SHALLOW WATER FARMING OF MARINE ORGANISMS, IN PARTICULAR BIVALVES, IN QUIRIMBAS NATIONAL PARK, MOZAMBIQUE

A LITERATURE STUDY PREPARED FOR WWF DENMARK

BY

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INTRODUCTION

Shellfish collected from local intertidal and shallow subtidal areas in the coastal zone form an important dietary component in many developing countries, especially in the tropics. Increased population pressure, whether from increased birth rates or migration, usually leads to increased pressure on such open access resources. Many development projects, therefore, include support for the implementation of stock enhancement and/or aquaculture activities. Before initiating new projects, information on previous successes and/or failures should be consulted to improve the chances of success. This report summarizes some of the available literature, especially from eastern Africa and from other developing countries in the tropics.

Mozambique has a long coastline, 2770 km along the tropical western Indian Ocean. Tidal range varies from less than 1 m to almost 4 m, and tides are semidiurnal. Mozambique lies within the monsoon belt and is affected by the cool, windy SE monsoon from April to October and the hot, rainy NE monsoon from November to March (Gullström et al., 2002). Average temperatures are around 26-27 °C, but diel variation may exceed 10 °C, i.e. from above 30 °C in the daytime to only 20 °C during the night. Except for river mouth areas, there is little variation in salinity, which is around 35 ‰ most of the time (Ministério das Pescas, 2003). Quirimbas National Park is located in the northern part of Mozambique where the coastal waters are dominated by coral reefs (Fernandes and Hauengue, 2000).

Shellfish resources in eastern Africa have been exploited for at least 100,000 years as evidenced by the presence of shell middens. However, present day coastal communities in Mozambique do not have a long history for fishing and exploiting the coastal resources (de Boer et al., 2000). Many people are recent migrants who moved to the coastal areas during periods of civil unrest (Bryceson and Massinga, 2002). This means that there is little traditional knowledge about resources and sustainable harvesting. On the other hand, it may be easier to encourage these recent migrants to engage in alternative employment, e.g. tourism activities.

Food security is an important issue in Mozambique as in most other countries in Africa. Collecting molluscs, crustaceans and other marine invertebrates by coastal people provides a significant dietary supplement, especially of animal protein, as well as a source of income for women and children. Intertidal areas are usually “open access”, i.e. anybody can collect anything anywhere and anytime. This often leads not only to overexploitation of resources, but also to conflicts among resource users and ultimately to habitat deterioration.

Several methods have been employed to increase the yield of invertebrate resources. These methods range from deployment of simple "spat collectors" such as empty bivalve shells spread out on the sea bottom or wooden sticks inserted into the sediment, to the construction of "high-tech" intensive aquaculture ponds. The latter are associated specifically with species that have high market value and are often sold for export. Experience primarily from Southeast Asia have shown that these intensive aquaculture set-ups operate at a "boom-and-burst" economy, i.e. investors from outside move in, and intensive exploitation yields high profits for a few years after which the system crashes, and the operations are abandoned with whatever problems that may cause both for the environment and the local economy. Obviously this should be avoided in an area associated with a national park.

For this report information has been collected on the biology of the species under consideration for culture at Quirimbas National Park as well as on the ecological effects of shellfish collecting and culture. Scientific studies from Mozambique are scarce (e.g. de Boer et al., 2000, 2002; de Boer and Prins, 2002a, b) and hence information from the Indian Ocean coast of South Africa has been included (e.g. Hockey and Bosman, 1986; Lasiak and Field, 1995). Information about different culture systems used in other tropical developing countries will be evaluated and some relevant experiences will be presented. The main focus has been on different species of bivalves, but other invertebrates and seaweeds have been considered briefly. Socio-economic effects, although important, have not been the direct focus here, and only information present in the papers on ecological effects and culture techniques has been included. A final section is devoted to identifying major knowledge gaps that should be addressed either before or concurrent with the implementation of any culture system.

