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BalticSea2020

MUSSEL FARMING AS AN ENVIRONMENTAL MEASURE IN THE BALTIC

FINAL REPORT

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Preface

One main objective for BalticSea2020 is to contribute to reduced eutrophication in the Baltic Sea. Cutting the anthropogenic loads of nutrients from agriculture, intensive livestock production and waste water are fundamental actions for this objective. Unfortunately it will take a long time before the effects can be seen and measured as improved water quality.

This project has investigated the potential to speed up the recovery process by using mussel farming as a measure to harvest nutrients in the Baltic and recirculate them on land. This has been done successfully on the Swedish west coast. Unfortunately the challenges seem much larger in the Baltic.

We hope that the experiences from this project will be useful for other actors who consider mussel farming as an environmental measure in the Baltic Sea.

Stockholm in March 2012

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Summary

The main objective of the project was to investigate if mussel farming is a cost-effective environmental measure in order to remediate eutrophication and improve coastal water quality in the Baltic. A sub goal was to adapt and optimise the farming- and harvesting technique for the small and fragile mussels of the Baltic. Another sub goal was to investigate if farmed Baltic mussels can be utilized as feedstuff and replace fish meal as a sustainable high protein source in organic feeds, e.g. for layers.

All the goals and objectives were unfortunately not reached. The main reason for this failure was the two cold winters in 2009 – 2010 and 2010 – 2011 with thick ice and ice drift which caused disturbance, loss of settled mussels and damage and loss of farming equipment. An important conclusion of this adversity was that future mussel farms in the Baltic must be able to manage ice and ice drift, most probably through lowering the farms below sea surface.

Three years was a too short project time in a new area like the Baltic to fully demonstrate the potential of using mussel farming as a measure to counteract eutrophication and improve coastal water quality. At least another three years would be needed. However, the obtained results indicated that it should be possible to reach a biomass of mussels of about 150 ton ha^{-1} in 2 to 2.5 years in the Kalmarsund area and about 100 ton ha^{-1} the Hållsviken area. Further, it should be possible through harvest of the mussels to return about 0.12 ton ha-1 of P and 1.8 ton ha^{-1} N from sea to land in the Kalmarsund area and about 0.08 and 1.2 ton ha^{-1} of P and N respectively in the Trosa area.

A risk assessment of farmed mussels from the Kalmarsund area clearly demonstrated that the concentrations of analysed elements in the soft tissue and the shells were safely below the regulatory limits for use in feed or fertilizer. Further, the study showed that all measured contents of organic contaminants also were clearly below regulatory limits.

There is an ongoing interest to use mussel farming for remediation purposes in the Baltic and to use the mussels for feed (both poultry and fish) and biogas production. Some of the experiences and results gained during the project have already been translated into new projects and activities within the Baltic area.

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Introduction

The nutrient emissions coming from agriculture, rural living, the atmosphere and many other diffuse sources increases coastal primary production leading to increased biomasses of both filamentous algae and phytoplankton. Coastal eutrophication is one of the main environmental concerns in the Baltic, as well as in many marine areas, which needs to be remediated. Phytoplankton is the main feed for mussels and consequently mussel farming and harvest has since the 1980's by scientist been recognized as a possible measure to improve coastal water quality (e.g. Ryther *et al.*, 1972; Haamer *et al.*, 1999; Edebo *et al.*, 2000; Newell, 2004; Lindahl *et al*, 2005; Lindahl, 2011). One kg of live mussels can return 8.5 – 12 g of nitrogen (N), 0.6 – 0.8 g of phosphorous (P) and about 40 -50 g of carbon (C) from sea to land when harvested (Lutz, 1980; Petersen and Loo, 2004; Syversen, pers. com.).

