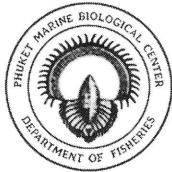


Marine bivalve farming – a sustainable food production

Åke Granmo, B. Hernroth & O. Lindahl



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Increased supply of nutrients to the sea is a serious environmental problem almost worldwide and many coastal areas suffer from eutrophication. This has led to raised phytoplankton production and increased growth of filamentous algae followed by increased oxygen consumption in bottom waters as well as decreased penetration of light through the water-column. One possibility to counteract this problem is to recycle nutrients from sea to land by the cultivation of filter-feeding organisms, such as bivalves. The paper points out that farming of bivalves is a sustainable way to produce food of high nutritional value, at the same time as the cultivation will result in advantageous environmental effects in areas where eutrophication is a problem. However, in many coastal areas man also introduces pollutants (heavy metals, hydrocarbons, pesticides, and detergents) into the aquatic ecosystem. The occurrence of toxic algae is another serious threat to bivalve farming. Furthermore, high densities of pathogenic bacteria and viruses are often present in coastal waters. Increased knowledge of the capability of molluscs to deal with pollutants, pathogens and toxic algae and how to optimise the location of farms is necessary in order to give important guidance to future management strategies.

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INTRODUCTION

Aquaculture has a long tradition in Asia and was first mentioned in a book by the Chinese Fan-Li 423 B.C. In Europe the Romans mentioned such farming, i.e. 2000 years ago. Most of these farms dealt with freshwater fish species probably due to an easier handling in ponds and easier technique due to bigger eggs and larvae compared to marine species. Also the culturing of bivalves started early as these species and especially filter feeders feed on naturally produced phytoplankton and then is less labour intensive to cultivate.

During hundreds of years our seas have been heavily exploited by man and used not

only as a food source but also as receiver of wastes and this may in many areas be problematic for aquaculture. However, by an increased knowledge of the nutrient cycling processes the drawbacks with eutrophication can be overcome and instead used as a resource.

MUSSEL FARMING COUNTERACTING EUTROPHICATION

In order to counteract the negative effects of eutrophication in coastal waters, a goal was set up by OSPARCOM (the Oslo-Paris Commission) in 1985 to reduce nutrient outflow from anthropogenic land-based

sources to the sea by 50 % within ten years. This goal has not been reached and it has been suggested that in parallel to source-related strategies, environment-related management strategies may be used to restore affected areas (Edebo *et al.* 2000). In Sweden, recycling of nutrients from sea to land by cultivating filter feeders, such as blue mussels, has been suggested and also tested and modelled at a limited scale within a project of the Swedish Foundation for Strategic Environmental Research (MISTRA). In fact, re-establishment of wet-lands, increased mussel farming and harvesting of short-lived filamentous macroalgae are, for the moment, the only realistic methods which may take care of the diffuse flow of nutrients entering the coastal waters in Western Sweden from non-point sources.

A schematic view of the nutrient cycling is given in Fig. 1.

Increased mussel farming means that a positive environmental effect is established at the same time as high quality food is produced under sustainable conditions since some part of the nutrient flow from land to sea could be brought back (Edebo *et al.* 2000). The negative effects of eutrophication, like turbid waters and dead bottoms, may be reduced with strategically localised farms, especially in areas with reduced water exchange with the open sea (Haamer 1996; Meeuwig *et al.* 1998).

There are several studies around the world, which all demonstrate the strong impact grazing by suspension feeders may have on the pelagic ecosystem as well as on the transport of organic material from the pelagic

