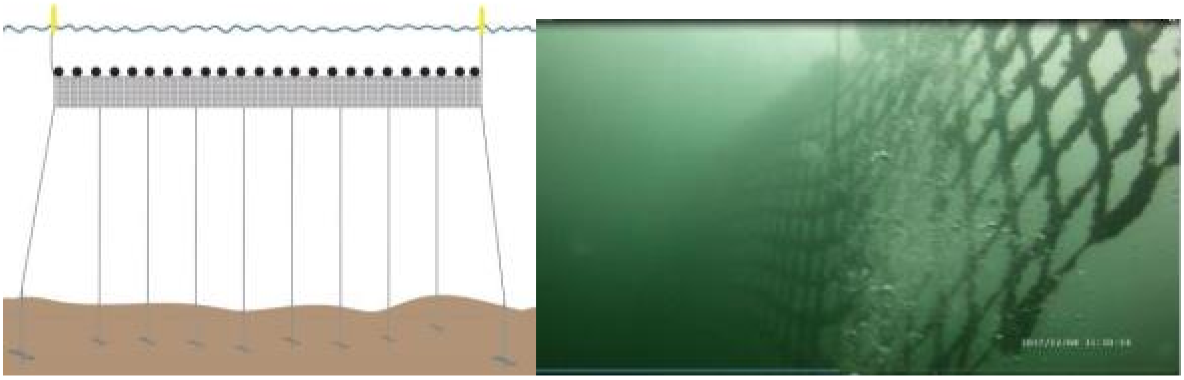


Figure 5. Design of the Byxelkrok farm

In Kalmar Sound there has been data collected for the project from 3 different sites, as summarized in Table 1 and 2. Byxelkrok in northern Öland Island was the main (and original) farm-site, at which activities were reported in the Mussel farmers Log, Here, a new design of mussel farm by the label Shelltech Offshore was tested for the first time in exposed conditions. This offshore farm-site was also where the experimental nets were set up for the production study described in the report "Recruitment, growth and production of blue mussels in the Baltic Sea"[4] published on the project website https://www.submariner-network.eu/projects/balticbluegrowth. The farm, a net farm made up of 10 units of 120 m*3 m rope nets (200mm mesh), was designed to be permanently submerged at 3-6 m depth, with no units at the surface. It was launched outside the village of Byxelkrok in June 2016. However, due to failure to set all drill anchors needed to install the farm correctly during the first summer in 2016, it was moved to a more sheltered site in the Grankulla bay during autumn 2016.

The next summer (2017), setting of the drill-anchors required to install the farm correctly continued, but in the end, only 3 of the 10 net units could be moved back to the intended farm-site. A big problem was the limited number of days that it was possible to perform the anchor drilling. This was due to a bobbing work vessel in combination with the exposed weather conditions at the site. The 3 units were then submerged, but despite the submerging to 1,5-3 m depth, they did not survive the winter 2017/2018 in a good condition. One of the nets was completely ripped off. In later evaluation a mussel farm expert commented that as the fixed anchoring did not allow the farm units to follow the waves. It should have been a rigid net attached to something stretchy, but instead it was the other way around. So the farm system had been working against the natures forces instead of with it. Also, the units should have been placed with at least 24 m in between them (1.5 times the depth) instead of 10 m to avoid collision. The farm was designed to be submerged and the buoys were not ice safe. Because it had unintendedly stayed

[4] Lyngsgaard M, Dolmer P, Kotta J, Rätsep M, Peterson A, Krost, P. 2019.

afloat during the first winter, there was a massive loss of buoys. For more information about the submerged Byxelkrok farm, technical details and work practice is described in a separate report[5].

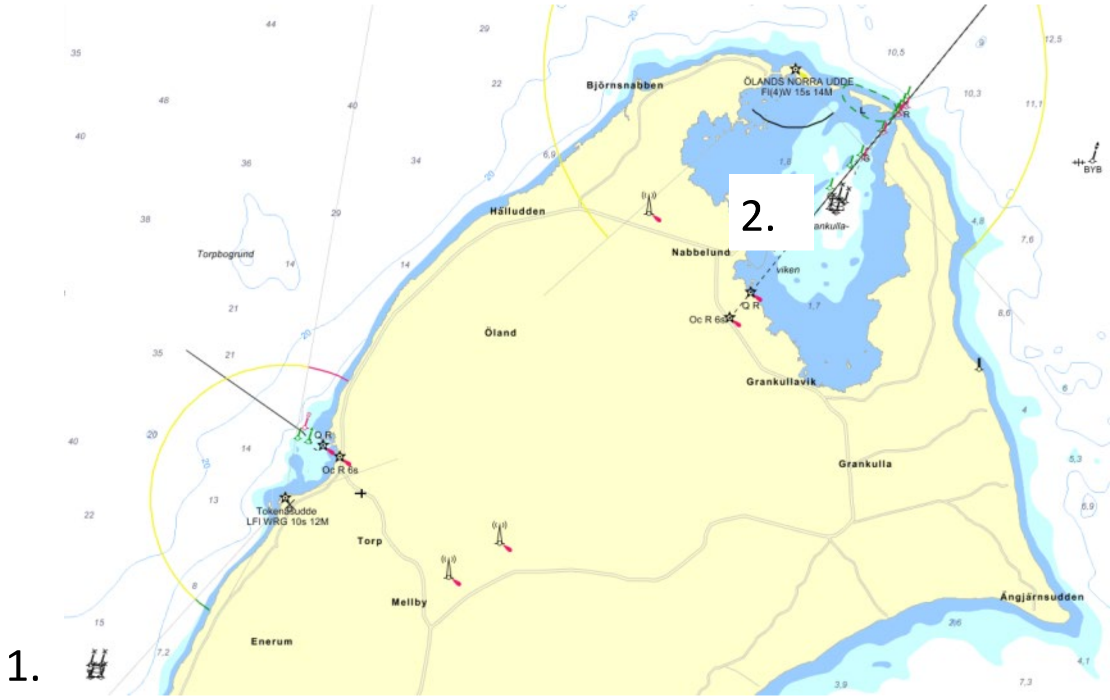


Figure 6. Map of the Byxelkrok farm-area, showing the move from the original offshore site (1) to an alternative farm-site within the sheltered Grankulla bay (2). The purpose of this move was to protect the farm-units from damage during winter 2016/2017.

Summary of observations and actions from the mussel farmers logs at Byxelkrok

2016	management	environmental	technical	biological
Apr	Not possible to start anchor drilling		Anchors delayed due to harbour strike	
Jun	10 farm units launched 1 km off the coast Anchor-drilling started		Not possible to submerge the farm units because the drill anchors are not in place	
Jul	20 out of 110 drill-anchors were set		Farm units still have just temporal anchors Not possible to submerge the farm	Very good settling

[5] Technical evaluation of submerged mussel farms in the Baltic Sea. 2019. Published on the project website https://www.submariner-network.eu/projects/balticbluegrowth.

Aug	All 10 units were towed to Grankulla bay for shelter	Storm 3-5 m waves	Mechanical damage Some units thrown over each other	Big loss of mussels
2017	**management**	**environmental**	**technical**	**biological**
Jan		Ice cover	Farm still in surface Cement anchors	
Feb		Very high water levels		
Mar	Grankulla: Inspection. All 10 units had survived winter		Offshore site: 2 navigation aids lost	Grankulla: 0,5-1 cm mussels growing at net crossings and around the weights. Offshore: Anchor ropes covered in 0,5-1 cm mussels
Apr			Offshore: Lost navigation aids were replaced	.
May	Byxelkrok: Information meeting. Boat, drilling rig and other equipment shown for neighbours		Offshore: Test nets for the production-study were launched	
Jun	Offshore: Anchor drilling resumed.			
Aug	Offshore: Anchor drilling finished after 27 anchors set (3 lines)	Grankulla: Biofouling by cockles, barnacles green and red algae	Net units still left in sheltered Grankulla bay	2 major size classes, 2+ and 1.5 cm mussels observed.
Sep	Offshore: 3 nets towed back to original site and submerged		Grankulla: 7 nets left	
Nov	Offshore: Dive inspection. Oceanographic instrument installed. Test nets sampled		Grankulla: > 330 floats lost from un-submerged units	Offshore: Test nets had 100% coverage of 5 mm mussels

Dec		Grankulla: Ice cover Offshore: Open water		
2018	**management**	**environmental**	**technical**	**biological**
March	Offshore: Dive inspection	No eider ducks	Offshore: Severe mechanical damage. 1 net completely ripped off	Mussel coverage 15 %
March	Grankulla: Dive inspection	Grankulla: Storm. Ice broke up	Grankulla: Nets severely entagled, adrift	Grankulla: Big swarm of eiders . Almost 100 % of mussels lost
Jul	Grankulla: 7 units l were taken up on land		Offshore: 3 submerged units remain	
Aug	Offshore: Oceanographic instrument was taken up		3 offshore units remain in bad condition	Settling from 2018 on units
Oct	Fuzzy ropes were taken up		3 offshore units remain in bad condition	Plenty of small mussels on the units

Full log-book can be acquired by request from the author of this report.

Associated mussel farms in Kalmar Sound

Figure 7. Associated farms in the Kalmar sound area. Left: The Västervik trawl net farm is sited in the archipelago area north of the sound. Right: The Hagby farm is sited a bit south from the middle of Kalmar sound. It is a Smartfarm from 2010 that was repaired in 2014. In 2016 its initial PP-pipes were replaced by ice-safe buoys.

