Can the EU agri-environmental aid program be extended into the coastal zone to combat eutrophication?

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Abstract Eutrophication of coastal waters is a serious environmental problem with high costs for society globally. This is a development which demands immediate environmental action along many coastal sites. Since the 1980s, mussel farming has been recognized by Swedish environmental authorities as a possible measure to improve coastal water quality. Concepts and management strategies on how to increase mussel farming and thus combat coastal marine eutrophication has recently been developed in Sweden. The main principle of this development has been the implementation of nutrient trading as a management tool. This imposes demands on those who emit the pollution through the establishment of emission quotas, which are traded and bought by the emitter. The seller is a nutrient harvesting enterprise, e.g., a mussel farmer. This principle is particularly straightforward when the nutrients are discharged from a point source. When examining the nutrient supply from all diffuse sources, the situation is more complex. However, since the major part of the nutrient supply to coastal waters in many areas of Europe has its origin in agricultural operations, we suggest that the EU agro-environmental aid program could be extended into the coastal zone in order to combat eutrophication. 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 at many coastal sites that will, at the same time, provide coastal jobs. However, this eutrophication combat method depends on the EU agro-environmental aid program being extended beyond the shoreline.

Keywords Eutrophication · Mussel farming · Nutrient trading · EU agri-environmental aid · Coastal water quality

Introduction

Eutrophication of coastal waters is causing anoxic bottom conditions and the formation of algal mats in shallow bays (Diaz & Rosenberg, 1995; Cloern, 2001). Several international agreements (e.g., HelCom and OSPAR) include goals to reduce the supply of anthropogenic nitrogen and phosphorus to the sea, but these have so far not been met. The common blue mussel (*Mytilus edulis*) could be used to reduce

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nutrients in the coastal zone since mussels feed mainly on phytoplankton which in turn act as nutrient sinks. Thus, harvest of mussels will decrease the nutrient level in the coastal zone. One kilogram of live mussels can remove 8.5–12 g of nitrogen, 0.6–0.8 g of phosphorous, and about 40–50 g of carbon (Lutz, 1980; Petersen & Loo, 2004; Syversen, personal communication).

Over the last 10 years, much of the research performed on the Swedish West Coast concerning mussel farming has focused on its positive environmental aspects. It became clear that society was lacking a direct tool to encourage and support this farming. For this reason, Lindahl et al. (2005) suggested the introduction of nutrient emission trading as a compensation measure where the mussel farm enterprise would be paid for the ecosystem service provided. Another possibility is to exploit an already existing system for environmental aid, e.g., the existing EU-program within the agricultural sector (EEC 2078/92 and 1257/1999), to apply it for organisms grown in the coastal zone. In the agricultural environmental aid programs, support is currently given only for the establishment of wetlands, spring cultivation, catch crops, and so forth in order to decrease nutrient release from farmland into the environment.

We postulate that large scale mussel farming is a realistic and cost-effective method to decrease the negative effects of eutrophication. At the same time, healthy marine food is produced from a low level of the food chain, nutrients are recycled from sea to land and new jobs are provided. The potential of the ecological and environmental benefits of mussel farming on improving coastal water quality are scientifically well known, as pointed out by, e.g., Ryther et al. (1972), Haamer et al. (1999), Edebo et al. (2000), Newell (2004), and Lindahl et al. (2005).

Mussel farming as an environmental measure—the Swedish experience

Long-line farming

There are numerous sites along the Swedish west coast which are suitable for mussel farming, according to the criteria: access to a water area in competition with other coastal activities, reasonable wind protection, water depths between 6 and 25 m, and average current speeds of more than 5 cm s^{-1}. Obtaining a farm license is normally not a problem.

In Sweden, long-line farming is the most common method of mussel farming. The blue mussel (*Mytilus edulis*) is grown on vertical suspenders attached to horizontal long-lines (Fig. 1). On the Swedish west coast, about 300 tons of mussels may be produced per hectare of sea surface in 12–18 months. Each hectare of mussel farming needs between 25 and 15 hectares of phytoplankton for mussel food, depending on how fast the mussels grow. This calculation has been made by using the long-term mean from 1985 to 2006 of the annual primary phytoplankton production of 243 gC m^{-2} $year^{-1}$ (Lindahl, 2007), a carbon content of 4% in the live mussel and a gross growth efficiency of 0.2 (Riisgård & Randløv, 1981). A similar calculation for the Baltic area showed that 7.5 hectares of food is needed for each hectare of farm area according to on-going mussel farm trials. This estimate was based on a production of 120–180 tons per hectare of long-line farmed mussels grown over 2–3 years (Lindahl & Kollberg, unpublished data) and a phytoplankton production of 160 gC m^{-2} $year^{-1}$ (Elmgren, 1984). It was assumed that the carbon content and gross growth efficiency was the same as above.