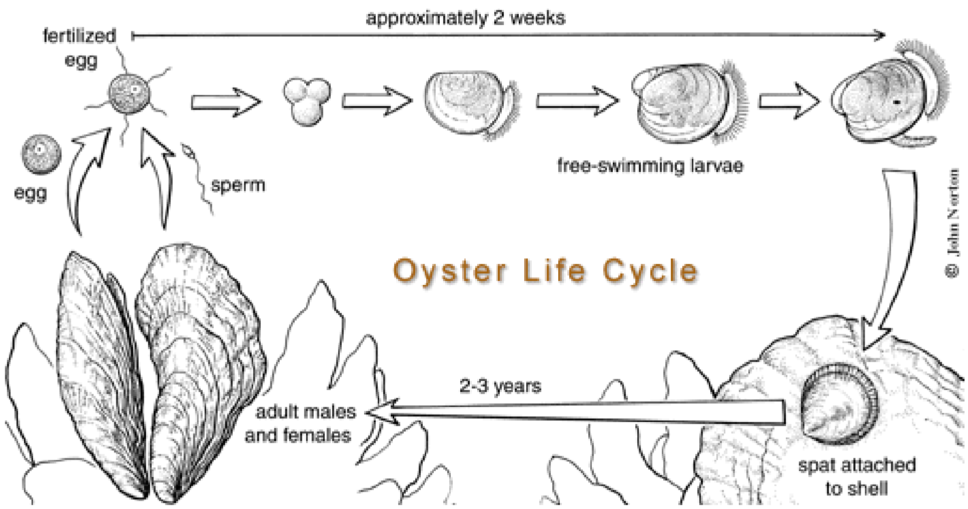
SUSTAINABILITY OF COASTAL RESOURCE EXPLOITATION

Most marine organisms produce pelagic propagules for reproduction and dispersal. Planktonic invertebrate larvae spend from less than a day to several weeks in the plankton and have the potential to disperse far away from the parent population. Although it may seem as if spat appears like "manna from heaven", it has actually been produced by broodstock from nearby – or more faraway – populations. Thus recruitment depends on the presence of viable populations that can function as broodstock. Therefore, the total elimination of a species from one area will also cause the lack of spat supply to populations further "downstream". Collectors should keep in mind that some large, sexually mature specimens should be left to spawn.

Many species of bivalves, especially oysters, are protandric hermaphrodites, i.e. they first mature as males, and in the following spawning season they may change sex and become females. Most bivalves also are broadcast spawners, meaning that sperm and eggs are released into the water and fertilization takes place in the free water masses. Obviously, for fertilization to be successful spawning of males and females must not only be timed to occur simultaneously; males and females also need to be located in close proximity of one another. A few bivalves, e.g. some species of oysters, have internal fertilization where sperm is drawn into the mantle cavity of the female and fertilization takes place either in the mantle cavity or in more or less specialized structures ("brood chambers") in the female. Unfortunately sexual dimorphism does not occur, so it is not possible to determine the sex of a given bivalve without opening it and examining the gonads. These special features of bivalve biology should be kept in mind if prospective management includes minimum legal size.

The period the larvae spend in the plankton holds numerous dangers. Most invertebrates produce thousands of larvae though only two (one male, one female) are necessary to maintain the parent population size. The larvae depend on phytoplankton and/or bacteria for food and their delicate bodies are usually more vulnerable than are the adults to environmental changes such as temperature, salinity, and contaminants. They also form the food for larger predatory organisms such as shrimps and small pelagic fish. Thus the supply of healthy spat depends on suitable environmental conditions, including a sufficient supply of phytoplankton. This is the reason why many commercial-scale bivalve farming operations have set up hatcheries where a constant supply of spat can be provided. However, this requires large investments and maintenance is technology as well as labour intensive. Small scale operations usually depend on wild collected spat and thus depend on the local environmental conditions. This should be kept in mind before deciding to deploy spat collectors for stock enhancement in a given area.

Figure 1 shows the typical life cycle of cupped oysters (*Crassostrea* spp.)