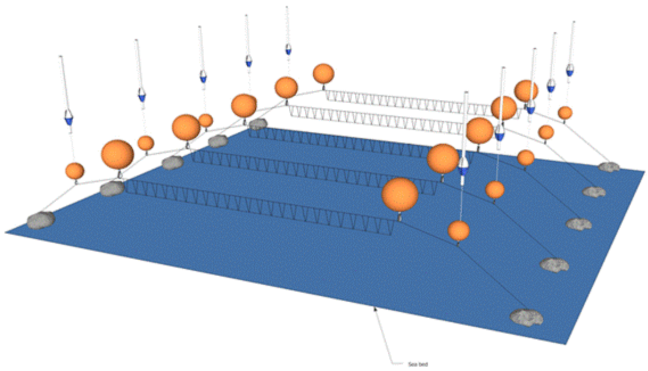
The other 2 mussel farms in Kalmar sound from which data has been collected to this report were two smaller pilot farms belonging to Kalmar and Västervik municipality. For technical details, see Table 2. This was done in order to get a better picture of farm conditions and production costs in the Kalmar Sound area.

The Hagby farm in the middle-south Kalmar sound was used to measure of the environmental effects of a mussel farms to its surroundings. This farm has been in the water since 2014, was bought by Kalmar municipality in 2016 and had fully grown mussels already from start of the BBG-project. Results from this environmental monitoring can be found in the report "Ecological impacts at the small-scale commercial mussel farms in the Baltic Sea"[6] at https://www.submariner-network.eu/projects/balticbluegrowth. The Hagby farm was submerged during the project. The PP-pipes used for flotation were removed and replaced by ice-safe buoys, keeping it submerged from 1.5-5 m depth. In 2018 the Hagby farm was harvested. Workhours and results were reported to BBG.

The Västervik mussel farm just north of Kalmar Sound was first involved in BBG in 2016 to harvest mussels for the manufacture of mussel meal. In 2018 it was harvested again, workhours and results reported to the project. This latter farm-site is protected from direct exposure from open sea, but has good water exchange and current.

Pavilosta farm

The Pavilosta mussel farm is another new design of musselfarms constructed by company AK Idarbi, built for scientific demonstration purpose and intended for very exposed offshore conditions at the Latvian Baltic Sea coast. It is located at ~20m depth, approx. 7.3 km from Pavilosta port, where the best results were obtained in pilot studies. The original farm was set up in summer 2017, consisting of 5 parallel single longlines. In order to protect it from the large waves at this site, the farm was submerged 5-7 metres deep.



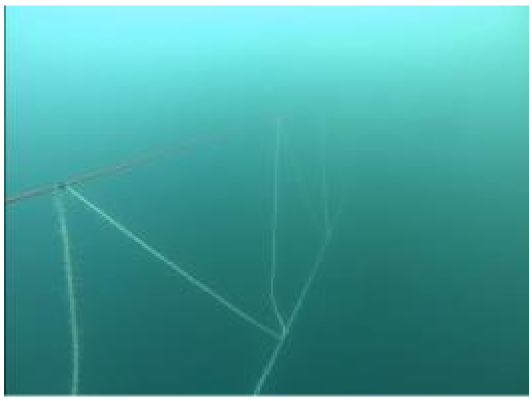


Figure 8. Design of the first Pavilosta farm.

When the 2017 season began for the preparation of the material, there were delays in equipment, and the environmental conditions were not favorable for installing the lines. The submerged mussel farm was successfully installed in May 2017 with the help of divers. The recruitment and growth of juvenile mussels on the collector ropes was successful, but the harsh autumn-winter storms in 2017/2018 caused significant damage of submerged longlines and collector ropes. The conclusion was that submerging the farm to 5 m depth was not enough to protect it from the waves and the very hard conditions at the

[6] Aigars J, Skudra M, Kalniņa M, Jurgensone I, Labuce A, Süßle P. 2019

Southern open Baltic Sea coast. It also appeared as if the large navigation aid buoy had been used by fishermen to fish by. This greater fishing activity around the site may have contributed to the damage incurred on the longlines

In May-June 2018 an improved construction of submerged longlines was successfully installed. This time it was submerged to 10m depth to avoid further damage. In August 2018, shellfish-solutions expert John Bonardelli evaluated the farm together with responsible BBG project partners. For more information about the Pavilosta farm, its construction, methods tried and the technology used, se report "Technical evaluation of submerged mussel farms in the Baltic Sea"[7] at https://www.submariner-network.eu/projects/balticbluegrowth. As the Pavilosta farm was more for research than production purposes, work hours and activities have not been reported in detail.

Summary of observations and actions at the Pavilosta farm

2017	**management**	**environmental**	**technical**	**biological**
Apr	Start of the growht and recruitment experiment		Pieces of fuzzy rope are attached at 2 and 5 m	
May			Farm installed at sea	No predators exept round goby
Jun	Farm construction improved	Bad weather	No sampling possible	Submerged long-lines covered with settling organic material
Jul	Dive inspection	Boat owners surprised by the new radar signals and buoy	Sampling	Recruitment on average 12 g ww/m of rope, 22 000 ind. per m of rope.
Aug	Sufficient weights needed to prevent ropes from wind-up		Lose rope ends are winded up the main ropes	Biofouling of the ropes, on average 3 g ww/m
Dec			Damage on the farm reported by local fishermen	
2018	**management**	**environmental**	**technical**	**biological**

[7] Mussel farming offshore – Technical evaluation of mussel farm located in Latvia and recommendation on best practice. Bonardelli J, Kokaine L, Ozolina Z, Aigars J, Purina I. 2018

Jan	Seems on the sonar that the UW-parts are still in place		All overwater parts are gone	
May-June	New installation, on greater depth than before		Improved construction of submerged longlines	No predators observed at any time except round goby

For further details, please contact the Pavilosta mussel farm manager (ingrida.purina@lhei.lv).

Vormsi

Figure 9. The Vormsi farm. For further details, please contact the Est-Agar company (urmas@estagar.ee).

This associated farm was established in May 2015 by the company Vormsi Arendus OÜ which is today owner of the Est-Agar AS algae factory. The enterprise's main business is the collection, processing and sale of red seaweed *Furcellaria lumbricalis.* The site outside Vormsi Island is visable from the coast, usually without ice and somewhat protected inside the archipelago. Depth is 9-10 m. We have not been collecting info on work hours, cost, vessels, or methods from Vormsi farm for this project, but a lot of biological and oceanographic data was collected instead. The original farm, designed by Nordshell A/S was made up by in total 126 m coils of trawl net (made from 45 mm mesh) hanging down to 3.5 m depth from single 50 m longlines. In summer 2016 the mussels measured up to 20 mm. In autumn 2016 the farm suspiciously lost all its buoys at the same time and the line had sunken and had to be recovered from the sea-bottom. The buoys, that were presumed stolen, were replaced again. Later, weights of 500 grams were put on top of each rope to submerge the farm, and all main buoys were removed to reduce curiosity by other persons. In 2017 it was upscaled to more lines with various substrates, net and fuzzy ropes. Maintenance is run by 1 person, visiting the farm once per 1.5 months. So far, the owners only got permission for research. For bigger production, they will need permission from all the involved administrations. The farm is located near shipping lanes, and the sea belongs to government.

Results and discussion

Technical comparison of the farms

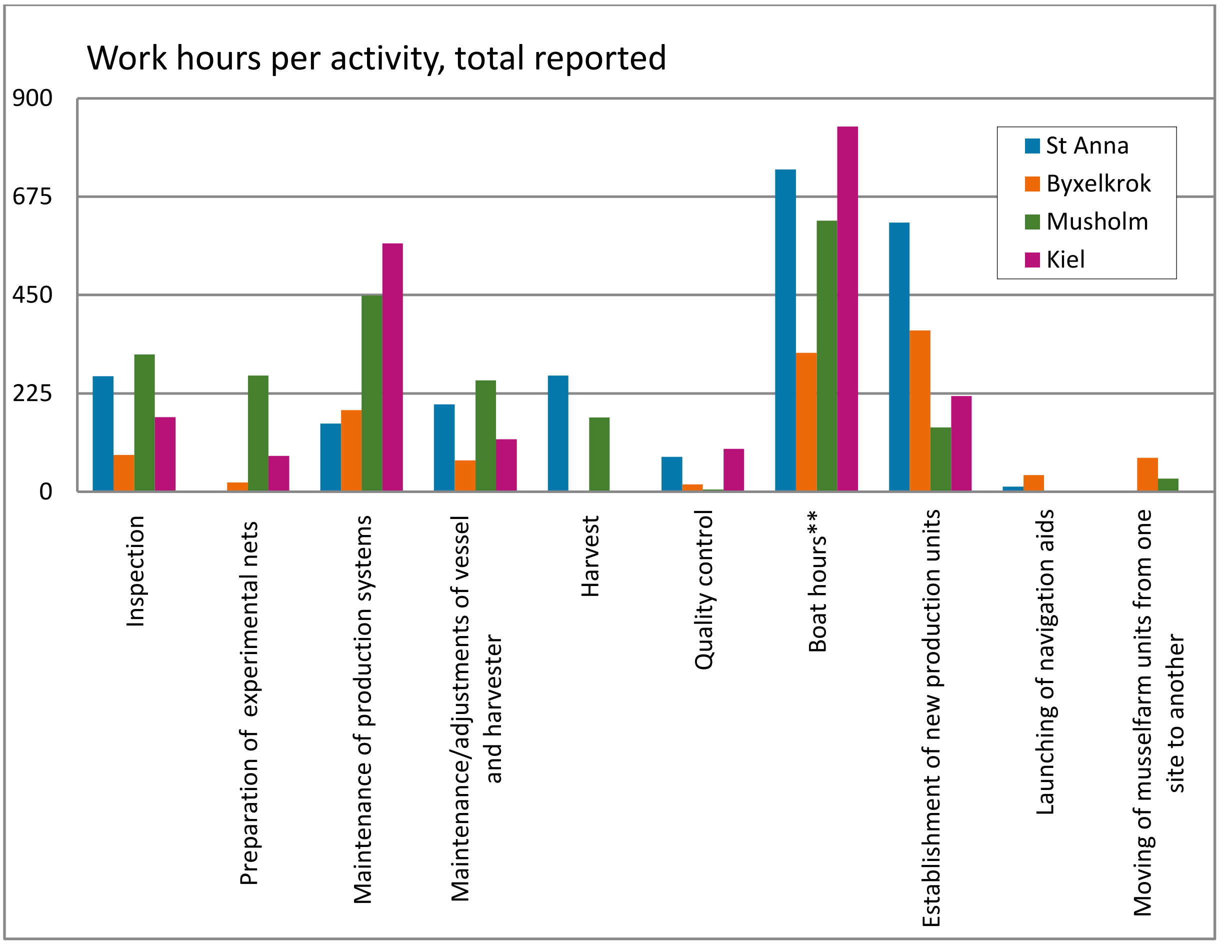


Figure 10. Summary of the workhours reported in musselfarmers logs, period from May 2016 to Sep 2018. The hours have been reported by Mats Emilsson, Hans Johnsson, Torben Wallach and Tim Staufenberger. In total, more than 5000 workhours were reported in this project. **Boat hours is a measure of fuel cost, logging the time worked from boats including the travel to and from a mussel farm-site.