One often-discussed drawback of long-line mussel farming is the bio-sedimentation below the farms. The negative effects depend on biological and technical farming conditions in relation to bottom water exchange at the site. It is very important that the sediment surface never becomes anoxic in order to maintain the nitrification and denitrification processes (Newell, 2004). Oxic bottom conditions are maintained through natural bottom water renewal, which supplies the sediment surface at the site with enough oxygen. Best practices when running a mussel farm should include monitoring the sediment below the farm and managing the farming according to how the conditions develop. If conditions deteriorate, it is comparatively easy to move a long-line system since it has only one anchor at each end.

First example of nutrient trading

In order to combat eutrophication of the Swedish west coast, it was suggested that the volume of farmed mussels should be raised significantly (Lindahl et al., 2005). Swedish mussel farming did not

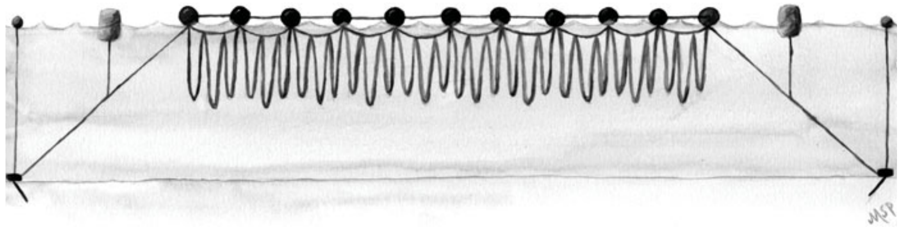

Fig. 1 Schematic drawing of long-line mussel farm

expand at all for many years until the community board of Lysekil was permitted (Fig. 2), as a trial between 2005 and 2011, to continue to emit nitrogen from the sewage plant, presupposing that the same amount of nitrogen was "harvested" and brought ashore by 3,900 tons of farmed blue mussels. The cost of 150,000 € for the Lysekil community was far below the price for nitrogen removal in the sewage plant. This payment goes to a mussel farming enterprise, which has been contracted for the removal of 39 tons of nitrogen from the recipient. This was estimated to correspond to 100% nitrogen treatment of the emission from the sewage treatment plant. Further, 3.6 tons of phosphorus are also removed annually from the recipient through the mussel harvest, which also could be traded (Lindahl et al., 2005).

The Lysekil case is a good example of the principle of trading nutrient emissions from a point source. However, the authors want to point out that mussel farming as a nutrient compensation measure should be reserved for diffuse emissions into the coastal zone coming from, for example, agriculture and atmosphere, because for these there are few other effective options available. This is important especially as the diffuse emissions into the coastal waters make up more than 80% of the total of which roughly half is coming from agriculture operations (Anon., 2001).

The EU agro-environmental aid program and mussel farming

Further growth of the mussel industry is still desired by the Swedish society. The authors therefore suggest that diffuse nutrient emissions into the coastal zone, e.g., from agriculture, should be traded and possible to compensate by mussel farming (Fig. 3). In the agricultural sector a legal system, the EU agro-environmental aid program, already exists to promote environmentally healthy methods of decreasing nutrient release from farmland into the environment. The legal framework is quite complex, but some of the measures are easily comparable with mussel farming.

Mussels can be considered as a type of catch crop. In the aid program, catch crops are compensated for at 100 € per hectare. The annual compensation for spring cultivation of a catch crop was in 2006 45 € per hectare. In Sweden, catch crops are farmed on 180,000 hectare of farmland, and spring cultivation is used on 90,000 hectare. The total annual cost for these measures is 22 million €. The Swedish Commission for the Environment of the Seas (Anon., 2003) has calculated that catch crops and spring cultivation together decrease nitrogen release by 2,000 tons. This gives a price of 11 € per kg of retained nitrogen. If the mussels were to be compensated according to the same price for retained nitrogen, it means an environmental subsidy of about 0.11 € per kg of live mussels. This is roughly 25% of what a mussel farm enterprise needs as gross income for harvested mussels (as estimated by the authors).

