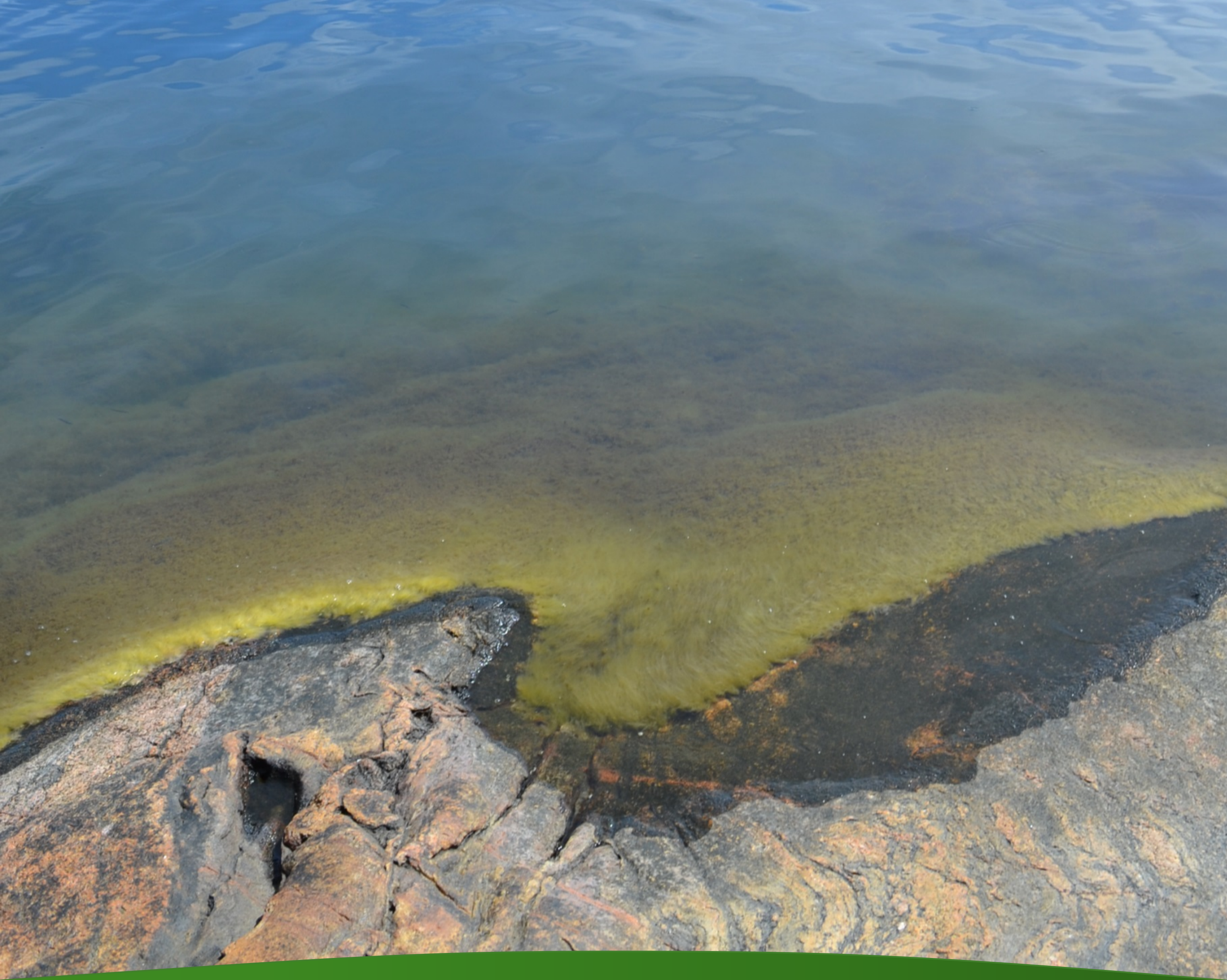

Existing data on environmental impacts related to mussel farming in the Baltic Sea

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Summary

Mussel farming has been proposed as a measure to reduce symptoms of eutrophication. The present review, produced as an activity of the Baltic Blue Growth (BBG) project, compiles current knowledge about environmental effects of mussel farming in the Baltic Sea. The existing data has also been catalogued and standardized into a GIS-useable format, which will be published online in the Baltic blue mussel farming Operational Decision Support System (ODSS).

