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Bivalve Culture in Asia and the Pacific

Proceedings of a workshop held in Singapore · 16-19 February 1982

Editors: F. Brian Davy and Michael Graham

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Le colloque a réuni trente-cinq participants de l'ASEAN (Association des pays du sud-est asiatique) ainsi que des délégués de Bangladesh, Burma, Chine, Fiji, Papouasie Nouvelle-Guinée, Sri Lanka, Tahiti et du Canada. On trouve des bivalves en abondance sur les côtes de presque tous les pays, où on les récolte comme aliment de subsistance. Mais quelques pays ont commencé à les cultiver et ils espèrent que des recherches appropriées leur permettront de tripler la production.

Il a surtout été question, au cours de la réunion, des possibilités d'adapter les techniques de culture à l'environnement des pays intéressés. Les participants ont été invités à visiter les élevages de moules suspendus à des radeaux et le système de traitement mis au point par le département de production primaire de Singapour.

Les domaines de recherche prioritaires déterminés par les participants sont : la formation aux méthodes de culture, un approvisionnement de naissain amélioré, des critères de sélection de site mieux définis, des études économiques plus détaillées, l'établissement de normes de salubrité des bivalves destinés à la consommation humaine et des mécanismes permettant l'échange d'information technique sur la recherche relative aux lamellibranches.

RESUMEN

Del 16 al 19 de febrero de 1982 tuvo lugar en Singapur un seminario auspiciado por el Departamento de Producción Primaria del Ministerio de Desarrollo Nacional de Singapur y el Centro Internacional de Investigaciones para el Desarrollo, destinado a examinar los métodos y el estado actual del cultivo de bivalvos —ostras, mejillones, almejas y coquinas— en Asia y el Pacífico y hacer recomendaciones sobre programas y actividades futuras en este campo.

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El seminario hizo énfasis en la adaptación de las técnicas actuales de cultivo de bivalvos a las condiciones locales de los países circunvecinos con miras a aumentar la producción. Los participantes tuvieron oportunidad de visitar el sistema de cultivo en balsas y el equipo postcosecha respectivo para mejillones, desarrollado por el Departamento de Producción Primaria de Singapur.

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India[1]

***E.G. Silas, K. Alagarswami, K.A. Narasimham, K.K. Appukuttan, and P. Muthiah** Central Marine Fisheries Research Institute, Cochin, India*

India has a 6100-km coastline, numerous estuaries and backwaters, and abundant marine bivalve resources that are exploited on a subsistence level at several centres. The major bivalves, in order of importance, are clams, mussels, windowpane oysters, and edible oysters. Pearl oysters are intermittently exploited — sometimes not for several years. The pearl fishery is managed by the state, and, for some clam beds, fishing licences are required.

Indians have traditionally cultured finfish and prawns, particularly in Kerala and West Bengal. Recently, in a small way, they have engaged also in mollusc culture in centres near Bombay and Madras, and interest in all forms of aquaculture is growing rapidly because of improved techniques developed during the last decade by the research institutes of the Indian Council of Agricultural Research. The federal and some state governments have accorded high priority to coastal aquaculture in the Sixth Five-Year Plan.

The Central Marine Fisheries Research Institute pioneered developments for the culture of marine prawns, pearl oysters and cultured pearls, edible oysters, mussels, clams, finfishes, and seaweeds. Advanced research has been initiated to identify and solve problems related to production and quality, and production-oriented programs using available technology have also been encouraged. The high production rates obtained for mussels and oysters indicate that bivalves have a high potential for increasing seafood production.

[1]This country paper from the Central Marine Fisheries Research Institute, Cochin, was presented at the workshop by K.A. Narasimham, Kakinada Research Centre, Central Marine Fisheries Research Institute, Kakinada 533002, Andhra Pradesh, India.

