Mussel farming in the Baltic Sea as an environmental measure

- *A positive outlook based on new data*

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A positive outlook based on new data

Mussel farms can support the advancement of a sustainable Blue Economy in the Baltic Sea Region and substantially contribute to the achievement of a number of Sustainable Development Goals[1]: New results show that mussel farms in the Baltic Sea can make a significant contribution to reducing eutrophication due to their ability to take up nutrients. If available in sufficient number, mussels can also provide a new sustainable (regional protein) resource for the feed industry or serve as a biological alternative to chemical fertilizers.

In order to take mussel farming in the Baltic to the next level, it is necessary to allow and fund more and larger demonstration sites to be installed in the coming years; to further advance cultivation and harvesting technologies; to gain better data through systematic monitoring and develop a coherent system, which optimizes the way of introducing mussels and the nutrients back into the food system by using them as a resource for feed production. It further needs to be clearly demonstrated to the feed industry that mussels for feed can be produced and delivered in sufficient amount and even bulk flow.

This will not only create a sustainable, circular system linking sea and land, but will also reduce reliance on imports and create a more climate friendly balance between exports and imports of nutrients in food, feed and fertilizers. Mussel farms offer complementary income for local fishermen, farmers and others looking for livelihood in the coastal region. Mussels also supply an ecosystem service by increasing water clarity and light penetration, thereby improving growth conditions for important aquatic plants. At present, the entire volume of the Baltic is filtered by the wild blue mussel population every year. Recent reported decrease in wild blue mussel populations due to invasive species preying on them might in part be mitigated by farming, as also the farmed mussel will filter water, but more importantly, release gametes to the wild. In addition, in all investigated ongoing Baltic mussel farms biodiversity has been promoted under the farm.

Mussel farms should also be allowed to serve as a compensation measure enabling new fish farms to be placed in selected places within the Baltic Sea. With todays' fish production for consumption having collapsed in the Baltic Sea, there is a need for a sustainable fish farming, based on local proteins as well as low content of toxins compared to the concentrations in wild salmon populations. Fish farming on land will have a high need for energy - and thus a high climate impact, and may at the same time discharge nutrients to the environment, whereas fish farming in open cages have a higher discharge of nutrients but a lower consumption of energy. To develop sustainable fish farming in the Baltic Sea Region - this needs to go hand in hand with nutrient mitigation (such as mussel farming) and/or development of plans for renewable energy in the case of land-based aquaculture.

[1] Mussel farming as nutrient-mitigation in the Baltic - contribution to the UN Sustainable Development Goals - analysed by Per Dolmer and Maren M. Lynsgaard, Orbicon, Daenmark.

The need to tackle the internal nutrient load

Over the past hundred years, the Baltic Sea region has built up a large surplus of nutrients including phosphorus (P) and nitrogen (N), mainly through the import of artificial fertilizer, animal feed as well as sewage water. Sooner or later, this excess of nutrients ends up in the Baltic Sea via watercourses and sewage treatment plants where it contributes to eutrophication with overgrown coves, algal blooms and dead sea bottom waters as a result.

More than 40 years of land-based measures have not succeeded in solving these problems. Even if the supply of nutrients from land would come to a halt completely, it would still take many decades before there would be acceptable water quality in the Baltic Sea[2][3]. The legacy of nutrients from previous emissions stored in the sediment, the so-called 'internal load', continues to leak out into the water every day.

In order to realize a recovery of the Baltic Sea within the foreseeable future, measures that actively remove existing nutrients from the water are crucial. What is needed is a comprehensive approach including both the continuation of land-based measures as well as active nutrient removal from the Baltic Sea. In addition to reducing the nutrient input from land, we must create a functional, long-term value chain that is based on the principles of the circular economy including both land and water.

New evidence at hand after three years of mussel farm demonstrations

Several active nutrient removal measures have been proposed in the past, including large-scale dredging, increased fishing of whitefish and locking phosphorus in the bottom sediments with aluminium, for example. Many measures will actually be needed, but at the current stage, only mussel cultivation is advanced enough as to serve as a sea-based measure to contribute to the environmental recovery of the Baltic Sea.

