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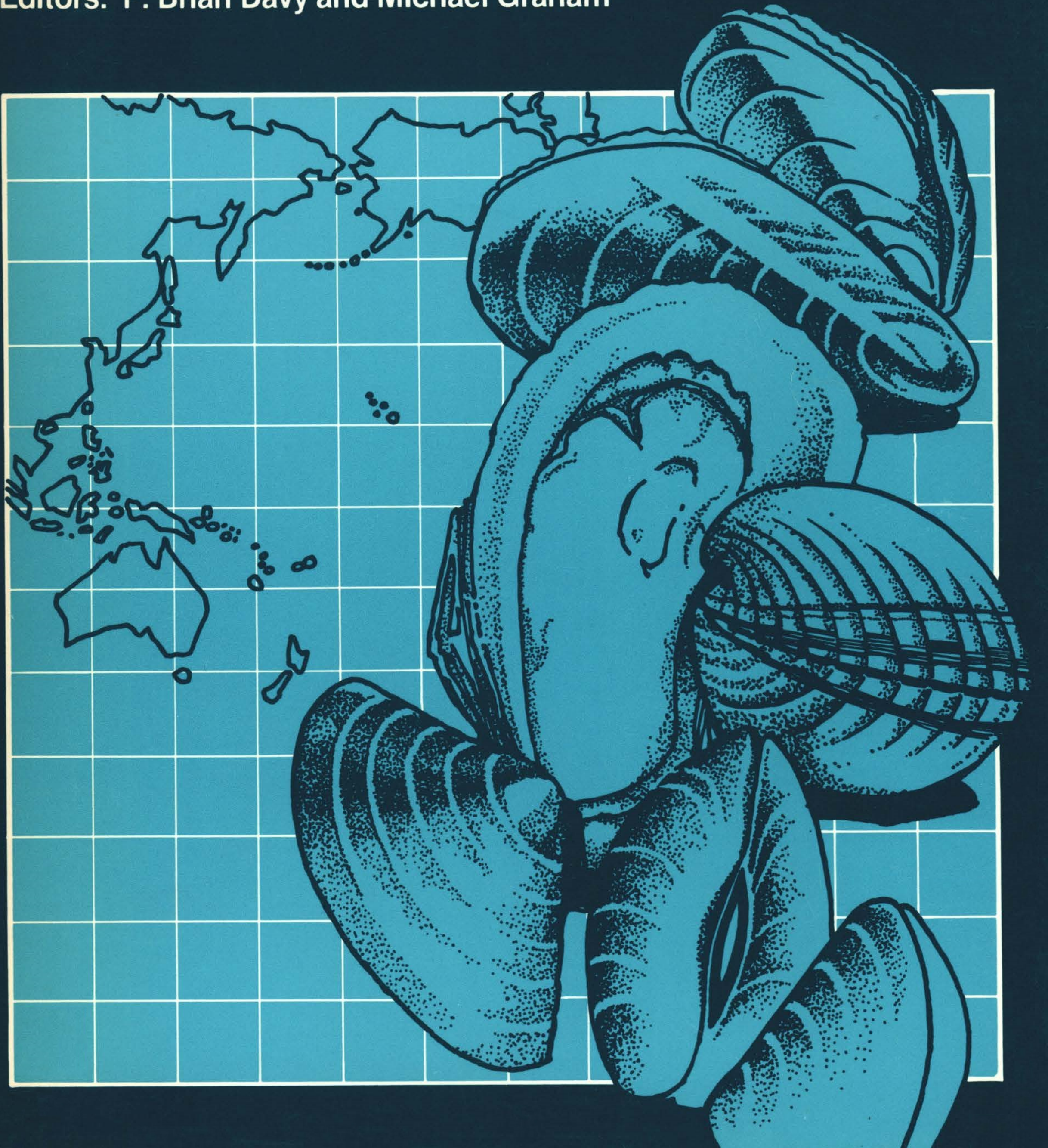
# Bivalve Culture in Asia and the Pacific

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

Editors: F. Brian Davy and Michael Graham



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# *Bivalve Culture in Asia and the Pacific*

## Proceedings of a Workshop Held in Singapore 16–19 February 1982

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## *RÉSUMÉ*

Du 16 au 19 février 1982, sous l'égide du département de production primaire du ministère du développement national et du Centre de recherches pour le développement international, s'est tenu à Singapour un colloque sur les modes d'élevage et l'état actuel de la culture des lamellibranches — huîtres, moules, clovisses, palourdes — en vue d'établir un plan d'avenir dans ce domaine.