Most bivalves are sessile organisms, i.e. they cannot escape from bad environmental conditions. The larvae have to be very specific about selecting a site for settling. The settling period is a time when the young bivalve is very vulnerable because it has to change all of its living habits; the swimming structure, the velum, is cast off or resorbed, but the gills have not yet developed to become feeding structures. This means that getting enough food will be difficult, and spat that have been able to build up reserves in the form of fatty tissue will be more successful than spat which have spent all their energy searching for a suitable substrate. Increasing the available substrate by deploying spat collectors may yield healthier spat. However, the site where these spat collectors are deployed must be carefully selected to be suitable also for the adult bivalves and to prevent pollution from other human activities.

Most bivalves are suspension feeders, i.e. they feed on organic particles suspended in the water column around them. The bivalve gill is a highly complex structure adapted for food collecting as well as for respiration. Ciliary currents create a water flow carrying food particles into the mantle cavity; other cilia sort and retain the suitable particles, which are covered in mucus to make them sticky so they can be transported to the labial palps at the mouth by yet other cilia in food grooves along the edges of the gill filaments. The gill is easily the largest organ of a bivalve. It is composed of four strongly folded "leaves", two on either side of the body/foot. This arrangement enables separation of inhalant and exhalant water currents and a very efficient system for retaining the food particles. If the water contains many particles of unsuitable size, these are also wrapped in mucus and dumped from the mantle cavity as "pseudo-faeces" ("pseudo" because they have never been inside the gut). If the amount of suspended particles becomes too high the bivalve will stop pumping water through the gills completely. This means that no food will be eaten until conditions improve. Therefore site selection for bivalve farming should include studies on particulate organic matter as well as currents. This should be studied at different times during the tidal cycle as well as at different times of the year as the amount of suspended particles will depend on speed and direction of current as well as on precipitation and wave action.

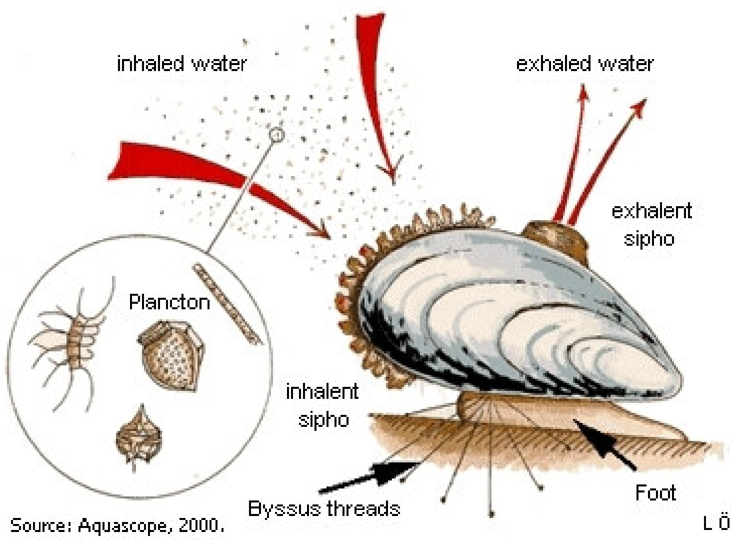


Fig. 2. Bivalves such as mussels feed on plankton particles suspended in the water.

The capacity of bivalves to pump water through their gills varies between species. In the pearl oyster, *Pinctada margaritifera*, rates up to 77 L h^{-1} have been measured (Pouvreau et al., 1999). This means that large volumes of water may be cleared of particulate matter. This has been utilized in aquaculture pond systems (fish or shrimp) in Asia. Water from the culture ponds is passed through a section containing mussels or oysters suspended on ropes before it is released to the environment. This will remove most of the particulate organic material from the water. However, this large pumping and filtration capacity of bivalves also makes them vulnerable to environmental contaminants. Many toxic substances such as heavy metals, pesticides and other persistent organic pollutants (POPs) accumulate in the tissues of bivalves and can cause serious health problems for people – and livestock – eating these bivalves. Toxins from red algal blooms, which are associated with increased nutrient levels, may cause paralytic shellfish poisoning (PSP) in humans (Thorarinsdottir, 1998)