In March 2018, some researchers at Stockholm University published a recommendation not to support mussel farming in the Baltic Sea as an environmental measure[4]; herewith further quoted as the 'Baltic Eye report'. This recommendation reflected earlier uncertainties about production rates, production/harvest cost and on nutrient content at harvest, using data from experimental farms trying to solve new technical and biological factors, i.e. data per default being unreliable and not significant for a developing technology. The Baltic Eye Report also highlighted, as a basis for their recommendation, the lower production rate of blue mussel in the Baltic proper, due to lower salinity, compared to the outer Baltic and North Sea region, with higher salinity.

[2] Murray, C., Müller-Karulis, B., Carstensen, J, Conley, D.., Gustafsson, B. And Andersen, J. 2019. Past, Present and Future Eutrophication Status of the Baltic Sea. Frontiers in Marine Science.
[3] Savchuk, O. 2018. Large-Scale Nutrient Dynamics in the Baltic Sea 1970-2016. Frontiers in Marine Science
[4] Hedberg N, Kautsky N, Kumblad. L and Wikström S. 2018. Limitations of using blue mussel farms as a nutrient reduction measure in the Baltic Sea. Report 2, 2018. Baltic Sea Center, Stockholm University

As will be shown in this report, thanks to more recent work, using more appropriate farming and harvest technology, most of these concerns have been addressed. Furthermore, the focus on comparing high versus low salinity is actually irrelevant. A measure aimed at restoring the Baltic proper must by default be performed in the Baltic proper. Thus, the only matters of concern are; *i*) is the activity competitive with other in situ measures in the Baltic Sea and/or delivers something that other counter measures to eutrophication cannot, *ii*) will the measure have an effect, *iii*) is the activity reliable and predictable and *iv*) can it be applied without causing unacceptable effects to the ecosystem.

This paper, developed by members of the SUBMARINER mussels working group, now presents the current state of the art, based on the evidence provided by several recently finalized EU-funded projects. Their results show that mussel farming can effectively constitute an important and cost-effective complement to land-based measures for controlling eutrophication in the Baltic Sea, and be used as a compensation measure for increased fish farming, if the right technologies are used and proper conditions are in place.

Adapted technology leads to higher production than previously assumed

Salinity is the most important factor determining mussel production in the Baltic. Mussels tend to grow slower in low saline areas, reach smaller sizes and are more likely to be dislodged from where they are growing. These limiting factors must not be ignored, but they do not prevent the possibility of successful mussel farming in the Baltic proper. New data show that the mass of mussels harvested per production unit in the Baltic proper is much higher than previously assumed. Results show that there is no difference in the total amount of mussel meat (dry matter) between mussels cultivated in high or low salinity areas (see Table 1 and Figure 3).

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

Table 1. In this table, data from analyses of mussel flesh from the Western Baltic (high salinity), the Swedish East Coast (medium salinity) and the Baltic coast and Åland (low salinity) is presented. Parameter values that are followed by the same letter show no statistically significant difference between regions.

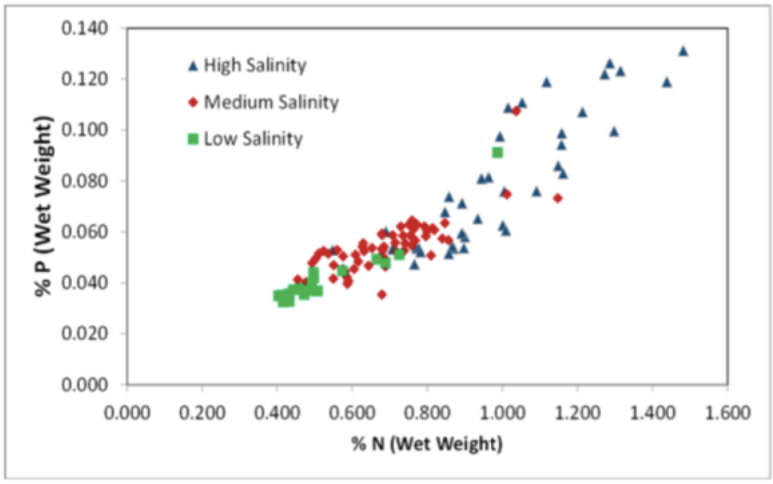


Figure 1. Covariation between dry weight (shell and soft tissue) concentrations of nitrogen (N) and phosphorus in mussels harvest at different levels of salinity across the Baltic. Data are from the Interreg Baltic Blue Growth project (BBG).