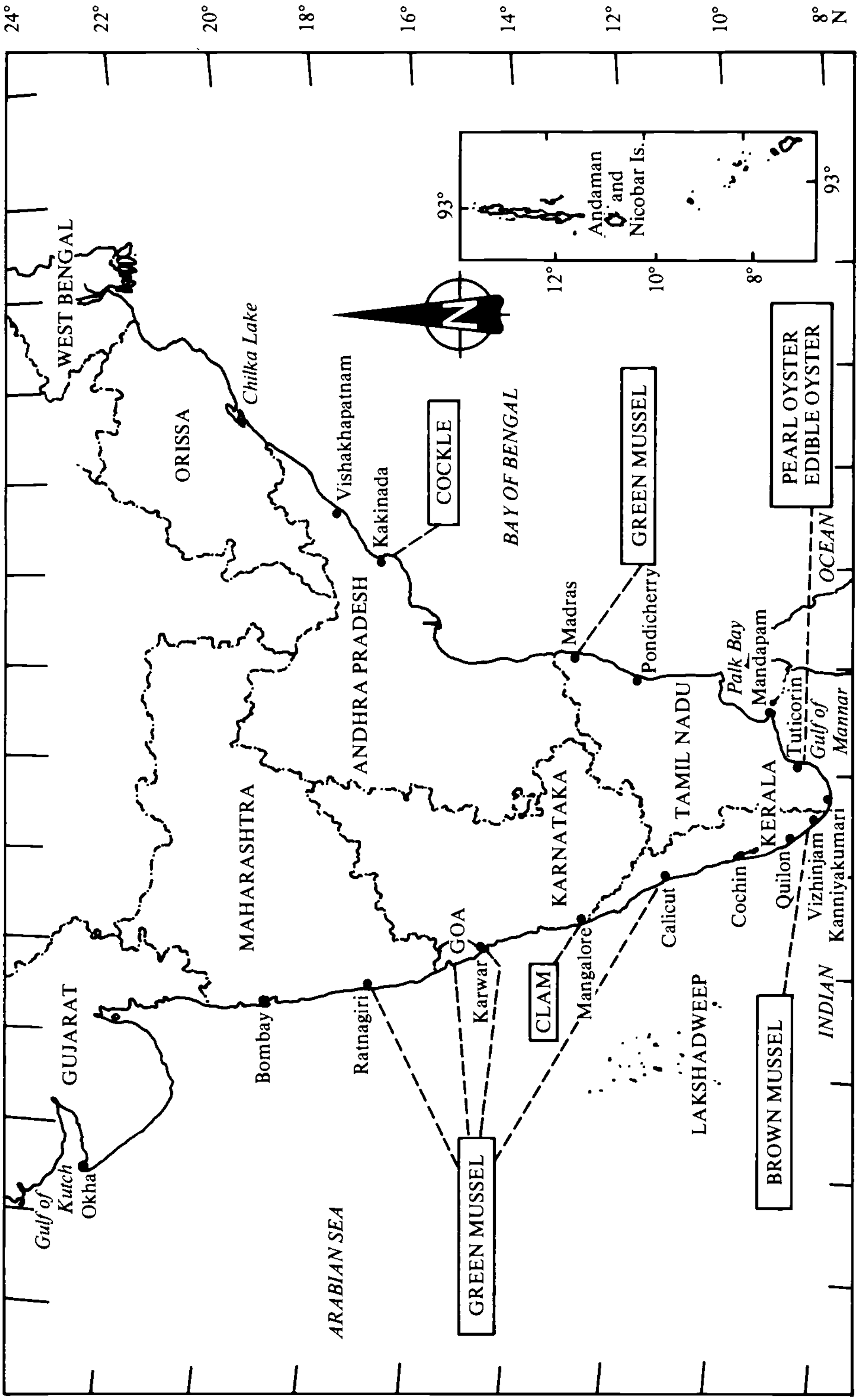
Production

A number of oyster species occur in Indian waters (Rao 1974); those that are exploited are *Crassostrea madrasensis, C. gryphoides,* and *C. discoidea*, which occur in estuaries, backwaters, and creeks. *Crassostrea cucullata* is found on intertidal rocks but is not exploited.

Alagarswami and Narasimham (1973) have reviewed Indian oyster resources: *C. discoidea* occurs along the coast of Gujarat State (Fig. 1) and *C. gryphoides* along the Maharashtra coast. *Crassostrea discoidea* and *C. madrasensis* are present in Karnataka. The entire east coast and Kerala are dominated by *C. madrasensis*. Oyster fishing centres along the west coast include the muddy creeks of Kutch, Aramra Creek, Poshetra Point, Port Okha, Dwarka, and Porbandar in Gujarat; Malad, Boiser, Satpuri, Palghar, Kelwa, Navapur, Utsali, Dahisar, and Mahim Creek around Bombay, and Alibag, Ratnagiri, Purnagad, Jaytapur, and Malwan in Maharashtra; and Ribander, Siolim, and Curca in Goa. In Karnataka and Kerala, small oyster beds exist at several centres but are little exploited. Along the east coast, exploitation is limited to Ennur near Madras and Sonapur backwaters in Orissa. Production of oysters has not been estimated so far because the fishery is only operated seasonally on a subsistence basis at several small centres.

Traditional oyster farming is practiced at Kelwa, Navapur, Utsali, and Ennur. Elementary principles of transplantation for growth are used, and production is minimal at present. The Central Marine Fisheries Research Institute at Tuticorin hopes to improve outputs by demonstrating and, hence, transferring more appropriate techniques in oyster culture.

Both the green mussel (*Perna viridis*) and the brown mussel (*P. indica*) occur in India, although the former has a wider distribution. It is found on small beds along Chilka Lake, Vishakhapatnam, Kakinada, Madras, Pondicherry, Cuddalore, and Porto Novo along the east coast, and extensively around Quilon, Alleppey, Cochin, Calicut



Maritime states of India.

to Kasaragod, Mangalore, Karwar, Goa, Bhatia Creek, Malwan, Ratnagiri, and the Gulf of Kutch (Kuriakose 1980a). In contrast, *P. indica* is found only along the southwest coast from Varkalai near Quilon to Kanniyakumari, and from Kanniyakumari to Tiruchchendur along the southeast coast. Regular fisheries exist for the green mussel from Calicut to Cannanore along the Kerala coast, and annual landings are estimated at 2.6×10^3 t. Fisheries for brown mussel between Kovalam and Muttom yield 427 t/year. The total annual production of both species from traditional fisheries exploiting natural beds has been estimated at 3.1×10^3 t (Alagarswami et al. 1980c). Production from culture is small, being limited to demonstration and technology-transfer programs.

The blood clam (cockle) *Anadara granosa* is exploited in Kakinada Bay and has been experimentally cultured there. Total annual production is about 2.0×10^3 t, 10% of which is used as human food. The shells are used in the production of lime.

Clams are by far the most important bivalve resource in India, and the west coast accounts for the bulk of production. The species resources are rich, and the major exploited ones are *Meretrix meretrix, M. casta, Katelysia marmorata, K. opima, Villorita cyprinoides, Paphia malabarica, P. laterisulca,* and *P. textile*. Although a small percentage of the clams are eaten, production is mainly for shells for lime and cement. In addition to live clams, shell deposits (commonly referred to as subfossil deposits) are mined for industrial use.