In marine areas mussel farming is first of all a sustainable production of healthy and valuable sea food (Smaal, 2002). However, the Baltic blue mussel is generally too small be used as traditional seafood. Consequently, in the Baltic mussel farming must focus on the harvest of mussel biomass to be used for other purposes like feedstuff or biogas production/fertilizer. It should be pointed out that the commercial value of the products from the mussel farming in the Baltic generally will not cover the full production cost. Thus mussel farming as a remediation tool in the Baltic will have to rely on that the mussel farmer in some way gets paid for the environmental service provided (Lindahl and Kollberg, 2009). This in turn presupposes that political decisions are taken, probably at the level of the European Community.

It may be noted that "farming" a mussel is an incorrect expression since you do not have to add any seeds, larvae or spat. Further you do not add any fertilizer or feed. The blue mussel and its food intake are based on natural resources regardless if it is wild or "farmed". The bands, ropes, nets or whatever substrate which is offered to the mussel larvae to settle and grown on can be compared with e.g. ranging wild deer by fencing an area. Therefore, it has been suggested that "mussel farming" instead should be called "mussel ranging" (Lindahl, 2011).

Aim and activities of the project

The main aim of the project was to test if mussel farming could be used as a cost-effective environmental measure in the Baltic in order to improve coastal water quality. The sub goals of the project were the following:

- To adapt and develop the farming- and harvesting technique for the special conditions of farming mussels in the Baltic by using coarse nets.
- To investigate if farmed Baltic mussels can be utilized as feedstuff and replace fish meal as a sustainable high protein source in organic feed for e.g. layers.
- To explore if mussel farming can create new jobs for fishermen in Poland.
- Finally, to make use of the media interest in mussel farming and the Agro-Aqua recycling of nutrients in order to demonstrate and market that trading nutrient discharges is a simple and effective management tool for society to improve coastal water quality in the Baltic.

The main activity was to launch and test large scale mussel farms at two sites on the Swedish east coast and to use these to demonstrate that mussel farming can be used for improving coastal water quality in the Baltic by recycling phosphorus and nitrogen from sea to land.

The original plan was adjusted after the ice damage of the first winter where the number of farm units at Hagby location in Kalmarsund was reduced by half. A second adjustment was made after the second winter when all units at Hagby were lost. Finally, the mussel meal and feed production tests had to be cancelled due to lack of mussels (the biomass on the remaining units at Hållsviken in Trosa area in June 2011 was too small to be profitable to harvest).

Material and methods

Farm sites and farming equipment

Large scale mussel farm equipment, made by Smartfarm® in Norway (www.smartfarm.no), were launched in June 2009 at Hagby Hamn (N 56°33,51, E 16°14,08) in south Kalmarsund (10 farm units) and in Hållsviken (N 58°49,34, E17°31,69) south of Trosa (4 farm units).

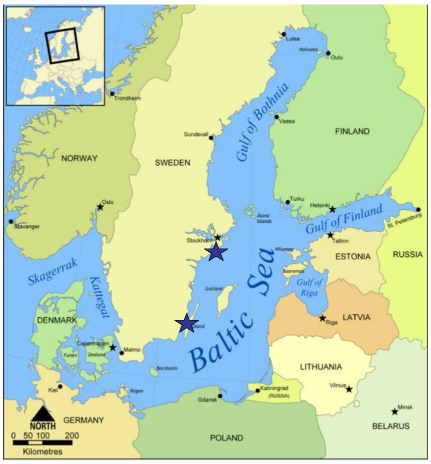

Figure 1. The blue stars show position of mussel farm trials of the project. Hållsviken at the top and Kalmarsund below.

Each farm unit was 125 m long and was anchored two by two. The farming nets were 4 m deep and used ø 250 mm PVC-pipes for floatation. Each net were made of rope of different thicknesses (10, 12 and 14mm) and with three different mesh sizes (100x100, 125x125 and 150x150 mm) in order to study the effect of mesh size and rope thickness on growth and development of biomass and other variables of interest.