The critical 'Baltic Eye Report'[5], published in 2018, was based on technologies that are typically used to produce large mussels in the Western coast of the Baltic Sea. The EU Interreg Baltic Blue Growth (BBG) project has now produced a comparable dataset on nutrients in mussels grown in brackish and salt water. Moreover, it has utilized new cultivation techniques at more advanced Technological Readiness Level (TRL), developed for small mussels like those in the Baltic Sea proper addressing earlier mistakes.

In the BBG farm in the Swedish St. Anna archipelago, a 4-hectare mussel farm was established in 2016 using the new and adapted Baltic Sea mussel technology. An expected harvest of 25 tons was calculated based on earlier results from old technology adapted for large mussels. When the 2-year cultivation cycle ended, almost 80 tons had been harvested: Effectively the farm realised a production of 3-4 kg mussel per running meter of cultivation rope, which is almost 4x more than what was previously achieved in the Baltic Sea and was thereby the first farm under Baltic conditions to produce above expectation rather than below when less appropriate cultivation techniques were used. Even more: the harvest could have actually been even bigger – as not only some ropes were left to follow the environmental impacts, but ropes could have also been placed closer.

The examples of cultivation with the new technology adapted for Baltic Sea mussels not only include the BBG project, but also the Life-IP "Rich Waters" project (in the Stockholm archipelago)[6]. Also in this project, a similar result of a 4x higher than expected production was

[5] Hedberg, N., Kautsky, N., Kumblad, L. and Wikström, S. (2019). Limitations of using blue mussel farms as a nutrient reduction measure in the Baltic Sea. Baltic Sea Centre, Stockholm University.

[6] Video of mussel farm and harvest in St. Anna, Sweden: http://www.vattenbrukscentrumost.se/sv/2018/06/11/ny-film-om-musselodlingen-i-sankt- anna/ and http://novaator.err.ee/634918/24-kilomeetril-koitel-elab-soodav-merepuhastusjaam (in Estonian)

obtained. Actually, here the production was so high that the buoyancy of the test rigs had to be increased continuously so that the large number of mussels would not sink them.

The case for farming blue mussels in low saline areas: nutrient content

In addition to a much higher production than previously assumed, the new data also shows that there is much less of a difference than previously expected between the nutritional content of mussels cultivated in the lower salinity areas (6-7 PSU) of the Baltic proper when compared with those produced in the higher salinity areas (10-12 PSU) of the Western Baltic.

The harvest weight of a mussel includes the shell, the meat and the free water that is found in- and outside of the shell. The mussel meat contains the nutrients such as phosphorus and nitrogen, protein and fat as well as some carbohydrates and minerals. The following figures present seasonal variability and show that the variations of nitrogen and phosphor uptake of mussel farms between low and high saline areas are much less significant. Furthermore, the data suggests that there is a variation in nutrient content seasonally. This means that there could be a potential to increase nutrient uptake by selecting the right harvest period. The averages presented in the figures below may therefore be seen as conservative.

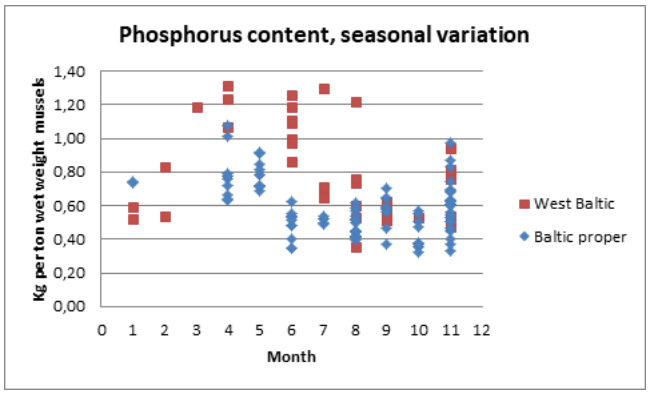


Figure 2. Phosphorus content, seasonal variation.