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.


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## *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.

El seminario conto con 35 participantes de las naciones de ASEAN (Asociación de Naciones del Sudeste Asiatico), asi como de Bangladesh, Birmania, China, Fiji, India, Papua Nueva Guinea, Sri Lanka, Tahiti y Canadá.

La mayoría de estos países tienen bivalvos abundantes en las áreas costeras, donde son recogidos para consumo local o de subsistencia. Varios de ellos han iniciado el cultivo artificial y se calcula que, con investigación adecuada, las técnicas de cultivo pueden triplicar la producción.

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.

Entre las prioridades identificadas esta la capacitación en técnicas de cultivo, la mejora en el suministro de semilla y en los criterios de selección de sitios de cultivo, la necesidad de estudios económicos detallados y de normas sobre calidad sanitaria de los bivalvos de consumo humano, asi como de medios para intercambiar información sobre investigación en bivalvos.

# CONTENTS

# *Foreword*

Bivalves such as oysters, mussels, clams, and cockles are widely distributed throughout tropical waters. Typically, they occur in mangrove areas or in coastal regions where, following a brief period of juvenile motility, they attach to rocks, wharves, fish traps, and other static objects. In many countries of Asia and the Pacific, it is a tradition to collect the naturally occurring molluscs as a cheap source of food. Once upon a time, molluscs were a cheap food for poor people in many European countries. Now, they are expensive, luxury items in Europe and North America. In the tropics, however, they can be harvested from the wild or cultivated relatively inexpensively. Consequently the interest in mollusc culture is growing rapidly in a number of countries.

It has been demonstrated in several tropical regions that it is both technically and economically feasible to culture bivalves to produce a marketable product in high yield in less than a year. Reported yields of green mussels, grown on ropes suspended from rafts, for 5 months are 10–12 kg/m of rope in a number of countries in the region. The yield of nutritionally high-quality protein per hectare of surface water far exceeds the protein that could be produced on a hectare of land by any known terrestrial plant or animal.

Since 1973, the Agriculture, Food and Nutrition Sciences (AFNS) Division of the International Development Research Centre (IDRC) has supported bivalve-culture research projects in several tropical countries. Projects in Asia, Africa, and the Caribbean have studied oysters and mussels; other projects in Latin America have examined oysters, mussels, and cockles.

In recognition of the growing interest, a regional meeting was convened to review past and current work in bivalve culture in Asia and the Pacific and to attempt to establish regional priorities for future research. The emphasis of this meeting, held in Singapore from 16 to 19 February 1982, was on bivalves for human food. A mussel-culture raft system, developed by the Singapore Primary Production Department in Changi Strait, was used as a valuable focus for demonstration. The culture of molluscs such as pearl oysters, windowpane oysters, and clams — used in the shellcraft industries — was also discussed because similar culture systems can be used for these economically attractive species.

The working meeting reviewed culture practices, postharvest handling, the economics of mollusc management, and future research needs, with some lesser reference being made to the taxonomy of bivalves. The names and pattern of distribution of known species are listed in Table A; throughout the meeting, common names were used where taxonomic identification was not available.

Several countries have demonstrated that cultured bivalves will grow more quickly than those that occur naturally. The increase in yield is substantial and offers an attractive opportunity for aquaculturalists, fisheries research and development organizations throughout the Asian region. Some of the constraints encountered in bivalve culture appear in the status reports presented by participants at the meeting and edited for inclusion in this volume. For some species (e.g., cockles, *Anadara granosa*), further extensive culture research appears unnecessary, as the present system of relaying or sowing seed cockles appears to be both technically practical and economically efficient.