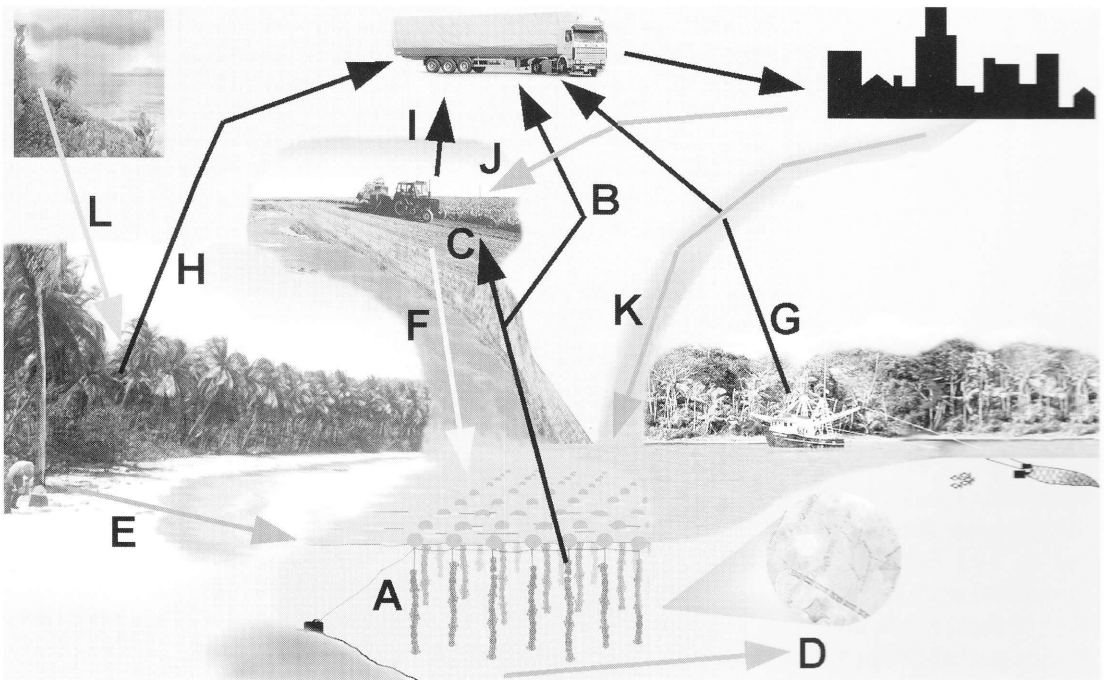


Fig. 1. Recycling of nutrients from sea to land. Suspension-feeding bivalves in the sea consume phytoplankton and produce organic material (A), which will be used as food (B) or fertilisers in agriculture (C). Some nutrients are released to the water column (D). There is a diffuse leakage of nutrients from land to the sea (E) and from agriculture (F). This supply stimulates production of phytoplankton but also fish, crustaceans or shellfish, which are utilised by man (G). Man uses nutrients from forest (H) and agriculture products (I), but the crops also need fertilisers added by man (J). From human consumption and activities there is a huge loss of nutrients, which finally enter the sea (K). There is also input through precipitation (L).

to the benthic system (Dame 1996). Benthic suspension feeders are reported to be able to control phytoplankton dynamics and water quality in coastal areas (e.g. Loo & Rosenberg 1989; Möhlenberg 1995). The filtration capacity of blue mussels, *Mytilus edulis* L., is significant and large volumes of waters can be processed. In the Öresund Strait between Denmark and Sweden, it has been shown that a turbulent, non-stratified flow of $50\,000\text{ m}^3\text{ s}^{-1}$ was filtrated effectively, as about 75 % of the plankton biomass was removed by the natural mussel banks covering the sill area (Norén *et al.* 1999). In this study it was also shown that the grazing by the mussels had a selective impact on the phytoplankton community so that small, fast-growing species became dominant down-stream the mussel bank. In estuaries in Prince Edward Island, Canada, Meeuwig *et al.* (1998) found a decrease between 45 and 88 % in chlorophyll *a* concentrations, due to the presence of mussel farms.

