VATTEN 41:218–224. Lund 1985

BLUE MUSSEL SEA FARMING – EFFECTS ON WATER QUALITY

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Abstract

Water currents through a blue-mussel culture have been studied together with inorganic nutrients, oxygen, salinity and temperature. A hanging long-line culture of *Mytilus edulis* L. was followed from June 1978 to March 1980. There were considerable changes in all parameters during the farming period. These changes were to some extent attributable to the seasonal cycle. However, still greater and more rapid changes in concentrations of the nutrients were caused by changes of the water masses in the area. The conclusions are that in this case the mussel culture did not give rise to any measurable effects on the water quality in the area with respect to inorganic nutrients and oxygen. Nevertheless, special sections through the culture showed that nutrient excretion from the mussels could be measured in situ on some occasions, especially by warm water and low current velocity. On these occasions the concentration of ammonium-nitrogen was doubled and the concentration of phosphate-phosphorus was quadrupled in the water mass that passed through the culture.

The phosphorus quantities of different items concerning with the culture are discussed.

A mean current velocity of 2–6 cm/s is suggested as optimum for mussel farms with the technique used today along the Swedish west coast.

Sammanfattning

Förutsättningarna för odling av blåmusslor längs den svenska västkusten är mycket goda och antalet odlingar ökar stadigt. En fortsatt expansion fordrar kunskap om hur musselodlingar fungerar i det naturliga ekosystemet och hur de påverkar den omgivande miljön. I detta syfte påbörjades 1978 ekologiska undersökningar i ett odlingsområde utanför Tjärnö söder om Strömstad. Denna artikel redovisar den hydrografiska delen av undersökningen. Vattnets omsättningshastighet, salthalt och temperatur samt halter av oorganiska näringsämnen och syrgas mättes under en odlingsperiod (ca 20 mån.). Halterna av samtliga parametrar varierade avsevärt. Variationerna följde delvis en normal årstidscykel, men dessutom orsakades stora och snabba haltändringar av vattenutbyten i området. Inga mätbara förändringar av halten näringsämnen och syrgas noterades under mätperioden bortsett från enstaka förändringar vid några tillfällen med varmt stillastående vatten.

I artikeln redovisas dessutom en fosforbudget för odlingsområdet samt att en optimal strömhastighet genom en musselodling med dagens svenska odlingsteknik bör vara 2–6 cm/s.

1 Introduction

On the NW Swedish coast (Figure 1) blue mussel (*Mytilus edulis*) culturing commenced in 1971 and expanded to 1000 tons in 1983. As the potential for culturing is considerably higher, further increases can be expected.

The expansion of aquaculture has caused a debate about possible environmental effects on the marine ecosystems. If a marine area is chosen for intense mussel farming, it is necessary to know the prerequisites for optimum localisation and culture size, in order to obtain maximum harvest and keep environmental effects at a minimum.

An integrated project was initiated in 1978 to learn about mussel cultures in natural conditions in the sea. The project includes a study of the development of the *Mytilus* community in relation to e.g., currents, nutrients, phytoplankton, bacteria and sedimentation (Mattsson and Lindén 1984, Loo and Rosenberg 1983, Romare et al. 1982, Wiigh–Mäsak 1982, Hagström and Larsson 1982, Dahlbäck and Gunnarsson 1981). An overall model for the energy flow in a mussel culture has been presented by Rosenberg and Loo (1983).

The aims of the present part of the project were to describe the nature of water movements in a culture area together with an estimate of the current influence on the growth rate of the mussels and to investigate and quantify the in situ magnitude of nutrient intrusion and oxygen consumption in a full scale three-dimensional mussel culture.

2 Investigation area and observations

The mussel culture studied is situated outside the island of Tjärnö of the northern part of the Swedish west coast (Figure 1). The area is like a 3 km long channel running approximately east-west. The water depth in the culture area varies between 10 and 18 m. The culture was built using 14 horizontal, 180 m long lines moored near the sea surface and anchored to the bottom. Six m bands of polypropylene were attached to the long-lines at 1 m intervals. The culture covered an area of 4500 m^2. The mussels had grown to about 6 cm after 20 months from settlement. The total harvest after this time was 12 tons of musselmeat (dry weight), i.e. about 160 tons wet weight with shells.

