

Aquaculture of Green Mussel *Mytilus viridis* L.: Cultivation on Ropes from Floating Rafts

S. Z. QASIM, A. H. PARULEKAR, S. N. HARKANTRA, Z. A. ANSARI & AYYAPPAN NAIR
National Institute of Oceanography, Dona Paula 403004, Goa

Received 31 March 1977

M. viridis is a fairly widely distributed species along the coastline of India. In Goa, rich beds of this mussel are found in inshore waters and estuaries. Rope culture of green mussel in Goa has been started in 1974. Mussel seeds are transplanted from the natural bed at Velsao to Dona Paula, about 20 km away, and are allowed to grow on nylon ropes suspended from floating rafts. Environmental conditions both at Velsao and Dona Paula are almost similar. Growth of mussels on ropes is much faster than in natural beds. Mussels grow at a rate of about 8 mm/month on ropes and attain marketable size in approximately 5 months. The most difficult period for mussel culture is the monsoon season, when because of turbulent sea conditions, the rafts require constant attention. Total caloric content of cultured mussels is higher than those from the natural beds. Fouling of mussels on ropes by bryozoans and barnacles is common. Annual production of mussels is of the order of 23 kg mussel meat per rope or approximately 1150 kg of mussel meat per raft. In terms of yield in area, it works out to be 480 tonnes of mussels/ha/year approximately. Cost of production is about Rs 2500/raft and the value of mussels produced is about Rs 6900. Rope culture thus gives high rate of returns of about 181%. Various constraints and advantages of mussel culture have been indicated and the potential of mussel farming in Goa has been compared with that of the other regions of the world where mussel culture is being practised. For the production of high quality protein food, mussel culture is perhaps the simplest and the easiest form of farming.

OF all the edible bivalves, the green mussel (*Mytilus viridis* L.), because of its wide distribution in marine and estuarine regions of India, offers an excellent scope for cultivation. An interim report on the success of mussel culture, achieved at Vizhingam (Kerala) has been published earlier¹. However, no precise details of the rope culture of this mussel from floating rafts have been published so far from India.

The present communication forms a part of several investigations carried out under an institutional research project, entitled, "Coastal Aquaculture". The cultivation of green mussels in Goa has been initiated in April 1974 and this paper presents results obtained on rope culture from floating rafts, including some aspects of ecology and economics of mussel culture. Spawning and larval rearing of this species in the laboratory have been reported².

General Distribution

Members belonging to the family Mytiliidae are well distributed along the coastline of India³. The green mussel, has not been previously recorded from the coasts of Gujarat and no mussel fishery has been reported from Orissa and West Bengal⁴. It is fairly abundant in Maharashtra, Goa, Karnataka and Kerala (Fig. 1). On the east coast of India, the green mussel is common in Tamil Nadu and Andhra Pradesh (Fig. 1). Rao *et al.*⁵ have described the biology of this species from the Goa waters and have indicated the scope of its culture.

In Goa, the green mussel occurs profusely along the shores and in estuaries (Fig. 2). There are several beds in the estuaries of Chapora, Mandovi and Sal rivers which are being regularly exploited. Mussels are greatly relished as food by the Goans and are regularly on sale in local markets of Mapusa, Panaji and Margao almost throughout the year. During the monsoon season, when trawling and other conventional methods of fishing in the sea are suspended and fresh fish in the local fish market

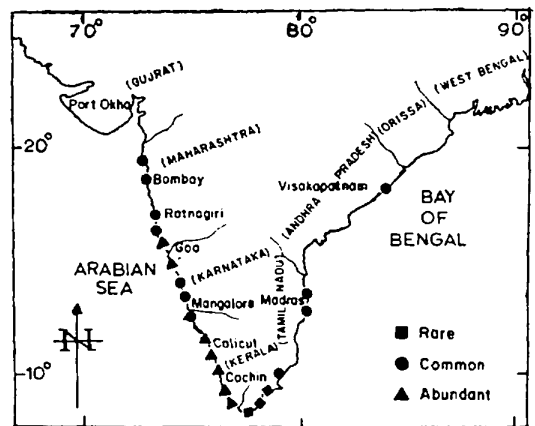


Fig. 1 — Distribution of *M. viridis* along the coastline of India

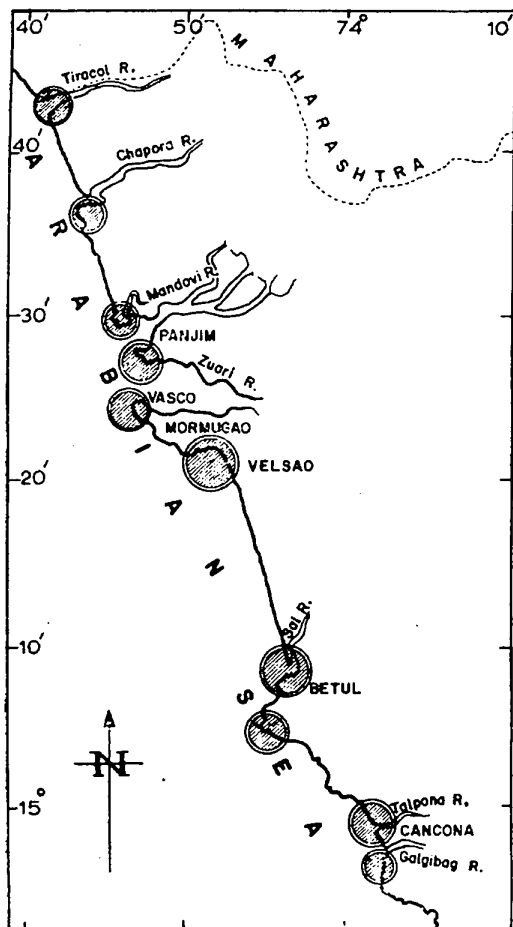


Fig. 2 — Mussel beds (shaded circles) on shores and estuaries of Goa

is not easily available, mussels form the main seafood. The average market price of mussels with shell is about Rs 3 per kg and the mussel meat is sold at the rate of Rs 4.5 to Rs 5 per kg. The annual yield of this mussel from the natural beds of Goa is approximately 200 tonnes.