It is hoped that this publication, together with IDRC's earlier contributions to this subject — a bibliography on oyster culture produced in 1975 (IDRC-052e), a handbook on the culture of tropical oysters published in 1979 (IDRC-TS17e), and a 16-mm colour film produced in 1979 on oyster farming in the tropics — will be of practical interest and help to all who are engaged in the improvement of mollusc culture as a source of food and greater income for the coastal peoples of the region.

IDRC wishes to express its gratitude to Dr Siew Teck Woh, Dr Leslie Cheong, and the staff of the Primary Production Department in Singapore for arranging a field trip and for assisting in the organization and execution of the working group meeting.

**Joseph H. Hulse**
*Director*
*Agriculture, Food and Nutrition*
*Sciences Division, IDRC*

# WORKSHOP SUMMARY

# Plans and Recommendations

Bivalves represent a high-quality food source, with considerable potential in most countries in Asia and the Pacific, although the progress toward realizing the potential varies widely and suggests the need for regional collaboration between countries with relatively developed systems and those in initial stages of development. There are other obvious needs for training, information exchange, and research.

## Training

Lack of qualified personnel is the major critical constraint to further development of bivalve culture. On-the-job training, such as that provided in Malaysia, is needed, and governments are urged to facilitate its provision. It could be supplemented by special courses, such as the short course arranged by IDRC in association with Dalhousie University in Canada for practical training in the general biology and culture principles needed in tropical regions. This course, given on a trial basis in June and July 1982, is a first step toward relevant training. Also, the Food and Agriculture Organization of the United Nations (FAO) Network of Aquaculture Centres in Asia offers a 1-year training program that includes bivalve culture.

*Practical on-the-job training in oyster culture using racks has been offered to farmers in Sabah, Malaysia.*

## Information

Increased exchange of information on the results of bivalve research is needed, and future meetings, such as the regional exchange reported here, are recommended. Production of manuals, state-of-the-art reviews, and synopses for mussels, oysters, and cockles is also suggested. Simple taxonomic keys are needed for species identification, and, as improved production techniques are established, more extension efforts will be required.

## Research Priorities

Priorities for research in the region include:

- Detailed economic studies, particularly related to market information and alternative culture practices in areas of existing or potential culture;
- Standardization of mussel- and oyster-culture production systems;
- Ways to increase seed supply for certain species and development of related transportation techniques;
- Depuration studies in a number of countries to ensure a quality food product (such studies should be part of a general bivalve quality-control program that in the short term should concentrate on flesh quality within the marketplace);
- Examination of regulations and lease arrangements to provide a stable base for ownership in culture operations; and
- Development of acceptable quality standards for local and export markets.

## COUNTRY REPORTS

A review of bivalve exploitation in 13 countries of Asia and the Pacific indicated that, in some countries, resources are not being exploited, whereas, in others, an industry involving several million dollars exists. Exploitation ranges from collection of natural stocks to major culture operations. High production figures for oysters, mussels, cockles, and clams were reported from many countries: in China, 43% of mariculture production is from bivalves; in 1979 alone, Malaysia produced about $6.3 \times 10^4$ t of cockles; and Philippine export earnings from shell production are 850 million pesos, or more than US$100 million. The economically important genera in the region are *Crassostrea*, *Perna*, and *Anadara* (Table A), although *Pinctada*, *Paphia*, *Meretrix*, and *Solen* are also valuable. Bivalve-

*Cockles* (Anadara granosa) *are extensively grown in a number of countries in the region.*

Table A. Occurrence of major groups of bivalves in Asia and the Pacific region.

| Country | Ostreidae (oyster) | Mytilidae (mussels) | Arcidae (cockles) | Other |
|---|---|---|---|---|
| Bangladesh | na[a] | na | na | *Lamellidans marginalis; Parreysia corrugata; Placuna placenta* |
| Burma | *Crassostrea* sp. | *Perna viridis* | *Anadara* sp. | *Solen* sp.; *Siliqua radiata; Meretrix* sp., *Donax* sp.; *Paphia* sp., *Pinctada maxima* |
| China | *C. rivularis; C. plicatula; C. talienwhenensis* | *Mytilus edulis; M. crassitesta; P. viridis* | *A. granosa; A. subcrenata; A. inflata* | *P. martensii; Chlamys farreri; C. nobilis* |
| Fiji | *C. glomerata; C. gigas; C. echinata* | *P. viridis* | *Anadara* sp. | *Batissa violacea* |
| India | *C. madrasensis; C. gryphoides; C. discoidea; Saccostrea cucullata* | *P. viridis; P. indica* | *A. granosa; A. rhombea* | *Pinctada fucata; P. sugillata; Paphia textile; P. malabarica; Meretrix meretrix; M. casta; Katelysia opima; K. marmorata; Villorita cyprinoides; Donax faba; D. cuneatus; D. incarnatus; Solen kempi; Placenta placenta* |