In the above diagram, the reports from Musholm, Kiel, Byxelkrok and St. Anna has been summarized to show an overview of the work hours (no. persons*h) used for different activities at the mussel farms. Only hours spent on hands-on work and inspection of the farms were noted. Work hours spent by the farm-managers for other tasks such as administration, meetings or research have not been included here. The above diagram shows what kind of actions that were necessary on the different farms, brought on by the choice of different technology and different environmental conditions at the farm-sites.

In order to facilitate the comparison of efforts and results between the different types of farms, the data in following diagrams have been normalized with a method that was recommended by external mussel farm experts. Because we are working with very different farm systems, the recommendation was to normalize the data to “100 m farm unit” (PP-pipe or long line). The diagram below (Fig. 12) shows the farm sizes in 100 m units to which data on harvest and workhours from the different farms were normalized. Here we can see that the biggest farm, St. Anna, was 8 times the size of the Kiel Marine Farm.

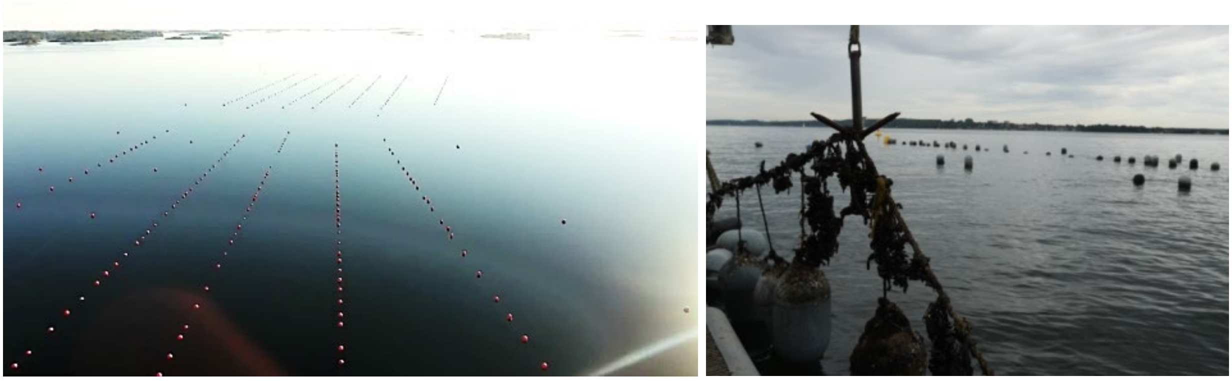


Figure 11. The biggest farm. St. Anna (Left), was 8 times the size of the Kiel Marine Farm (Right).

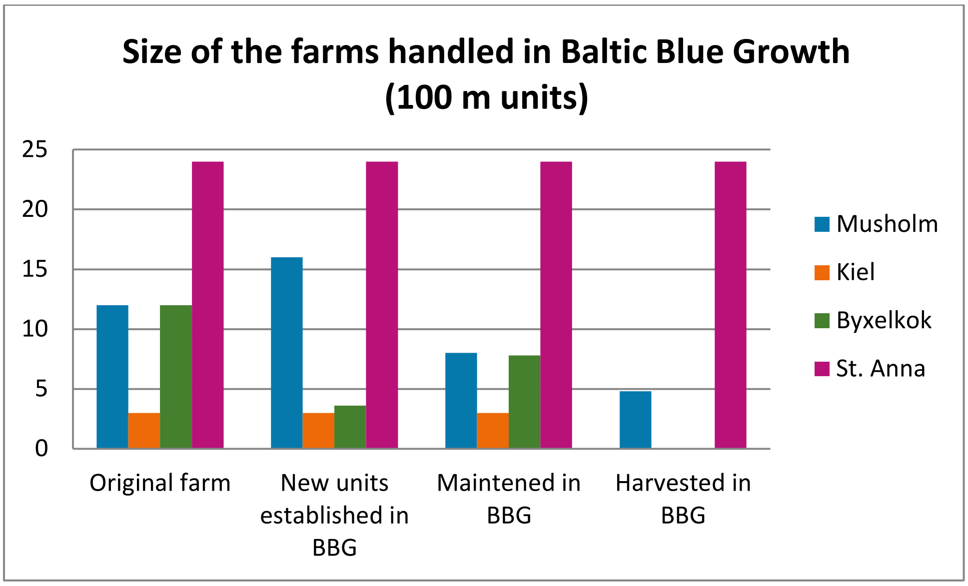


Figure 12. Size of the different farms, in 100 m units, that was used to normalize the data in order to facilitate comparison between the project farms. When analyzing the work effort, it is important to keep in minds how some of the farms changed setup during the course of the project. At Byxelkrok the original farm had 10*120=12 100 m units, but only 3 of them were fully established. The rest were left behind in Grankulla bay after Sep 2017 without much further attendance. At Musholm there were 18 older mussel farm units on the site from the beginning of project, but these were stepwise moved and taken over by other projects, while new stronger units were installed in BBG.

The farms in Kiel and St. Anna had the same setup throughout the whole project. But at Musholm and Byxelkrok, the number of units for which workhours were logged was altered during the course of the project. This was not planned from the beginning, but a consequence of the less favorable conditions for mussel farming at Byxelkrok and Musholm.

Also, mussels grow more or less fast depending on the salinity. In the western Baltic it is possible to harvest small mussels already after 7-8 months and in the Baltic proper after 16-17 months, but since recruitment of new mussel larvae happen only in spring or in the early summer, the growth cycle is either 1 or 2 full years. When comparing the reported work effort between farms, it is more relevant to look at the management per growth cycle than per month. A farm with fast-growing mussels will likely require more management per month than a farm with slow growing mussels, but on the other hand, storms, predation and other troubling events will likely happen more in two years' time than in one year. It is the *total work-hours spent per potential harvest* that is most interesting.

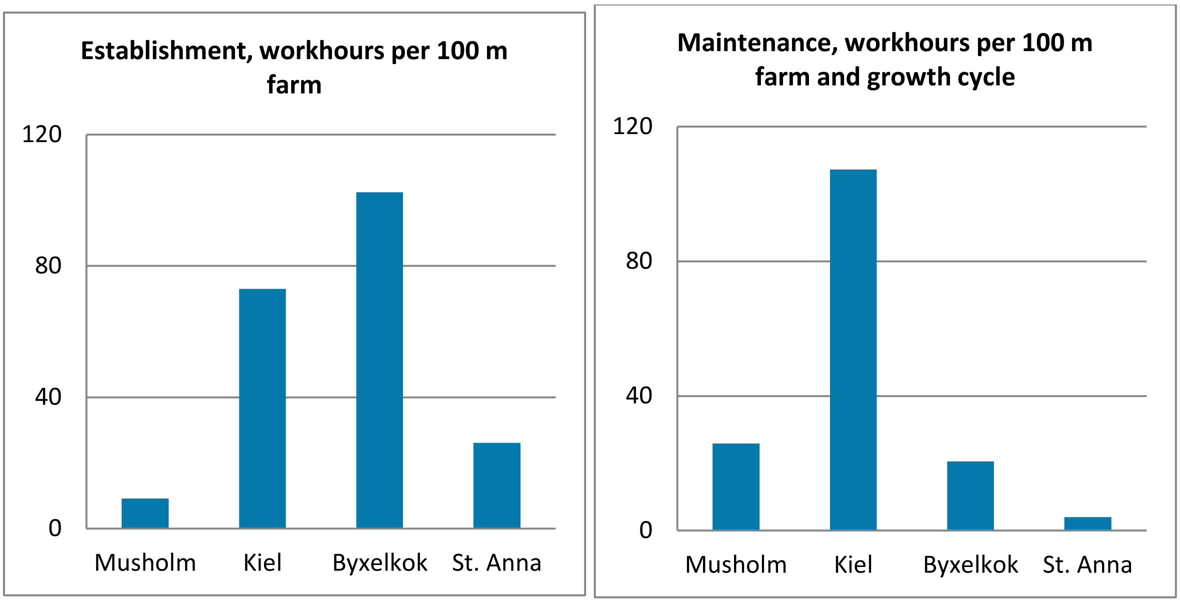


Figure 13. Left: Work hours spent on establishment of new production units in 2016-2018. Right: Time spent for maintenance of the production system (e.g. adjustments and repairs– not including hours reported for inspection). Data have been normalized through division with the length of the long-lines or PP-pipes keeping up the farm substrate at the different occasions (Fig 12) and in the right figure also by the number of mussel growth cycles for which the work hours were spent.

Without the background given from the Mussel farmers Logs, results from this comparison between the project farms are not easily explained. There were a lot of challenges encountered by the farm-managers such as predators, storms, ice and delays in the delivery of necessary equipment. From the regular web-meetings it was explained that mussel farmers' practices also differed due to workers laws and combinations with their other businesses. And when comparing the work hours spent at different tasks, we must also consider factors such as different experience of the farm-managers and their different capacity in terms of boats and personnel.