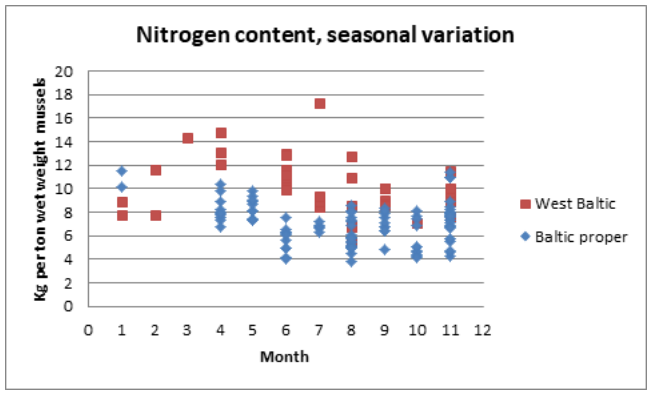


Figure 3. Nitrogen content, seasonal variation.

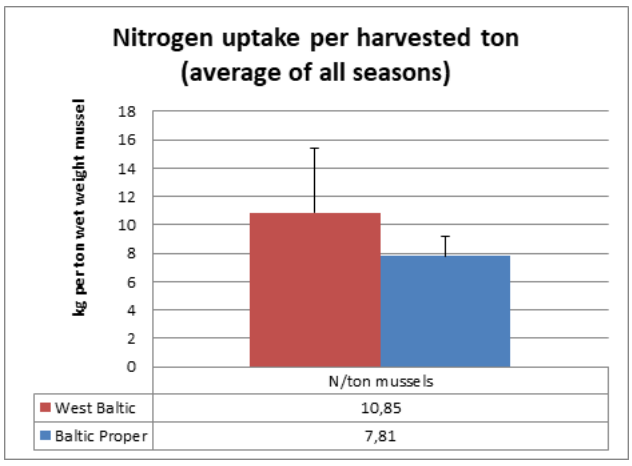


Figure 4. Nitrogen uptake per harvested ton.

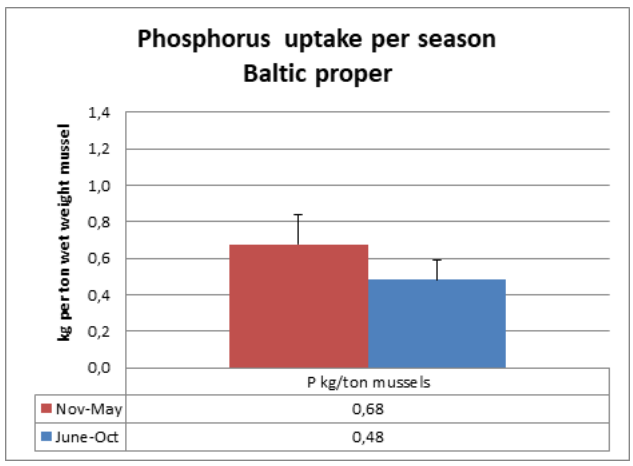
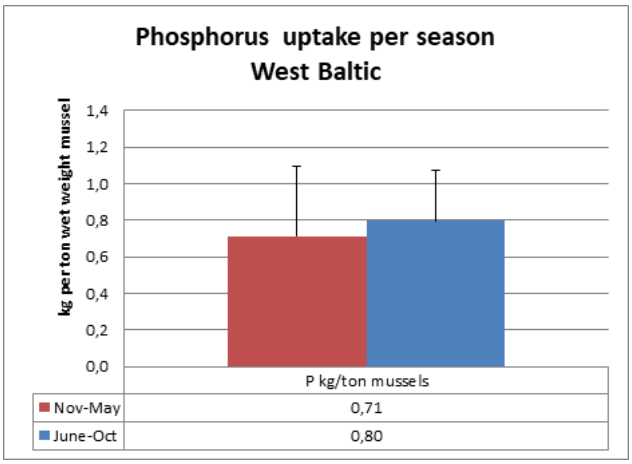


Figure 5. Phosphorus uptake per season Baltic proper



The farms considered in the calculations that Figure 2-6 are based on include: Kiel, Kalundborg, Musholm and As Vig in the West Baltic, Tillöglorna, Genböte Rågholmen, Köpmanholm, Tjockö, Erstaviken, Torskholmsgrynnan, Norrör, Åland, Pavilosta, Vormsi, St. Anna, Hagby, Byxelkrok and Västervik in the Baltic Proper. They are considered in the projects Baltic Blue Growth (2019), Life IP Rich Waters (on-going) and Kombi-Opdraet (2015).

Figure 6. Phosphorus uptake per season West Baltic

Mussel farms, situated in areas where nutrient removal is most important, are therefore much more effective than previously expected when considering content and production efficiency. Also, the new data allows a much better prediction of nutrient removal by farms in different areas and seasons.