Methods

Collection of Mussel Seeds

Mussel seeds were collected from the Velsao Bay, about 20 km away from Dona Paula, where rich mussel beds exist on laterite rocks and boulders, from about mid tide to low tide marks (Plate I, Fig. 1). The beds get exposed at low tides of even 0.2 m range. At Velsao, dense spatfalls occur from September to December. In these months the density of spats is about 11000/m² (Plate I, Fig. 2). However, the bed is heavily exploited and most of the larger specimens are hand picked by fishermen and local villagers from time to time. The Velsao beach is the northern most extension of a large sandy

beach of Goa and it gets seasonal fresh water discharge from a nearby perennial stream. This sandy beach at other places is devoid of rocks and hence, except for the Velsao Bay, no natural mussel beds are found in nearby areas. Collection of mussel seeds was made by hand picking a large number of specimens from time to time (Plate I, Fig. 1).

Fabrication of Wooden Rafts and Transplantation of Seeds

Floating raft (Plate II, Fig. 1) used for mussel culture consists of a wooden frame made from logs of wood fixed tightly at the corners. The wooden frame (2.5 m × 2.5 m) is supported by 2 broad planks (2.5 m in length). These planks are fixed on to the frame by nuts and bolts. In each frame, 9 bamboos (2.85 m in length) are tied with thin nylon ropes. These bamboos are placed equidistantly and are used for suspending the ropes. The wooden frame of the raft is mounted on 4 heavily tarred metal drums (200 l). The total weight of the raft including 4 barrels is about 0.5 tonne. Fabrication of the raft is normally done on the shore, near the aquaculture site, and the raft is towed to a convenient place and moored with an anchor weighing 50 kg, connected by a steel chain of 20 m length and 3.8 cm diam. The raft was anchored where the depth of water is at the average low tide was about 5.5 m in Dona Paula Bay. Two rafts, both of the same dimension, were initially used for mussel culture. The servicing of each raft was done after 4-6 months. The rafts remain in good condition even after continuous use for more than 2½ yr.

Mussel seeds suitable for transplantation become very abundant at Velsao from September to November. Size of the selected seeds was 5-10 mm and these were about 4-6 weeks old. Seeds were first brought to the laboratory and kept in well aerated sea water for 12-18 hr. They were then transplanted on to nylon ropes, dyed blue, by arranging them all along the length of the rope. The rope was placed over strips of mosquito curtain cloth of suitable width (Plate II, Fig. 2). The cloth was then stitched around the nylon rope with mussel seeds (Plate II, Fig. 3), and a thin twine was wrapped round the stitched cloth. To prevent the mussels from clustering, small bamboo sticks (about 10 cm long) were inserted through the twist of rope (Plate II, Figs. 2 and 3) at suitable points on the rope. After enclosing the seeds over the rope in this fashion, the rope is hung from the raft. The seeds get attached to the rope by their byssus threads within 48 hr. The covering net perishes within a fortnight or so. In the initial stage of handling and transplantation, the mortality of the seeds was of the order of 20-30%, probably because the seeds were quickly pulled off from their natural substrate. If, on the other hand, they are carefully picked, the mortality is considerably reduced. However, when they get reattached to the ropes and growth begins, there is practically no mortality. From each raft of the size mentioned above, 40-60 ropes could easily be suspended. Initial experiments conducted on different types of ropes (coir, manilla