LONG-LINE FARMING

Mussel farming can be carried out in a number of different ways. The farming method used in Sweden is the long-line system (Fig. 2), developed by Haamer (1995). The gross farming capacity of an average Swedish long-line farm unit is about 200 tons of mussels in two years, and each farm occupies a water surface area of 2000 m^2 . Fresh mussels are made up of 40 % shell, 40 % meat and 20 % juice. The proportion of dry protein is about 5 % of the total weight. The primary phyto-

plankton production in Swedish West Coast waters is about $240\text{ g C m}^{-2}\text{ year}^{-1}$ (Lindahl 1995), which corresponds to about 9.5 kg phytoplankton wet weight biomass per m^2 and year. Using a conversion efficiency factor of mussels of about 20 %, a theoretical production of about 1.9 kg of mussels $\text{m}^{-2}\text{ year}^{-1}$ was calculated. However, a long-line farm acts as a large three-dimensional filter and the growth of the mussels is, besides the food availability, much dependent on water currents flowing through the farm. Thus, at an optimal site along the Swedish West Coast, the production is about 50 kg of fresh mussels per m^2 and year, filtering off the phytoplankton biomass from about 25 m^2 of sea surface. Each farm unit of 2000 m^2 will thus filter the surface water from at least $50,000\text{ m}^2$ (5 hectares) of sea area (Haamer 1995).

About 50 % of the total biomass (mussels as well as algae, ascidians etc.) settled on a long-line farm will be made up of mussels, which can be consumed as food. In order to achieve the maximum purification effects on the sea, all this biomass should be harvested (possibly too small mussels can be resettled), collected and brought ashore. If possible, also the mussel sediment under the farm should be sucked up. However, at least in Sweden, more research has to be carried out in order to find sustainable methods to recycle the organic wastes from the mussel farming.

WATER QUALITY

During the last decades much attention has been focused on marine farming, the

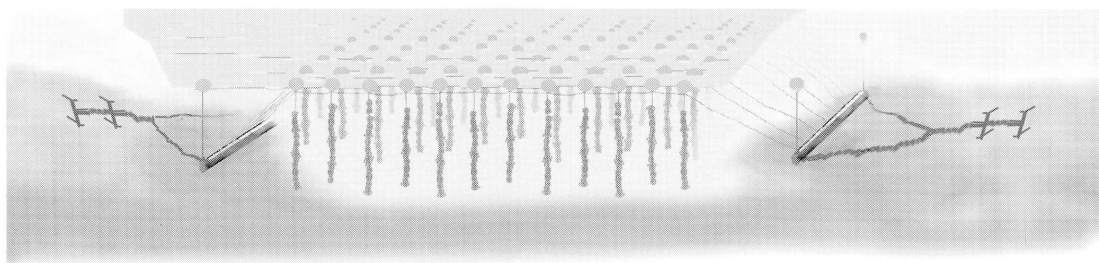


Fig. 2. The Swedish long-line system with the dimensions $10 \times 200\text{ m}$. The long-lines can carry $20\,000\text{ m}$ of farming strips with a production capacity of about 200 tons in two years. (redrawn from Haamer, 1995).

importance of a high water quality and the need for an effective organisation for food control. Today pollution catastrophes, which led to Minamata and Itai-itai diseases, are history, but these acted as an alarm for a better environmental management.

The localisation of marine farms is an important factor for many reasons. First, and probably the most important one, is the water quality aspect. The distances to industrial- or sewage-outlets as also to polluted rivers or cities may have drastic impacts on the health and quality of the cultivated organisms. Not only the presence of toxic chemicals but also pathogenic bacteria must be considered.

There are different processes involved in marine farming, which may generate environmental problems but also, problems for the use and quality of the cultivated species. The main effects of cultivation of fish and shellfish have been described in a series of lectures by M. Kayser (Kayser *et al.* 1998) and now available on an Internet web page. According to Kayser *et al.* (1998) it is possible to define different main processes involved in bivalve cultivation which may be of environmental importance (Table 1.).

Seed collection: For many bivalve maricultures this part seems to be without problems as many seeds and larvae normally are colonising the ropes or cultivation equipment naturally. However, for some species where seeds or larvae are collected by dredging, disturbances of bottom structures may cause problems as release of sediment-bound pollutants, increased turbidity or an altered composition of bottom fauna.

For the *seed nursery and on-growing* with its feeding activities, faeces-production constitutes also an organic input. Dead bivalves will cause an organic enrichment to the surrounding sediment, which in severe situations will result in anoxic conditions. Increased sedimentation rate and oxygen depletion will at time also change the bottom structure and fauna composition, attracting numerous birds and marine organisms, which feed on bivalves or the enriched organic

material.