The minimal differences between the nutrient content of mussels cultivated in high or low saline areas, has probably to do with the percentage of soft tissue of the total harvest weight. Since the results have shown that there are no differences in the nutritional content of the mussel meat from farms in low and high salinity areas, and we know that the shells of larger mussels (found in high salinity areas) are heavier than those of smaller mussels, the difference are most likely due to the fact that smaller mussels from Sweden's East Coast contain a greater proportion of free water in and around their shells.

New evidence also shows positive impact on sediments

For some time there has been concern that mussel farms in the Baltic proper may cause sedimentation of organic material, which may lead to hypoxic or even anoxic conditions. New results show that sedimentation from mussels was highly local and less than expected, and that no oxygen depletion in the near-bottom waters were caused by the mussel farming. The content of nutrients and carbon in the sea bottoms were about the same at the mussel farms and in reference areas not affected by the mussel farming. Studies showed that the benthic communities had higher species richness in and around the mussel farms. Sedimenting shells and mussel faeces seem to benefit the biodiversity under the farms. This effect has also previously been investigated at the Åland mussel farm[7].

Apart from removing nitrogen and phosphorus from the water, mussel farms also provide a clearer water body by filtering out particles from the water. The greater visibility at depth improves the breeding grounds for fish by promoting the growth of macro-algae and bottom-

[7] Kraufvelin & Diaz. 2015. Sediment Macrofauna communities at a small mussel farm in northern Baltic proper. Boreal Envir. Res. 20: 378-390

living plants. Studies on key environmental variables in and around mussel farms show that the environmental impacts of mussel farms in the Baltic Sea were highly positive. Nutrients were removed from the water phase and an underwater video recording showed a clearer water due to the filter feeding mussels.

To conclude, mussel farming can be seen as a sustainable way of removing excess nutrients in the Baltic Sea. Any negative impacts of mussel farms are likely to be minimal when placed in suitable locations. It is, however, highly important to continue the environmental monitoring at the mussel farms with the focus on bottom conditions, e.g. oxygen levels and benthic fauna.

Location, location, location … and husbandry

The number of mussels produced by farms in the Baltic proper are heavily influenced by a number of environmental conditions, including food availability, temperature and movement of the water, as well as the occurrence of predators such as Eider ducks and starfish. Through the BBG project and its five mussel farms pilots, it became clear that numerous areas are simply unsuited and that the selection of the appropriate site is crucial for the success of a mussel farm.

Site selection needs to be driven by the environmental conditions as to avoid potential negative consequences as well as by the need to determine the purpose of the mussel farm; e.g. whether it should be placed in a nutrient hot spot as an environmental measure or whether it should serve as a compensation measure for an expanded or new fish farm. **In short: mussel farming is not 'the' solution for all sites in the Baltic proper; but may be a good measure and/or maritime activity in well selected locations.**

Mussels feed on microalgae in water, which depend on the availability of nutrients and the temperature of the water. Also, the level of water exchange and the turbidity are highly important: too high or too low may mean lower phytoplankton availability. It is therefore recommended to also see whether wild mussels are located in a specific area, since this is an indication that enough microalgae are available for the mussels to grow.

The **Operational Decision Support Tool** (ODSS), a computer tool developed by BBG, provides initial guidance to identify possible locations for mussel farming. The tool will be continuously updated with the latest information on a range of issues relevant to mussel growth potential, including salinity levels, food availability and information on oceanographic challenges. Moreover, the ODSS also shows the spatial allocation and intensity of other human uses such as fisheries or maritime traffic to avoid any potential conflicts with the existing uses of the Baltic Sea.

At the same time logistical issues drive up the costs of running a mussel farm: both for maintenance and harvest, a farmer needs to send out vessels for inspection and maintenance

of the farm, putting out buoys, sampling and harvesting. Placing a farm closer to a harbour may reduce such logistical costs. An alternative considered is the possibility of remote surveillance and control, reducing intensity of visits to the farm or visits during bad weather conditions.

The BBG pilot farms have also shown that the structure of a farm (including the anchoring, flexibility, buoys etc.) and logistics (frequent inspections, adjustments, accessibility, transport etc.) must be investigated properly before a new farm is installed. It is indeed a risk that mussel farming in the Baltic Sea proper may be more difficult since smaller mussels may dislodge from the substrate if there are rough weather conditions such as large waves, strong underwater currents, strong winds and winter ice. Project results therefore recommend that mussel farmers in the near future, until better offshore technology is developed, select locations in more sheltered areas to prevent such dislodging, increase production and keep down costs.