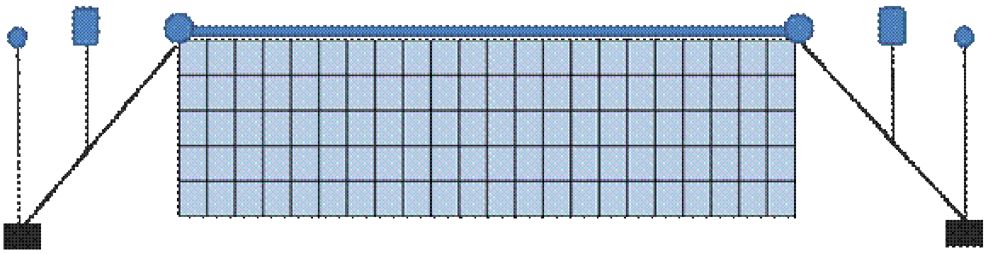

Figure 2 The schematic principle of a mussel farm unit using a net for settling of the mussel larvae and growth of the mussels and a pipe for flotation.

Figure 3. Four farm units anchored two by two in Hållsviken.

Mussel biomass analyses

Samples for mussel biomass estimation were taken from the nets by a diver on two occasions. Samples were also taken when farm units were lifted due to repair and when the project was terminated. Each sample was made up by all four sides of a mesh, or by a two or one side of a mesh, depending on the density of attached mussels. Subsamples of between 200 and 500 mussels were taken out of each sample and the number of mussels in five size classes was counted. Some selected samples were also weighed for biomass estimation. Finally, all subsamples data were recalculated to m^{-2} farm net in relation to the different mesh size and rope thickness of the nets, where after the biomass per m farm unit could be calculated.

Results and discussion

Assembling and launching the farm units

To assemble and launch mussel farm units according to the used concept an open space and 3 – 4 m water depth at the waterfront are required, as well as power, a forklift or a mobile crane.

***Figure 4. Top:** The PVC pipes (in 12 m lengths) used for flotation is welded together inside a container. **Middle:** the net is stuck on automatically when the pipe is ejected and with Kalmar Castle in the background. **Bottom:** The farm unit is launched directly into the water.*

The Smartfarm technology, as well as other similar systems, requires a steady work vessel with a large working deck, and a powerful crane and winch of good capacity. These are important requirements in order to launch and anchor the farm units safely and in a controlled way. Surprisingly, there are a limited number of available vessels in the Kalmar and Trosa areas which fulfil these requirements. Looking in retrospect it may have been better to have performed the farm trials at Hagby and Hållsviken by using a "lighter" farming technology which can be more easily handled from smaller and less sophisticated vessels.

***Figure 5.** The transport of an anchor and anchor chain from Hagby Hamn to the farming site, situated 0.5 nautical away and behind the anchor in the background.*

One of the greatest challenges was to launch and anchor the mussel farms due to lack of useful vessels. The lack of locally available vessels with capacity to easily carry out repairs on the farm units, re-anchoring, salvage and reparation of wrecked units and finally the termination of the surviving units turned out to be an unexpected problem.

Once the farm units were in place, supervision could be carried out by using a smaller boat, but roughly once a year the anchors needed to be stretched which required a more powerful vessel. Under water inspection of nets, buoys, shackles and anchor ropes as well as sampling of mussel biomass were best performed by a diver.

Figure 6. First inspection of settled larvae, August 2009.

Ice and ice drift

The winters 2009 – 2010 and especially 2010 – 2011 were unusually cold involving thick solid ice as well as drift ice at the farm locations. Especially in Kalmarsund, the heavy drift ice turned out to be disastrous for the farm units, with a lot of damage after the first winter, and a complete break down during the second winter, although measures had been taken after the first winter in order to improve ice performance. An obvious problem first winter was that anchors (150 kg each) were too small which resulted in dragging of the farm units. This was solved before second winter by Smartfarm who added heavier anchors (350 kg) to the first ones. Also the large surface buoys were replaced in Kalmarsund after the first winter to a type which should withstand ice and ice drift better. The Smartfarm nets and flotation pipes worked well and those in Hållsviken had no signs damage although thick ice during two winters.

Figure 7. Top: Farm units in frozen disorder in Hållsviken.
Bottom: Broken farm units after first winter in Kalmarsund.