The velocity and the direction of the water currents in the area were measured using three different methods: (1) continuous registration of current meters (Aanderaa) over longer periods, (2) small electronic current meters (Gyttre) every time water was sampled and (3) dye (Rhodamine B) on given occasions. Water samples were taken with a plexiglass sampler. Chemical analyses were performed in the laboratory within a few hours. Oxygen and dissolved inorganic nutrients (ammonium, nitrate, nitrite, phosphate and silicate) were analysed according to the Baltic Manual (Carlberg 1972). The total amounts of nitrogen and phosphorus were simultaneously analysed by the method of Koroleff (1972).

Observations were performed during the period of cultivation about every second month at stations 1–4 (Figure 1). Furthermore, special investigations were developed to study daily variations and small scale spatial variations of nutrients and oxygen inside the culture.

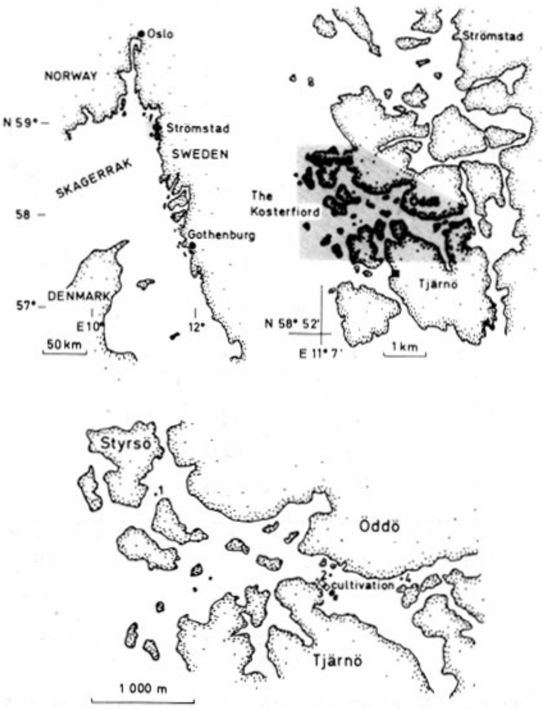

Figure 1. *Area investigated.* Points 1–4 indicate sampling stations. The cross (x) outside the culture indicates position of current meters. Tjärnö Marine Biological Laboratory is marked with a square (■).

3 Results

3.1 Water movements

The tidal currents in the channel kept the water in continuous motion through the culture. The mean tidal current velocity was of the magnitude of 2 cm/s and changed direction every sixth hour in accordance with changes of the water level. However, obervations revealed that the velocities sometimes were considerably higher. The highest observed speed of the surface current measured was 30 cm/s. The higher speeds were caused by additional effects of the local winds, differences in the atmospheric pressure and water movements in the Kattegat–Skagerrak. The river discharge is usually too small to affect the currents.

Because of the complex pattern of the currents it is not possible to calculate the actual amount of water which passed through the culture. However, typical mean movements of the water – apart from direction – are given as 2.8 cm/s at 3 and 10 m depth and 1.7 cm/s at 6 m depth. If the speed component in the direction of the channel is taken into account this gives a net inflow at 3 m of 1.2 cm/s and a net outflow at 6 and 10 m of 0.7 cm/s (Larsson 1984).

3.2 Temperature and salinity

In the summer the temperature was at least 12°C at all depths. A thermocline was developed just a few times at seasons for heating or cooling the water. In the winter the whole water column was cooled down to –1.0°C. Ice covered the culture from January to the beginning of April in 1979 and during January and February in 1980.

The salinity values varied owing to the total effect of currents, precipitation and river runoff. Since the currents were always highly variable, salinity at all depths changed rapidly independent of season.