It was expected that net-farms, as those used in Byxelkrok and Musholm would be faster to establish than the long line farm units in St. Anna and Kiel. On the long line farms the substrate rope needed to be mounted manually at the site out in the sea, while the net units were already prepared on land before establishment started, and then towed to the site. However, Fig 13 left show the long-line farms in St. Anna and Kiel were faster to establish than the net-farm at Byxelkrok. This was probably because the Byxelkrok farm used screw-anchors, as was also done in Kiel. Drilling anchors into the sea-floor is time-consuming compared to other anchoring methods. Depending on the site and work-vessel used, it can also be very weather dependent.

Figure 14. Left: The net farm in Byxelkrok arrived to the quay in pre-made units. Right: Drilling anchors into the sea-floor is time-consuming compared to other anchoring methods.

Work hours spent on maintenance (Fig 13, right) seem to somehow reflect the different sizes of the farms, the St. Anna farm being considerably more easy to maintain than the Kiel farm. Bigger farms need less work hour for maintenance per unit, simply because it is more efficient to do a lot of adjustments and repairs on the same day. But we also know from the Mussel farmers Logs that there were factors like predators, delayed work schedule and weather events that had a big impact on the time spent on maintenance of the production system. The outcomes from the farms in terms of harvest and final status of the production systems also differed considerably.

Based on the limited number of farms we cannot conclude if one farm system is more efficient than the other. But from the information given by the logs it seems that, besides making the right choice of mussel farm site, some technical details like anchoring, type of buoys, accessibility and a practice of regular inspections is very important.

The expert's comments to this section can be summarized as follows: It is risky to draw any conclusions from comparison between such different farm systems in different environments. Site-specific conditions have a very big impact on the operational costs for mussel farms, even if they basically use the same technology. Bigger farms are more efficient and stronger in exposed sites but can have down sides like high investment costs and larger boats requirements. Smaller farms usually have lower efficiency leading to higher production cost, but they are easier to handle for the small entrepreneur. The problems reported from the project related to farm construction (Byxelkrok, Pavilosta) were most likely due to things like differential wear, friction impacts and wrong kind of floats. The materials and installation chosen should have resulted in less "snapping" (=wave-impact). Also, the access to these exposed sites with suitable work-vessels should have been planned more carefully beforehand. As it was now, the farms were inadequately maintained because of limited access. It is important to consider the more demanding conditions in the open waters. Most places are good for growing mussels, including low salinity, exposed and offshore sites. But it will never be good business.

Harvest of the farms

Harvest was only accomplished at two of the original project farms, Musholm and St. Anna. Musholm did a harvest in 2016, but in 2017 and 2018 the eider ducks consumed more or less the whole biomass from the farm-units that were supposed to be harvested within the project. The St. Anna farm was successfully harvested, and also had a considerably higher harvest in biomass than what had been predicted from start, close to 80 tons compared to the predicted 30 tons. At Byxelkrok and Pavilosta, the high level of exposure on the farms from waves and current had damaged the farm-units and mussels were lost. The Kiel and Vormsi farms had not planned any harvest within the project, but at the Kiel farm the harvest volume after 1 growth cycle was estimated scientifically from sampling. In order to gain more data, results from harvest occassions within the cooperational projecs Nutritrade and Blue Biomass were used together with the results from Baltic Blue Growth. These results came from harvest of the associated farms in Hagby and Västervik in the Baltic Proper. Harvest results are here presented in the same unit as work-effort for establishment and management: Tons per 100 m farm (Fig. 15).

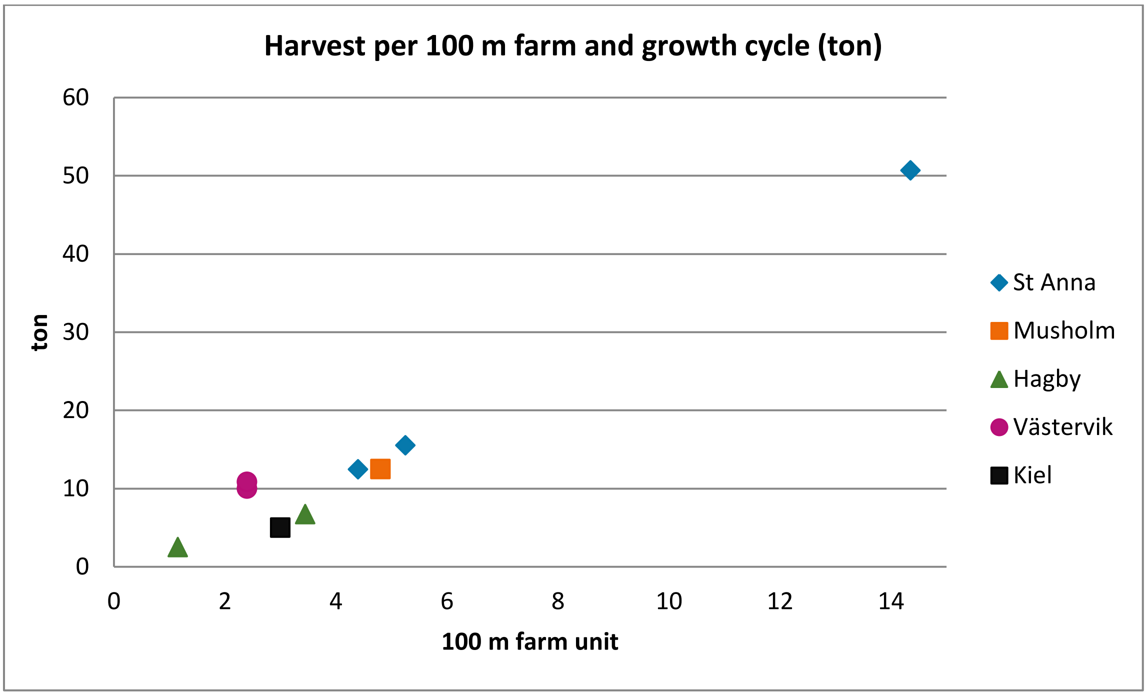


Figure 15. Harvest resuts in ton per 100 m farm unit. Also showing results from two associated farms from the Kalmar Sound area, Hagby and Västervik (Table 2).

When normalized in this way, harvest results were similar in the Baltic proper (St. Anna, Hagby, Västervik) compared to the farms in the western Baltic (Musholm, Kiel). But one must remember that the growth cycle is twice as long in the Baltic proper, so if normalized per year, the western farms would have done better in this comparison. The purpose here is, however, to compare the technology. It seems surprising at the first glance that the performance of eastern and western farms was so similar. It can be partly explained by how much growth substrate there was on each unit. The St. Anna farm had almost twice as much growth substrate per 100 m farm unit as compared to the Kiel farm (table 1). This explains why it got equivalent (or bigger) harvests per 100 m. The depth and density of the substrate matters, and so does also the “fuzziness” of the ropes.

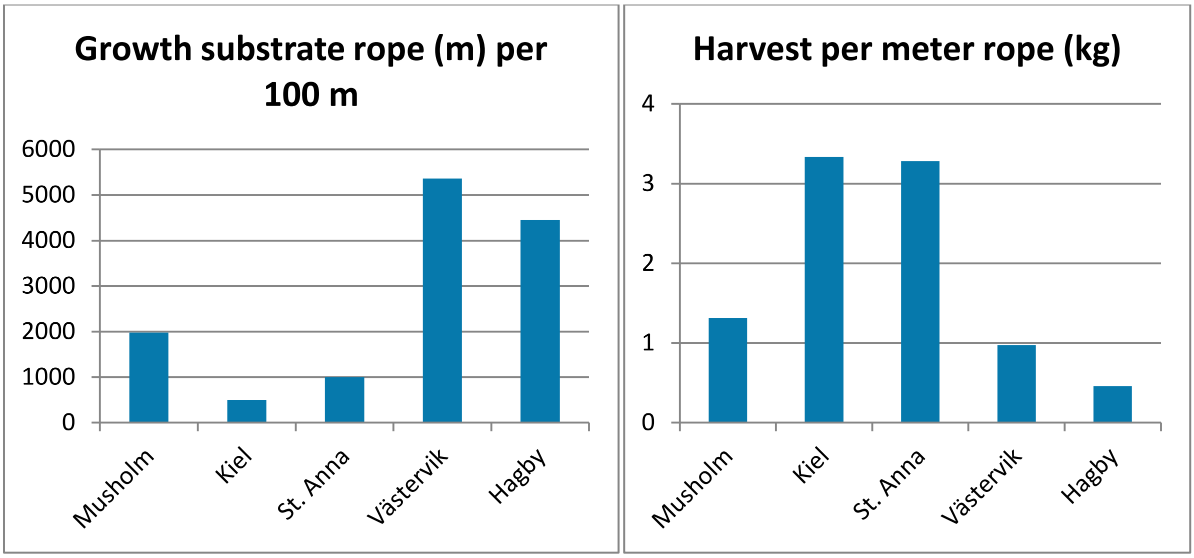


Figure 16. Left: Length in meters of growth substrate available on each 100 m farm unit. The rope nets of Musholm, Västervik and Hagby farms have been re-calculated into rope meters, estimated as the sum of all rope lengths in a net. Right: If harvest results are presented in kg/m substrate rope, the fuzzy ropes at St. Anna and Kiel had more biomass per rope meter than the net farms.

The net farms in Musholm, Västervik and Hagby had more meters of net rope per unit than both long line farms (Fig. 16, Left). But not surprisingly, the long line farms using fuzzy substrate ropes got a lot more biomass per m rope meter than the net farms (Fig. 16, Right). When comparing the substrate available for mussels between the different types of farm designs, it is not ideal to recalculate the square-meters of rope mesh in net farms into rope length and then compare with the fuzzy rope substrate used at the longline farms. It does say something about the magnitude of substrate put out in water, but because the fuzzy ropes have a lot bigger surface compared to the slick ropes used in net farms, the actual surface provided for mussels to settle on is very difficult to compare between net farms and long line farms. There were also differences in rope structure, as well as growth depth between the different net and longline farms. The Christmas-tree rope used at S. Anna was "fuzzier" than the settling rope used at the Kiel farm, and the substrate was hanging down to 10 m depth compared to 3 m. Hagby and Musholm had a similar rope-quality of Ø14 mm but the farm in Västervik was made out of trawl net ropes Ø5 mm and had 4 m deep nets instead of 3 m. In parallel to this difficult comparison in mussel production between the bigger scale mussel farms, we also did controlled substrate tests. Here, all project farms used the same kind of settling rope and trawl nets during the same period of time (0,5-1 years). These test showed that when all differences in farm structure were eliminated, the mussel production was most efficient in Kiel, followed by Musholm, Western Baltic proper and the Eastern Baltic proper. For more information about this, see the report "Recruitment, growth and production of blue mussels in the Baltic Sea"[8] published on the project website https://www.submariner-network.eu/projects/balticbluegrowth.