The use of chemicals in connection with cultivation as chemotherapeutants (drugs used to cure or prevent diseases), vitamins, antifoulants and pesticides are other factors that may cause problems, mostly in combination with fish farming. These drawbacks have been identified and described more thoroughly in a report by the international organisation GESAMP (1997).

Also during *harvesting* some environmental impact will occur by disturbance of the sediment or by organic addition to the sea bottom through organisms lost at mechanical harvesting procedures.

POLLUTION IMPACT

The pollution aspect is probably one of the most difficult parts to tackle. Many pollutants as heavy metals and less water-soluble organic compounds have a tendency to accumulate in the cultivated organisms and this may cause harm not only to the organisms but also on the quality of the farmed products and their use as human food. Even pollutants, which are present at very low water concentrations, or considered as non-accumulating or not acutely toxic may cause problems with taste e.g. oil products (Nishihama *et al.* 1998) or phenolic compounds.

For the use of rest products from bivalve farming as fertilisers in agriculture special attention must be devoted to heavy metals which gradually may accumulate in soil and crops. However, recent studies have shown that a certain depuration of metals is possible by transplanting the bivalves from contaminated to clean sites up to three months before harvest (Chan *et al.* 1999). Metals are adsorbed onto suspended particles to a different degree, i.e. lead, copper, nickel, mercury and zinc are more easily adsorbed than cadmium and chromium. When adsorbed, the metals are less bioavailable and thus less toxic. Then, in highly turbid waters the majority of the adsorbed metals will be more rapidly deposited in the bottom sediment. Most attention should therefore be

given to the less adsorbable metals.

An increased knowledge of the temporal and spatial pattern of distribution of metals in the aquatic environment may give guidance to for example a suitable harvesting time in order to diminish the risk of marketing and health problems due to high metal contamination. In an Italian study (Cardellicchio *et al.* 1998) the metal contents and distribution in different organs were determined in reared mussels during 6 months. It was found that hepatopancreas is the preferential organ for the accumulation of the different metals and that the amount is influenced by the reproductive cycle, with the highest values observed at the end of the cycle.

For human consumption the presence of organic pollutants is critical as bivalves generally have a lower ability to transform and excrete these compounds compared to fish. However, for the use of bivalves as fertilisers the soil bacteria have generally a great degradation capability, which reduces the risk of contamination of soil and crops.

Contamination by tributyltin (TBT) from boat-paints or use in aquaculture activities may be a serious problem at least in countries and areas with unregulated use. This aspect has been dealt with in earlier presentations in this forum (Granmo 1997, 2000, Svavarsson *et al.* 2000) and in reports from different parts of the world and will not be especially treated here. However, the recently published Asia-Pacific Mussel Watch progress report (MONBUSHO project, Tanabe 2000) shows that there is a widespread contamination by organotin and also organochlorines in the coastal waters of Asian developing countries.

TOXIC PHYTOPLANKTON

Always when harvesting shellfish for human consumption the eventual occurrence of biotoxins in the shellfish should be known. Of the 5000 known phytoplankton species (Sournia 1991), some 300 may cause dense blooms and about 40 produce toxin, which through shellfish or fish may reach humans (Hallegraeff 1995). Some species produce cysts

under certain conditions, which also may be toxic and with harmful effects as a consequence. Basically, occurrence of harmful phytoplankton, often called "red tides", is a natural phenomenon and has been known (as toxic shellfish) in certain areas of the world for several hundreds of years. However, there is a conviction among many researchers that the frequency, scale and distribution patterns of the harmful events have increased during the last decades (Anderson 1989; Smayda 1990; Hallegraeff 1993). The number of biotoxic compounds found in the marine food chain has also increased, partly due to improvements in techniques for analysing the toxin complexes (Yasumoto 1990).