The specific combination of salinity and temperature in the area indicated different types of water masses during the year. The most frequent salinities varied between 20 and 30 ‰. This water either originated

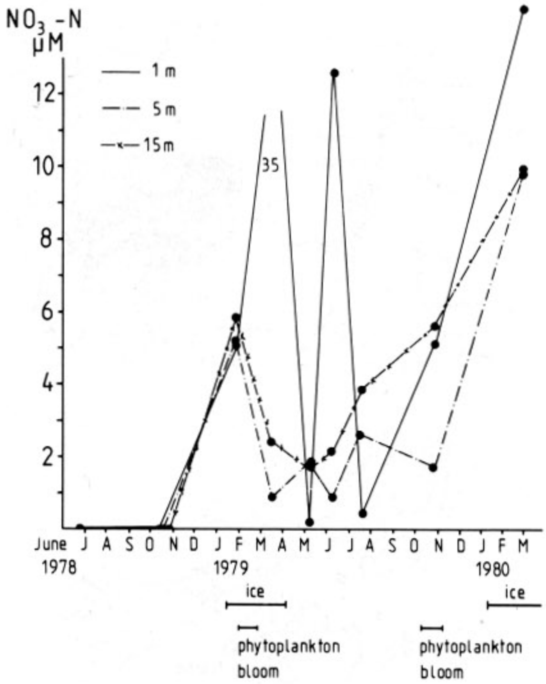

Figure 2. *The nitrate concentrations at 1, 5 and 10 m inside the culture during the period of cultivation.* The point for the highest value (35 μM) lies far above the diagram.

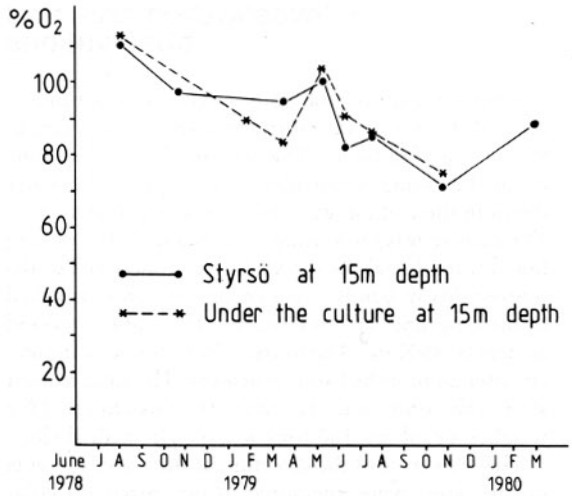

Figure 3. *Oxygen saturation in the bottom water during the period of cultivation.*

– – – samples at 15 m, 0.5 m above the bottom under the culture.

●———● samples at 15 m, 10 m above the bottom at a reference station.

in the Kattegat or was a result of mixing processes between less saline surface water and saltier deep water in the inner part of the estuary. Surface water with lower salinity occurred in the spring both years and on one occasion during the second summer. The lowest salinity measured was 14 ‰ under the ice in March 1979. Intrusions of saltier water from the Skagerrak occurred. In January, March and June 1979 cold Skagerrak water was found at greater depths. In July and October 1979 warm Skagerrak water appeared in the area. The highest salinity value found inside the culture was 32.2 ‰ in October 1979.

3.3 Nutrients

The distribution of dissolved inorganic nutrients in estuary water is controlled by the nature of the estuarine circulation, mixing and other physical processes, together with biological, chemical and sedimentological effects. Inorganic nutrients in our coastal water usually have high winter concentrations and low spring and summer values. Together with this normal seasonal variation there was another variation in the investigational area due to water intrusion from land or from deeper nutrient-rich water.

An example of the variation of the nutrients surrounding the culture during the period of cultivation is given for nitrate in Figure 2. During the "settling" in the summer of 1978 the concentrations at all depths were low or near zero. They increased from November to January 1979 due to convection and low algal production. The spring bloom occurred under the ice in February 1979. The nitrate was depleted at all depths, except just below the surface. Here, instead, low salinity water containing high amounts of nitrate caused higher concentrations. During the summer of 1979 the nitrate concentrations were comparatively low but never near zero. In June there was a considerable intrusion of saltier water, which caused salinity changes at all depths. In the surface water the salinity changed from 16 ‰ to nearly 30 ‰.

This was accomplished by mixing processes and an equalization of the concentrations of the nutrients. The amounts decreased at 1 m depth but increased simultaneously at 5 and 15 m. This took place in spite of high production of organic matter (Lännergren, personal communication). The winter values of nitrate in 1980 were higher than those in 1979, probably due to intrusion of low saline water. On the whole, a comparison with the equivalent diagram for the salinity variations indicates that the variations in the nitrate concentrations followed the variations in salinity. Nitrate maximum value was 36 μM NO_3–N in water with a salinity of 13.8 ‰. In the medium saline water of the Kattegat (20–30 ‰) the nitrate concentrations were higher in winter and lower in summer (i.e. they were completely determined by the extent of mixing).