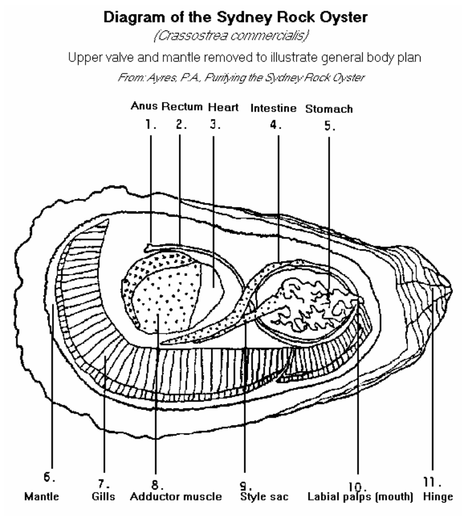


Fig. 3. Oyster anatomy showing the large folded gills.

SPECIES AVAILABLE FOR CULTURE

Many marine invertebrate species have been used for culture in tropical waters. Bivalves, such as oysters and mussels, are probably the most common and also successful examples, though shrimp (prawn) culture may yield the highest economic value. Other examples are abalone and other snail species, sea cucumber and various crab and lobster species. For successful culture of the high value species it is usually necessary to establish hatcheries for a constant and dependable source of offspring. In addition to invertebrates, culture of certain seaweeds has also become popular in many countries.

Four species of bivalves have been proposed for culture around the islands of Ibo and Matemo (Min. Pesc. 2003): *Chloromytilus meridionalis* (Krauss, 1848) (Black mussel, Fam. Mytilidae), *Atrina pectinata* (Linnaeus, 1767) (Comb pen shell, Fam. Pinnidae), *Saccostrea cuccullata* (Born, 1778) (Hooded or rock oyster, Fam. Ostreidae) and *Pinctada capensis* (Sowerby, 1889) (Cape pearl oyster, Fam. Pteriidae). With the exception of *S. cucullata* these species have not been cultured elsewhere. In the following some basic facts about the biology of these and related species that have been cultured will be presented.

Chloromytilus meridionalis (Krauss, 1848)

This species is supposed to be a cold-water species in South Africa (Kilburn and Rippey, 1982). Hence its presence in Mozambique should be reconfirmed. Paula et al. (1998) identified larvae of *C. meridionalis* and another mytilid, *Modiolus philippinarum* Hanley, 1843, in the plankton near Inhaca Island in southern Mozambique, but this may be a misidentification as bivalve larvae are generally difficult to identify to species level. Two other edible species of the family Mytilidae do occur in Mozambique, *Perna perna* (Linnaeus, 1758) and *Modiolus philippinarum* and possibly also the invasive alien species *Mytilus galloprovincialis* occurs here. *M. philippinarum* is commonly found in shell middens, whereas *P. perna* may have been exploited to extinction in southern Mozambique (de Boer et al., 2000; Bryceson and Messinga, 2002).

Mussel culture is practised in many countries, both tropical and temperate. Culture involving rows of hanging rope is probably the most common. Mussel larvae settle on the ropes and attach by byssus threads. Because mussels filter large amounts of water, they are very susceptible to contaminants as well as parasites. The toxins produced by some marine phytoplankton species (“red tides” or Harmful Algal Blooms) may also be accumulated in mussels and present a health risk to human consumers. Therefore the health of the mussels as well as presence of toxic algae has to be closely monitored. Mussels are often used as pollution indicators ("Global Mussel Watch") (Rainbow, 1995). The density of both natural populations and cultured mussels also make them susceptible to parasites such as copepods and flukes. Natural predators are starfish, crabs, whelks and other predatory gastropods. Also sea birds, especially diving species, are frequent and serious predators on mussels.