The experiences made during the first winter of the effects of Baltic ice on farm units were used when moorings and buoys were designed for a mussel farm trial at Kumlinge in the east part of the Åland archipelago. This farm survived well during the hard ice winter 2010 – 2011, and is still doing well, which demonstrates that technical improvements is a part of the solution for successful mussel farming in the Baltic.

Ice was listed in the risk assessment of the project, but not at the scale which occurred during the winters in 2009 – 2010 and 2010 and 2011, and especially the drifting ice in Kalmarsund. As a result, it must be strongly stated that lowering of farm units during winter below surface or a complete sub-surface farming is a necessary future development. The two leading companies selling mussel farm equipment in Europe, Smart farm and Kingfisher, are both at present developing equipment to enable lowering of the farm units below the sea surface and the ice.

Thus, the most negative lesson of the project was the problem with ice and ice drift. The lesson is of course that the used farm methodology was not good enough to survive the harsh ice conditions which may occur in the Baltic now and then. However, it should be noted that the ice cover 2011 was the worst for 25 years (SMHI, 2011). The result of the mussel farm trials, especially in Kalmarsund, should most likely have been much more successful if "normal" winters had been prevailing.

Settling, growth and biomass

Altogether 47 samples from five different sampling occasions were analyzed regarding number and size of mussels (tab. 1). The biomass was calculated on four occasions. The outcomes of the settling of mussel larvae was first studied in early June 2010 on farm units which still were intact after the ice impact. At Hagby, a high settling of mussels had occurred and a large number of mussels were growing on the nets. Most of the mussels were smaller than 10 mm, but there were also a small amount of up to 15 mm in length. On the nets in Hållsviken, the number of the smallest individuals was roughly the same as at Hagby, but there was less than half the number of the size class 5 – 10 mm and no bigger ones. The growth had, as expected, been better in Kalmarsund compared to Hållsviken, probably due to slightly higher salinity and stronger water currents.

Figure 8. *Diver taking samples in Hållsviken.*

In June 2010 an older and smaller pilot test net was also sampled (mesh size 200x200 mm, 10 mm rope, 3 m deep), also situated at Hagby but closer to the shore (no drift ice). The first settled mussels on this net were about 2 years old and ready for harvest (Fig. 9). From one single sample of mussels it was estimated that the number of mussels was about 32 000 m^{-2}, of which 2/3 were in the size range 10 – 20 mm and 2 300 individuals up to 25 mm. The calculated biomass was 14 kg m^{-2} or more than 40 kg m^{-1} net length. This sample was the best of all sampled and showed clearly that mussel farming on a net is a possible technique in the Baltic.

***Figure 9**: The pilot test net with a large biomass when sampled in June 2010.*

Table 1. Summary of farm trials at Hagby Hamn and Hållsviken. Sample "Hagby pilot" was sampled from a smaller and older pilot test net. n is the number of samples. The numbers of mussels of five size classes are given per m^2 net. The biomass is expressed in kg m^{-2} net.

Site	Date	n	0-5 mm nr. m^{-2}	5-10 mm nr. m^{-2}	10-15 mm nr. m^{-2}	15-20 mm nr. m^{-2}	20-25 mm nr. m^{-2}	Bio-mass kg m^{-2}
Hagby Hamn	2010.06.02	15	21900	22900	1500			
Hagby Hamn	2010.10.14	2	2500	8300	20400	8500	600	10.1
Hagby pilot	2010.06.02	1	3800	5200	10200	10800	2300	14.0
Hållsviken	2010.06.01	12	23100	9200				
Hållsviken	2011.05.31	9	480	740	800	440	90	0.9
Hållsviken	2011.11.10	8	55350	16400	5075	980	450	4.0

A second check of the development at Hagby was carried out in October 2010. It was then found that the number of mussels had decreased by 13% compared to in June, but the mean size of the mussels was considerably larger (Tab. 1). Half of the mussels were 10 – 15 mm long and there were also some few larger than 20 mm indicating good growth. The biomass of this 1.5 year old mussel population was calculated to be 10 kg m^{-2} net or 30 kg m^{-1} net length (the top m of the net not included due to ice damage).