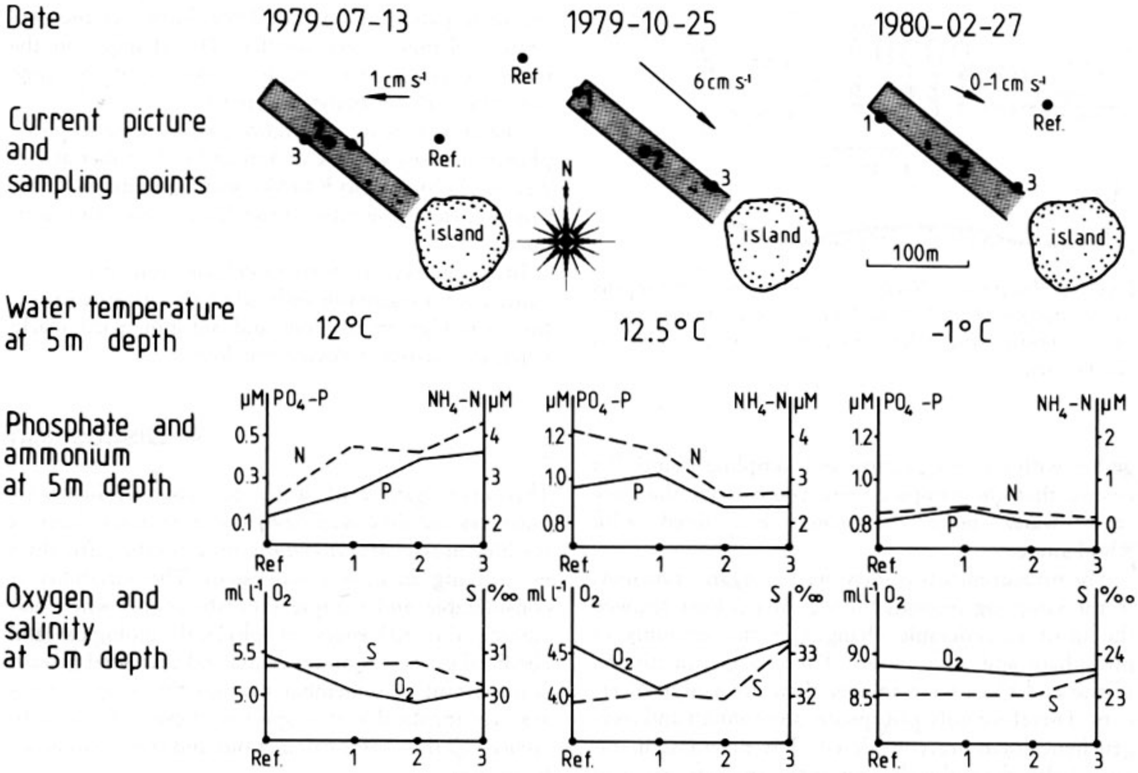

Figure 4. *Sampling sections through the mussel culture on three occasions.* Upper part: date of sampling, sampling points (references and stations nr 1–3), current pictures and water temperatures. Lower part: phosphate, ammonium, oxygen and salinity at the four stations and at 5 m.

In the water of high salinity from the Skagerrak the concentrations of nitrates were higher than those in the medium saline waters.

The features of distribution and variations in concentrations of nitrate were generally also valid for the other dissolved inorganic nutrients. The variations between two occasions of sampling during the same season were sometimes much greater than the variations due to seasonal changes.

3.4 Oxygen

The dissolved oxygen status in the water close to the bottom below the culture was of certain interest. Here the amount of organic matter consuming oxygen during decomposition was considerable. Figure 3 shows the variations in the oxygen saturation during the period of cultivation and just near the bottom under the culture. A comparison with the oxygen curve for a station not at all influenced by the culture indicates that the variations were quite similar in time as well as in magnitude. The samples were taken from the same depth. Notice that the distances to the bottom were different. Both stations had decreasing values of oxygen saturation during the period of cultivation which leads to the question of whether this was due to the mussels or not. Again, one way to answer is to relate the variations in oxygen content to variations in salinity. It is obvious that the oxygen primarily changed according to the salinity. Lower oxygen content was associated with higher salinity. Thus the lowest oxygen saturation values in October 1979 were due to intrusion of highly saline water.