Pinctada capensis **(Sowerby, 1889)**

This species occurs from South Africa to Mozambique. It grows to a maximum size of about 130 mm. It has a thick shell with a deep byssal sinus. It is mainly subtidal and often lives in rock crevices (Kilburn and Rippey, 1982). A closely related species, *P. nigra* (Gould, 1950), is smaller (max. length about 70 mm), has thinner shells with shallow byssal sinus and is usually found in sheltered tidal pools among seaweed (Kilburn and Rippey, 1982). *P. capensis* appears to be rare among the bivalves collected for food in Mozambique (De Boer and Prins, 2002a), whereas *P. nigra* is the most common bivalve species in the shell middens (De Boer et al., 2000).

Pearl oysters, *Pinctada* spp., are also cultured in many countries. The larger species are usually cultured for pearls whereas smaller species as those found in Mozambique, are cultured for food. Spat collectors can be wooden sticks or mesh-bags ("onion bags"). Grow out can be in hanging baskets to protect from large predators, e.g. crabs, fish and birds. Oysters have to be monitored for fouling organisms and parasites which decrease growth rates (see http://www.spc.int/aquaculture/). Experimental studies on culture of "half pearls" from the black-lip pearl oyster, *Pinctada margaritifera* (Linnaeus, 1758), have been conducted in Tanzania (Southgate et al., 2006). This project is supported by WWF, and experiences from this project should be shared before culture of pearl oysters in Quirimbas national park is initiated.

Most oysters are not able to efficiently retain picoplankton (<2 μm). However, the black-lip pearl oyster, *Pinctada margaritifera* is well adapted to low particle densities. It has a large gill area and a very high specific clearance rate ($l\ h^{-1}\ g^{-1}$) (Pouvreau et al., 1999).

Atrina pectinata **(Linnaeus, 1767)**

Three very similar species of *Atrina* occur in southern and eastern Africa. *A. squamifera* (Sowerby, 1835) is a South Africa endemic. *A. pectinata* and *A. vexillum* (Born, 1778) are both tropical species, the latter having a much darker shell than the former. *A. pectinata* appears to be the most common one in

Mozambique (Kilburn and Rippey, 1982). They live almost completely buried in sand or muddy sand. The shells may be 300 mm or more in length.

Species of *Atrina* and the closely related genus *Pinna* appear to have high growth rates, but are rarely utilized by humans; they were not reported from shell middens, either recent or abandoned (de Boer et al., 2000). The shells may be sold as curios, but it is doubtful whether they will be suitable for culture.

Saccostrea cuccullata (Born, 1778)

This species is also known as *Crassostrea cuccullata*; the species name is sometimes spelt *cucullata*. This appears to be a widespread species in the tropical Indo-Pacific region. It has been cultured in many countries for many years, and it is likely that specimens have been transplanted among populations. It has a highly variable shell shape with a black adductor muscle scar. The maximum size is about 70 mm. It lives on rocky shores in the mid tidal zone and can tolerate low salinities. Spat will settle on almost any hard surface. Hence deploying spat collectors can be very simple.

This species probably has the best potential for culture in Quirimbas National Park, if stable broodstock populations can be identified. Spat collectors can be empty oyster shells laid out on sheltered flats with little or no wave action; wooden sticks attached in the sediment; hanging ropes with empty shells attached; or more elaborate arrangements (see Delmendo, 1989). Unfortunately *S. cuccullata* matures at rather large size (de Boer et al., 2000), which makes it vulnerable to exploitation. Furthermore it may make it difficult to maintain a viable broodstock population. Larvae of *S. cuccullata* are most abundant in the plankton around April in southern Mozambique (Paula et al., 1998), and spat collectors should probably be deployed around this time. There is some conflicting information about growth rates in species of *Saccostrea*. The species cultured in Australia, *S. glomerata (=S. commercialis)* appears to growth fast (Bayne et al., 1999). *S. cuccullata*, on the other hand, is considered a slow growing species. Culture of Australian rock oysters, *S. commercialis*, based on wild collected spat can be a large-scale operation in Australia (see http://www.ozemail.com.au/~dkgsoft/oyster/oysintro.html).