The next sampling was carried out in late May 2011, but only at the farm site in Hållsviken due to the fact that all farm units of the project at Hagby had been destroyed during the second winter. Of the large number of mussels m^{-2} one year earlier, very few were still on the nets and together with large amounts of barnacles. Dominating size range was 10 – 15 mm and there were also a considerable number of the size range 20 – 25 mm. The most probable explanation to the loss of mussels from year one to year two was that one or two of the four moorings had dragged, which caused that the farm units for some time chafed against each other before the units could be re-anchored in March 2011. Another possible explanation for the loss of mussel biomass was grazing of vendace (in Swedish "sik"), which had been observed to occur on mussel farm bands exposed in St. Anna archipelago (Mats Emilsson, pers. com.).

Last sampling was performed when the mussel farm trials was terminated in Hållsviken in November 2011 (Fig. 11). On this occasion a large number of mussels were found of which the majority was less than 5 mm, e.g. the result of a strong settling during summer 2011 (Fig. 10). However, about a quarter was of size range 5 – 15 mm and some few were as big as 15 – 25 mm. The biomass of mussels was calculated to be 4 kg m^{-2} and totally 7.5 kg m^{-2} if the biomass of barnacles also were included. This means that 6 ton of mussels were harvested at the termination. An interesting observation made during the termination was that the anchor lines were completely covered of mussels down to about 15 m depth (Fig. 10). This can serve as an indication that lowering farm unit may not result in a reduced settling, slower growth or smaller biomass of mussels.

***Figure 10, Top:** A considerable biomass of mussels and barnacles were growing on the net at the termination in November 2011 in Hållsviken.*
***Bottom**: Large abundance of mussels down to ca 15 m depth on anchor lines.*

The obtained results (table 2; 35 kg m^{-1} farm unit resulting in 150 ton ha^{-1}) indicated that it should be possible in Kalmarsund to farm a biomass of mussels according to an assessment presented in a Swedish EPA report on a nutrient emission permit fee system (SEPA, 2010a). In this assessment, the potential of mussel farming as an environmental measure in Swedish marine and brackish coastal waters has been estimated. According to the same assessment for Hållsviken the biomass should reach 25 kg m^{-1} or 100 ton ha^{-1}, but this was, unfortunately, not possible demonstrate during this project.

*Figure 11. **Top**: The termination required a large vessel with a big crane.*

M/S Fyrbyggaren of the Swedish Maritime Administration was perfect.
***Middle**: The large deck was necessary to accommodate all equipment.*
***Bottom**: Harvesting was a dirty job. Project leader standing to the right.*

Nutrient harvest estimation

One kg of live mussels contains 8.5 – 12 g of N, 0.6 – 0.8 g of P and about 40 -50 g of C (Lutz, 1980; Petersen and Loo, 2004; Syversen, pers. com.). The biomass of mussels on the nets at the termination of the farm trial in Hållsviken was calculated to be 6 ton. By using the nutrient content given above it was calculated that about 70 kg of nitrogen and 5 kg of phosphorous could be returned to land through the harvest. These small amounts were of course far from what was planned. However, based on the few results of measured mussel biomass (tab. 1) and the nutrient content given above, it seemed realistic to assume that a nutrient harvest in range with the values given in table 2 should be possible.

Table 2. An estimate of farm potential per m farm unit and hectare, the meat content and the resulting content of nitrogen (N) and phosphorous (P) at the two project farm sites based on project biomass results and data in Swedish EPA report (SEPA, 2010a).