*continued*

*Table A. (concluded)*

| Country | Ostreidae (oyster) | Mytilidae (mussels) | Arcidae (cockles) | Other |
|---|---|---|---|---|
| Indonesia | *Crassostrea* sp. | *P. viridis* | *A. granosa; A. indica; A. antiquata; A. inflata* | *Pinctada margaritifera; P. maxima; Modiolus* spp.; *Tridacna gigas; Gafrarium* spp.; *Solen* sp.; *Amusium* sp. |
| Malaysia | *C. belcheri; S. cucullata* | *P. viridis* | *A. granosa* | *Paphia* sp.; *Solen* sp.; *Elizia* sp.; *Glauconome* sp. |
| Papua New Guinea | *C. amasa; S. echinata* | — | — | *P. margaritifera; P. maxima; T. gigas* |
| Philippines | *C. iredalei; S. echinata; S. cucullata* | *P. viridis* | *A. granosa; Arca* sp. | *Modiolus metcalfei; Placuna placenta; P. margaritifera; P. maxima; Pteria* sp.; *Amusium pleuronectes; Cyrtopleura costata (Pholas orientalis); Protapes* sp.; *Katelysia (Paphia)* spp.; *Atrina* sp.; *Pharella acutidens; Geloina striata; Circe gibba; Mactra mera; M. maculata; Donax radians; Corbicula fluminea* |
| Sri Lanka | *C. belcheri; S. cucullata* | *P. perna; P. viridis* | *A. antiquata* | *Larkinia rhombea; Pinctada vulgaris; Pinna bicolor; Geloina coaxans; Gafrarium tumidum; M. meretrix; Marcia opima; D. faba* |
| Tahiti | *S. echinata; S. cucullata* | *P. viridis* | — | *P. margaritifera; Venerupis semidecussatus* |
| Thailand | *C. commercialis; C. lugubris* | *P. viridis* | *A. granosa* | *Modiolus senhausenii; Paphia undulata; Solen abbreviatus; P. maxima; P. margaritifera; Pteria penquin* |
| Singapore | — | *P. viridis* | — | — |

[a]na = no information available.

production figures (Table B) based on status reports reveal considerable yields from raft culture of mussels in the Johore Straits in Singapore and in India (135 t ha a year or 12 kg m of rope). The culture of oysters has been promoted in several countries and has become an established industry in the Philippines. Relaying of seed cockles in Malaysia and the harvesting of other bivalves in estuaries throughout the region have demonstrated the recognition of the value of these resources. It is apparent, however, that present production could be considerably increased in most countries if production techniques were intensified or culture areas expanded. In some countries, culture does not exist or has had a very brief history, and cooperation between such countries and those with more developed industries seems possible.

As well as the considerable potential for food, there is also the employment that can be provided in rural communities involved in shellcraft and pearl-culture activities. Several such enterprises exist to various degrees in most countries of the region.

A general review of the shellfish industry suggested that the major problems are:

- Limited market demand and low prices for collected bivalves in some countries;
- Uncertain supplies of seed for culture and relaying as well as uncertainty in appropriate site selection;
- A shortage of trained personnel for biological studies, culture-processing operations, and extension activities;
- Lack of administrative management, regulatory, and developmental measures for effective promotion of bivalve fisheries; and
- Inadequate sanitary and processing systems.