Another method to decrease nitrogen emissions is the establishment of wetlands, which reduces nitrogen by an average of 120 kg per hectare. Contracts for maintenance are set up for a 20-year period, in 2006 allocated as a yearly compensation of 325 € per hectare, equivalent to 2.7 € per kg of nitrogen. The construction costs could be compensated for by 90% at the most and with an upper limit of 11,000 € per hectare. One hectare of wetland (=120 kg N) would be equivalent to approximately 12 tons of mussels. A long-line mussel farm covering 1 hectare will cost about 46,000 € and produce 300 ton of mussels per 12–18 months—in practice, 150 tons per year. The harvest of these will therefore, with a focus on nitrogen, correspond to about 12.5 hectares of wetlands. If the mussel farm construction costs were

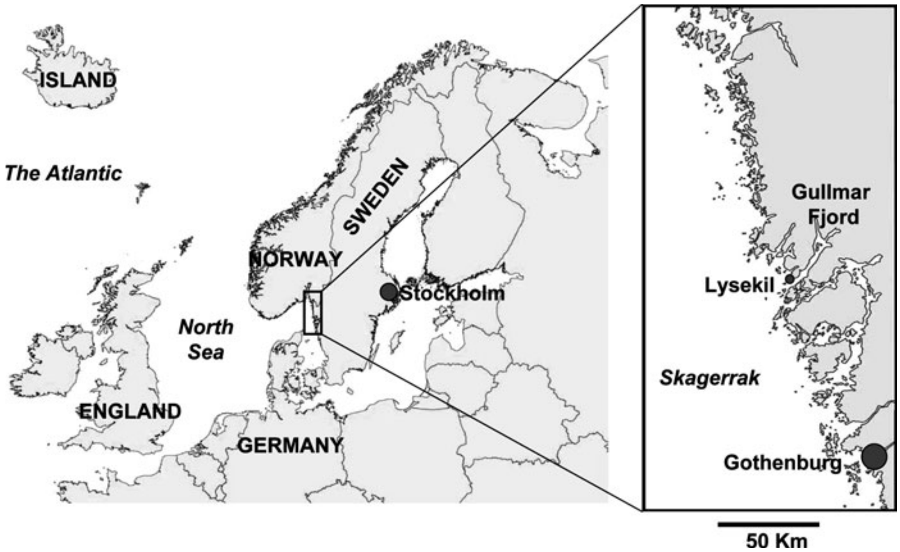

Fig. 2 Map of north-west Europe and the Swedish west coast

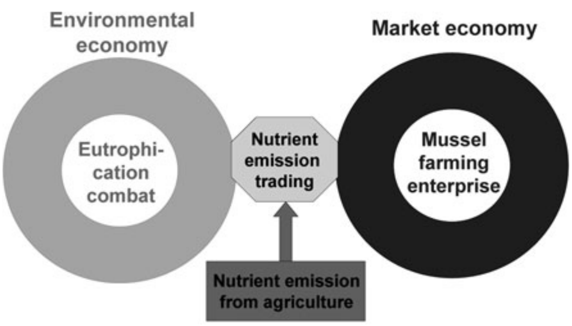

Fig. 3 The principle of nutrient trading, which connects the environmental and the market economies

compensated for by 41,400 € (90% of 46,000 €), it is far below the maximum limit of 137,500 € for 12.5 hectare of wetland construction.

A full comparison should include a comparison of the low running costs of wetlands versus the much higher costs for mussel farming. Harvesting costs alone amount to 0.10–0.15 € per kg. On the other hand, a wetland does not produce a commodity of commercial value, while the first-hand value of mussels is between 0.3 and 0.5 € per kg.

During the years 1998–2001, 25 hectares of wetlands were established on the Swedish west coast. The investment costs seen over a 20-year period were calculated to be 3,400 € per hectare per year. With a calculated reduction of 120 kg of nitrogen per hectare per year, the costs per kg of reduced nitrogen would be 28 €. This cost transformed to nitrogen uptake by mussels corresponds to about 0.23 € per kg.

Another option to finance the trading of nutrient emissions from agriculture would be to use the environmental tax paid on fertilizers. This Swedish tax has been introduced to decrease the elevated levels of fertilizer spread in the fields. In the opinion of the authors, this tax could have a double effect if some of it were used to further decrease nutrient levels in the sea through subsidizing extended mussel culture. This could, at least partly, pay for the nutrient removal service mussel farming provides.