Alagarswami and Narasimham (1973) have reviewed clam resources and their exploitation. The coastal states of Maharashtra, Goa, Karnataka, and Kerala have abundant clam resources in estuaries. *Meretrix meretrix, K. opima, K. marmorata,* and *P. laterisulca* are the major species along the Maharashtra coast, and annual production is about 1.1×10^3 t (Ranade 1964). The clams in the estuaries of Goa are *M. meretrix* and *V. cyprinoides*; total production has been estimated at 887 t and that of *V. cyprinoides* alone at 500 t (Parulekar et al. 1973; Ansari et al. 1981). The estuaries of Karnataka have *M. meretrix* and *P. malabarica* in northern areas and *M. casta* and *V. cyprinoides* in the south. Ullal near Mangalore is an important lime-producing centre, and about 3.0×10^3 t of shell lime is produced annually, mainly from clam shells of the Tadri River. Kerala has immense clam resources (both living and subsoil shell deposits), but exploitation is mostly for industrial production of white and grey cement, calcium carbide, bricks, shell lime, etc. The clam resources of Vembanad Lake, which is a backwater ecosystem, are very important for the state. Ashtamudi and Kodungallore lakes and the estuaries of the Kadalundi and Korapuzha rivers are the other important sources of clams. There are two dominant species — *M. casta* in the saline areas and *V. cyprinoides* in the less saline and freshwater areas. About 2.0×10^5 t of lime shells are exploited annually (1968) from Vembanad Lake alone, and live *V. cyprinoides* constitute about 2.7×10^4 t (Rasalam and Sebastian 1980).

Along the east coast of India, clam resources are less abundant. In Tamil Nadu, *K. opima* and *M. casta*, which were once plentiful in the Adyar estuary near Madras (Abraham 1953), have largely been depleted by domestic sewage pollution. *Meretrix casta* is fairly abundant in Pulicat Lake, Kovalam backwaters, Muthupet swamps, Vellar estuary, and Vaigai estuary. Clam production in Vellar estuary is about 730 t/year. In Andhra Pradesh, *M. meretrix* occurs conjointly with *A. granosa* in Kakinada Bay. Along the Orissa coast, *Meretrix* spp. occur in Chilka Lake and Sonapur backwaters.

The species *Placenta placenta* is fished mainly for the shells but also for seed pearls. The major centre for windowpane oysters is Kakinada Bay, which produces about 4.0×10^3 t/year (Narasimham 1973). The shells are used for production of lime, and small quantities (right valves only) are exported to Hong Kong and Japan (Murthy et al. 1979). Other important centres are Poshetra in Pindara Bay in the Gulf of Kutch, where annual production is 4.5 million oysters (Varghese 1976), and Naukim Bay in Goa, where 8000–10000 oysters are harvested almost daily for human consumption (Kutty et al. 1979).

The pearl-oyster species of most commercial importance is *Pinctada fucata*, although several other species occur along the Indian coast (Rao 1970). The pearl fisheries of the gulfs of Mannar and Kutch are well known for production of orient pearls. Resources fluctuate widely. In the Gulf of Mannar, the natural beds (known locally as paars) are found on the rocky or coralline substrata at depths of 15–25 m. Fisheries were conducted annually during 1955–61, but this activity was preceded by a nonproductive period of 27 years and has been succeeded by nonproductivity. During 1955–61, annual (restricted season) production of pearl oysters ranged from 1.18 million (1957) to 21.48 million (1958), the average being 10.85 million oysters per fishery (Mahadevan and Nayar 1973). In the Gulf of Kutch, where pearl oysters occur in intertidal beds called khaddas, the fisheries used to be conducted every 3 or 4 years, with an average annual production of about 19000 oysters for the seven fisheries between 1950 and 1967 (Easwaran et al. 1969). Since 1967, there has been no pearl fishery.

The culture of pearl oysters is limited to experimental spat collection. Moderate spatfall is obtained in Vizhinjam Bay on the southwest coast where the spat are collected on fibrillated nylon ropes. Similarly, spatfall takes place on the harbour breakwaters at Tuticorin. The pearl-oyster populations settling in the artificially enclosed inshore areas are mixed species of *Pinctada*, including *P. chemnitzii* and *P. sugillata*, which are generally dominant, and *P. fucata* (25% or less) (Alagarswami 1977).

RESEARCH AND DEVELOPMENT

The Central Marine Fisheries Research Institute (CMFRI), Cochin, under the Indian Council of Agricultural Research (ICAR), is the main institution involved in bivalve culture at the national level and has developed techniques for the culture of various species during the last decade (CMFRI 1978). Research on bivalves by the Institute dates back to the early 1950s and is now carried out at several regional centres.

The ICAR/United Nations Development Programme (UNDP) Centre of Advanced Studies in Mariculture at CMFRI has postgraduate- and doctoral-level teaching and research programs on bivalve culture. The progress made in mussel farming was reviewed recently at a workshop, and an action plan for research and development programs was developed (Silas and Rao 1980).

The science of spatfall forecasting is yet to be developed. Spawning seasons of bivalves under culture are known, and this information is used as a key to the laying of spat collectors. For oysters, culturists monitor the stage of maturity and the appearance of straight-hinge larvae in plankton of the bay to determine when to place the spat collectors. Once spat are collected and seeded on the sites, they remain within the area until harvest.