Coastal area	Biomass per longline or pipe kg m^{-1}	Estimated harvest per ha farm area ton ha^{-1}	Mussel meat content %	Estimated amount N ton ha^{-1}	Estimated amount P ton ha^{-1}
Kalmar Sound	35	150	30	1.8	0.12
Trosa area	25	100	30	1.2	0.08

Mesh size and rope thickness for biomass development

There was no significant difference in the amount of mussels m^{-2} of the different mesh sizes and rope thicknesses tested. On the other hand, the data set on mussel density in relation the different nets was probably too short in time and too few samples could be taken to be able to really demonstrate if one combination of mesh size and rope thickness was better than another. However, a smaller mesh size in combination with coarser ropes reduces the water flow through the net and thus the food supply to the mussels; furthermore the net becomes heavier and more expensive due to that more material is needed. Thus, until further notice, it can be suggested to use a mesh size of about 150x150 mm and rope thickness of 10 – 12 mm for mussel farming in the Baltic.

Risk assessment of using mussels from the Kalmarsund area as feedstuff and fertilizer

A risk assessment was compiled based on an existing report from a previous study on the occurrence of environmental contaminants in blue mussels from the Kalmarsund area (Nilsson, 2009), in relation to existing Swedish regulations for limits of contaminants for use of the mussels as feedstuff or fertilizer (Kollberg and Ljungqvist, 2005).

The sampled blue mussels used in this risk assessment was farmed at Ljungnäs situated about 20 km north of Kalmar and at Kungsholmen close to Mönsterås and the content of contaminants in these mussels has been reported by Nilsson (2009). At both localities mussels were sampled at 1, 2 and 3 m depth at several positions and then pooled. The sampling was carried out in October and December 2008 respectively. The analyses were carried out by an accredited laboratory (ALS Scandinavia AB) according to the same methodology as used by the recipient control of the coastal water of Kalmar County. Stations of this monitoring program were used as references.

The content of all elements in the soft tissue was lower in farmed mussels compared to bottom mussels from the reference stations except for manganese. Comparable data was not available for three of the elements, namely silver, cesium and tin and the measured levels of these elements were just above the detection limits.

The content of elements was in most cases lower in the shells compared to the meat. Five of the elements, silver, chromium, cesium, mercury and tin, were under the detection limits both in farmed and fished mussel shells. With an exception for the content of arsenic, which was somewhat higher in shells from farmed mussels, the concentrations were about the same in farmed respectively fished mussels.

The concentration of polycyclic aromatic hydrocarbons (PAH) was higher in farmed mussels compared to mussels from the reference stations. This was especially evident in mussels farmed at Kungsholmen in Mönsterås, where the concentration of e.g. PAH(16) was almost 70 times higher compared to the mean value of the reference stations and about six times higher compared to the mussels farmed at Kalmar. The increased concentrations of PAH at Mönsterås indicated that this mussel farm had been exposed for a local source of contamination. There is no limit for PAH in feed or fertilizer and therefore it was difficult to judge the measured concentrations. Further, the concentrations of polychlorinated biphenyls PCB(7) followed about the same pattern as for PAH, with the largest concentrations at Mönsterås. The concentrations of PAH(7) was roughly five times higher compared to the reference stations. However, the measured concentrations were with a considerable marginal lower than existing limits for occurrence in feed and fertilizer.

The concentrations of chlorinated pesticides were in most cases under, and only in some few cases above, the detection limit. The concentrations were thus far below the actual limits. The concentration of organotin compounds was low and far below what was measured at the reference stations. An eventual occurrence of dioxins and furans did not seem to be a problem since the measured concentrations of all analysed compounds were below the detection limits.

The concentration of dioxin-like PCB vas somewhat higher at Mönsterås compared to Kalmar, but data to compare with non-farmed mussels was missing. However, the total content was below the limit for feed at both sites. The concentrations of brominated flame retardants were in most cases below the detection limit. Two compounds could be detected; PBDE 47 and PBDE 99, which concentrations were lower compared to the reference. Finally, the concentration of nonylphenol was far below the current limit for fertilizer as well as the content of toxaphene which was far below the current limit for feed.