The main positive environmental effect of mussel farming is that nutrients are removed from the marine ecosystem upon harvest of the farmed mussels. The uptake of nutrients, through filtration of phytoplankton and other particulate matter, may result in reduced ambient concentrations of nutrients and phytoplankton, resulting in an increased water transparency. The improved light conditions may in turn promote benthic macroalgal growth and increase overall coastal species richness.

Intensive mussel farming may also have local negative impacts on the environmental due to nutrient regeneration in the water column and through sedimentation of biodeposits (e.g. faeces). The organic enrichment of the underlying sediments may lead to hypoxic conditions and release of nutrients from the sediments. The overall environmental impact of mussel farms may differ between sites and change over time during the production cycle. Negative effects of mussel farming can probably be avoided or reduced if choosing a location with well-oxygenated sediments. The environmental monitoring of mussel farms within the BBG-project will help in evaluating environmental impact and in identifying key factors to optimize the positive environmental effects of mussel farming.

On-going national environmental monitoring programs will not detect any direct environmental effect of mussel farming, unless the monitoring stations are localized very close to the mussel farms. National monitoring can be used to evaluate long term and large scale changes in nutrient concentrations within the Baltic Sea, and serve as reference to mussel farm monitoring if the same methodologies are being used. National criteria for assessing ecological status within the Water Framework Directive can be used for evaluating environmental status at a mussel farm area, and for mussel site selection. Future studies of environmental impact of mussel farming in the Baltic Sea should have special focus on the sediments (e.g. nutrients, oxygen condition and benthic fauna) and water transparency. Data is also needed for other water quality parameters to achieve a deeper understanding of the overall impact of mussel farming on the marine ecosystem.

Background

Large inputs of nutrients, arising from various human activities, have led to nutrient enrichment in the Baltic Sea. Eutrophication is one of the largest threats to marine ecosystems, especially in coastal areas with high run-off of nutrients from intensive agricultural soils. The ecological consequences of eutrophication are habitat destruction, shifts in species composition and distribution range, loss of biodiversity, invasion of non-native species and changes in food web efficiency (Cloern 2001). It is necessary to reduce the concentrations of nitrogen (N) and phosphorus (P) to combat eutrophication. Many measures need to be taken to achieve good water status as defined by the Water Framework Directive and Marine Directive. Discharges of nutrients to coastal waters within the EU now mainly originate from non-point sources, which are more challenging to control than point sources. Another significant source of nutrients, especially phosphorus, in the sea is due to the so called internal loading. Nutrients that have accumulated in the sediments of the seabed due to past pollution is released to the water under certain environmental conditions (e.g. anoxic conditions).

Mussel farming has been proposed as a mitigation tool to reduce symptoms of eutrophication (e.g. Officer et al. 1982; Haamer 1996; Edelbo et al. 2000; Lindahl et al. 2005; Gallardi 2014; Petersen et al. 2014; 2016; Ferreira and Bricker 2016). The filter-feeding mussels take up nitrogen and phosphorus and bind these substances in their body tissue, and the nutrients are removed upon harvesting of the mussels.

There are also concerns about possible negative impact of mussel farming, questioning the overall effect of a mussel farm (e.g. Nizzoli et al. 2011; Stadmark and Conley 2011). Consequently, the activity 2.2 of the Baltic Blue Growth (BBG) project will;

- Identify, assemble and synthesize existing environmental data and experiences, both positive and negative, relevant to mussel farming in the Baltic Sea.
- Increase knowledge on how farm characteristics and local hydrography modulate effects on water quality.
- Examine the potential of utilizing national monitoring data and assessment schemes of the Water Framework Directive for mussel farm perspective.

Currently, there is very limited experience of farming mussels in the Baltic Sea, and comprehensive studies on environmental effects of mussel farming in the Baltic Sea are so far lacking. This compilation therefore mostly covers studies performed in Danish fjords. The identified environmental data gaps and concerns will be addressed in the environmental monitoring and evaluation of the project mussel farms within the Baltic Blue Growth project.