Which of these farms showed the best practice? Overall, the harvest outcomes in this project depended on appropriateness of the farm methods used to the specific environment at the growth sites. It can perhaps be concluded that the deep and fuzzy St. Anna farm and the Västervik trawl net farm had smart designs that worked in their specific conditions. Their designs with plenty of growth substrate per m partly compensated for the lower mussel production in Baltic proper compared to the western Baltic. Musholm changed their farm design during the course of the project. The new farm units that were

[8] Lyngsgaard M, Dolmer P, Kotta J, Rätsep M, Peterson A, Krost, P. 2019.

established in 2017 and 2018 had stronger PP-pipes to withstand hard weather and increased magnitude of substrate of 100 mm trawl net, to compensate for the low production in the Great Belt.

Figure 17. Left: The Västervik farm, made of double-knitted trawn net, have a lot of growth substrate per 100 m. This partly compensate for the fact that mussels growth rate is lower in Västervik in the Baltic proper compared to in the western Baltic. Right: Mussel production on fuzzy settling rope in Kiel in the western Baltic.

St. Anna, Västervik and Kiel were the most protected farm sites, and likely had less loss of mussels due to wave impact compared to the more exposed sites in Hagby and Musholm. At Byxelkrok and Pavilosta, the high level of exposure on the farms from waves and current had damaged the farm-units severely and the mussels were lost.

The total workhours reported on core mussel farming activities, here defined as: Establishment, Inspection, Maintenance of the production system and vessels, and Harvest, were similar between the 4 farms that kept regular Mussel farmers Logs (for details about all different activities, see Fig. 10). But unfortunately, the result in terms of “Harvest per effort” could only be calculated for St. Anna and Musholm. For St. Anna, the total harvest per effort (core activities) was 65 kg/h and for Musholm the harvest per effort was 9 kg per h. Without normalization these numbers turn out very unfair for Musholm, considering that only 4 of the 16 units that were established and taken care of in this project were harvested. The reason why the rest of the units were moved out of project before harvest, was because of the heavy predation from eider ducks and the lack of efficient predator mitigation tools. Should all the units at Musholm have been harvested with the same result as the first four (and twice, because of the 1-year growth cycle), the “harvest per effort” at Musholm would have been closer to 70 kg/h.

The expert’s comments to this section can be summarized as follows: Results shown here can be very different next year, so none should be considered “achieved”. The magnitude of settling surface is important, but equally important are the surrounding conditions. Negative growth (compared to the expected) can be observed on many farms in the world when there is either predation, density driven self-thinning, or losses due to storms on the present population, followed by a second settlement and observation of those mussels left on the line.

Comparison of the different harvesting techniques used

In order to gain more knowledge about the costs and efficiency of different harvest techniques, data from harvest occassions within the cooperational projecs Nutritrade and Blue Biomass were used together with the results from Baltic Blue Growth. Basically, there have been 3 different harvest techniques tested within these three projects: 1. Harvest of long-line farm, using a conveyer belt to lift up the longline on a harvest platform and a scraper to clean the mussels from the substrate. 2. Automatic harvester with UW-brushes that clean off the mussels from net farm units and pump them up to deck to be packed directly into big bags, 3. Over-water netfarm harvesters, where the whole net-unit has been lifted over a platform and washed off from mussels using a high preassure cleaner. All the methods tried needed at minimum two, and were better off with three persons in the work team.

Harvest	Date	kg	h	units (100m)	kg*h-1	h*unit-1	Method
St Anna	2017-12-15	15540	50	5	311	10	1
t Anna	2018-05-15	50670	168	14	302	12	1
St Anna	2018-09-15	12471	48	4	260	11	1
Musholm	2016-05-15	12500	170	4	74	43	2
Limfjorden*	2017-01-15	360000	90	18	4000	5	2
Hagby**	2017-08-15	2525	12	1	210	12	3
Hagby**	2018-11-07	6745	48	3	141	16	3
Västervik	2016-05-31	10000	54	2	185	27	3
Västervik**	2018-05-25	10870	56	2	194	28	3

Table 3. Harvests occasions from which data has been collected for the project. * Data from Blue Biomass project. **Data from Nutritrade project.

Figure 18. 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. Method 1.

Figure 19. Harvest of a netfarm (Musholm), using a UW harvester. Method 2.

Figure 20. Harvest of a netfarm (Hagby), using a catamaran platform to lift up the net and wash off mussels using a high preassure cleaner. Method 3.

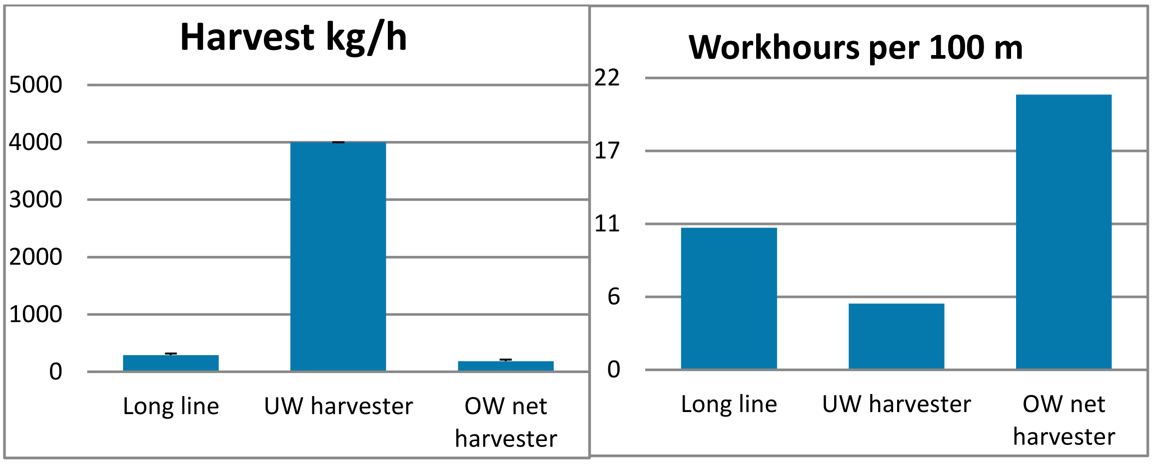


Figure 21. Comparison of efficiency of the different harvest techniques tested. Left: Efficiency in kg harvest/workhour. Right: Efficiency in 100 m units/workhour.

When comparing the workhours spent for harvest with different techniques, it seems that the UW-harvester is the most efficient in kg/h (Fig 21, left). In this comparison however one also have to take into account the difference in production between the Eastern Baltic, where the over-water harvest techniques were tested, and Western Baltic, where the UW-harvester was tested. More biomass can be harvested from the same size of substrate in the western Baltic compared to the east. Because of this bias, the numbers from harvest of net farms are also presented in no. of harvested 100 m farm units per hour, (Fig 21, right). Even though it is more job to harvest a 100m unit with high biomass, the UW-harvester is still the most fast and efficient harvester. The efficiency of a harvester does not only reflect what time it takes to strip a substrate from mussels, but also the number of persons needed in a work team. A factor that increased number of workhours especially for the teams working with overwater net harvesters was large work teams and limited experience.

The expert's comments to this section can be summarized as follows: Workforce is not the only cost for mussel farming. When planning a mussel farm, one also has to take into account the prize for investment of the different farm-systems. Mechanized UW harvesters specialized for net farms are the fastest in kg/h, but these are only cost efficient if harvests are large. It is important to plan how to harvest the farm before installing. That is: Design the farm by an affordable and usable harvester (because that's a big investment).

Investment and operational costs

One of the project aims was to to calculate the production costs for mussel farming in the Baltic Sea in EUR/kg. But due to the limited number of study objects, different prerequisites in terms of boats and other equipment, and the high variation in harvest success, this turned out to be a difficult task.

In this report we list *investment costs* for our project farms, and *operational costs* based on the 2-3 years' time period that activities at the farms were reported. As in the previous sections, the costs have been normalized per 100 m farm unit and growth cycle in order to facilitate the comparison between farms. The operational costs listed here are based on interviews and invoices, with support from the Mussel farmer's Logs when available. They cover the cost for work, fuel, and/or external entrepreneurs. They do not include costs for transports or quality check, and also not all costs related to farm repairs.

Costs EUR/kg	St. Anna	Byxelkrok	Musholm	Kiel	Pavilosta	Västervik	Hagby	Åland
Investment + Establishment	170427	145638		20000	112000	37037	58536	89817
per 100 m farm unit	7101	12137	13403	6667	44800	15447	12725	19525
Operational costs per growth cycle	14358			7441		10512	17222	28934
per 100 m farm unit	598			2480		4380	3744	6290
Harvest (kg) per growth cycle	78681		12500	5000		10500	9270	14400
per 100 m farm unit	3278		3125	1667		4375	2015	3130
Operational cost EUR per kg mussel	0.18	N/A	N/A	1.49	N/A	1.00	1.86	2.01

Table 4. Investment and operational costs for small scale mussel-production in the Baltic Sea. The data has been collected by interview of the farm responsibles Mats Emilsson, Tim Staufenberger and Susanna Minnhagen and the managers of associated farms, Mikael Wennström from Åland Government and Gun Lindberg from Västervik municipality.