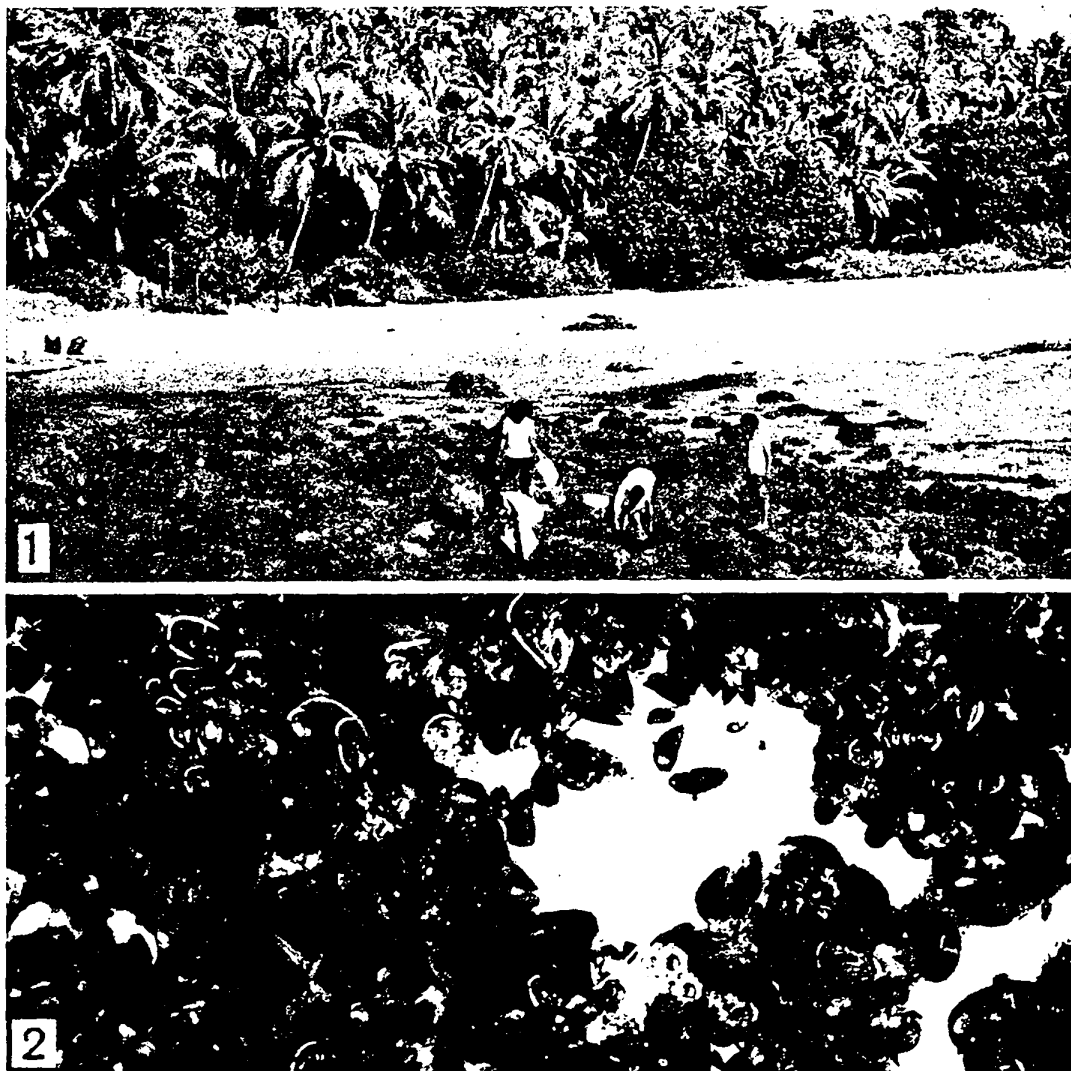


Plate I --- Mussel beds at Velsao Bay, Goa. Fig. 1: Natural beds. Fig. 2: Portion of mussel bed greatly enlarged showing dense spatfall]

and nylon) showed that nylon ropes in the long run are more economical. In a recent study, use of synthetic rope dyed with carbon black has been found to be an improvement over natural fibres for mussel farming⁶.

The length of all the nylon ropes hung from the raft was 3 m. One end of the rope was used for tying to the raft and a little portion of this rope remained above the surface of the water, free from mussel attachment. Thus only about 2.5 m long portion of the rope remained hanging underwater with mussels. In many ropes, the portion with attached mussels was even less than 2.5 m, because despite the bamboo sticks inserted through the ropes to keep them uniformly distributed, they tended to form clumps (Plate II, Fig. 4). Selection

of thin (12 mm diam.) and 3 m long ropes at a site where the depth of water was 5.5 m (average) at low tide was because of convenience of lifting the ropes at all tides by hand, particularly when the ropes became loaded with mussels. In longer ropes, a mechanical device for hauling the ropes would probably become necessary. Moreover, if thick and long ropes are used, it would be desirable to build stronger and more robust rafts, otherwise there will be the risk of rafts getting collapsed with the weight of the mussels. The water at the site always remains turbid (Secchi disc readings 0.47-2.17 m) and hence it was thought that the mussels up to 2.5 m depth will largely remain within the euphotic zone and will thus get the maximum amount of food material.



Plate II—Mussel culture using rafts and ropes [Fig. 1: Floating raft (Two rafts joined together and anchored in Dona Paula Bay). Fig. 2: Rope and mussel seeds kept over strips of cloth netting (Cloth is stitched over the rope. Small bamboo sticks are inserted through the rope to prevent the mussels from clumping). Fig. 3: Rope with stitched cloth netting ready to be suspended from floating rafts. Fig. 4: Portion of rope with fully grown mussels. Fig. 5: Portion of rope showing mussel attachment (Arrow indicates fresh settlement of spats on ropes). Fig. 6: Progressive increase in size of mussels within 5 months on ropes (Fouling organisms settled on mussels are also seen).]

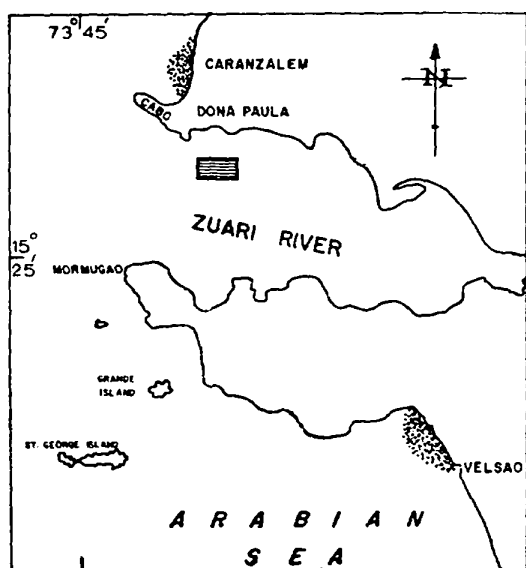


Fig. 3 — Mussel culture site in Dona Paula Bay (shaded block) and natural mussel beds (stippled areas) at Velsao and Caranzalem

Selection of Culture Site

Selection of Dona Paula Bay (Fig. 3) was made because of the information available on diurnal and seasonal changes of the environmental features and productivity of this area⁷. The site is easily accessible in all weather conditions because of proximity to NIO. No natural beds of mussels are found in this area.

In early 1974, when experiments on mussel culture began, a site in the Mandovi estuary (Caranzalem Bay) was first selected and rafts were anchored there. However, during the monsoon months, because of considerable sand movement at the bottom, the depth of the site increased drastically, the anchors got dislodged from the bottom, and as a result of severe wave action, the rafts were brought ashore. No such sand movement occurred in Dona Paula Bay, where the rafts remained in position throughout the year.

Results

Sea Conditions at Natural Beds and Culture Site

To determine ecological conditions at the sites where mussels were growing in natural beds and on ropes, regular monitoring of temperature, salinity, dissolved oxygen, particulate matter and phytoplankton counts was carried out practically throughout the year (1975-76).