Overall, the new results show that production costs, and thus the cost of recycled P and N, approaches the costs seen in salt water harvest, with the potential for further cost reduction by adopting work-saving technologies, including video surveillance (see above). Furthermore, costs can be further reduced by collaboration between farmers purchasing larger volumes, or sharing harvesting equipment, transport or processing technologies.

Bigger farms are more efficient and have stronger protection against rough weather, but there are also downsides like high investment, maintenance and equipment costs. Smaller farms often have high production costs and related lower efficiency, but at the beginning a smaller farm may be easier to manage.

Production costs and ecosystem service payments

As shown above, the investment and operational costs of mussel farms depend on their location and size. Currently, the costs for single farmers within the Baltic Proper are still too high in comparison to income that can be generated from selling the mussels on the non-food market (e.g. as fertilizer, biogas or feed resource), but they are expected to drop substantially when more farms are installed. This is due to knowledge gains as well as the opening of a market for mussel feed once a sufficient and reliable quantity of mussel production can be guaranteed.

As the target for reduced nitrogen- and phosphorus-levels in the Baltic Proper is not reached at present, further measures are necessary. In this context, mussel farming can be cost-effective even in brackish water. Although mussels grow better in salt water, it is in the Baltic Proper that mussel cultivation must be carried out to realize maximum benefits. Other measures that aim to reduce the level of nutrients in the Baltic Sea, such as wetlands or water treatment facilities, can currently receive ecosystem service compensation. This should also be the case for farms producing mussels for the feed or fertilizer market.

The table below shows that even under the current conditions, the amount which would need to be paid for a mussel farm as an ecosystem service provider for nutrient removal, is within the range of land-based nutrient reduction measures. **Taking the BBG pilot farms as a baseline, the cost-efficiency of mussel farming for nutrient uptake is on a medium level compared to other measures, depending on locational factors**. Whereas earlier studies undertaken by the Kalmar municipality on the basis of their mussel farms situated in the Kalmar Sound indicated a cost of 43 €/kg N uptake, the newest data based on the BBG St. Anna test farm show a much lower payment need of 19-25 EUR/kg N and 250-500 EUR/kg P in order to allow a financially viable operation of mussel farms in this region under current conditions. The range of figures derives from different scenarios assuming either no further support; some start-up support and finally a growing market for mussels to be used in the feed industry.

Measure	Costs (€/kg reduced N)
Catch Crops	0,3 – 41,6
Intercrops	7,5 – 13,7
Reduced Fertilization	15,7 – 27,1
Buffer Zones	9,9 – 34,9
Set Aside Farmland	20 – 69,7
Mussels	13 – 42

Table 2. Comparison of mussels with other measures for nutrient reduction.

For mussels to be used for human consumption, production costs can reach up to 0.60 or 0.70€ per kg in order to financially viable. In the case of producing mussels for feed rather than human food, production costs – under current market conditions – should not exceed a maximum of 0.10€ per kg.

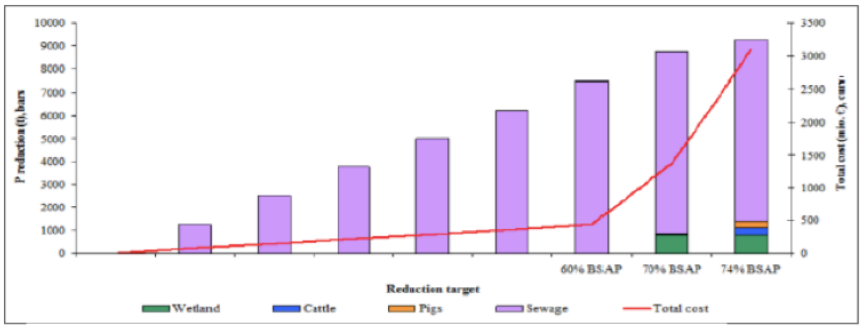


Figure 6. Cost-curve and P reductions in Baltic Proper by measure (HYYTIÄINEN ET AL., 2014).