Data from the island states of Micronesia indicated generally slower growth rates than obtained in South and Southeast Asia for many bivalve species, apparently because of the low primary productivity in these waters. Some interest was expressed in the use of freshwater bivalves

Table B. Status of bivalve production in South and Southeast Asia and the Pacific (February 1982).

| Country | Bivalve | Production (shell-on, t, except where noted) | Source of seed | Culture method[a] | Status of culture | Major constraints |
|---|---|---|---|---|---|---|
| Bangladesh | Oyster; windowpane oyster; freshwater mussel | —[b] | Wild | BI | Experimental | Lack of trained personnel, experts |
| Burma | Oyster; mussel | —[b] | Wild[c] | BI; S | Experimental | Extreme hydrographic conditions |
| China | Oyster; mussel; razor clam; cockle | $2 \times 10^5$ t fresh flesh (1978) | Wild[c]; hatchery | BI; S | Highly developed | Need mechanization (development under way) |
| Fiji | Oyster; mussel | —[b] | Wild[c]; imports | S | Experimental | No local species available for culture |
| India | Pearl oyster; clam; cockle; mussel; windowpane oyster | 21 million pieces (1958); $2 \times 10^5$; $2 \times 10^3$; $3.1 \times 10^3$; $4 \times 10^3$ | Wild[c] | S (except cockle — R) | Pearl culture advanced; edible bivalves collected for sustenance; large numbers of clam shells used for lime | Limited seed supply for some species |
| Indonesia | Cockle; mussel; oyster; clam; pearl oyster | $5.1 \times 10^4$ (1979) | Wild[c] | BI; S,R | Experimental | Low demand (except for cockles); lack of trained personnel; no leasing arrangements |
| Malaysia | Oyster; cockle | 12-13 (1979); $6.3 \times 10^4$ (1979) | Wild[c] | B,S; B,R | Oyster culture experimental; cockle culture advanced | Fouling; siltation; seed supply of *Anadara* sp. (in future) likely limited |
| Papua New Guinea | Pearl oyster | —[b] | Wild; experimental hatchery for giant clam | S | Experimental | Red-tide paralytic shellfish poisoning; mercury occurs naturally |
| Philippines | Oyster; mussel; windowpane oyster; cockle; other | 799; $3.0 \times 10^3$; —[b]; $2.0 \times 10^3$; 109 (1979) | Wild | S,BI; S; BI; BI; BI | Oyster culture developed; others experimental with subsistence collection from the wild | Poor sanitation; limited markets; irregular spatfall |
| Singapore | Mussel | 500 | Wild | S | Developing | Inadequate techniques for postharvest processing |
| Sri Lanka | Oyster; mussel; clam | —[b] | Wild[c] | | | Little work to date |
| Tahiti | Pearl oyster; mussel; clam | $1 \times 10^5$ (1979); $2.8 \times 10^5$ oysters;22;9 | Wild; hatchery | S | Pearl oyster developed; others experimental | Low-nutrient water; extreme temperatures and salinity |
| Thailand | Mussel; cockle; oyster | $9.0 \times 10^4$ (1979) | Wild[c] | BI; S | Developed | Limited seed supply |

[a]B = bottom; I = intertidal; S = suspended (raft or rack); R = relaying.
[b]Small amounts collected in wild, but exact statistics not available.
[c]Bivalves are collected (fished) from the wild at subsistence level.

(Fiji) and tridacnid clams (Papua New Guinea), spatfall-forecasting procedures, and polyculture.

It was acknowledged that bivalve culture is thriving in the region and is not limited to the major producers in Asia such as Japan, Korea, Australia, and New Zealand. However, it was also recognized that there are considerable differences in the development of bivalve culture among the countries concerned and that, therefore, there is a need to identify and define more specifically the real potential for bivalve culture in each country.

## *Culture Methods*

Although a number of bivalve genera occur throughout Southeast Asia, those of main concern for aquaculture development are mussels (*Perna*), oysters (*Crassostrea*), cockles (*Anadara*), pearl oysters (*Pinctada*), and windowpane oysters (*Placuna*). The tremendous potential of these species as a food supply and a source of rural employment was cited repeatedly. However, appropriate technologies must be applied if this potential is to be realized.

To be suitable for culture, a native molluscan species must have three attributes:

- A reliable, inexpensive supply of seed;
- A rapid growth rate; and
- Relatively high value.