Water temperature (Fig. 4) at the 2 sites ranged between 25.4° and 30.6°C. Seasonal cycle of temperature was almost similar at both the places but the annual mean was definitely higher at Dona Paula. From May to August, the temperature of Velsao Bay was significantly lower than at Dona Paula (Fig. 4). Salinity values showed wide variations with a minimum during the peak monsoon

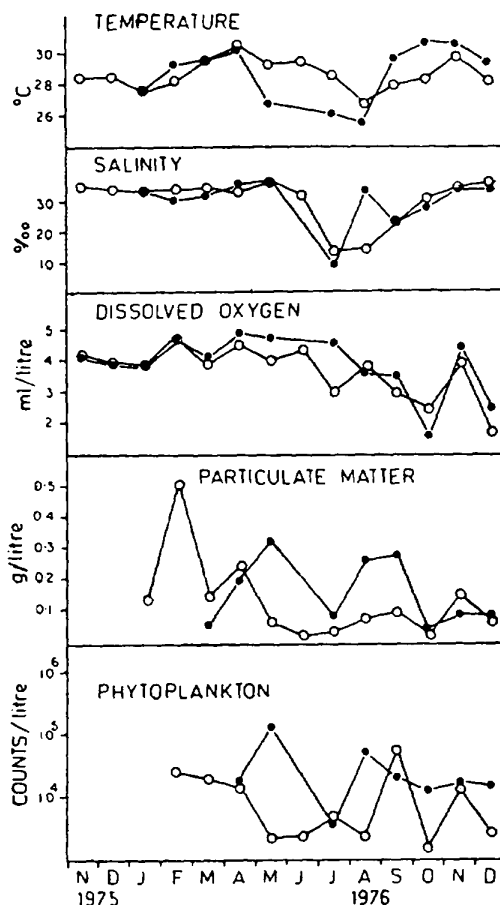


Fig. 4 — Environmental characteristics of Dona Paula Bay (○) and Velsao Bay (●)

month (July) and maximum in May at both the places. Although the site at Dona Paula Bay was close to the Mandovi-Zuari estuarine system (Fig. 3), salinity variations in the Bay were not lower than at Velsao. Except for 3 months (July-September), salinity for most of the year at Dona Paula was above 30‰. Dissolved oxygen values ranged between 1.5 and 4.5 ml/litre at both the places. Oxygen minima recorded in September and October agreed with the earlier findings⁸ and the annual mean of dissolved oxygen (3.56 ml/litre) was close to findings of Singbal⁹. However, the decrease in oxygen recorded at both the places in Dec. 1976 was an unusual feature and seems difficult to explain. Particulate (suspended) matter was high in February and April which coincides with the peak productivity period for the Dona Paula point reported earlier⁷. Maximum turbidity at Velsao from May to September can probably be related to premonsoonal and monsoonal turbulence which gives rise to stirring up of sediments in nearshore regions of the west coast of India¹⁰. Phytoplankton abundance, as determined from numerical counts, showed higher (average) values for Velsao than at Dona Paula (Fig. 4).

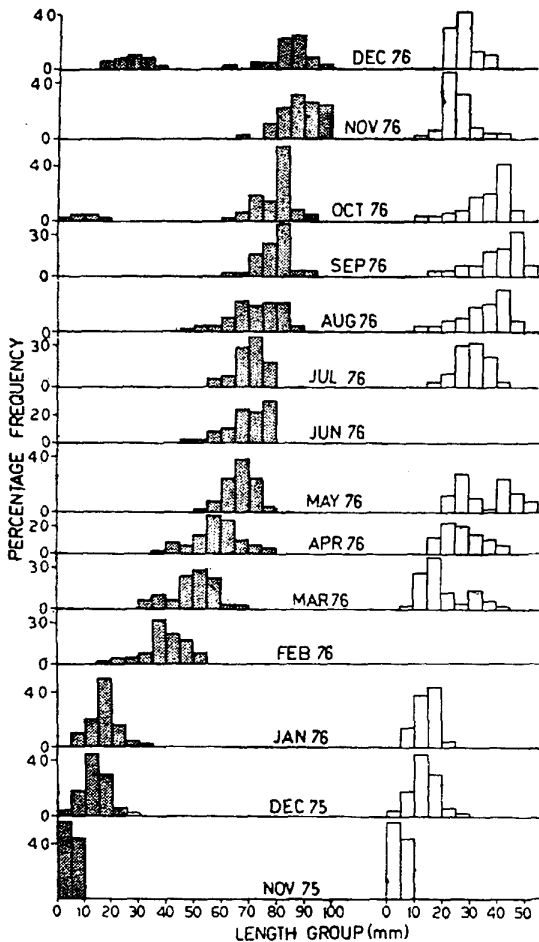


Fig. 5 — Length-frequency distribution of mussels from rafts (stippled bars) and Velsao Bay (open bars)

Growth Rate on Ropes and in Natural Beds

Length frequency distribution for the entire period of observation (14 months; Nov. 1975 to Dec. 1976) are given in Fig. 5. In all, 2118 specimens were measured. Of these, 1098 were from Velsao (natural bed) and the rest from ropes. Measurements were made accurately up to 0.1 mm using a Vernier callipers. The specimens were in the size range 1-100 mm, and hence the measurements were grouped in 5 mm size class. Altogether 20 size classes were taken for mussels from the ropes.

In the natural bed at Velsao, spatfall occurs at least 4 or 5 times during the year and hence it becomes difficult to show the continuity in the rate of growth of any one brood. Spats produced from different broods give rise to considerable overlap in the size range (Fig. 5). This feature is totally overcome on ropes, where the transplanted mussels continue to grow with little overlap throughout the year.

Rao *et al.*⁵ have reported that *M. viridis* breeds intermittently throughout the year. Mussels mature when about 3 months old and the minimum size

at maturity is 15.5 mm. An interesting feature noticed from the length frequency study was the occurrence of fresh settlement of seeds on ropes (Plate II Fig. 5). This was first observed in Oct. 1976. The seeds had a size range of 5-20 mm (Fig. 5). Their average size of 11.4 mm indicates that the seeds had probably settled in September when a heavy spatfall was recorded in the natural beds also at Velsao. By the end of Dec. 1976, their average size becomes 26.8 mm, thus showing an average monthly growth increment of 7.7 mm. This is slightly greater than the growth increment (6.6 mm) recorded in mussels of similar size range transplanted from the natural beds on to ropes (Table 1); and in the latter case it may be because of their handling during transplantation.

Monthly increases in length and weight (Fig. 6, A and B) show that growth was much faster on ropes than in the natural beds. From Nov. 1975 to Jan. 1976, mean length and mean weight for both the populations were almost similar. Thereafter, the growth on ropes became very rapid. The mussels on ropes (Figs. 5 and 6) grew to 85 mm in length in 11 months, thus recording an average growth of almost 8 mm/month on ropes as against 5 mm in natural beds. On ropes, the mussels attain marketable size (60-64 mm) in less than 5 months (Plate II Fig. 6). Rao *et al.*⁵ found that mussels reach 60 mm in length in about 6 months on floating buoys.