It has been suggested that the observed increase in frequency, as well as the number of species identified as causing harm, is basically a result of eutrophication of coastal areas (Smayda 1990). The anthropogenic increase of nutrient supplies to the sea has in many areas involved not only increased nutrient concentrations but also, for example in NW European waters, an increase during the last decades in the nitrogen to phosphorus ratio, and a decrease in the silicate to phosphorus and nitrogen ratios (Hickel *et al.* 1995; Anderson 1996). By this development, blooms of flagellates causing harm may have become enhanced (Schöllhorn & Granéli 1993; Hickel *et al.* 1995) as well as the toxin production of some species (Granéli *et al.* 1993; Johansson & Granéli 1996).

MONITORING AND IDENTIFICATION OF TOXIC PHYTOPLANKTON AND BIO-TOXINS

Physical, chemical and biological processes in the sea are important for the occurrence and distribution pattern of harmful algae and thus also for the occurrence and distribution of biotoxins in the shellfish. Consequently, a monitoring programme must, in part, rely on an understanding of the hydrography and plankton ecology of the area to be used for the mussel farming operation (Lindahl 1998). Experience from e.g. Western Europe makes

obvious that the localisation of a farm may be very important to avoid accumulation of biotoxins in the mussels (Edebo *et al.* 2000).

An ideal monitoring programme dealing with harmful algae would be one in which the phytoplankton species composition is determined throughout the year. However, it must be pointed out that by itself, phytoplankton monitoring does not provide sufficient protection to public health. It may give an early warning on which an intensified monitoring of fisheries or aquaculture products can be based. Given the need to minimise health risks to human consumers and economic losses caused by these outbreaks, two monitoring strategies should be used:

- i) screening waters for the occurrence of harmful phytoplankton species, and
- ii) testing for toxicity in shellfish. The harvest of the mussels should be avoided if a warning indicates that a bloom of a toxic species is under development. The best way to avoid toxins in seafood will be to have an effective monitoring programme, which can guide the choice of the most suitable time for harvest.

Yet there are no robust techniques that have been developed for the routine assay of harmful algae in water samples from the field. A number of seemingly promising avenues have been explored in recent years, working on the detection of specific toxins, or other characteristic chemical signatures and even on the morphology of the algae. The only unambiguous method of determining the presence of a harmful species is by labour- and time-consuming microscopic analysis of water samples. For practical and economical reasons it is in most cases not possible to keep a monitoring programme at a temporal and spatial frequency of a desirable level based only on microscopic examination of water samples. Consequently, a number of new automated methods for identifying harmful algae have been developed; from epifluorescence techniques (Andersen & Kristensen 1995) to flow cytometry and the use of molecular probes (Anderson 1995; Vrieling

et al. 1996; Scholin *et al.* 1997).

SHELLFISH-TRANSMITTED INFECTIONS

According to a United Nation report, present knowledge indicates that the most clearly identified health risk associated with coastal pollution by urban wastewater is transmission of diseases through consumption of shellfish, harvested in contaminated areas (United Nations Report 1990). When culturing the bivalves in shallow, in-shore areas where nutrient levels are high and the waters are sheltered, high numbers of pathogenic microbes can accumulate in the bivalves. The traditional way in many countries to consume oysters, mussels, cockles and clams is to eat them raw, or only lightly cooked. As the whole animal is consumed, also the viscera, there is a particular hazard to human health and numerous outbreaks of shellfish-transmitted infections have been documented (Matches & Abeyta 1983; Wilson & Moore 1996).

To fight severe infections reliable control methods have to be developed. So far, estimation of bacterial contamination of seawater and bivalves has usually been performed with enumeration of the traditional indicator organism, thermotolerant *Escherichia coli*. However, the most common diseases associated with bivalve shellfish are caused by viral pathogens like Norwalk like viruses (NLV), hepatitis A and enteroviruses (Sindermann 1990; Enriques *et al.* 1992; Cliver 1997). In marine environments, viruses, compared to bacteria, have both better survival in water and persistence in shellfish (Power & Collins 1990). These factors greatly limit the effectiveness of bacteria as indicators for contamination. However, more than 100 types of human pathogenic viruses may be present in polluted water and only few can be detected with available methods. Advances in molecular biology make it possible to recover enteric viruses by amplification using polymerase chain reaction (PCR). Development of such direct detection of viral pathogens will improve the quality assurance