3.5 Sections und scrutiny

The variations in dissolved inorganic nutrients and oxygen concentrations during the whole period of cultivation indicated that there were no measurable effects due to the *Mytilus* cultivation. However, laboratory experiments have shown an increase of nutrients and a decrease of oxygen as the water passes through a mussel (Bayne et al. 1976).

In order to study whether these results also existed in situ under natural conditions, a marked water mass was followed on its way through the culture. These experiments were performed under three different sets of climatic conditions, as given in Figure 4 to-

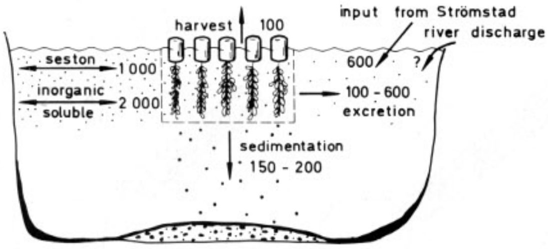

Figure 5. *Phosphorus "budget"*. Phosphorus in the mussel culture designed for 200 tons. Numbers indicate total quantities of phosphorus in kg during the period of cultivation (20 months).

gether with current pictures and sampling points. To ensure that the samples were taken from the very same water mass the water was dyed with Rhodamine.

The measurements of dissolved inorganic nutrients in the sampling sections through the culture showed the most considerable changes in the amounts of phosphate and ammonium. The changes in nitrate, nitrite and silica were smaller than the analytical errors. Therefore only phosphate, ammonium and oxygen henceforth are considered. The diagrams in Figure 4 also show the changes in the concentrations of phosphate, ammonium, oxygen and salinity at 5 m depth. These changes may be real and attributable to the existence of the mussel culture. They could also be a consequence of mixing when the water passed through the culture. The mussel bands caused some turbulent effects, which may be observed through the movements of the dye or through measurements of salinity and temperature. Because of mixing effects, saltier water with higher nutrient concentrations penetrated to higher levels in the water column. In June 1979, with warm water, gradual increase in salinity from surface to bottom and low current speed, the concentrations of phosphate and ammonium at 5 m clearly increased due to nutrient release in the culture. At the same time oxygen was consumed, thus decreasing the oxygen concentrations. These changes were found at all sampling depths. At 5 m the phosphate-P concentration quadrupled from 0.1 μM to 0.4 μM when the water passed through the culture. At the same time the concentration of ammonium-N doubled from 2.4 μM to 4.2 μM.

In October 1979 salinity profiles showed a narrow halocline at 3–5 m depth at stations 1 and 2. The halocline moved upwards towards station 3 due to changes in the bottom topography. Thus, this time the changes in concentrations of phosphate, ammonium and oxygen at 5 m were caused by intrusion of water with different concentrations of these parameters. Above the halocline the changes showed the same pattern as in June 1979. However the percentual changes were smaller. The changes on the other occasions were much smaller or of the same magnitude as the analytical errors.

The atomic ratios of ammonium increase to phosphorus increase in June at 5 m and in October at 3 m were 6. According to Kautsky and Wallentinus (1980) this is close to the ratio of the *Mytilus* excretion products.

In summary, the nutrient release from the mussel culture was measurable only when the water temperature was high in summer and autumn, particularly when the current velocity was low.

4 Discussion

This investigation of water movements, inorganic nutrients and dissolved oxygen in a natural culture of the blue mussel *Mytilus edulis* indicates the difficulties in studying an in situ ecosystem. The variability is considerable and complex. Furthermore, when discussing the influences of physical, biological and chemical processes on nutrients and dissolved gases it is important to remember that no two coastal areas are ever identical with respect to these influences. In spite of all this, some calculations and conclusions can be drawn.