Fig. 6A also gives the rate of growth of 4 different broods settled in the natural beds at Velsao. The rate of growth of these broods can be traced from the length-frequency distribution. Unfortunately, larger mussels are hand-picked from the natural beds and hence there is an absence of mussels larger than 45-50 mm in length (Figs. 5 and 6A). Nevertheless, from Fig. 6A, it is clear that the growth rate of each brood is of a similar order of magnitude.

Table 1 gives the seasonal variations in growth rate on ropes and in natural beds. During the postmonsoon period, a uniform growth rate of 6.6 mm occurred in both the areas. In the premonsoon period, the average growth in length on ropes was found to be almost twice as high, and about 3 times greater in weight as compared to that in natural

TABLE 1 — SEASONAL GROWTH IN LENGTH AND WEIGHT ON RAFTS AND IN NATURAL BEDS AT VELSALO

[Values represent length (mm) and weight (g) obtained in 4 months]

	Raft		Velsao	
	Growth rate	Av. growth	Growth rate	Av. growth
POSTMONSOON (OCT.-JAN.)				
Length	26.6	6.6	26.4	6.6
Weight	1.6	0.4	1.6	0.4
PREMONSOON (FEB.-MAY)				
Length	50	12.5	25	6.2
Weight	41.2	10.3	14	3.5
MONSOON (JUNE-SEPT.)				
Length	15.0	3.7	10	2.5
Weight	92.8	23.2	10.6	2.6

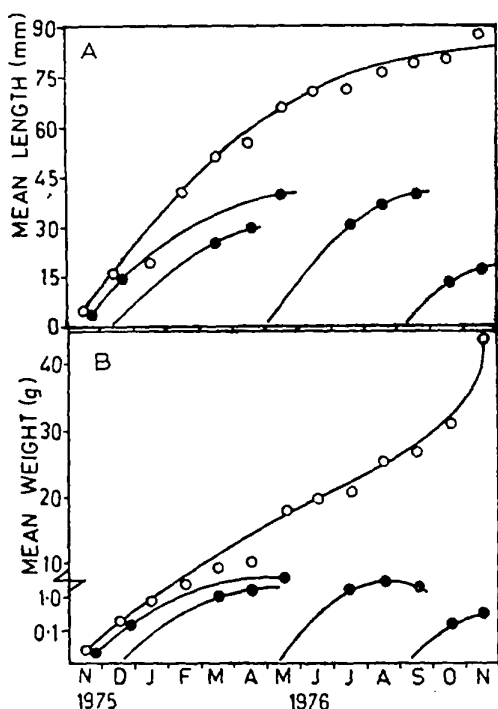


Fig. 6 — Growth in length (A) and weight (B) of mussels from raft (○) and Velsao (●)

beds. In the monsoon season, the growth in length fell sharply. However, taking the overall growth pattern of cultured mussels for the whole year, the rate of growth in Goa waters was found to be higher than that reported from the Ratnagiri area¹¹.

Fig. 6B shows increase in weight in relation to time. In the beginning, it was almost similar in both the populations growing on ropes and on natural beds. However, from December onwards, when multiple broods start appearing in natural beds, the situation becomes similar to what was noticed with the length. Growth in weight, however, continues on ropes with varying rates throughout the year except in the largest size group where it slows down (Fig. 6B). On the ropes, the rate of increase in weight was found to be much higher than that reported earlier by Rao *et al.*⁵ from the natural beds.

The increment in weight also showed a marked seasonal variation (Table 1). It was maximum during the monsoon season, when growth in length was minimum. Similarly, during the premonsoon months, the increase in weight was minimum when maximum growth in length occurred. On the ropes, the average monthly increase in weight was 11.3 g which was almost 3 times greater than that reported for cultured mussels from the Ratnagiri area¹¹. The main reason for this difference is that Ranade *et al.*¹¹ did not record the growth in weight during the monsoon period when it is maximum.

Relative increase in weight in relation to length was calculated using the linear regression equation: $\log y = b \log x - a$, where y and x are the mean

weight and mean length respectively, and a and b are 2 constants to be determined. The equations obtained were:

$$\log y = 2.5689 \log x - 3.4044 \text{ for raft, and}$$

$$\log y = 2.6648 \log x - 3.4849 \text{ for Velsao}$$

Test of significance was applied to the 2 equations of length-weight relationship and the values of r were found to be highly significant. These were 0.998 for raft and 0.987 for Velsao.

Seasonal changes in growth were further studied by taking into account the shell weight and meat weight (wet and dry). Growth in shell and wet meat was found to be exponential (Fig. 7), and there was no marked seasonal difference in between these 2 components. Ratio of shell weight to wet meat weight was 1:1. However, increase in dry meat by weight varied seasonally with a maximum increase in the postmonsoon period and minimum during the monsoon period. Thus, the seasonal variation in the dry meat weight was entirely dependent on the water content of the mussel. The ratio between wet meat to dry meat was 4:1 by weight.