If oysters are to be consumed raw, there are some health problems to be considered. High temperatures of tropical climates permit fast growth and multiplication of bacteria. So, even if bacterial counts in the water at the culture sites are low, bacteria in the oysters may exceed sanitary and human health limits by the time the oysters are sold at the market or in restaurants. In tropical regions, it is therefore safest to cook oysters before consumption. Parasites and shell fouling organisms may be a problem for oyster growth though not necessarily for human health.

OTHER SPECIES

Many mollusc species are collected for their shells rather than their food value. So far culture of such species has not been reported in the literature. Some species may be used both for food and ornamental purposes. Abalone, *Haliotis* spp., is an example of this. Abalone culture now takes place in some countries in Southeast Asia, Australia, South Africa and the USA. However, these are based on hatchery cultured larvae, thus requiring large-scale high-technology operations.

Giant clams, *Tridacna* spp., are protected species on CITES Appendix II and in the Redlist of IUCN. It has been attempted to culture these species for restocking of natural populations, but so far this is only on an experimental stage.

Some gastropod shells, once considered abundant, have been collected to near extinction at least locally. This seems to be the case for several species of cowries, *Cypraea* spp. and cones, *Conus* spp. Whether it might be possible to culture these to supply the tourist industry with curios has not ben investigated. In the South Pacific experiments have been carried out with community management of shell resources, e.g. top-shells, *Trochus* spp. (David, 2006), the shells of which are used for making mother-of-pearl buttons.

Non-mollusc resources:

Sea cucumbers are collected in many countries, mostly for export to Hong Kong and China. This has led to overexploitation of this resource in many countries (Conand, 1998). Preliminary studies have been carried out in south-eastern Africa (Conand et al., 2006) to assess the resources and potential for exploitation. Sea cucumbers are often associated with sea grass beds (Gullström et al., 2002), which are often considered vulnerable habitats. Hence culture seems a suitable option. Culture has been attempted in Vietnam (Pitt et al., 2001; Pitt and Duy, 2003).

Crustaceans, e.g. crabs, shrimps and lobsters are also cultured in many countries. Except for cage grow-out of mud-crab, *Scylla* spp., this usually requires large investments in land for pond construction and often also high technology for establishing hatcheries, commercial food pellets, medication and waste water treatment.

Seaweeds (macro-algae) are cultured for production of various food additives (e.g. agar agar). The most widespread species in culture are the two red algae, *Eucheuma denticulatum* and *Kappaphycus alvarezii* (Rönnbäck et al., 2002). In the Western Indian Ocean these species are currently cultured in Tanzania, Kenya and Mozambique. The culture method is simple: tying pieces of seaweed to thin ropes attached to wooden sticks. After a period of growth the seaweed is harvested. One problem apparently has to do with repeated asexual reproduction (from cuttings) and associated low genetic variability. Growth slows down and the plants become more susceptible to disease (Rönnbäck et al., 2002). Thus, like shrimp farming, seaweed culture may be a "boom and bust" activity.

ENVIRONMENTAL IMPACTS OF COASTAL AQUACULTURE/FARMING

The exploitation of coastal living resources by collecting has adverse impacts on the coastal ecosystems. Simple overexploitation may lead to the collapse of target populations. Since most marine invertebrates have planktonic larvae, it has been assumed that even if a population is locally extinct, the absence of fishing pressure will lead to re-colonisation of such species, provided the environment remains in suitable condition. However, this turns out not to be the case in all systems.

Exploitation of resources by intertidal collecting often results in decrease in biomass and average size of exploited species (de Boer et al., 2000). A decrease in size may result in lower fertility of the population. It has been claimed that a low to moderate exploitation of sessile species would actually have a positive effect on biodiversity (Hockey and Bosman, 1986) because it would create a mosaic of habitats, which could harbour more different species ("Intermediate disturbance hypothesis"). However, other studies have failed to find significant changes in biodiversity (de Boer et al., 2000; de Boer and Prins, 2002a). Previous studies on exploitation of rocky shores in South Africa have shown that only biomass of macrofauna is affected by exploitation. Other differences detected could not be unequivocally attributed to exploitation (Lasiak and Field, 1995).