OYSTER FARMING

Oysters are cultured in intertidal regions, bays, and estuaries. In Tuticorin Bay, the tidal range is 0.3–1.3 m. The bottom — fine sand and mud — is firm. The annual range in seawater temperature is 23.0–30.2°C and in salinity 26.1–34.4 ppt. The oysters are exposed during low tides — a condition that helps to control fouling. Experimental and production-oriented oyster farming is being carried out only at Tuticorin Bay (Mahadevan et al. 1980). At the Vaigai estuary near Mandapam, a 2-year experiment proved successful in terms of growth of oysters, but freshwater conditions prevailed in the estuary during the monsoons (November–December) and resulted in high mortality among the oysters (Rao et al. 1980). The normal annual salinity range of the Vaigai estuary is 6.94–35.53 ppt, but in certain years an extreme range of 0.44–62.39 ppt has been recorded. Several short-term projects on various aspects of oyster culture have been carried out in the Cochin backwaters in Kerala (Purushan et al. 1980), Mulki estuary in Karnataka (Dhulkhed and Ramamurthy 1980; Joseph and Joseph 1980); and in Goa (Parulekar et al. 1980), and the data indicate that many bays, estuaries, backwaters, and creeks in the country are suitable for oyster farming. The tidal amplitude is generally within 1 m, and the rapid growth recorded in experiments indicates there is adequate food. The ambient temperature is suitable, but the low salinity during monsoons causes excessive mortality. Still, one crop could be harvested between the monsoons each year. Spatfall is good in the areas studied. Long-line culture of oysters in the open sea has not been investigated yet but has potential.

The rack-and-tray culture method is employed for oysters at Tuticorin. Each rack (13.2 m × 2.0 m) comprises a series of teak poles. Two rows (2 m apart) of six poles are driven into the muddy bay, and the poles in each row are connected near the top by a long pole. Six short poles connect the two rows horizontally and are connected to each other by two long poles that run parallel to the other long poles but are inside the structure. This rack provides a platform for suspending oyster cages during the nursery stage or for supporting the oyster trays during the grow-out phase. The oyster cage is 40 cm × 40 cm × 10 cm, with a lid, and is made of 6-mm steel rods covered with nylon webbing (12-mm mesh). The tray is 90 cm × 60 cm × 15 cm, without a lid, and is constructed the same way as the cage except that the webbing is 22-mm mesh (Mahadevan et al. 1980).

An experimental hatchery for oysters has been set up at Tuticorin (Nayar and Easterson 1980). *Crassostrea madrasensis* has been spawned by thermal stimulation and the larvae have been reared to a 250 μm size. Spat settlement has not been achieved so far. Spat is collected on semicylindrical roofing tiles in the natural grounds at Tuticorin. The tiles, which are 24.5 cm long and

17.5 cm in diameter, are dipped in a solution of 25 kg lime in 50 L of seawater (which can treat 1000 tiles). After drying, they are coated with a mixture of 60 kg lime, 100 kg river sand, and 80 L of water. The lime-coated tiles are placed in iron cages (100 cm × 90 cm × 15 cm), 50 to a cage. Several other materials, such as oyster and mussel shells and coconut shells, have been tried but did not prove as effective as the tiles. *Crassostrea madrasensis* has two spawning seasons, April-May and August-September. At the beginning of the season, the cages with tiles are laid on racks in the oyster farm at Tuticorin and in the adjoining creek. The average number of spat was 33.5 (with a maximum of 97 and minimum of 11) per tile in April-May 1979 (Mahadevan et al. 1980). The August-September season was less productive, with an average of 5 spat/tile. More spat (5:1) settle on the concave surface than on the convex surface of the tile. At Vaigai estuary, near Mandapam, an average 2.35 spat/m^2 settle in February and 11.69 spat/m^2 in March — about 2 spat/tile (Rao et al. 1980).

Oyster spat are allowed to grow on the collectors for 2 months until they reach a mean size of 36 mm and are then detached from the tiles with an iron scraper. They (150-200) are placed in rearing cages (40 cm × 40 cm × 10 cm) and suspended from the poles of the rack. The oysterlings reach a mean size of 52 mm in about 3 months and are then transferred to trays (90 cm × 60 cm × 15 cm) on racks for grow out. The trays hold 150-200 oysters and are positioned so that the oysters are only exposed during the lowest tide. Each rack occupies 26.5 m^2 and holds 20 trays. Average annual production is 0.48 t/rack, about 135 t (whole weight)/ha (Mahadevan et al. 1980).

The predatory gastropod *Cymatium cingulatum* is found in the farm during July-December and preys on oysterlings 35-45 mm long. They caused 15% mortality of the stock in 1979 (Mahadevan et al. 1980). The gastropods are located, handpicked, and destroyed.

At Tuticorin farm, *C. madrasensis* attains 36 mm 2 months after spatfall. At 3 months, mean size is 52 mm; at 8 months, 60 mm; at 10 months, 74 mm; and at 1 year 90 mm. In the Vaigai estuary, at 1 year, the same species attains a mean of 86.7 mm and a maximum of 110 mm (Rao et al. 1980). The size attained after 1 year is the marketable size, and the oysters are harvested. At Mulki, Joseph and Madhystha (1980) observed a mean shell height of 9.15 cm and 14.20 cm at the end of the 1st and 2nd years, respectively. For 1-year-old oysters, the wet-flesh weight is 8-10% of total weight. The condition factor (1000 × dry-flesh weight/volume of shell cavity) of Tuticorin farm oysters varies from 40 during May-June and November (postspawning period) to 170 during February-March and July-August (prespawning period).

MUSSEL FARMING

There are no protected bays on the Indian mainland, but there are lagoons and bays suitable for mussel culture in the oceanic islands. Mussel farming on the mainland is done in the open sea, in water up to 10 m deep. The southwest monsoon in the Arabian Sea and the northeast monsoon in the Bay of Bengal create unfavourable conditions for mussel culture for 4-5 months, but, because mussels reach harvestable size in 5-6 months, there is one harvest a year. When submerged raft culture is developed, two crops will be possible.