The condition index, which reflects on the metabolism of the mussel in different seasons, was estimated using the following equation given by Walne¹².

$$CI = \frac{\text{mean dry meat weight (g)}}{\text{mean dry shell weight (g)}} \times 100$$

The index (Fig. 8) for the rope-grown mussels was found to be higher than for the mussels from

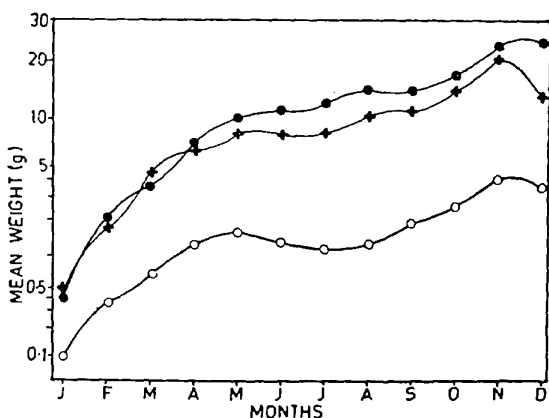


Fig. 7 — Seasonal changes in growth of shell weight (●), wet meat weight (x) and dry meat weight of mussels (○) from raft

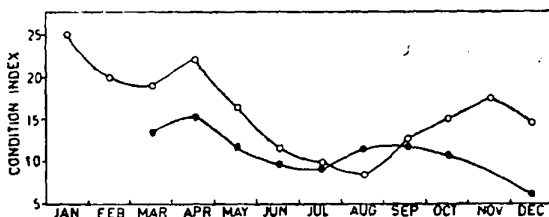


Fig. 8 — Seasonal variation in condition index of mussels from raft (○) and natural beds at Velsao (●)

the natural beds. However, the seasonal cycle in CI values was similar at both the places with a decline in values during the monsoon period and an increase thereafter. The high average values of condition index for rope-grown mussels indicate their better state of health and fatness than those from the natural beds.

Biochemical Composition

Biochemical composition of the mussels grown on ropes was determined and it was compared with that of mussels from the natural beds. The components estimated from the meat were protein, total carbohydrates, lipids, water, ash, edibility and caloric value. All the major metabolites were determined throughout the year using standard laboratory techniques. The per cent edibility was calculated as the amount of water content in relation to the total weight of mussel meat.

Fig. 9 gives the variation in each component in different months. There was no marked difference in the biochemical components in mussels from the ropes and natural beds. However, the annual mean, especially for protein and caloric content, was higher in the rope grown mussels (56.5% and 6.283 kcal/g dry wt respectively) than those from Velsao (54% and 5.687 kcal/g dry wt). Per cent edibility was also higher in cultured mussels.

Seasonal changes in the biochemical components were probably related to metabolic processes of the mussels such as feeding and spawning. Thus the lipid content and per cent edibility decreased from August to December which coincided with the maximum spawning of mussel. Similarly, the high protein, carbohydrate and lipid values obtained in some months probably synchronized with the maximum feeding and building up of reserves during these months.

Fouling of Mussels on Ropes

Fouling was found to be quite common on the cultured mussels (Plate II, Fig. 6), but it was not a serious problem. The occurrence of fouling and parasitic organisms has been reported earlier in pearl oysters cultured on rafts where it leads to mortality of oysters¹³. The intensity of fouling in mussels cultured on ropes was estimated quantitatively in terms of wet weight of scrapped organisms settled on mussels in relation to the total weight of the mussel. This has been shown in Fig. 10. The intensity of fouling varied seasonally. It was maximum from December to March and minimum from December to March.

In the order of predominance, bryozoans were 50% and barnacles 32%. Other associates were algae 5%, flatworms 4%, crabs 3% and amphipods 2%.

Fouling in natural mussel beds at Velsao was found to be negligible. A far greater fouling of the mussels growing on ropes was probably because they were submerged continuously. In contrast to this, the mussels in the intertidal zone were exposed to atmospheric conditions at the ebb tide. Thus periodic desiccation seems to prevent the growth of fouling organisms. Raft grown mussels showed no infection of *Mytilicola* sp. or trematodes,

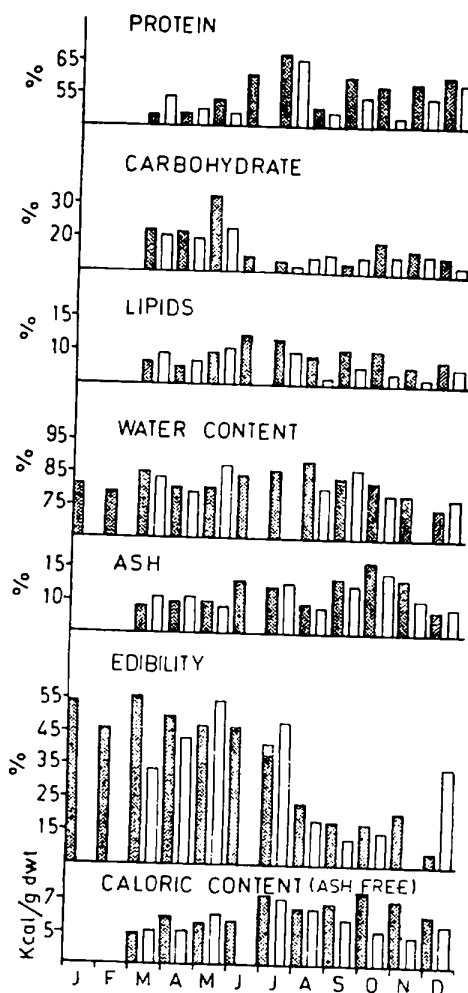


Fig. 9 — Seasonal variations in biochemical composition of mussels from raft (stippled bars) and natural beds at Velsao (open bars)

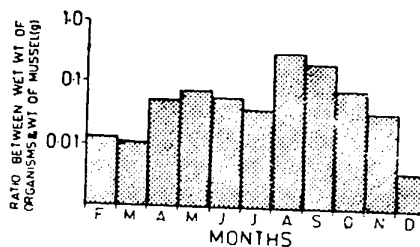


Fig. 10 — Seasonal variation in the quantity of fouling organisms settled on raft-grown mussels

but at times, the commensal crab (*Pinnotheres* sp.) was found in the mantle cavity.

Economics of Mussel Culture

A number of reports on the culture of mussels from other countries have given the yield¹⁴, but not the cost-benefit ratio. In the present investigation, the cost structure of mussel culture was maintained throughout, and the details are given in Appendices I and II. Prolonged breeding of mussels and intermittent spatfalls make it possible to have continuous harvesting and relaying of mussels on ropes for 8-9 months during the year. The annual estimated yield of 480 tonnes of mussels per hectare (Appendix I) is lower than 600 tonnes reported from Spain¹⁴, and it is about 6 times greater than what was recorded in the preliminary study at Vizhingam¹.