In the tropics, the first two needs are generally met. The third depends partially on whether the culture is to be artisanal or entrepreneurial.

In areas where there are not suitable native species, an exotic one may be introduced but only as a last resort and after thorough analysis of the dangers and consequences. Local species already occupy the environment most suited to their needs, although they may not be amenable to cultural practices, regardless of whether the environment is oceanic or estuarine. The alternative culture sites can be subtidal, intertidal, or mid-water. Site selection usually represents a compromise between the ecological requirements of the species and the characteristics of the various types of culture.

There are only a few basic systems of mollusc culture but many variations on these. Many modifications result from the ingenuity of the culturist and are designed to take advantage of local conditions and materials. Many attempts have been made to make mollusc culture less labour intensive, but the cost and supply of labour remain the prime factors in selecting a culture system.

### *Oyster Culture*

Oyster culture can be divided into bottom and off-bottom systems. In the former, oysters are grown on the bottom, either intertidally or subtidally. Intertidal culture requires a relatively firm substrate, the correct tidal height, and protection from excessive wave action. For subtidal culture, a suitably firm substrate, a moderate depth, and minimal predation are needed. The basic method involves planting the seed, usually on ground particularly suited to small oysters; transplanting the seed to grounds where growth is rapid; and finally transplanting the oysters to fattening grounds. Procedures vary, depending on the availability of the types of ground.

Off-bottom systems include rack culture, suspended culture, and stake culture. In the first system, racks of various designs and materials are constructed in or near intertidal zones and are used to suspend trays or strings or to support sticks. The racks are usually 1–2 m high.

The stick type of culture is direct and uncomplicated. Seed is collected on sticks that are placed horizontally on the racks and where the oysters grow to maturity. Those less than market size when harvested are allowed to continue to grow in trays also held on racks.

Strings of shells or other types of cultch may be suspended vertically from racks or placed horizontally like sticks. A great deal of oyster seed is collected this way.

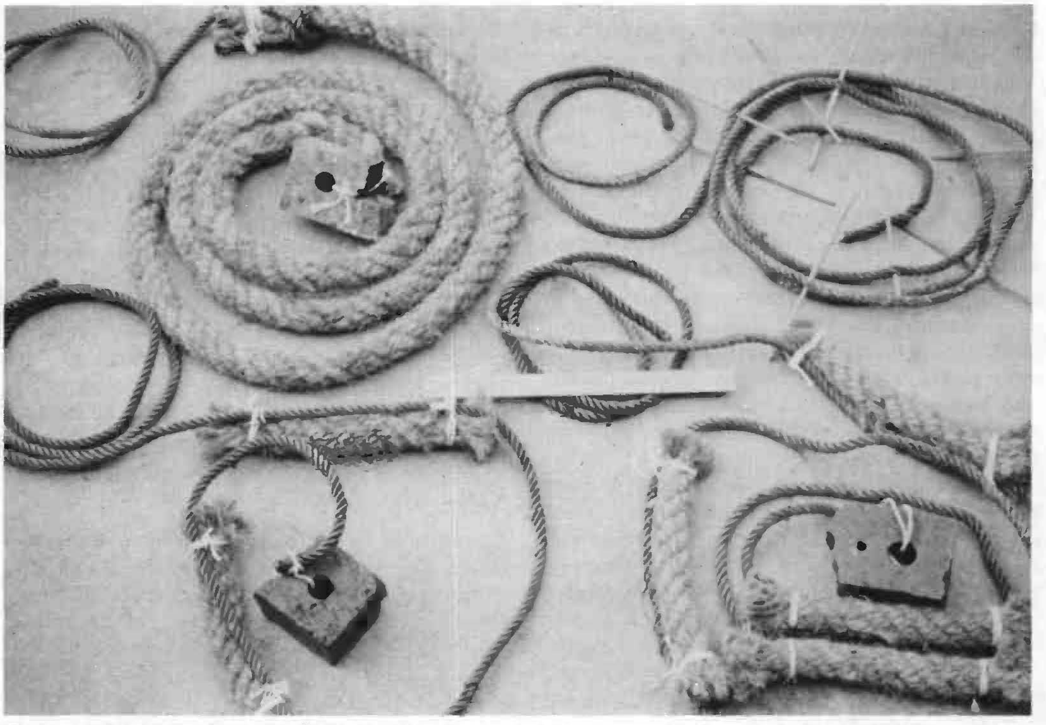
In the suspended-culture system, strings or trays are suspended from floating rafts or long lines. The latter are simply cables supported by floats and anchored at each end. They can withstand greater wave action than can rafts.