The expert's comments to this section can be summarized as follows: Operational cost must not be too high compared with one ton harvested mussels. In this project, operation cost seems to be too high at all places, maybe with the exception of St. Anna. We can expect more efficiency when farmers get to know their farm and area and optimize procedures and equipment. Costs for the St Anna farm represents what we can expect from well operated submerged longline fa rms. For mussels to be used for human consumption on the fresh market (50-60 mm, 65 pieces/kg), production costs of up to 0.6-0.7 € pr kg may result in a viable business. But for small mussels for meal or other purposes, production costs cannot exceed max 0.1 € pr kg unless somebody pays for the ecosystem goods and services provided by the mussel farming. The expert's recommendation was not to try and guesstimate production costs for mussel farming in the Baltic Sea based on limited sized test farms, because it is always going to be expensive when calculated on the small scale.

The project has produced country specific ”Business plans for blue mussel production in the Baltic Sea”[9] that can be found on the project website https://www.submariner-network.eu/projects/balticbluegrowth. Just to give an approximate number, a Swedish mussel producer with a yearly harvest of 130 ton mussels using long-line system in the archipelago of the Baltic proper could have yearly operational costs of 0,3 EUR/kg mussel and a total production cost (including investments) of 0,5-0,75 EUR/kg. This calculation was based on input data from the St. Anna farm, but the result may vary a lot depending on factors like life time expectancy of the farm, loan interests, transport costs, administration costs, possible support from investment aid, and so on. Please refer to these site-specific business plans for a deeper understanding of the factors that determine mussel production costs.

Environmental conditions at the farm sites

The environmental conditions at the different farm-sites in this project differed considerably in terms of waves, ice, salinity and chlorophyll a (as a measure of food availability). All these factors could influence mussel production. The optimal environmental conditions for mussel farming are described in more detail in the report "Addressing the mussel farms in maritime spatial planning process"[10] published on the project website https://www.submariner-network.eu/projects/balticbluegrowth. University of Tartu has launched a useful tool for the prospective Baltic mussel farmer, which allows the extraction of oceanographic data based on modelling. This tool, called "Plan your farm" is available at http://www.sea.ee/bbg-odss. Figure 22 gives an overview over environmental conditions at the sites, based on modelled data that is extracted from the "plan your farm"-tool. These low-resolution data do not show exact conditions at the site, put the purpose is to illustrate key characteristics and differences between the sites.

[9] Business plan Kieler Meeresfarm. Staufenberger T, Lemcke R. 2019.
Examples of two Danish business plans for production of environmental mussels. Schriver A, Lyngsgaard M, Dolmer P. 2019.
Mussel farm business in east-coast Sweden. Minnhagen S, Ozolina Z, Emilsson M, Bailey J.2019
Marketing aspects of blue mussel production in the Baltic Sea. Ozolina Z, Kokaine L, Gaile Z. 2018

[10] Przedrzymirska J, Olenycz M, Turski J, Pardus J, Lazić M, Matczak M, Zaucha J, Licznerska-Bereśniewicz J and Rakowska I. 2019

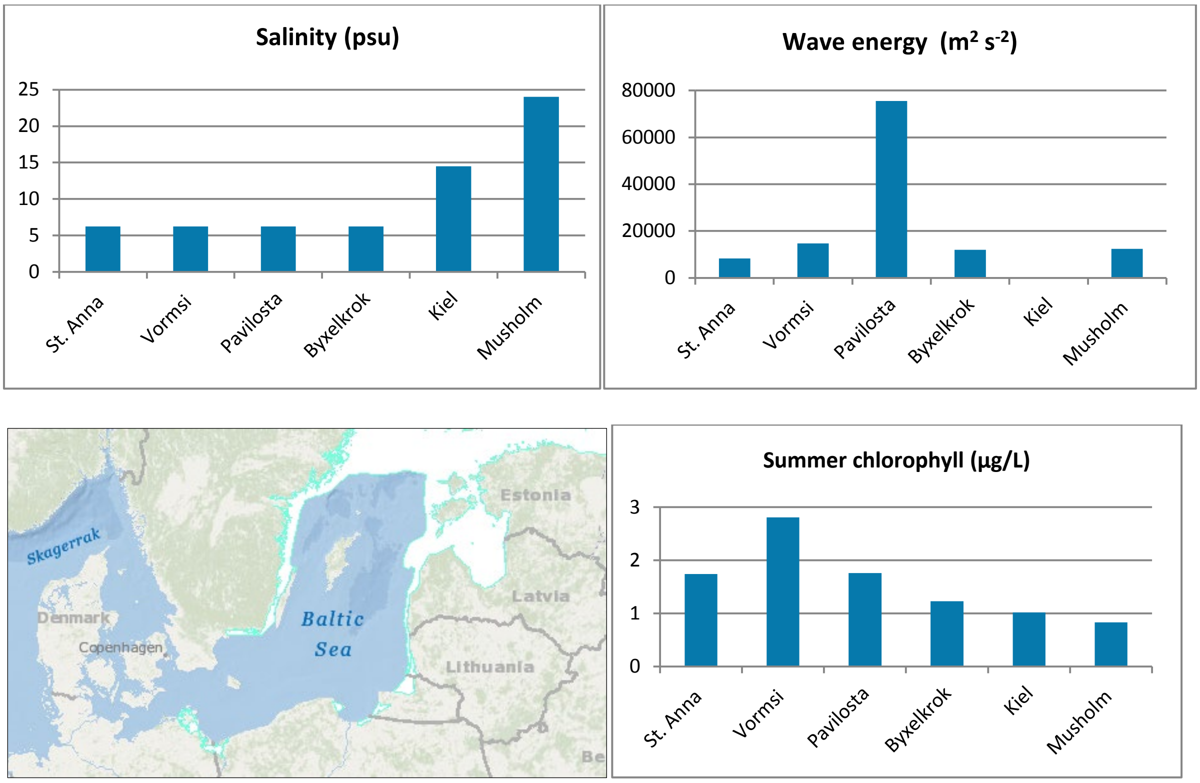


Figure 22. Top, and lower right: Modeled data that gives an approximate overview of the environmental conditions at our farm sites. Lower left: Baltic Sea ice maximum 2005-2009. Source: http://www.sea.ee/bbg-odss.

Salinity is directly linked to mussel growth rate. Mussels respond to low salinities through the reduction of growth rate, maximum size, number of byssus threads produced and thickness of the shell. The report "Recruitment, growth and production of blue mussels in the Baltic Sea" [11] confirm that that the overall pattern in mussel length and biomass growth is linked to the difference in salinity between Eastern and Western Baltic, but mussel production was higher at Kiel than at Musholm due to systematic loss of big mussels from the substrates at Musholm.

Summer chlorophyll reflects the food-availability. Best Chl-values for Danish waters are 3-6 $\mu g \cdot dm^{-3}$ (Riisgård and Lundgreen 2012[12]), but for the Baltic proper, the optimal is between 1-3 $\mu g \cdot dm^{-3}$ (Jonne Kotta, pers comm.) The reason for this is that values > 3 in the Baltic Proper indicate cyanobacterial blooms. These blooms will cause the mussels to shut down their filtration system so they starve, despite the high chlorophyll. It can be suspected from Fig 22, lower right that the mussels at Musholm are slightly food-limited. However it is not only the plankton concentration but also water exchange at the farm site that matters.

[11] Lyngsgaard M, Dolmer P, Kotta J, Rätsep M, Peterson A, Krost, P. 2019. Published on the project website https://www.submariner-network.eu/projects/balticbluegrowth.

[12] Riisgård H. U. and Lundgreen K. 2012. Field data and growth model for mussels Mytilus edulis in Danish waters. Marine Biology Research 8: 683-700.

None of the farms included in this project seems to have had problems with too little water exchange. On the opposite three of the farms, Pavilosta, Byxelkrok and Musholm, had problems with having too exposed conditions for their farm-design or installation. At Musholm this was solved with stronger PP-pipes. But severe farm damage and loss of mussels was seen at Pavilosta and Byxelkrok. Rough weather conditions that limit the number of days it is possible to work at a farm, clearly increases the risk of damage to farm-units. The Musholm company, thanks to the daily job at the fish farm, had suitable work vessels and experienced personnel. Here inspections and repairs were possible also in bad weather.

Figure 23. Left: Equipment and boat used for mussel production tests at the Musholm fish farm. Right: A new farm system with extra strong PP-pipes was developed at Musholm to withstand the weather conditions in the Great Belt.

Waves have a negative impact on mussel production. Strong wave action can dislodge mussels from substratum and cause their higher mortality. It can also damage or even destroy mussel farms. At the Pavilosta coast, wind and waves are the major hydrodynamic forces that influence the coastal habitats (Fig. 22, Upper Right). Submerging of mussel farms can minimize negative effects of heavy waving, but in the case of Pavilosta, submerging to 5 m depth was not enough. The re-constructed farm is submerged to 10 m. For more information about submerged farms, see the report "Technical evaluation of two submerged mussel farms in the Baltic Sea"[13] available at [https://www.submariner-network.eu/projects/balticbluegrowth.](https://www.submariner-network.eu/projects/balticbluegrowth)

Temperature for mussel farming, from 1.5 to about 10 m depth, should not exceed 20 °C during the warmest months of the year. In the hot summer of 2018 water temperatures of up to 25^{o} was measured at St. Anna, and this could perhaps explain some of the loss in biomass from May to September that was noticeable from harvest results. On a bigger scale the summer temperatures are usually between 17.5-20^{o}C and comparable at all the farm sites covered in this project, It is especially important for the mussel farmer to check how fast the temperatures rise in spring, because the warming of the sea will start the spring phytoplankton blooms that determine the time for mussel spawning. In this project mussel settling started in May in Kiel, mid-June at St. Anna and was first reported in July at Pavilosta.