Mussel culture has been carried out in the open sea off Calicut (Kuriakose 1980b), in Vizhinjam Bay (Achari and Thangavelu 1980; Appukuttan et al. 1980), in Dona Paula Bay of Goa (Qasim et al. 1977), in Ratnagiri (Ranade and Ranade 1980), off Madras (Rajan 1980; Rangarajan and Narasimham 1980), and in Karwar Bay. Easterson and Mahadevan (1980) reviewed environmental conditions in the open sea with reference to mussel culture, and the coastline between Karwar and Kanniyakumari, with an abundant supply of seed, seems particularly suitable for production. Appukuttan's (1980a) report of predation by fish (*Rhabdosargus sarba*) and lobsters indicates that effective measures to prevent predation are essential. No work has so far been done on mussel culture in typical estuarine conditions. An attempt at pole culture of green mussels at Kovalam near Madras failed because the poles were washed away by strong currents.

Hatchery technology has not been developed for mussel-seed production. Rao et al. (1976) have done experimental work on spawning and larval rearing of *P. viridis* and Kuriakose (1980c) on *P. indica*. Alagarswami (1980) reviewed mussel-seed production. Spawning occurs in May-September, and seed mussels are collected from natural beds during October-December for farming along the west coast. Spatfall takes place in the farm itself. Seed are collected on frilled nylon ropes at Vizhinjam. In the mussel-culture farm at Kovalam, near Madras, spatfall is sometimes good.

The spat are collected on tiles suspended from rafts (Rangarajan and Narasimham 1980). The rafts range in size from 5 m × 5 m to 8 m × 8 m and, like the racks for oysters, are a series of teak poles. The frame is mounted on 4–5 cylindrical, 200-L metal barrels for buoyancy. Each raft is moored by two anchors connected to the raft by chains. Seed mussels are attached to ropes suspended from rafts. The ropes are either nylon (12 mm) or coir (14 or 20 mm) (Kuriakose and Appukuttan 1980). These surface rafts cannot withstand monsoons. Experimental work on submerged rafts for all weather conditions has been partially successful (Rajan 1980).

Green-mussel seeds (20–30 mm) are transplanted, and 500–700 g of seed are used per metre of rope at Calicut (Kuriakose 1980b). The juvenile mussels are secured with a knitted cotton cloth 25 cm wide. The seeded portions of the ropes range from 5 m to 8 m, and the ropes are suspended from the raft 0.5–1.0 m apart, the lower, free end being about 2 m above the bottom. The mussels attach to the rope within 2–3 days, and the cloth cover disintegrates in about 10 days. Brown-mussel seeds are 25–29 mm when transplanted, and the seeding technique is the same. Old cotton fishing net, cheap bandage cloth, or mosquito netting is used for wrapping the seed on the ropes. Wooden pegs are inserted in the ropes at fixed intervals to prevent slippage during the initial stage of growth (Appukuttan et al. 1980b).

For the grow-out period, some of the mussels are transplanted to new ropes. Under these conditions, mussel growth is good. From November 1978 (seeding) to April 1979 (harvest), green mussels grew from an initial weight of 0.57 kg to a final weight of 12.3 kg/m rope (Table 1). In Dona Paula Bay in Goa, Qasim et al. (1977) found that the green mussel attained the average marketable size of 62 mm in 5 months, during which time the average production was 6 kg/m of rope. The ratio of shell weight to wet-flesh weight was 1:1 and that of wet flesh to dry flesh 4:1.

Average production of green mussels at Calicut in open-sea culture ranged from 4.4 kg/m rope in 1976–77 to 12.3 kg/m rope in 1978–79 when conditions remained favourable during the 5-month season (Kuriakose 1980b). An estimated 12 000 seeded ropes can be cultured in 1 ha. Rope length depends on depth: off Calicut 6–7 m seeded ropes can be used. Qasim et al. (1977) projected a yield of 480 t/ha for the green mussel in Dona Paula Bay.

In Vizhinjam Bay, the brown mussel *P. indica* reaches the modal size of 55-60 mm in 8 months, an average growth of 2.94 mm/month. In the adjoining open sea, growth is faster, and the modal size of 60–65 mm is attained in 5 months, a growth rate of 5 mm/month. The wet-flesh weight forms 41.31% of total weight in the bay and 43.33% in the open sea in May. The average weight of mussel seed per metre of rope ranged from 1.4 to 2.0 kg, and, at harvest, the final weight of mussels was 10–15 kg/m rope after 7 months in the Bay and 15 kg/m after 5 months in the open sea. An estimated yield of 150 t/ha is possible inside the bay. Achari and Thangavelu (1980) reported production rates of 10.16 kg, 15.81 kg, and 22.69 kg/m in 7, 9, and 12 months, respectively, in Vizhinjam Bay.

Table 1. Mean size of green mussels (*P. viridis*) under raft culture at Calicut at seeding in November 1978 and at harvest in April 1979 (Kuriakose 1980b).

	Length (mm)	Weight (g)		Flesh (as % total)
		Total	Flesh	
November 1978	23.6	1.10	0.40	38.0
April 1979	88.2	37.50	15.18	40.5

Cockle Farming

The cockle *A. granosa* is cultured in the subtidal area of Kakinada Bay, where the site is enclosed by split-bamboo screens (Narasimham 1980). It is also grown in unenclosed areas, poles being used to mark the site.

The natural distribution of *A. granosa* is limited. In Kakinada Bay, the species is cultured in a subtidal region that has a minimum of 25 cm of water during low tides. The bottom is mud, composed of clay (64%), silt (25%), sand, and dead shells. The monthly average water temperature is 28.9–33.5°C, salinity 22.29–34.4 ppt, and dissolved oxygen 4.98–7.00 ml/L (Narasimham 1980). The *Anadara* bed in Kakinada Bay is about 44 km^2, much of which is also suitable for clam farming.