Within the NutriTrade project, data on planned mussel production and production costs have been collected from projects in the Baltic Proper and in Denmark. Analysis of these data shows that if farm equipment is used throughout its lifetime, the cultivation cost amount to 0,47€ per kg of whole mussels harvested. In this calculation, no future cost efficiency improvements have been considered, nor have possible scale effects on production cost been considered. This means that **the cost of using farmed mussels in suitable locations to remove nutrients from the Baltic Proper, even with the current evidence base, will be lower than those of some measures that receive support via rural development programmes**

today. Also, a recent study, originating from the Bonus project "Optimus" concludes that mussel farming is a highly competitive mitigation measure in the Baltic proper[8].

To date, no operational ecosystem service payment scheme exists, while numerous studies have shown that there is high willingness to pay among the general population for the services provided by mussel farming, especially when it comes to achieving cleaner waters; avoiding harmful algal blooms or improving fish species composition. A study undertaken within the BBG project has shown, that already today the national European Maritime and Fisheries Funds (EMFF) can be used to support investments and other cost associated to install mussel farms throughout the Baltic. However, they do not provide for an ongoing payment scheme to sustain the operational costs. For these new forms of ecosystem service payments have to be ensured as to bridge the time gap until a sufficient number of mussel farms allows for a fully developed feed market to be established.

A potential way of realising such ecosystem service payments for mussel farms, is to target beneficiaries of the services, including the coastal regions, private philanthropic organisations, crowdfunding (including the NutriBute Platform) or targeting companies that may include the financing of mussel farms as part of their Corporate Social Responsibility strategies. **A pre-condition for such schemes to realise is the certification of the given ecosystem service**: Mussel farms have to prove – through commonly agreed and monitored data and indicators – that they actually provide the ecosystem services they are paid for. However, the burden for such proof should not only be placed on them, but be covered by society as a whole.

Producing small mussels for the feed industry

Although there are certain limiting factors, mussel farming in the Baltic proper with the aim of nutrient reduction and feed production, must be further adjusted in terms of technologies applied and a sustainable market must be created in the feed industry. In order to realize this, however, a certain number of mussels must be produced relatively consistently – otherwise the feed industry cannot justifiably get involved. The development of mussels as feed ingredient would reduce the need to import feed ingredients from outside the Baltic Sea Region and would result in the reuse of nutrients in a local nutrient loop. Again, the raw material would need to be available year-round in large volumes and at a reasonable price to maintain a stable feed production.

Under the BBG project, two studies were undertaken to show potential breeders and the chicken industry how mussels from the Baltic proper could be used as a protein source in feed for poultry. The studies were conducted at a breeding and feed development facility in cooperation with a feed producer. The studies showed that **mussel meal is an interesting raw**

[8] The economic value of mussel farming for uncertain nutrient removal in the Baltic Sea, PLOS ONE, juni 2019, doi.org/101371/journal.pone.0218023, https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0218023

material and a feed ingredient with no deviance from reference feed containing soy protein, with regard to growth and health of the chickens.

Furthermore, analyses of unwanted substances were conducted on mussels, mussel meal and chicken tissue (muscle and liver), in order to map any transportation of hazardous substances through the food chain. The substances were mapped with regard to EU food and feed regulation. **No substances on either mussel, mussel meal or chicken tissue were found that exceeded the limits of the regulation**.

The Baltic blue mussel could also act as a high-quality protein source in animal feed through a different production method. This approach relies on a biological separation through the use of the black soldier fly and larvae processing. With this method, the blue mussels should be grinded after they are harvested. In the treatment, two products are generated: fly larvae, that can be refined into fish feed, and treatment residue, that can be used as an organic fertilizer. The economic evaluation performed within BBG of this process route indicate that it will not be economically feasible using only mussels, as the shell makes the density of organic matter to low. However, recent studies within BBG[9] show that mixing Baltic small mussels with other pre-consumer waste, as bread returns, improved significantly efficiency and nutrient content of the larvae. These results are now included in several research and industry-based projects towards fish and poultry feed[10].

Conclusion

New results show that mussel farming in the Baltic is a promising tool for reducing marine eutrophication and an important complement to land-based measures. To promote the further realisation of viable mussel farms in the Baltic proper, **it is crucial that they are officially accepted as a nutrient mitigation tool** – either to be used as an additional environmental measure to combat eutrophication or as a compensation measure enabling sustainable fish aquaculture. In all cases this is to be based on careful site selection.