Baltic mussels as feedstuff

Due to the lack of harvest of mussels, the planned feed trials with layers could not be performed. However, one sample of mussels from Hagby Harbour was steamed and dried. Meat and shells were grinded and sent for analyses of protein, fat and minerals. This single result pointed out that this non-separated meat/shell meal mixture could, without further processing, be used as a high protein feedstuff and calcium source for layers. Mussel meal has been shown to be an excellent high protein feed for poultry (Lindahl and Kollberg, 2008).

Further, measurements have shown that the meat content, expressed in %, of Baltic mussels in general is higher compared to west coast mussels, which probably is due to the thinner shells and a valuable factor for feed production. The mean meat content in 12 samples of farmed mussels from Ljungsnäs in northern Kalmarsund was 22 % (Lindahl, unpubl.) and another 12 samples of farmed mussels from Kumlinge in eastern Åland Archipelago had a mean meat content of 26 % (Torbjörn Engman, pers. com.).

Poland

Unfortunately it turned out to be impossible to establish a mussel farm trial in Puck Bay as was planned, mainly due to that no Polish partner who could take part in mussel farming trials was found. However, the BalticSea2020 project inspired a polish PhD-student, Iza Zgud, from the

University of Gdynia to study settling and growth of mussels in Puck Bay. The results were promising after the first year, however, the ice also became a problem in Puck Bay and the study was terminated. However, a study on the potential of using mussel farming in the Polish coastal waters has been compiled where it was concluded that mussel farming is a simple, flexible, cost-effective and straight-forward concept for improving coastal water quality at many coastal sites, including the Baltic (Lindahl, 2009). Further, that mussel farming can be compared to Open Landscape Feeding, but in the sea, as a measure to improve the environment. Finally that mussel farming is a sustainable production of valuable seafood and may provide coastal jobs.

Trading nutrient emissions

The concept and principle of Agro-Aqua recycling of nutrients using mussel farming as a part of a nutrient discharge trading system (Lindahl *et al.*, 2005) has been presented at a number of meetings, symposia and in media. Another option is a cap and trade system, e.g. as suggested by the Swedish EPA (EPA 2010b), in which mussel farming can be used as a compensation measure for nutrient discharges. The main idea in both cases is that a mussel farming enterprise should be paid for the environmental service it provides in returning nutrients from sea back to land. In turn, this could enable a competitive price for mussels to be used for feed production for poultry and fish production. However, it must be pointed out that a political decision on how nutrient trading should be performed still is missing.

Since the major part of the nutrient supply to coastal waters of the Baltic has its origin in agricultural operations, it has been suggested that the EU agro-environmental aid program could be extended into the coastal zone to be used for remediation (Lindahl and Kollberg, 2009). In practice, this should involve support paid to mussel farming enterprises through their harvest of mussels (and thus their harvest of nutrients) in the same way as support is paid to agricultural farmers for operations that reduce nutrient leakage from their farmland. This is a simple, cost-effective and straightforward way of improving coastal water quality. However, this eutrophication remediation method depends on the EU agro-environmental aid program must be extended beyond the shoreline. At present there is some hope that such a decision can be taken in 2014 (Ulrika Bergman, Swedish Agriculture Board, pers. com.).

Criticism of mussel farming as a remediation tool in the Baltic

Recently a paper by Stadmark and Conley (2011) was published criticising mussel farming as a remediation tool in general and to be used in the Baltic in special. Their main criticism was that benthic bio-geochemical processes below the farms may get seriously disturbed in a negative way that the net effect of returning nutrients from sea to land may become negligible. They also postulated that mussel farming for improving the environment is not cost-effective in the Baltic.

The Stadmark and Conley paper resulted in two rebuttals by Petersen et al. (2012) and Rose *et al.* (2012) who strongly argued especially the role and positive effect of the bio-geochemical processes on the nutrient net effect. In turn, this was responded by Stadmark and Conley (2012). It was obvious that there was no clear consensus between the different views and that this discussion must likely will continue.