Anadara granosa spawns during January–April, and heavy settlement of seed on natural beds takes place from February to May in Kakinada Bay (Narasimham 1980). Seed is collected from the bed with a scoop net at low tide (1 m).

Seed clams of *A. granosa* 19–29 mm in size (mean length 24.3 mm; mean weight 6.7 g) were experimentally stocked at densities of 140/m^2 and 175/m^2 (Narasimham 1980). In April 1981, smaller seed (mean length 17.8 mm and weight 2.74 g) was used, and stocking rate was nearly doubled (300/m^2). The baby clams are dispersed evenly on the area from a boat at high tide. During culture, no maintenance is necessary. The species grows in 5 months to 40.6 mm and 31.06 g at harvest (Narasimham 1980). The survival rate is 88.6%. Flesh weight is about 20% of total weight.

In Kakinada Bay, the production of *A. granosa* was 0.39 t/100 m^2 in 5 months, 2.6 t/625 m^2 in 5.5 months, and 6.1 t/0.16 ha in 7 months (Narasimham 1980). These figures represent production rates per hectare of 39 t, 41.6 t, and 38.1 t, respectively. It is remarkable that, despite different stocking densities (140, 175, and 300 seed clams/m^3) in the three experiments, the production results are consistent.

OTHER BIVALVES

Other bivalves with potential in India include clams and pearl oysters; windowpane oysters are not cultured at present, but techniques are being investigated and possible culture sites are Kakinada Bay, Nauxim Bay in Goa, and Balapur and Rann bays in the Gulf of Kutch.

Experiments on clam culture have been limited. In the Mulki estuary near Mangalore, culture of *M. casta* has been attempted in the channel leading to the state fish farm. Bottom culture was used. During the February–June culture period, the salinity range was 15.10–34.62 ppt and the temperature 28.7–33.4°C (K.S. Rao, personal communication). Experimental transplantations of *M. casta* were done in Vellar estuary near Porto Novo (Sreenivasan 1980), and the species has been observed (at Mandapam and Kakinada) to colonize fish/prawn farms. Clam resources in India are great, and the preparation of sites, seed collection, and transplantation of clams should be considered for vast areas of backwaters and estuaries.

In Mulki estuary, *M. casta* grows from an initial mean length of 17.9 mm to 31.5 mm in 4 months, and the survival rate is 48.2% (K.S. Rao, personal communication). In Vellar estuary (Tamil Nadu), it grew from a mean 7.3 mm, 0.25 g in September 1976 to 41.5 mm and 31.34 g the next September (P.V. Sreenivasan, personal communication).

The Gulf of Mannar has already proved to have potential for pearl-oyster farming (Alagarswami and Qasim 1973; Alagarswami 1974 a,b). Unlike pearl culture elsewhere, the practice in India is in open-sea areas. The experimental farm at Veppalodai near Tuticorin has been successful, and rafts have been maintained in the open sea for nearly a decade. The ecological conditions at the Veppalodai farm have been dealt with by Victor (1980).

Pearl oysters reared temporarily in the harbour basin at Tuticorin gave particularly good results. An intertidal pearl-oyster farm has been established at Sikka near Jamnagar in the Gulf of Kutch, whereas a farm in Vizhinjam Bay had to be abandoned because of heavy silting and other problems. Several potential sites for pearl-oyster farming exist in the Andaman and Nicobar islands. Water depth and clarity as well as relative freedom from biofouling and boring organisms are important in site selection.

In experiments with pearl-oyster culture, Alagarswami et al. (1980a) used thermal stimulation, salinity variation, and chemical control (using NaOH, NH_4OH, Tris-buffer, and H_2O_2) in controlled breeding. They found that increasing the pH and raising the temperature of the water encouraged spawning of *P. fucata*. They (1980b) reared the larvae to straight-hinge veliger and, in October 1981, succeeded in bringing larvae to spat setting. The flagellate *Isochrysis galbana* was used as food. Spat setting takes place 22 days after fertilization. Thousands of spat have been obtained and are being reared in the farm. At setting, the mean size of the plantigrade stage is 300 μm × 330 μm. Spat settlement takes place on frosted and clear glass plates, split-bamboo pieces, and on the sides of fiberglass tanks and glass beakers.

Although hatchery-reared oysters will be used for cultured pearl production in future, mother oysters were previously obtained from natural beds. In Vizhinjam Bay, spat were collected, mainly within 1 m of the surface, on frilled nylon ropes.

Raft culture is the standard method employed for pearls (Alagarswami and Qasim 1973; Alagarswami 1974a), although farming has also succeeded on the slopes of harbour breakwaters at Tuticorin.

The hatchery-reared spat are transferred at an early stage (about 4 mm) to boxes covered with nylon mesh and lined on the inside with a fine-mesh synthetic fabric. Here they are kept until they can be transferred to plastic baskets with rigid mesh. Spat from natural grounds are removed from collectors and, like the hatchery-produced spat, are placed in plastic baskets. When they measure 25–30 mm dorsoventrally, they are grown in iron cages (40 cm × 40 cm ×10 cm) covered with 20-mm mesh nylon webbing.

The number of cultured pearls as a percentage of total numbers of oysters is 62.8% after single implantation and 180.6% after multiple implantation, and these rates could be improved (Alagarswami 1974b). Pearl growth in the Gulf of Mannar has been found to be 2–3 times as fast as that in temperate waters (Alagarswami 1975).

Problems and Constraints

Silas (1980) discussed the constraints and prospects for mussel culture in India, and these generally hold true for all bivalves. Interest in bivalve culture is quite recent, and, although production-oriented techniques have been developed, commercial culture has not begun.