Stake culture is also a simple system. A stake about 1.5 m long is driven into intertidal ground at an appropriate tidal height. A piece of cultch, such as an oyster or scallop shell, is placed on top of the stake. The cluster of oysters is allowed to grow to maturity in situ. The equipment is straightforward, and the system is useful in intertidal areas of soft mud.

### *Mussel Culture*

As with oysters, the two main systems for mussels are bottom and off-bottom culture. In bottom culture, mussel seed, collected in various ways, is spread on the bottom where it remains until harvest.

There are several methods of off-bottom culture, but the main one is raft culture. Seed is collected from natural populations on the shore or from ropes suspended from rafts. Sometimes



*Ropes used for mussel culture. Clockwise from the top left: 4 m coconut coir rope, 4 m polyethylene rope, 4 m polycoco rope, and 2 m polycoco rope.*

the seed from the ropes is reattached to other ropes or placed in mesh bags for suspension. In another method, seed on ropes or mesh bags is attached to heavy vertical poles in the intertidal zone. Mussels may also be grown subtidally on long vertical poles: the seed collects on the poles and grows to maturity in situ.

### *Cockle (Clam) Culture*

Cockle culture is not an advanced art and is not as widely practiced as oyster or mussel culture. Cockle seed is harvested from natural grounds and replanted on areas with a suitable bottom but where seed is not abundant. The cockles are then allowed to grow to market size.

## ***Problems***

There seems to be a tendency toward sophistication where simple, inexpensive techniques would suffice and even be more appropriate. Selection of the most appropriate culture technique requires consideration of not only the biology of the species but also the physical and socioeconomic environment. To develop a low-cost, simple method to suit the target user, one must research and evaluate the available alternatives.

Seed production and supply are a problem with many species. Hatcheries are often considered to be the panacea for this problem, but these require expensive, sophisticated equipment and qualified personnel. Providing hatchery-produced seed with food appropriate to the tropical milieu is also a problem, and the nursery culture of juveniles, in particular, is technically difficult and costly.

Spatfall-forecasting techniques are used in temperate countries and deserve attention, particularly in tropical environments where the bivalve-breeding season frequently extends over several months. Methods include plankton sampling or monitoring of the gonad condition of the adults, but the most effective method is probably the routine examination of initial spatfall on sample collectors put in place for this purpose.

The introduction of foreign bivalve stocks is often proposed as a means of establishing a new resource or of enhancing a meagre, local seed supply. The problems associated with such introductions are that they may be accompanied by pests or diseases and there is no guarantee that a local, self-sustaining population will result. Successful introductions have been few.

Security of tenure of bivalve grow-out areas is important in encouraging ventures in mollusc culture. Current legislation for the leasing of grounds in the region (Table C) is minimal, and regulations must be considered in the future. Security of tenure should be contingent on productive and diligent use of a lease. Also required are an accurate delineation of boundaries and security against harmful encroachments.

Throughout the world, many foreshore environments are being destroyed. Mangrove swamps are particularly sensitive to disruptions, and, in Southeast Asia, the maintenance and the extension of bivalve resources are contingent on their preservation.

Because of the reproductive capacity of most bivalves in the tropics and their growth rates (high enough to produce two crops a year in some instances), they are a food resource that cannot be ignored. And, although there has been considerable utilization of the resources of the region, their full potential has yet to be realized.

## *POSTHARVEST MEASURES*

Bivalves are an important source of inexpensive protein; the flesh of green mussels, for example, contains about 67 g protein/100 g flesh at 0% moisture. They are especially suitable as comminuted products for mass or institutional markets. At present, however, their sanitary quality is often unreliable. This unreliability adversely affects sales and needs to be eliminated through postharvest measures, especially sanitation and quality control.