When comparing the uptake of nutrients by catch crops and wetlands to mussels, the temporal aspect is important. In agriculture and for wetlands the uptake is far higher when temperatures are high (during summer). The primary production in the sea and also the mussel filtration capacity is much less temperature-dependent (Loo & Rosenberg, 1983). The phytoplankton growth period is more light-dependent and may last from March to October (Lindahl, 1995). This means that nutrient emissions during 8 months of the year are more or less rapidly assimilated by the phytoplankton, which then is grazed by the mussels.

The market for mussels

Food

The economic basis of mussel farming and harvesting is generally to produce food for human consumption. The world production of mussels today exceeds

1.5 million tons, of which half is produced in Europe. The demand is steadily increasing but the main production areas in Europe have reached a level where they can no longer expand due to the shortage of suitable farm areas (Smaal, 2002). The farms produce a valuable and healthy marine food product, since mussel meat is high in protein with a fat content of only about 2%—of which 40% is Ω3 long-chain fatty acid molecules (Berge & Austreng, 1989). An increase in production to 50,000 tons annually on the Swedish west coast seen over a 15-year period seems therefore from a market point of view to be quite realistic.

Issues include elevated levels of diarrheic shellfish toxins (DST) in blue mussels have caused sales problems. These toxins have been recorded along Swedish marine waters in varying amounts every year since 1983, when the first outbreak was reported (Haamer et al., 1990). This is regarded as a minor obstacle which can be handled by the producers who have to follow the regulations set up by EU directive 91/492 EEG. The same directive also regulates the harvest of mussels in relation to the occurrence of pathogenic bacteria and viruses. Chemical and other harmful substances must also be controlled. According to data in the literature and reports from the Swedish west coast, harmful substances are generally low and well below existing limits for use as food, in feed and as fertilizer (Kollberg & Ljungqvist, 2007).

Feed and fertilizer

A mussel farm can be regarded as the engine in an Agro-Agua recycling system of nutrients from sea to land. To optimize the environmental effect of mussel farming, all organisms attached to the lines should be harvested and brought ashore, with nothing discarded back to the sea. While not all harvested mussels can be used for human consumption, the remainder, consisting of small or damaged mussels, is also important for the removal of nutrients and can be used for feed or as an organic fertilizer. Large-scale experiments to evaluate mussel meal as a replacement for fish meal in organic chicken poultry and egg production have been performed (Jönsson, 2007). The results were most promising.

Since mussels are at the second step of the marine food-chain, the use of mussels instead of fish for meal production also has a large ecological advantage. Furthermore, there is increased public opinion that fish should be left for human consumption, with the exception of pure industrial offal. A possible scenario is that mussel meal for use in feed will become so interesting for the market that special cost-effective farming and harvesting techniques for "feed mussels" will be developed for this purpose.

Further, successful use of waste from mussel processing lines as fertilizer in the organic farming of grain has also been documented (Lindahl et al., 2005; Olrog & Christensson, 2008). Successful composting experiments were done to produce a "mussel fertilizer" which can be stored and used when the farmer needs it and which lacks the bad smell of decomposing mussels.

Conclusions

Many different measures have to be used in the fight against eutrophication. However, economic resources are always short, and therefore it is necessary to use solutions that give the best return—in this case, the most nutrient reductions for the money spent. Mussel farming has shown to be a socio-economically sound measure that meets the requirements of the European Water Framework Directive in a cost-effective way (Sánches-Hjortberg, 2003; Anon., 2004). It also gives rise to new jobs on the coast. At the same time, the drawbacks seem to be small and manageable, and the licensing procedure gives society the possibility of avoiding conflicts arising from the fact that the coastal zone is of great interest for many activities.

The authors are convinced that mussel farming would be a competitive compensation measure for agricultural emissions in a trade bidding system, and that it has a number of added values. However, if mussel farms are going to be subsidized according to the EU agro-environmental aid program, legislation must regard the sea surface utilized for mussel farming as farmland. This, in turn, requires that the directive regulating the agricultural aid program be updated.

The simplistic beauty of using nature for self-healing challenges today's focus on high-technological advances to solve all our environmental problems. The usefulness of the mussel farming concept in combination with nutrient emission trading has significance on a global environmental scale.

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