The major constraint is the lack of a properly organized development effort despite the high priority given to aquaculture in India. The eating of bivalves is popular only in a few pockets along the coast. Consumers in India prefer other foods, and even oysters are not widely consumed. The low demand results in a low price, and, in some instances, adequate economic returns on investment cannot be ensured except at a price slightly higher than that for noncultured bivalves. The integrated development of increased production, increased consumer demand, and a marketing strategy for molluscan products is required.

Extension is badly needed. CMFRI has organized several training programs in bivalve culture (CMFRI 1977). Direct transfer of technology is effected through the Lab-to-Land program in which scientists help local people to adopt the techniques of mussel farming and oyster culture (CMFRI 1979). However, these extension efforts are localized and are not sufficient.

Development of bivalve culture will depend on means to ensure seed availability for large-scale production. Although mussel-seed abundance in the wild is adequate for culture operations, its collection conflicts with the interests of traditional mussel producers. The natural beds of oysters are limited, and the paucity of pearl oysters has prevented commercial projects. Hatchery production of seed is necessary to reduce dependence on nature. The technology for artificial production of pearl oysters has already been developed and will be applied to other species. This development will necessitate mass production of algae as food for the larval stages.

At present, the costs of farming are too high, and efforts need to be devoted to finding low-cost methods and to developing the means to cultivate bivalves year round in the open sea. The Indian experience is unique because the farming systems must be developed under unfavourable sea conditions caused by monsoons.

Postharvest technology and quality control need to be developed along with production. Venkataraman and Sreenivasan (1955) investigated pollution at Korapuzha estuary near Calicut and found that the *P. viridis* beds in shallow coastal areas were continually polluted and contained *Escherichia coli*, type 1, throughout the year. Pollution peaked immediately after the beginning of the southwest monsoon. Although the *Salmonella–Shigella* group as well as *Cholera vibrios* were absent, *Paracoli, Proteus*, and *E. coli*, which cause infectious gastroenteritis, were present. After the monsoon abated, there appeared to be a recovery, and coliform numbers, as well as total counts, were low. Mussel pollution has been attributed to the stormwater carrying town refuse during the monsoon. People in the Calicut area used to believe that mussels were poisonous or unwholesome during the monsoon (Jones and Alagarswami 1973). They attributed this to water turbidity, presence of sand and mud in the mantle cavity, lowered salinity, and increased numbers of the peacrab *Pinnotheres* sp. in the mussels. Pillai (1980) found that the bacterial load of the brown mussel cultured at Vizhinjam was relatively higher (10^6) than that of mussels in the natural beds (10^5) and that the occurrence of coliforms, *E. coli*, fecal streptococci, and coagulase-positive staphylococci was almost steady both in the mussels and in the seawater. *Pseudomonas, Vibrio*, and *Micrococcus* were seen as normal flora in mussels and seawater.

In August 1981, a case of shellfish poisoning was reported from Vayalur village in Tamil Nadu. Three children died, and 82 others had neurotoxic symptoms. Investigations conducted by the National Institute of Nutrition, Hyderabad, showed that the clam *M. casta*, consumed by those affected, was contaminated with toxins secreted by dinoflagellates. Because of isolated cases of contaminated bivalves in the coastal waters, estuaries, and canals, appropriate depuration and other sanitary measures should be taken to make the bivalves safe for human consumption before they are marketed.

Bacteriological and toxicological analysis at the Inspection Laboratory of the Marine Products Development Export Authority, Cochin, showed that *E. coli, Staphylococcus*, and *Salmonella* were absent from the oyster flesh from Tuticorin farm. The heavy metal contents (mercury, copper, and cadmium) were well within admissible limits.

Bivalves collected from the wild are not currently depurated: they are sold fresh immediately after collection. However, cultured bivalves and those meant for export are depurated. CMFRI has constructed depuration tanks at Tuticorin and Calicut (Nayar et al. 1980). Balachandran and Nair (1975) found that mussels kept alive in seawater for 24 h and then in chlorinated water (5 ppm) for 2 h had reduced sand content (0.02% on a dry-weight basis of the flesh) and no fecal or pathogenic bacteria.

STORAGE, NUTRITIONAL DATA, AND PROCESSING

The Central Institute of Fisheries Technology (CIFT), Cochin, leads research on postharvest technology for bivalves, as well as for finfishes and crustaceans. Balachandran and Prabhu (1980a) have summarized developments in postharvest techniques for mussels in India. Chinnamma et al. (1970) observed that mussels (*P. viridis*) and clams (*Villorita cornucopia*) preserved in ice for up to 9 days were acceptable organoleptically (Table 2).

Table 2. The proximate composition (%) of mussel (*P. viridis*) and clam (*V. cornucopia*) following preservation in ice in organoleptically acceptable conditions for up to 8 and 9 days (Chinnamma et al. 1970).

	Mussel		Clam	
	8 days	9 days	8 days	9 days
Protein	12.13	13.82	7.63	11.05
Fat	2.24	2.55	0.91	2.17
Glycogen	8.31	10.58	1.31	7.91
Inorganic phosphorus	15.10	43.18	22.16	29.40
Ash	4.50		4.70	

Chinnamma (1974) reported that whole mussels (*P. viridis*), removed from the shell, stored on ice for 8 days, and then frozen, remained in acceptable condition for only 15 weeks, whereas fresh-frozen flesh remained acceptable for 40 weeks. Fresh-frozen clam (*Villorita* sp.) remained acceptable for 35 weeks, and the shelf life of material iced for 8 days and then frozen was only 4 weeks.

Some work has been done on bivalve-product development. Muraleedharan et al. (1979) developed the smoke-curing of mussels. After the smoked product was either sun or mechanically dried to 10% moisture level, it could be stored without spoilage for more than 6 months. The yield was 22%, and the product included total nitrogen, 8.765%; glycogen, 22.15%; and fat, 11.51%.