The reason for the yield being lower in Goa than that of Spain is because we used smaller rafts with shorter ropes. However, since these experiments were conducted on a small scale, further refinements in the techniques to be used on a commercial scale are likely to increase the yield further and reduce the cost of production. It is clear (Appendix II) that mussel culture even on a small scale gives very high return. The cost of the raft can be further reduced by servicing and reusing the same rafts over and over again. As compared to the rafts used in other countries¹⁴⁻¹⁸, our rafts were cheaper but equally effective and perhaps well suited for Goa conditions.

Shortcomings and Constraints

In these calculations, although we have taken into consideration the labour charges for the fabrication and maintenance of the rafts, we have not included the salaries of the scientists involved in mussel culture because we feel that it is not necessary. Once the techniques are standardized, anyone can undertake mussel culture. Therefore, even if we include some reasonable cost of consultancy or supervision, the return will still far exceed the technical assistance rendered. We have also not taken into account the cost of a dinghy boat used in the culture operation, because we expect that the fishermen or any other person who might undertake mussel culture will probably be having such a facility with him. Moreover, the boat will not be engaged full time and hence the hire charges of a boat on certain days for to and fro visits to the raft would be fairly nominal. On similar grounds, we have not included the cost of a vehicle or its running expenses because for the collection and transportation of seeds or harvested mussels, the use of any public or hired transport, whenever needed, could be availed at a fairly modest cost. For this and for hiring a boat, we have made provision under travel and unforeseen expenditure (Appendix II).

In our opinion, the major constraints in mussel culture, in spite of its being highly profitable, are:

(i) Labour intensive operations at least in the initial phase. (ii) Losses of ropes, anchors,

mussels, etc. because the rafts are tampered with by inquisitive fishermen. However, this difficulty was totally overcome in Goa once the villagers were told and they got familiar with the work. In fact, they became extremely helpful and interested once the production of mussels started. (iii) Intensive care of rafts during the monsoon months due to turbulent sea conditions. (iv) Damage to the raft if timely repairs are not carried out in rough weather.

Advantages

(i) Tolerance of *M. viridis* to wide fluctuations in salinity makes it ideal for cultivation in marine and estuarine environments of tropical areas. (ii) Growth in length and in weight occurs almost throughout the year and culminates in attaining marketable size within 5 months. (iii) Prolonged breeding of this species and continued settlement of spats in natural beds for a long period ensure quick multiplicity of ropes on rafts which finally gives rise to 3 harvests (possibly more) from each raft during the year. When there are several rafts in operation, harvesting can easily be synchronized at monthly or even fortnightly intervals. (iv) Intensity of fouling can be reduced considerably by exposing the ropes to air for 6-8 hr/week, or by coating the ropes with carbon black⁶. (v) Initial expenditure involved in mussel culture is small and this can further be reduced by using the material of the same rafts for several years. (vi) Despite the vagaries of nature, commercial production can be achieved in all weather conditions. (vii) Production of high quality meat in a unit area and time guarantees a very substantial return on the investment.

Discussion

From these investigations it has been possible to demonstrate on a small scale the culture potential of mussels in Goa. Mussels are known to be a world food resource of great potential¹⁷. Being sessile, they are easy to handle and transport from one area to another; they live on floating microscopic algae and detritus, and when kept submerged they grow very fast. The average size of 62 mm on ropes in 5 months, recorded in Goa, is perhaps one of the highest in the world. In Spain, *M. edulis* takes a year to grow from 10 to 75 mm¹⁴, and in Wales it takes more than 3 yr to reach this size, for there is practically no growth in winter¹⁷. On coir ropes, *M. edulis* took 1½ to 2 yr to reach 60 mm in the Menai Straits (North Wales)¹⁸.

Mussel farming on a commercial scale is being practised in many countries of the world. Notable among these are France, Spain, Britain, Holland and the Philippines. In France, mussel seeds are collected on loosely woven ropes from the southern parts of France, where natural beds are found, and these ropes are transported to northern coasts of Brittany, where they are wrapped round wooden poles planted in the sea bed and arranged in rows¹⁴. These poles are fixed in mud flats which are unsuitable for mussel settlement. The total production of cultured mussels in France is about

50000 tonnes. However, France imports more than 100000 tonnes of mussels from other European countries, particularly Spain. In Britain and Holland, mussels are cultured by transplanting them from the intertidal zone to deeper areas where they remain submerged. These beds are harvested by dredging^{17,18}. Such a simple operation yields more than 8 tonnes of mussels in a small area of 0.25 acre¹⁷. However, the wide fluctuations in the spatfall in Britain has led to the propagation of mussel seeds from the larvae in hatcheries. In Spain, mussels are cultured on heavily built rafts (40 m x 40 m) which can accommodate about 1000 hanging ropes¹⁶. The yield from these rafts is of the order of 600 tonnes/ha/year¹⁴. In the Philippines, mussel culture is carried out on bamboo stakes which are also used as spat collectors. These bamboos, once laid with seeds, are driven into the sea bed so that the mussels remain continuously submerged. The average yield from such poles is 125 tonnes/ha¹⁴.

In India, although there are innumerable beds along the coast, many of these are rapidly getting depleted. During the last few years, the present authors have observed many old and productive beds getting exhausted in Kerala, Karnataka, Tamil Nadu and Andhra Pradesh, because of indiscriminate exploitation of mussels — not much for food — but to support lime making by burning the shells, particularly in Kerala. Construction of jetties, boat pens, oil terminals and a rapid increase in the industries along the coast have also contributed a great deal to the depletion of natural beds. Human habitation along the coast and population increase have changed many of the stoney and gravelly beds, ideal for spatfalls, to muddy and polluted areas, totally unsuitable for mussel settlement. The mussels occurring in these areas, are lean, unhealthy and unfit for human consumption.

Mussel culture, therefore, besides being highly profitable, offers the best scope for resource management and resource utilization. The yield of quality meat from mussel culture is perhaps the highest in the world when compared to any other type of farming. It is at least 50 times greater than live-stock farming or agriculture¹⁷. In fact, if in the warm waters of India mussel culture is taken up as an industry on a fairly large scale, as it is done in Spain, all our calculations of yield and profit shown in this paper will become an underestimate.