of shellfish but still the methods are complicated and expensive for routine analyses. As an alternative, pollution indicator organisms have been suggested since these are more representative of viruses than the bacterial indicators currently used. Male specific (F⁺) RNA bacteriophages, somatic coliphages and phages infecting *Bacteroides fragilis* have been suggested as candidates for such markers of faecal viruses. These plaque-forming organisms are possible to detect after incubation with the host-organisms. The agreement of the occurrence between these phages, the human viruses and the traditional bacterial indicator, as well as seasonal and geographical variations, are investigated in the EU-programme "Development of techniques for monitoring and control of human viral contamination of shellfish" (FAIR-CT98-4039) and the results will be evaluated during 2001. However, the relevance of using phages as indicator organisms with respect to their persistence and viability in water and mussel tissue has still to be explored.

UPTAKE AND FATE OF PATHOGENIC MICROBES IN BIVALVES

The retention time and the survival of pathogens in bivalves will highly influence the possibility of transmission to human. Thus, the knowledge about uptake and fate of the micro-organisms in bivalves is of great interest. The optimal size of filtering particles in mussels has been shown to be $> 5 \mu\text{m}$ (Wilson & Seed 1974). Despite the fact that both bacteria and viruses are significantly smaller, the content of the microbes in the mussel can reach high concentrations compared to the surrounding water, even though these are not adhered to other particles. It has been shown that mussels have the ability for pre-ingestive selection of particles, presumably on their gills or labial palps. The selection is not only related to size but also to other particle characteristics (Allison *et al.* 1998). In addition a post-ingestive selection including intra- and extracellular degradation in the digestive tract has been explored (Shumway *et al.* 1985; Smith

& MacDonald 1997). A study by Hernroth *et al.* (2000) showed that uptake, distribution and elimination of *Salmonella typhimurium* in blue mussels were significantly effected of the cell surface charge of the bacteria. Thus, the cell surface properties of microbes seem to regulate both the amount of ingested microbes and the degradation of them. Epithelial cells and hemocytes in the diverticular folds phagocytes and digest particles selected for intracellular digestion and the hemocytes also take part in the immune defence. Rögner & Uhlenbruck (1984) found that invertebrates are able to recognise and bind so-called heterophilic antigens or ubiquitous chemical structures like lipopoly-saccharides (LPS) and zymosan. Still, it is unknown how these substances, often present at the surface of microbes, influence the immune response of the bivalves. The effectiveness of the immune defence against different microbes could highly influence their persistence and it might be possible that resistant microbes can use mussels as vectors and presumably even multiply there. Further studies on the role of cell surface properties of microbes in interaction with phagocytic cells of mussel, are necessary to reveal the survival of microbes in mussel tissue and consequently also the choice of faecal indicator.

ENVIRONMENTAL CONDITIONS

Variability of the survival of microbes in seawater, due to environmental factors like temperature and salinity, regulates the presence of viable microbes accessible to bivalves. Bacteria like *Vibrio cholera* can stay viable but non-cultivable in a dormant state in a wide salinity range (5-30 psu) and in that state they have also been detected in zooplankton. Zooplankton and their passengers can be translocated by currents and through fish and shellfish contribute to seasonal outbreaks of cholera in humans (Colwell 1996). Several outbreaks of shellfish-borne gastroenteritis caused by NLV have been connected to temporal runoff due to heavy rains (Richards 1985; Truma *et al.* 1987;

Bird & Kraa 1995). To perform predictive models of outbreaks inter-disciplinary studies on the ecology of the microbes, climatic influences and epidemiological data are required.

Control methods for health security and farm management must simultaneously be improved to sustain the expanding bivalve production, especially in developing countries where production of bivalves could limit both poverty and malnutrition.

CONCLUSIONS

Marine bivalve farming could be a reconditioning tool in eutrophicated waters

Localisation of farms should be carefully chosen.

A monitoring programme and development of control methods in respect to pollutants, pathogenic bacteria and algal toxins should be established for all marine farming.

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