Lessons learned from the implementation of the project

Unfortunately, no opportunity arose to practise large scale harvest of the mussels during the project time. Rational and cost-effective harvesting requires specially designed and equipped harvesting rafts, which must be adjusted for harvesting the small and fragile Baltic mussels. It is essential that future mussel farming projects and trials, along the Swedish east coast, try to agree on a more or less common farming and harvesting technology in order to be able to share an expensive investment like a harvest raft. A raft was built with some support from the project and was used during the repair of the farm unit after the first winter (fig. 12), but unfortunately was never tested for harvest of mussels.

Figure 12: Special designed raft for harvest and maintenance of mussel farm units. Here in Kalmar Harbour.

Important lesson to be pointed out that three years project time in all was a very short period for testing mussel farming under new conditions and especially in the Baltic where it takes minimum two years from settling of mussel larvae until the mussels reach harvest size. This means that there was almost no time to solve any eventual technical or methodological problems, e.g. like ice. Furthermore, the project had only one chance with the settling of mussel larvae to reach success. This means that if e.g. the settling of mussel larvae of some reason failed the first spring, there was no time for a second trial. Looking in retrospect, it can be concluded that available time to reach the goal and objectives according to the project plan was too short and too optimistic.

Outreach of results and information

Presenting information and results on mussel farming as an environmental measure in the Baltic, including the gained experiences from the project, have been one of the most important activities.

Table 3. Projects and activities to which experiences and results have been transferred.

Project or activity	Status	Transferred experience and result
Future use of Polish Maritime Areas	Ended	Evaluation of mussel farming as an environmental measure
Large scale farm test in Åland	Ongoing	Improved ice performance, exchange of growth, quality and biomass
Small scale farm test in St. Anna archipelago	Ongoing	Exchange of growth data and on substrate efficiency
EU-project SUBMARINER	Ongoing	Gained experience and results transferred into a Baltic scale
Project SEA-U in Lommabukten, Öresund	Ongoing	Gained experience and results transferred to environmental mussel farm
Region Kalmar Biogas project	Ongoing	Gained experience and results on mussel farming and biomass development
BONUS-project AQUABEST	Starting up	Production of fish feed from Baltic farmed mussels
Danish Wind Mill Park	Planned	Gained experience on farming mussels in the Baltic
County Board of Halland	Planned	Gained experience on farming mussels in the Baltic
Biogas East	Planned	Gained experience and results on mussel farming and biomass development

Conclusions

- All goals and objectives were unfortunately not reached. The main reason for this failure of the project plan was the two cold winters in 2009 – 2010 and 2010 – 2011 with thick ice and ice drift. This caused disturbance, damage and loss of settled mussels as well as broken and lost equipment. Future mussel farms in the Baltic must be able to manage an ice winter, most probably through lowering the farms below sea surface.
- It turned out to be an unexpected big step to go from the small scale test farms which preceded the project to the full scale farms of the project. This became obvious through the lack of available vessels, large and enough powerful to be used for maintenance and repair (and harvest).
- The use of nets as substrate for settling and farming seemed from a biological point of view to work well for mussel farming in the Baltic. It can be recommended to use a mesh size of around 150 mm and a rope thickness of the nets of 10 to 12 mm. PVC-pipes for floatation also work well, but require special equipment for handling, maintenance etc. At a large farming scale, it is strongly recommended to buy equipment from experienced companies instead of using homemade solutions.
- It seemed possible to reach a biomass of mussels of about 150 ton ha^{-1} in two to 2.5 years in the Kalmarsund area and about 100 ton ha^{-1} in the Hållsviken area.
- Three years is a too short project time in a new area like the Baltic to fully demonstrate the potential of using mussel farming as a measure to counteract eutrophication and improve coastal water quality. At least another three years would be needed.
- There is an ongoing interest to use Baltic mussels for feed production (both for poultry and fish farming) and for biogas production. Some experiences and results of the project have already been translated into new projects and activities within the Baltic area.
- A risk assessment of farmed mussels from the Kalmarsund area clearly demonstrated that the concentrations of analysed elements in the soft tissue and the shells were safely below the regulatory limits for use in feed or fertilizer. Further, the study showed that all measured contents of organic contaminants also with a clear marginal were below regulatory limits.

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