Despite the many advantages noted above, we feel that without proper incentive, mussel culture in India would be slow in its growth. Demonstration of farming techniques to fishermen and others interested, in their regional languages, would be essential, if mussel farming is to become widespread along the coastline. Considerable extension work using different mass media would be required to create general awareness in mussel farming. The technology of mussel culture, simple as it is, must receive a high priority for its application and growth in rural areas.

Today in India, mussel is largely a poor man's food and perhaps enjoys the same position as shrimp did about 25 years ago. It is most likely, that like the shrimp, the biggest incentive to mussel culture will

come when mussel becomes a luxury food and an export-oriented commodity. If this happens, it would be rather a sad thing because we hope that the mussel — one of the most nutritive and delicious foods — would continue to remain the food of the poor and the hungry millions. In future, if any animal food production is going to make any substantial difference in the total food production of the world, it is going to be the mussel, particularly in tropical countries where its production is cheap and perhaps most urgently needed. It so happens that one of the most productive and the highest yielding farming systems known today is of mussels in the sea. It is also perhaps the simplest and the easiest. With the standardization of mussel culture technology in Goa, if mussel farming becomes popular and widespread in India, it would be a spectacular achievement of marine fisheries.

Acknowledgement

The authors are grateful to Dr (Miss) Aditi Pant for considerable assistance in the phytoplankton counts and to Shri N. B. Bhesle and Shri S. G. Prabhu Matondkar for help in biochemical analysis of the mussels and for the determination of some of the environmental parameters, particularly oxygen.

References

1. QASIM, S. Z. & ACHARI, G. P. K., *Seminar on mariculture & mechanized fisheries* (Dept. of Fisheries, Govt. of Tamil Nadu), 1972. Abstract, 13.
2. RAO, K. V., KRISHNAKUMARI, L. & QASIM, S. Z., *Indian J. mar. Sci.*, **5** (1976), 113.
3. JONES, S., *Proceedings of the symposium on mollusca*, Vol. 2 (Marine Biological Association of India, Cochin), 1968, 906.
4. JONES, S. & ALGARSWAMI, K., *Proceedings of the symposium on living resources of the seas around India* (Spl. Publication, Central Marine Fisheries Research Institute, Cochin), 1973, 641.
5. RAO, K. V., KRISHNAKUMARI, L. & DWIVEDI, S. N., *Indian J. mar. Sci.*, **4** (1975), 189.
6. TORTELL, J., *Aquaculture*, **8** (1976), 383.
7. DEHADRAI, P. V., *Proc. Indian Acad. Sci.*, **72B** (1970) 56.
8. SANFARANARAYANAN, V. N. & JAYARAMAN, R., *Curr. Sci.*, **41** (1972), 204.
9. SINGHAL, S. V. S., *Indian J. mar. Sci.*, **2** (1973), 90.
10. SARMA, G. S., *Bull. nat. Inst. Sci. India, Symposium on Indian Ocean*, **38** (1969), 263.
11. RANADE, M. R., RAJE, P. C. & RANADE, A. M., *Curr. Sci.*, **42** (1973), 584.
12. WALNE, P. R., *Aquaculture*, **8** (1976), 371.
13. ALGARSWAMI, K. & QASIM, S. Z., *Indian J. Fish.*, **20** (1973), 533.
14. BARDACH, J. E., RYTHER, J. H. & McLARNEY, W. O., *Aquaculture — The farming and husbandry of freshwater and marine organisms* (Wiley Interscience, New York), 1972, 863 pp.
15. MILNE, P. H., *Fish and shellfish farming in coastal waters* (Fishing News, Books, Ltd, London), 1972, 208.
16. ANDREU, B., *Proceedings of the symposium on mollusca*, Vol. 3 (Marine Biological Association of India, Cochin), 1969, 837.
17. DAVIES, G., *Proceedings of the symposium on mollusca*, Vol. 3 (Marine Biological Association of India, Cochin), 1969, 873.
18. DARE, P. J. & DAVIES, G., *Aquaculture*, **6** (1975), 257.
19. KORRINGA, P., *Proceedings of the symposium on mollusca*, Vol. 3 (Marine Biological Association of India, Cochin), 1969, 818.

APPENDIX I

Details of Rope Culture of Green Mussels in Goa

Time taken for commercial production	5 months
Average marketable size of mussel	62 mm
Average weight of marketable size	24 g with shell or 12 g meat
Number of 3 m long ropes per raft	40-60
Average production per rope in 5 months	18 kg mussels or 9 kg meat
Annual production per rope (3 harvests)	46 kg mussels or 23 kg meat
Annual production per raft (6.25 m ² area with 50 ropes)	2300 kg mussels or 1150 kg meat
Annual production per m ²	368 kg mussels or 184 kg meat
Annual production per hectare by computing $\frac{1}{4}$ area of water occupied by 400 rafts	480 tonnes mussels or 240 tonne meat
Value of produce per raft per year (@ Rs 3 per kg of mussel)	Rs 6900

APPENDIX II

Investment, Return and Profit in Mussel Culture in Goa

A. COST	
(a) <i>Direct cost</i>	<i>Amount</i>
(i) Material for fabricating the raft including wooden poles, planks, bamboos, drums, paint etc.	Rs 450
(ii) Anchor, mooring, chains, etc.	Rs 750
(iii) Ropes and other materials	Rs 200
(iv) Labour charges for fabrication, transportation and anchoring of raft	Rs 150
	Total Rs 1550
(b) <i>Indirect cost</i>	
(i) Servicing and upkeep of raft (per annum)	Rs 200
(ii) Travel cost and overtime allowance to staff	Rs 200
(iii) Unforeseen expenditure	Rs 200
(iv) Depreciation of raft and other materials (per annum)	Rs 300
	Total Rs 900
	Total cost Rs 2450
B. RETURN	
Value of mussels per raft (from Appendix I)	Rs 6900
C. PROFIT	
(i) Value of produce	Rs 6900
(ii) Cost of production	Rs 2450
(iii) Gross profit	Rs 4450
D. RATE OF RETURN ON INVESTMENT	
	181%