Method

A literature review has been performed of existing environmental data and experiences relevant to mussel farming in the Baltic Sea. The data has been summarized in the current report, and been catalogued and standardized into a GIS-useable format in the Baltic blue mussel farming Operational Decision Support System (ODSS; www.sea.ee/bbg-odss). The ODSS is a GIS enabled user friendly web application for sharing information relevant to mussel farming in the Baltic Sea, developed by the University of Tartu as part of the Baltic Blue Growth project. The studied water quality parameters are e.g. water chemistry, water transparency, sediment conditions as well as pelagic and benthic communities. Possible effects of farm characteristics and local hydrography (e.g. currents) are also covered, as well as the potential of utilizing national monitoring data and assessment schemes of the Water Framework Directive for mussel farm perspective.

Results and Discussion

Effects on water quality parameters

The mussels play an important role in the transfer of organic and non-organic suspended particles from the water column to sediments through filtration and biodeposition, and thus, contribute in the coupling of energy fluxes between pelagic and benthic systems (Kautsky and Evans 1987). They are also a very efficient biological filter, purifying water masses from suspended matter and the associated elements. Filtration rate is dependent on e.g. food concentration and water flow. Under optimal conditions, bivalves filter the ambient water at a maximum rate but under suboptimal environmental conditions, including low or very high algal concentrations, the filtration rate is reduced (Riisgård et al 2011).

The main positive environmental effect of mussel farming is that nutrients are removed from the marine ecosystem upon harvest of the farmed mussels. The uptake of nutrients, through filtration of phytoplankton and other particulate matter, result in reduced ambient concentrations of nutrients and phytoplankton and increased water transparency (Officer et al. 1982; Strohmeier et al. 2008, Petersen at el. 2014; Holmer at al. 2015; Nielsen et al. 2016). The increase in water transparency and underwater light conditions may in turn promote benthic plant growth (Petersen at el. 2014; Ferreira and Bricker 2016; Nielsen et al. 2016). Studies of a large scale mussel farm (18.8 ha) in an euthrophic Danish fjord (Skive fjord) showed that the farm could remove 0.6-0.9 t N per ha and year, and 0.03-0.05 t P per ha and year (Petersen at el. 2014) and that the water clarification increased through seston and phytoplankton depletion inside and outside the farm (Nielsen et al. 2016). Studies on mussels feeding behaviour have shown that under conditions of high zooplankton density, mussels may inhale and ingest substantial quantities of mesozooplankton (Davenport 2000). These findings may have implications for intensive mussel farming that can have direct impacts on local recruitment of benthic animals and pelagic fish.

Mussels growing in suspended culture can create favourable habitats for other invertebrates, fishes and birds. Bottom structures (for example anchor blocks) used for suspended mussel aquaculture may provide a surface area for hard bottom associated organisms that are normally not found on soft bottoms, where mussel cultivation is often practiced (Norling and Kautsky 2008, Norling 2009) (Fig. 1). Mussels and their associated fauna that drop from farm may also enhance the food availability to benthic predators and scavengers. In areas of intensive mussel farming a local reduction in current speed can be observed. Consequently, mussel farms can act as a form of shore protection structure (Stohmeier et al 2008). Intensive mussel farming may, however, negatively affect the nutrient cycling in the local environment through nutrient regeneration in the water column and through sedimentation of biodeposits. The resulting organic enrichment of the underlying sediments may lead to hypoxic conditions and release of ammonia and phosphates from the impacted sediments (Christensen et al. 2003; Callier et al. 2006; Carlsson et al. 2009, 2010, 2012; Nizzoli et al. 2011; Nunes et al. 2011; Holmer et al. 2015).