4.1 Nutrients

A rough "budget" of phosphorus in the mussel culture and its surroundings has been drawn up (Figure 5). The aim is simply to give information about the magnitude of the phosphorus content in some parts of the system. There are some complications in finding the proper values for calculation. Some references are only given for laboratory experiments. The physiological state of the individual mussel, which varies, for example, with size, temperature and salinity, may be of great significance when dealing with nutrients and oxygen (Bayne et al. 1976). None of these complications are taken into consideration here. Calculations of the different amounts in the "budget" are accounted for in Larsson (1984). It is interesting that the phosphorus input from the city of Strömstad is only six times higher than the amount of phosphorus which is removed when harvesting the mussel farm. Thus, at least as an intellectual experiment, it should be quite possible in this case to absorb the sewage disposal by mussel farming. A relatively small part of this area is covered by cultures and the water renewal is good. Consequently there are normally no measurable effects of the nutrient excretion, as this is small compared to the "natural" amounts. However, Figure 5 also indicates that the effects have to be reconsidered if the area is to be more intensely utilized or if the water circulation is reduced.

4.2 Water movements

The water movements in the area and the food concentration are the most important factors limiting the size and the growth of a mussel culture. A typical speed of the water movements in the area is given as 2.8 cm/s at 3 m. This is a weak current, and the mussels might have grown better with a higher water speed. Incze and Lutz (1980) have offered a model for calculations of the energy requirements in a cultivated population. From this model the current velocity for different sizes of the culture and different seston concentrations can be calculated. In our case with fourteen long-lines and the mean energy content in seston of 10 kJ/m^3 (Rosenberg and Loo 1983), the current has to be more than 1 cm/s to enable the mussels to grow. Considerable differences in the production rate of the mussels in different areas of cultivation have been observed (Wiigh–Mäsak 1982). However, experience of hard winds and harvesting have shown that the falling off is much greater from cultures with higher production. Consequently, it is suggested that a moderate typical mean current velocity of 2–6 cm/s is the optimum for mussel farms with the techniques used today along the Swedish west coast.

4.3 Oxygen

The increased rate of sedimentation under the mussel culture can, during some periods, causes anoxic conditions in the sediments (Dahlbäck and Gunnarsson 1981), which deteriorate the benthic fauna (Mattsson and Lindén 1984). This increased sedimentation of organic material does not give rise to anoxic conditions in the *bottom water*, provided that there is no evidence for this in the undisturbed system. Our determination of the oxygen content in the water just above the sediment surface showed a saturation value of at least 65 % in spite of anoxic sediments.

In addition to the oxygen consumed in the mussel sediment, mussels also consume oxygen through respiration, which varies with the physiological status of the mussels and has marked seasonal changes. The reported ranges of oxygen consumption differ greatly, but 0.5 ml/h for a mature mussel seems to be high (Bayne et al. 1976). At harvest there were 400 mussels per meter band (Loo and Rosenberg 1983). In this culture with a volume of $27 \cdot 10^6$l and 30.000 m band there was a total oxygen demand of 0.2 ml O_2/ l·h. The concentration of dissolved oxygen in the water was normally about 7 ml O_2/l. If the water is completely stagnant, the oxygen content inside the culture will be sufficient for the mussels to breathe for 35 h. When the water has a velocity of 1 cm/s, it will pass the culture in 3 h, so new water is always transported to the culture fast enough not to deplete the oxygen supply. There were no measurable differences in oxygen concentration between the water inside and outside the culture.

5 Concluding remarks

The total amounts of phosphorus and nitrogen decrease in the surface water of an area with mussel farms. At harvest phosphorus and nitrogen are removed from the ecosystem. The increased sedimentation also causes removal or delay of the recirculation of phosphorus and nitrogen. Any local effects on inorganic nutrients and dissolved oxygen are mainly determined by the nature of the water exchange in the area and by the extent of exploitation compared to the total water mass.

In summarizing our findings, a mussel culture has positive effects on the ecosystem. In fact, it offers a unique opportunity to act against the eutrophication of the sea, provided that it is of the proper dimensions and at the right location. Optimum determinations must be made for each specific case.

Acknowledgements

This work has been made possible thanks to the cooperation of Mr Per-Ingvar Sehlstedt. I also wish to express my thanks to Dr Rutger Rosenberg, the leader of the project. The project was sponsored by The Bank of Sweden Tercentenary Foundation. During the project period I had a scholarship from the Nordic Council for Physical Oceanography and grants from the Carl Tryggers Foundation.

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