Ice. The Baltic Sea ice maximum (2005-2009) show that most coastal areas of the Baltic Proper must occasionally expect ice conditions. From 2017 and 2018, ice conditions were reported from the farm in St. Anna. In the winter of 2018 thin ice was also reported from Kiel, with the note that this was a rare occasion. Drift-ice can occur, especially in the spring when it ice is melting. In spring 2018, the 7 left-behind farm units in Grankulla bay (that should have been submerged at the Byxelkrok farm site but

[13] Bonardelli J, Ozolina Z, Aigars J, Purina I, Persson P, Persson K, Johnsson H, Minnhagen S. 2019

never were, because of lack of time) suffered severe damage when the ice in the ice-covered bay suddenly broke up. Several of the anchor lines were torn off. In contrast the farm at St. Anna survived the ice break-up without too much damage. This was probably thanks to its specialized buoys that were designed to slip under the ice. For more tips on how to prepare a mussel farm for drift ice, see the report "Technical evaluation of two submerged mussel farms in the Baltic Sea"[13] available at https://www.submariner-network.eu/projects/balticbluegrowth.

Figure 24. St. Anna. Left: Picture from 16 March 2018. Ice-cover is 12 cm. Right: Picture of the ice break-up in 6 April 2018. NW winds, 15-20 m/s.

The expert's comments to this section can be summarized as follows: An important reason for loss of growth occurs when mussels are stressed due to constant wave motion. Exposed conditions increase the risk to loose mussels due to wave impact or damage to the farm. The latter can be avoided with good choice of materials and installation design. But in low salinity: don't go offshore, go in easy sites, because that is where eutrophication is worst and conditions for mussel farming are the best.

Predators and biofouling

In this report, only observations of predators and biofouling from the Mussel farmers Logs will be discussed. For more information there is a special report available on mussel predators and eider mitigation techniques, "Eider predation mitigation tools for Baltic Sea mussel farming"[14] at https://www.submariner-network.eu/projects/balticbluegrowth.

Eider ducks were the number one predator observed in this project. Eiders were reported from Musholm, Kiel, Byxelkrok and the associated farm Västervik archipelago, but not from St. Anna archipelago or Pavilosta. The Sea Eagle, now returning from population crash in the 70s, is a character species at St. Anna. So they could have reduced the number of hatching eider ducks in the area. According to the farm manager however there has never been many eider ducks at St. Anna, even before the eagles returned. At Kiel there were eiders seen in lower numbers (5-15) around the farms site on occasions in Feb to April

[14] Lyngsgaard M, Schriver A, Dolmer P, Lejbach A and Wallach T. 2019

2018, and one note about 2000 migrating eiders in Feb 2017. At Byxelkrok were the farm unintendedly spent most time in Grankulla bay, a large flock of several hundred eiders were observed in March 2018. At Musholm some eider ducks stayed in the Great Belt all summer in 2017 and were scared off the farm with various methods. In Sept when the migrant birds arrived, it was estimated that this predator alone reduced the biomass on substrates at Musholm with 80-90 %. In Kiel, no impact from eider predation could be seen. In Grankulla bay there were many factors that could have led to the massive loss of mussels seen. In Västervik, only minor loss of mussels could be seen (Fig. 25).

Figure 25. Left: Musholm trawl net substrate from August 2017 with high mussel biomass. Middle: The same net photographed after eiders arrived a month later in September. Right: Minor loss from eider predation at the Västervik farm in April 2018.

Starfish Because of the complete lack of starfish in the Baltic Proper, this otherwise common mussel predator was a minor problem. At Musholm and Kiel some starfish were observed and reported in the logs, but they were not stated as a threat to production.

Round Goby are mussel-eating bottom fish. They were reported from Pavilosta, Vormsi and the associated farm Hagby in Kalmar Sound. Round gobies have consumed all small mussels at the bottom under the Pavilosta farm. But even when counted in high numbers directly under the farms, they were never observed feeding on the mussels from the pelagic substrates, or having any obvious effects on farm-production.

Figure 26. Left: Eider ducks caught in action at the Västervik farm. Right: Starfish at the Kiel farm. Middle: At some locations in the Baltic Sea, the round goby is now the most common fish-species to be found (photo by Juris Aigars, Latvian Institute of Aquatic Ecology).

Biofouling from cockles, barnacles, green and red algae at the farm substrates were reported from St. Anna, Musholm, Kiel and Grankullavik. The more saline sites at Kiel and Musholm only reported biofouling from algae while St. Anna had biofouling from cockles and Grankullavik reported biofouling from cockles and barnacles. At all sites, however, it seemed that the competitors mostly were a temporary problem in the first months after settling. Barnacles could possibly represent a more long-term competitor for space, but as they were only present at the un-intended farm-site in Grankulla bay, we did no follow-up on this issue.

Figure 27. Left: Biofouling on the nets left in Grankulla bay, Kalmar Sound in August 2017. Middle: Biofouling by cockles on the NZ-ropes of St. Anna during the first summer in 2016. Left: Biofouling of algae at the trawl nets at Musholm.

The expert's comments to this section can be summarized as follows: Eiders prefer thin shelled mussels. Also in other regions, eider ducks are one of the biggest threats to mussel production. Their impact can be recurrent in areas along their migrating path, or periodic. Learn about the eiders' ecology and document the trials to scare them off. There are some techniques available to prevent eider ducks (for more information, see Report "Eider predation mitigation tools for Baltic Sea mussel farming" [15] available at https://www.submariner-network.eu/projects/balticbluegrowth). Starfish can only be found on long-lines or nets if these touch the bottom, or if starfish larvae have settled on mussel farming material. And even if settled on the mussel farming material, the starfish will not stay if the mussel substrates are near surface with high amounts of fresh water. This is why they are not a problem even in the western Baltic where they exist. The round goby may not be able to feed on vertical substrates, but in other areas like the west coast of USA, predatory fish like goby can have a huge impact on the natural mussel population and spat survival. So this needs to be carefully observed. Mussels in general most often out-compete other organisms settling on the substrate intended for mussels. This is seen in relation to filamentous algae and most other invertebrates. Mussels will in most cases overtake the substrate also in a competition with barnacles. However, barnacles settling ON mussels can be a problem, because on today's mussel market it reduces the value of the mussels.

Conflicts and interactions with neighbors and stakeholders

Luckily, not too many conflicts with external groups were experienced in this project. Musholm and St. Anna reported no conflicts at all from tourists and yachting or commercial and recreative fishing. In Kiel, swimmers, walkers and cyclists noticed the "grey things" in the water. Their positive response, or lack of negative opinion, could partly have been a result of informative signs, study visits and reports in different local media about the project.

[15] Lyngsgaard M, Schriver A, Dolmer P, Lejbach A and Wallach T. 2019

Figure 28: Information for neighbors and stakeholders at Byxelkrok harbour, 28 May 2017.

A few conflicts or problems were reported from the Byxelkrok, Pavilosta and Vormsi farms. In Byxelkrok the work to establish the farm was delayed and due to the necessity to work through two busy tourists' seasons, there were repeated arguments with the harbor administration about where to berth the work-vessel. There were also complaints from small-boat owners and water scooters that the ropes and the buoys from the mussel farm were in the way for them. It did not solve the problem that the mussel farm area had navigation aids and was marked on the charts. These summer-cruisers had poor maritime skills and lacked proper navigation equipment. Also at Pavilosta, boaters reacted with surprise to "the new buoy of isolated danger and the strange radar signals in the dark". Then the problem shifted towards boaters actually seeking out the buoy, to use it for mooring and fishing. At Vormsi, it was suspected that buoys were stolen from the mussel farm.

Expert's comments: All these situations are very typical worldwide. The acceptance from neighbors can be very different from place to place. One of the important reasons for submerging lines in offshore environments is to prevent boats from snagging the lines near the surface. Large navigation buoys like the one at Pavilosta are expensive and not appropriate to mark mussel farms. There are smaller and cheaper more effective ones available. It is for sure an important focus to document experience with public acceptance in relation to mussel farming. If larger mussel farming operations are planned, it is always good to inform about the positive environmentally impact and to give general knowledge about what is going on under the surface. When people understand they will most likely appreciate the effort, but sometimes, one or a few people can be very aggressive against any change in their neighborhood.

Lessons learnt and good practice

The very first thing to consider when planning a mussel farm in the Baltic Sea is the purpose. Every choice in terms of equipment and location of the farm depends on the purpose of farming. Is the aim to grow large volumes of bulk mussel to take up nutrients, or to frequently harvest fresh mussel for the local restaurant? Think about how to maintain and harvest the farm before installing. Don't think "small" if your purpose is to mitigate eutrophication.

How to choose a good mussel farm site

Some areas are unsuited for mussel production due to predation by (eider ducks), rough weather conditions, strong currents, poor settling and/or poor food availability. One can grow mussels almost everywhere, but the economy must drive. In order to achieve a viable business, it is extremely important to choose the best possible site for mussel farming. Low salinity gives lower production, but this can be compensated by adding more growth substrate to the farm units, which is a rather cheap investment. The most determining factors in this project were exposure conditions, predators and logistic issues. Food availability did not seem to be a problem at any of the sites in the Baltic proper, but the mussels at Musholm in the Great Belt could have been slightly food limited. Areas that lack a wild mussel population should be avoided because: a) this is an indicator of less good conditions for mussel growth, and b) they might suffer from a lack of planktonic mussel larvae.

Exposure conditions: In areas with ice and wave-impact, ideally all growth substrate should be submerged to at least 3m sub-surface. Given that the depth of ropes and nets of mussel farms is normally 3-6 m, this means that the water-depth at a chosen farm-site should be at least 9-12 m. An advantage with the Baltic proper compared to western Baltic is that mussels can thrive down to 10 meters depth. Sites with too little water exchange should be avoided, but in the BBG-project, farming of mussels at off-shore and other exposed sites have proven more expensive and less successful compared to the more protected sites. Best areas to be recommended by the project are middle to outer archipelago in the Baltic Proper and fjords of the Western Baltic.