Low oxygen levels and increased sedimentation of organic matter and mussel shells may have a negative impact on the benthic community. Any adverse effects have however been restricted to the immediate vicinity of mussel farms. The environmental impact may vary over the year due to differences in e.g. temperature, hydrodynamical conditions (depth, bottom topography, bottom currents), phytoplankton density and the biomass of mussels (Nielsen et al. 2016). Studies on a mussel farm in a Danish fjord showed that mussel farming was most efficient in nutrient removal in the early stage of the production cycle (Petersen et al. 2014; Holmer at el. 2015). In the late production cycle the farm became a net source of nutrients, mainly due to excretion by mussels but also due to the release of nutrients from the sediments. It was therefore recommended to harvest the mussels within the first year of the production cycle. It is not known if the same conclusion also is valid for mussel farms within the Baltic Sea, where the blue mussels are smaller compared to mussels in more saline waters.

Figure 1. Lumpfish (Cyclopterus lumpus) guarding its nest, built on concrete block, covered with mussels

Effects of farm characteristics and local hydrography

With current knowledge, the environmental effects of mussel farming can be optimized if the following natural and environmental conditions of a potential mussel farm area are considered;

1. The area should have elevated concentrations of the nutrients (nitrogen and phosphorus) and chlorophyll a (high phytoplankton biomass), providing surplus of feed for the filter feeding mussels.
2. The water should be well circulated (i.e. rapid water turnover) to avoid low dissolved oxygen concentrations due to the accumulation of organic matter (e.g. faeces) beneath the farm. Furthermore, water currents are important to replenish the food supply in the mussel farm.
3. Mussels should not be cultivated above bottoms with anoxic sediments, to avoid the release of ammonia and phosphate from the sediments.
4. An appropriate time for harvesting should be selected to optimize mussel biomass and nutrient uptake. Danish studies indicate that mussels should be harvested after one year to avoid loss of mussels from the lines as the mussels grow larger, and to reduce the risk of negative impact on sediments and nutrient regeneration.
5. The water must have salinity above 4 to allow a successful reproduction of the blue mussel *Mytilus edulis*. The low salinity may be a limiting factor in estuaries with high run-off from rivers and streams.

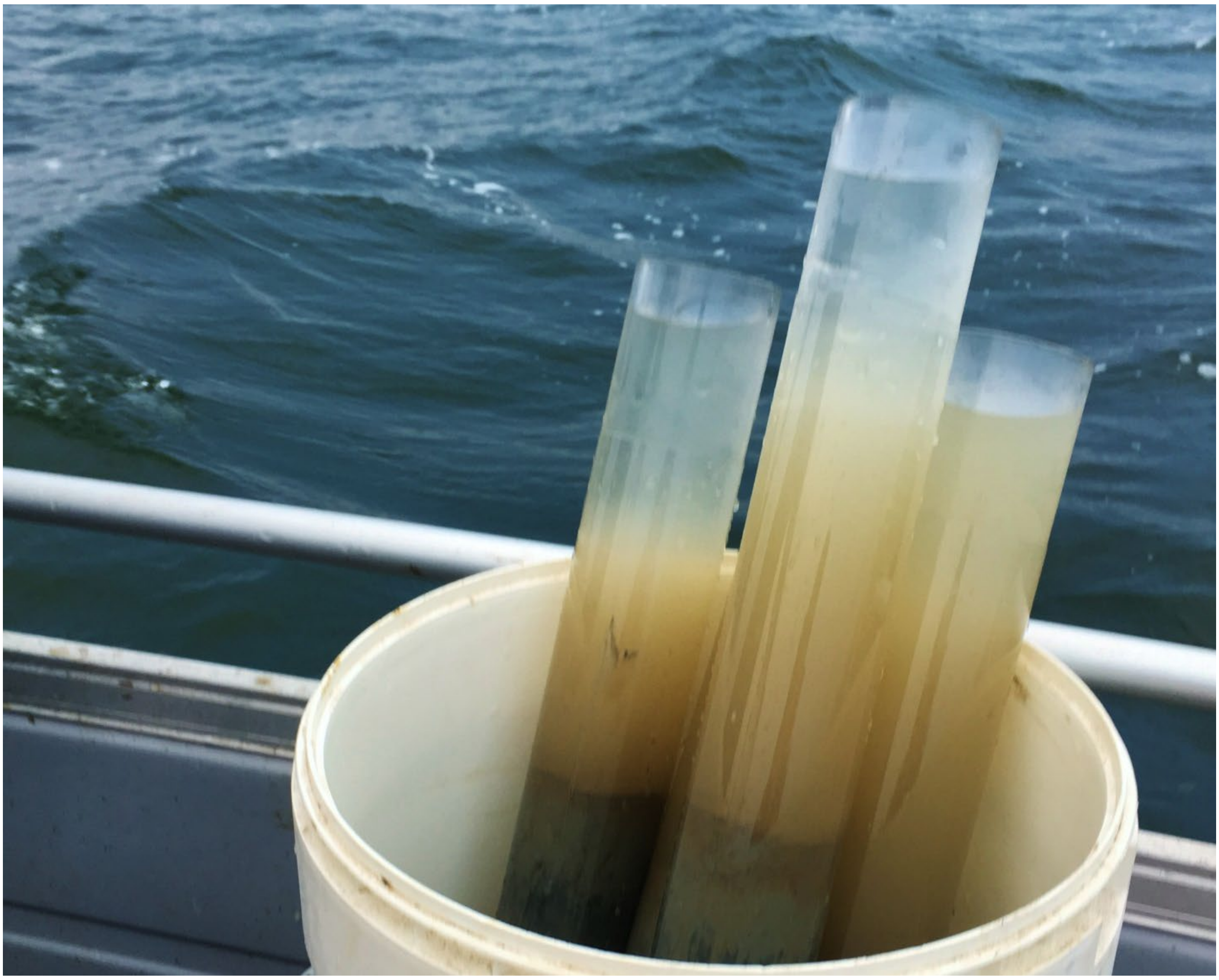
Although estuaries often are eutrophic hotspots, they may not be suitable areas for mussel farming due to low salinity and hypoxic conditions in sediments. The conditions listed above may instead be fulfilled in coastal areas exhibiting a "moderate level" of eutrophication. If the environmental conditions of a potential mussel farm area are not known, it is recommended to perform a pre-study before starting the mussel cultivation. If mussel farms are established in suitable areas, they should contribute to a net removal of nutrients and thereby contributing to a reduced nutrient load on the Baltic Sea.