Balachandran and Nair (1975) developed a process for canning clams and mussels in hot, refined groundnut oil, and Balachandran and Prabhu (1980b) found that a canned product prepared from ice-stored whole mussel or fresh shucked flesh had good organoleptic characteristics for up to 2 days of storage. The products had better colour, flavour, and juiciness than a canned product from boiled flesh. Balachandran and Prabhu (1980b) also reported a method for preparing mussel pickle having a shelf life of up to 6 months.

Other work is under way. For example, CMFRI and CIFT are cooperating in a project for product development and quality control; Badonia (1980) has canned the rock oyster *C. cucullata* in several media; and the Integrated Fisheries Project, Cochin, is working on product diversification with edible oysters from the Tuticorin farm. Live oysters can be kept out of seawater for up to 30 h without mortality and can withstand transport over long distances. Canned, smoked and canned, and frozen products have been developed.

Bivalves have been exported on a trial basis since 1970 when 6.0×10^3 kg of frozen mussel flesh was sent to the Federal Republic of Germany. Canned mussel flesh has been exported to Muscat and Saudi Arabia, and exports of mussel pickle to the Middle East are increasing. In 1981, 6 t of frozen clam flesh was exported to Japan.

FUTURE PLANS

An economic data base for bivalve culture, based on pilot-scale operations, is yet to be developed. The technical feasibility of culture systems for oysters, mussels, blood clams, and pearls has been established through experiments and small-scale field trials. Fisheries development departments should initiate pilot projects to demonstrate the economic feasibility of bivalve culture.

A cost-benefit study of oyster culture by the rack-and-tray method on 0.25 ha, producing 3 t of oyster flesh annually, has been made. With an investment of Rs 19.00/kg flesh, and at a selling price of Rs 28.00/kg, the net income before tax would be Rs 27000 — about a 30% return on the investment. For mussel culture, several projections have been made. Qasim et al. (1977) have given the rates of return on investment as 181% for the green mussel in Goa; Ranade and Ranade (1980) have visualized a return of 168% on investment for the same species in Ratnagiri; and Achari (1980) has projected a return of 76.71% on capital for single-raft production of brown mussels in Vizhinjam Bay. Appukuttan (1980b) has given a net profit rate of Rs 1480–2680 from a single raft for the same species. However, these projections must be tested in commercial operations.

The national policy for bivalve culture should be to:

- Promote molluscs as a valuable food resource and show that their proper utilization would contribute substantially to the nutrition of the people (public education to promote a wider consumption of bivalves, even in the coastal areas, is perhaps the most needed strategy from the point of view of production and nutrition); and
- Promote the potential of bivalve culture in augmenting production. Research and development programs should derive strength and support from such a national policy.

In the current phase of bivalve development, state support is necessary to demonstrate the techniques and to prove the potential. Present programs are inadequate: extension programs should be organized on a large scale.

Bivalve resources are rich, but the present level of utilization is not based on any rational program. Exploitation is random and is generally by an open-entry system. At the existing level of demand, exploitation has not shown signs of depleting resources, thanks to the prolific breeding of bivalves. However, any sizable increase in demand — for example the opening of a steady export market — could change this situation. As bivalves are sedentary, they can be overexploited. Strategies for their judicious exploitation and utilization should be developed.

Clams of all species are exploited for industrial purposes, and little use is made of the flesh for human consumption. Estuarine shell deposits are considered a mineral resource and are mined under licence. However, live clams usually occur at shell deposits, and mining activities pose a threat to them as well as to the livelihood of the people who collect them. Policies must ensure the protection of the living resources.

Leasing of brackish-water and coastal areas for bivalve culture needs immediate consideration; however, the requirements for the culture of other organisms such as finfish, crustaceans, and algae must also be taken into account so that priorities can be set and areas assigned.

Financial assistance is also needed. Pearl culture requires the highest investment, followed by mussel, oyster, and clam culture. Because no commercial culture system has yet been established, financing agencies are hesitant and need encouragement.

Marketing as well is vital to the development of bivalve culture. Traditional local markets are restricted and efforts to explore new markets within and outside the country have only just started. Mussels and clams should cater largely to internal markets to improve the nutrition of the poor, whereas oysters, because of high production costs, could be considered an export commodity. Cultured pearls are in great demand domestically, but they also have export potential.

Training is essential and should be initiated for different cadres of personnel. The present ad-hoc training programs should be strengthened and linked with development programs.

Technological improvement is also necessary. The foremost need is for development of hatcheries for the low-cost production of quality seed. Natural seed grounds, seasons, magnitude, and quality should be assessed properly.

Farming technology is an area requiring considerable improvement, and engineering should become an essential component. As well as improving efficiency and reducing costs, researchers should develop systems suitable for the diverse ecological conditions of different regions of the country.

The present production-oriented technologies should be adequately backed by fundamental and applied research on ecological adaptations, reproduction, nutrition, growth promotion, genetic improvement of stocks, improvement of flesh quality, and disease diagnosis and control.

Product diversification and quality control must be developed, and standards prescribed and enforced. Depuration should be mandatory for all bivalves intended for human consumption, and pollution levels in production areas should be monitored and controlled.

Interest in bivalve culture among the governments of South and Southeast Asia is relatively recent, compared with that in the developed countries where oysters, mussels, and clams have been commercially farmed for several centuries. Whereas production in the West has been declining, there is great potential for increased bivalve production in Asia and the Pacific. A common strategy is needed to promote bivalve culture in the region and to realize the potential.

Exchange of information and interaction between the scientists and development personnel involved in bivalve culture in the region should be encouraged.