Logistic issues will largely influence the costs for maintenance and harvest of the farm. The on and off need of larger vessels for launching, anchoring, harvest and/or to do larger repairs of the mussel farms, access to cranes, trucks etc. for the loading and further transport of harvested mussels can easily raise the costs for mussel farming significantly, if this is not well planned from the beginning. In order to save work-time and fuel, the farm site or sites should be situated very close the harbor for the work-vessel/vessels that is used for inspection, putting out buoys, sampling and smaller repairs of the farm. The farm site should also be fairly close to a fishing port or some other quay accessible by larger work vessels.

Predators: Be aware of the seasonal and geographical pattern of hatching and migrating Eider ducks. Look for areas that are out of the most common migrant routes, that don't have many hatching or resident eider ducks that ideally have a population of Sea Eagles. Ask the marine biologists or fishermen about Round goby. Make sure that they haven't crashed the natural mussel population, so that lack of mussel larvae could cause a recruitment problem.

Toxins and bacteria: To manage the regulations for feed and food mussel production, it is important that the environment (water and bottom sediment) at the chosen site is reasonable free from heavy metals and environmental toxins such as PCB and DDT. Environmental authorities can usually provide information about known contaminated sites. Avoid larger harbors, and present or previous industrial sites. Another problem can be e-coli bacteria outlets from private sewage systems, emergency drains from municipal pump stations, or agricultural ditches. Contact the local municipality and land-owners for more information.

Conflicting interests: It is wise to aim for a site not too close to the following activities: Popular play areas for water scooters, water-skis and high speed boats, commercial fishing, shipping routes, harbors (buffer

500 m), anchorage points (buffer 250 m), bathing places (buffer 250 m), underwater cabling and underwater pipes. For more information about how to avoid conflicts and facilitate the licensing process with authorities, read the report "Addressing the mussel farms in maritime spatial planning process"[16]

How to choose the right technology

Specific substrates and mesh sizes are not key factors in successful production of small mussels. But it is important to have the right structure of the mussel farm in terms of anchoring, tension/flexibility, buoys and space in between the lines. This will be even more important if you are planning to farm at an exposed site. Respect and learn the forces of nature, or else avoid the exposed areas for farming. Design the farm and choice of harvest system by an affordable and usable boat (not the other way around!), because the boat is a big investment. When planning a mussel farm, consider the prize for investment of the different farm systems and consider how it would work to scale up production.

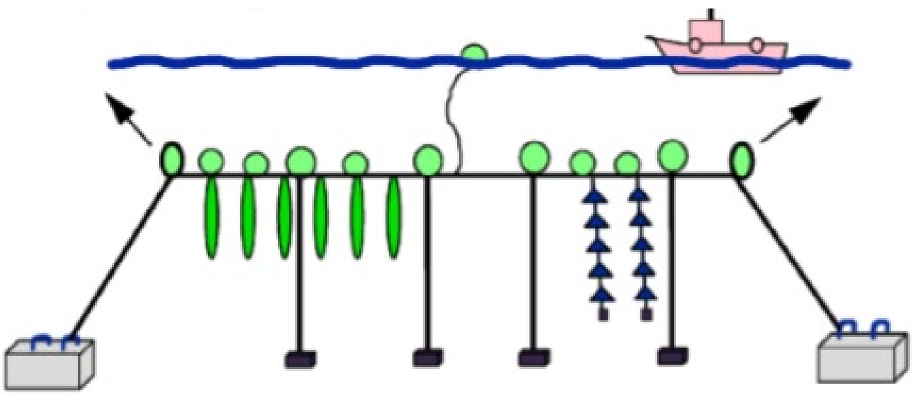


Figure 29. Submerged long line farm system. Sketch by Shellfish solutions A/S

Choice of farm system and harvester. There are two different models of mussel farms commonly used: The long line farm (farms with various type of substrate rope or bands hanging down in loops from a submerged long-line), and the net farm (rope nets of various mesh size typically hanging down from a PP-pipe floating in the surface). Both types have advantages and disadvantages. Long line farms, if placed at a protected site, can be harvested with smaller work-vessels and are easier to handle for the small entrepreneur. But the low efficiency of the harvester (Fig. 18, 21) can be a bottle neck in scale up of production, especially in the Baltic proper where if you want to harvest big volumes in the short period of March-April before the next settling. Net farms hanging on PP-pipes can use UW harvesters (Fig. 19), which are cost-effective if the harvests are big. But the PP-pipes are unsuitable in ice conditions, and the net farms generally require larger boats and bigger investments. In the Baltic proper it is better to use a

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[16] Przedrzymirska J, Olenycz M, Turski J, Pardus J, Lazić M, Matczak M, Zaucha J, Licznerska-Bereśniewicz J and Rakowska I. At: https://www.submariner-network.eu/projects/balticbluegrowth.

submerged construction because of the risk for occasional sea-ice. This submerged construction could have nets hanging down as substrate (Fig 5), but plan beforehand how to harvest, because as the UW harvester can't run without the PP-pipe, there is no standardized harvester for such farm to buy (Fig 20).

Figure 30. Left: Pontylus, the work platform used at the Kiel farm. This type of platform works at protected sites but could not be used in open water. Right: The fishing boat used as work vessel at the Byxelkrok farm. This is an example of boat not suitable for mussel farming. It did not act as a stable platform during anchor drilling or when attached to the mussel farm, so the work could only be done in calm days.

Choice of work vessel. Many different types of boats were used in this project and those that worked the best had stability, work space and low freeboard, like a catamaran or barge. Fishing boats turned out not so useful. The boat used for maintenance should be equipped with a hydraulic crane and a winch. The boat used for harvest, if not the same, should have space for the harvest equipment and some storage place for the harvested mussels. At St. Anna and Kiel raft-like platforms were used, but in more exposed conditions this won't work, you need a 10-12 m boat that can be stable in 1 m waves. At extremely exposed sites such as Pavilosta, it was a problem that the access to the farm was very limited. Planning is the key! Decide how many days are at hand when you can count on reasonable weather. If these days are few, you either need to pay for a large boat, or choose a more protected site. It can be dangerous to work at a mussel farm in bad weather. Safety must always come first.

Material and installation. Details and type of material in the ropes that keep up the mussel farm are crucial. Wrong type of ropes and unprofessional installations will lead to differential wear and friction impacts. Farm units must have a rigid structure, with strong tension in the lines. At the same time the farm should be attached to something stretchy to allow some flexibility with the waves. Having a heavy chain installed between the anchor line and anchor could help dampen the wave motion. To minimize "snapping" from waves, the ropes should not be too thin. There must be enough weight in the substrate material to prevent the substrate ropes from getting wind up, and don't leave any loose rope ends in water. Screw anchors are good, but since it is difficult to install maybe a better choice is concrete blocks (possibly serial anchor blocks). In most areas of the Baltic proper you will also need ice-safe buoys. It is important to have enough space between the farm units. Make sure to have 1.5 times the depth between the lines, so that they don't collide in bad weather.

Substrates. The most successful substrate in this project in terms of kg/m was specialized settling rope (fuzzy rope, or Christmas three rope). However, in terms of tons per farm unit, the trawl net was most successful. Ropes and band-like substrates can be harvested in a simple way, while the nets require some larger machinery. The Vormsi farm use trawl net strings that can be made out of second hand trawl nets and then harvested with an elevator and stripper. Since small mussels seem to grow on almost anything, it doesn’t really matter which of the substrates described in this report that is used, as long as it fits the farm system and harvester.

Figure 31: Left: The Västervik farm was harvested in April 2016 and 2018 to produce mussel meal for animal feed. Right: The Kiel farm will be harvested in the spring for nutrient uptake, but harvest is also done in the autumn and winter to deliver fresh mussels to local restaurants.

How to choose the right harvest period

It will depend on the purpose of farming when to harvest. If the purpose is to produce bulk mussel for nutrient uptake and animal feed, then generally a two year growth cycle (24 months from May to April) in the Baltic proper and a 7-12 months growth cycle for small mussels in the western Baltic can be recommended. Mussels have their highest nutrient- and meat-content per weight just before the spawning. Timing for the spawning can vary from March (Kiel) to May (Kalmar Sound) and will be different in different years depending on the spring phytoplankton bloom and water temperature. A master’s thesis work studying the Hagby farm[17] proposed an optimal harvest time at water temperatures of 5-5.5°C (measured at 5 m depth) which makes it possible for the mussels to utilize the spring bloom that occur around 3.5°C and then leave a window of 4-6 weeks before the mussels’ meat content will start to drop due to spawning. Harvesting in the springtime also minimize the risk of mussels accumulating harmful toxins from the special phytoplankton community of the Baltic Proper.

One week before harvest of mussels for animal feed, a quality control of 1 kg mussels should be sent for analyses according to EU-regulations for feed from aquatic animals[18] and marine biotoxins.[20] In the Baltic Proper, an additional check for the cyanobacterial toxins nodularin and microcystin is recommended. The legal framework and a recommended sampling strategy for feed mussels is described in more detail in the Swedish guidelines for production of feed mussels[19]. For the production of mussels for human food, EU regulations[20] and country-specific control programs exist, but unfortunately these control programs do not yet cover the Baltic Proper. This makes it possible to sell food mussels from the western Baltic (Denmark and Germany) but not from Poland, Lithuania, Latvia, Estonia, Finland, Åland or East Sweden.

[17] Berglöf, K. (2017). Optimal harvest time of farmed Mytilus edulis in southwestern Baltic Sea (Dissertation). Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-68874

[18] EU-regulations 744/2012, 277/2012 and 574/2012.

[19] Lindahl, O. 2019. Branschriktlinjer för primärproduktion av fodermussla. Requests: http://www.vattenbrukscentrumost.se/sv/kontakt/

[20] EG nr 853/2004; EG nr 854/2004 and EG nr 2073/2005.

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 Tartu (EE)*
- *Coastal Research and Management (DE)*
- *Orbicon Ltd. (DK)*
- *Musholm Inc (DK)*
- *Coastal Union Germany EUCC (DE)*
- *RISE Reseach institues of Sweden (SE)*