The potential of utilizing national monitoring data and assessment schemes of the Water Framework Directive

Since environmental impact of mussel farming only has been measurable on the local level, the potential of utilizing only national monitoring data for the evaluation of mussel farming is limited. National monitoring can, however, be used as reference to monitoring performed close to mussel farms when evaluating environmental effects of mussel farms. In this case, it is crucial to use standardised methodology for sampling and analysis, and it is preferred to use the same laboratory for the analysis. The legal requirement of public procurement may however hinder the use of the same performer, making the evaluation and comparison of data more challenging.

The setup of environmental monitoring at mussel farms and reference areas within the BBG project will help in evaluating environmental impact of mussel farms. Existing national monitoring data among BBG partner countries have been identified and georeferenced. The national monitoring data will be used to evaluate long term and large scale changes in nutrient concentrations within the Baltic Sea rather than the follow up of a mussel farm area. Consequently, environmental monitoring within the BBG project will be performed at both the mussel farm areas and at reference areas using standardised methods recommended by HELCOM.

National criteria for assessing ecological status within the Water Framework Directive (e.g. nutrients, light- and oxygen conditions, phytoplankton and zoobenthos) are useful also for evaluating environmental status at a mussel farm area, and for selecting areas with the right environmental conditions for mussel farming. The status of oxygen condition should be at least moderate while the status of phytoplankton or nutrients could be moderate, poor or bad. The assessment schemes can also be used for comparing a mussel farm site with a reference site, in addition to regular statistical evaluation. Local environmental monitoring data from a mussel farm area should not however be used in status assessment within the EU Water Framework Directive, because a monitoring station must be representative of a water body. Even though a mussel farm may have a local negative impact on the sediments and the benthic fauna, it should not affect the overall status assessment of the water body. In the long run, as the pool of nutrients reduces, the positive effects of mussel farming and land-based measures, will lead to improved status of the coastal water bodies.



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About

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

Partners

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