Denmark has already acknowledged the value of mussel farming as a nutrient removal measure. In 2017, the Danish Folketing adopted a law on 'Compensating marine measures for the licensing or expansion of offshore fish farms'; so far, the law is, however, not operational yet. A new Danish government took office June 27 – 2019. The Minister of Environment has on August 26 - 2019 decided, that she will **not** implement the law. Her message is that she does not want more off shore fish farms.

[9] Fatty acid composition of the black soldier fly larvae (Hermetia illucens) – limitations of modification through diet. Ewald et al, to be submitted.

[10] Five-ton sustainable fish in the counter, a 1:1 split between industry and the Swedish Innovation Agency (Vinnova). Budget 2 million euro for 2.5 years. Development of Swedish based circular feed to fish. Financed by the Kamprad foundation. Budget 0.5 million euro for 4 years. Feeding live insect larvae to laying hens – A locally produced, novel environmental enrichment to promote natural foraging behaviour, reduce feather pecking and replace imported proteins in the diet. Financed by Formas research council, Sweden. Budget 300.000 euro.

The Nordic Council of Ministers has recommended mussel farming to combat eutrophication, as well as the Norwegian MOM system for aquaculture (HELCOM minutes).

What is needed is a dedicated, systematic support – based on a jointly aligned approach with land-based measures - to enable more and larger demonstration sites; coupled with a cooperation scheme between the operating farmers, accompanied by a strategic research & innovation programme to continuously achieve technology improvements, a monitoring programme on a range of aspects as well as alternative support such as joint business planning, certification, labelling and Baltic-wide marketing campaigns.

Recommendations

1. Complement land-based measures with appropriate marine actions for nutrient removal

Despite decades of land-based measures, the total amount of nutrients in the Baltic Sea is not decreasing sufficiently, which shows that the rate of action is too slow and that the effects of internal fertilization are extensive. If we are to achieve our national and international Baltic Sea environmental goals, measures such as mussel farming, which also reduce the nutrients that have already leaked from land to sea, are therefore required.

2. Accept mussel farming as a nutrient mitigation and/or compensation measure

Despite all evidence showing that mussel farming is even under current conditions at selected sites a cost-efficient and effective nutrient mitigation and/or compensation measure for fish farms, this has not turned into political reality yet. What is also needed, is a generally accepted certification scheme using agreed indicators based on standardized monitoring data.

3. Invest in more and larger farms to increase knowledge of the environmental effects

To date, no significant environmental impacts have been observed from mussel farms in the Baltic Sea. On the other hand, positive effects such as improved visibility, reduced nutrient levels and increased biodiversity have been observed repeatedly. However, today's mussel farms are small and in order to ensure environmental benefits, the effects need to be *measured on more and larger crops according to standardized methods.*

4. Invest in more and larger farms at strategically selected sites to allow development of a feed market

Currently the development of the feed market is mainly hampered by the fact, that there is not sufficient and stable supply of mussels. Such supply can only be created through a systematic and cooperative approach between several farms; which at same time should be located at carefully selected sites, e.g. nutrient hot spots, which at same time also meet other criteria.

5. Identify and optimise appropriate technology development

A number of small-scale projects have tested and developed methods for the special conditions of the Baltic Proper and in less than 10 years, among other things, the harvest has been increased by several hundred percent. These new data indicate that we approach the

predicted potential for mussel production. It is likely that upscaling and continued technology development can further contribute to even higher production and lower costs.

6. Pick most optimal location – transport, salinity, exposure, biological conditions

The ODSS developed under the BBG project provides for a useful set of site selection criteria, to be coupled also with logistical aspects. It can be used as the basis for a comprehensive site selection plan across all Baltic Sea States.

The future of Baltic Sea Mussel Farming

The data that is now available after five years of simultaneous projects researching the possibilities of mussel farming in the Baltic proper for nutrient removal and feed production, show positive results that encourage continued monitoring, cooperation and scaling up.

The SUBMARINER Network has launched a Mussels Working Group to further research, promote and cooperate across the Baltic mussel production chain. A group of BBG farmers have agreed to continue cooperation, to work on joint monitoring standards and to share and publish their data. The Working Group will also continue working on legal issues and potential certification of mussels. If you want to learn more about mussel farming in the Baltic or (how you can join) the Mussels Working Group, visit submariner-network.eu/mussels.

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