Resources collected along the coast are generally "open access", i.e. anybody can collect anything in any amounts at any time. This often leads to serious conflicts among different resource users, especially between large-scale commercial fishermen and small-scale, subsistence collectors. This problem has been referred to as "the tragedy of the commons" (Hardin, 1968). The fact that nobody "owns" a resource means that nobody takes care of it. This eventually leads to overexploitation of resources, and possible to civil unrest among resource users.

Implementation of resource management systems, including constant monitoring of resource availability and environmental state, is one way of maintaining sustainability of resource exploitation. However, economic pressures on the people who collect these resources often result in non-compliance with the management regulations. Low-technology and low investment culture systems are another alternative.

Socio-economic concerns: Most shellfish collecting is small-scale and for local consumption, i.e. low value species are included. If collection of molluscs is to be a source of income, then more valuable species need to be included, but also marketing requires that guarantees can be made for safety and quality of the product. This is particularly a problem in tropical climates and where estuarine species are concerned. The combination of high temperatures and high organic content of water and sediment is highly conducive to the growth of bacteria, including pathogenic ones. In order for the profits to remain at the local level, it is important that requirements for investment are kept at a minimum. As has been shown previously, such set-ups often operate at a boom-and-burst economy. This has been experienced again and again with shrimp farming, especially in Asia, but also in eastern Africa (Rönnbäck et al., 2002). Particular problems in eastern Africa have included: illegal operations, corruption, "black" money (weapon), disputes over salaries.

KNOWLEDGE GAPS IDENTIFIED

First of all, we need to know the extent of oyster/mussel beds, the density of oysters/mussels within the beds, the marketable size and market value for each species. Information about which species or proportion of species collected are used for local consumption (collectors' families) and which are sold for cash. For evaluation of the success of culture set-ups, unexploited/unfarmed sites need to be selected for "control". These sites should be as similar to the exploited/farmed sites as possible. Number and size for exploited species should be measured as should number and size of selected non-exploited species. Also total number of species in each locality should be identified.

Site selection is an important parameter. Based on knowledge of the biology of target species, local environmental factors, information about local spawning seasons, and current resource utilisation, sites should be evaluated and selected. This means that information must be gathered on broodstock availability, spawning season, availability of phytoplankton and/or particulate organic matter of suitable size for larvae as well as adult bivalves. Most bivalves cannot filter picoplankton (<1 µm) (Pouvreau et al., 1999), so there needs to be sufficient organic particles of a suitable size for optimal growth rates. It is also necessary to ensure that culture will not be in conflict with other resource uses at a particular site. Hence all resource users should be consulted when identifying suitable sites.

Population biology of the target species should also be studied. It is important to measure growth rates and the size/age at which they reach sexual maturity. As many bivalves are protandric hermaphrodites (see above), it will be necessary to determine this size/age for males and females separately. Correlation between spawning period and time for maximum spat fall should also be determined.

Ideas for research project comparing exploited and unexploited area: Quantitative sampling should be done 3-4 times in a year (dry season, rainy season and in between). Species should be identified to lowest possible taxonomic level, preferably species level – at least for "target" species and other large, dominant species. Species richness, abundance, and biomass (dry weight) should be determined per sample. Diversity indices (Shannon-Wiener, Margaleff), Evenness (Pielou), Dominance (Simpson) should be calculate. From these data k-dominance curves (abundance and biomass versus species rank) and ABC-curves should be constructed to estimate the degree of disturbance (Lasiak and Field, 1995; de Boer and Prins, 2002a). Species could furthermore be classified according to mobility, feeding group, trophic level, etc., and differences between exploited and non-exploited sites compared.

If no effect of exploitation can be seen on biodiversity or community structure, and if there is no significant decrease in size and density of target species, it may be concluded that the exploitation is sustainable.

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