### *SANITATION/DEPURATION*

Pollution from fecal coliforms and heavy metals and paralytic shellfish poisoning (PSP) from dinoflagellate blooms are health hazards

Table C. Summary of bivalve lease legislation.

| Country | Regulations (requiring lease or permit) governing | Specifications[a] |
|---|---|---|
| Bangladesh | Windowpane oyster | na[b] |
| Burma | None of the bivalves | — |
| China | Oyster; mussel; cockle; pearl oyster; razor clam; little neck clam; etc. | No fee |
| Fiji | General fishing: inshore areas — permission to fish commercially must be granted first by the clan owning the area, then by the Fisheries Division; and outside the reef — permission and licence must be granted by the government | Inshore: $4 boat, $4 captain, $1 for each crew member, outside reef: $10 |
| India | Wild pearl-oyster population (no leasing arrangements for culture) | — |
| Indonesia | None of the bivalves (the department of agriculture is coordinating interdepartmental efforts to establish mariculture legislation) | — |
| Malaysia | Cockle | $25 |
| Papua New Guinea | Oyster (village owns inshore shelf areas) | No fee |
| Philippines | Fish traps for shellfish farm: municipal permit (not a lease) | $1 |
| Singapore | All floating cultures in coastal areas | $500 |
| Sri Lanka | None of the bivalves (no leases) | — |
| Tahiti | Green mussel, pearl oyster (*Pinctada margaritifera*) | Symbolic |
| Thailand | All mollusc culture (cockle, mussel, oyster) | $3–4 |

[a]All costs have been converted to US$/ha-year.
[b]na = no figures available.

from raw or semicooked bivalves. Food poisoning has been reported from Australia, India, and Sabah, and pollution has been associated with periods of heavy rain.

Because they are filter-feeders, bivalves can accumulate toxic levels of pollutants in their bodies. Hence, sanitation and quality-control programs are essential, and some are already under way — for example, the New Zealand Standard Recommendations for the Processing, Storage and Transportation of Molluscs and the National Shellfish Sanitation Program instituted by the Public Health Service of the US Department of Health, Education, and Welfare.

Most countries recognize the importance of quality control; however, personnel constraints in many countries make the introduction of effective pollution control unlikely. In practice, a program to monitor pollutant levels at the end point of farming — sales — rather than at the growing sites may be more feasible, although it is not a substitute for the much-needed controls. Consumers must be educated through pamphlets and brochures on how best to handle bivalves, and personnel must be trained in sanitation methods. Quality control of shellfish imports and exports should also be enhanced so that products meet acceptable standards.

To market fresh, shell-on bivalves, one must purge the bivalves of the pollutants and toxins; a simple method is to relay the animals to unpolluted waters or place them in sterilized waters under controlled conditions. Various methods of water sterilization are practiced commercially — chlorination, ozonation, and ultraviolet (UV) radiation. The UV method may be most suitable for the Asia–Pacific region because it has no residual effect, is easy, and is comparatively inexpensive.

In some countries, the poor sales of fresh bivalves are a reflection, partly, of their unreliable quality. Thus, quality-control measures should eventually improve consumer acceptance, and the increased sales would offset the cost incurred in taking such measures. In some areas, it may be necessary to make depuration mandatory for all bivalves, from natural or culture sources, intended for human consumption.

## *Postharvest Operations, Shelf Life, and Storage*

In all the countries, postharvest operations are carried out by hand, and the only place needing mechanization at the moment is Singapore where large quantities of mussels are handled at one time. Singapore is attempting to mechanize several operations, including the separation of clustered mussels, debearding of byssal threads, and deshelling of cooked flesh. The use of steam to facilitate opening of the oyster is also a possibility.

*Fresh mussels packed in moist gunny sacks.*

The shelf life of fresh bivalves could be extended through various forms of dry and wet storage.

## *Processing and Nutritional Data*

Bivalves eaten in the countries represented at the meeting are either cooked or pickled. Because of their perishable nature, fresh bivalves are not readily available in inland areas. Smoking and drying the flesh is suggested as one relatively inexpensive means of preservation that would make the product available in such areas. With refrigeration facilities, cooked flesh could be frozen in blocks or glazed in individual portions. Interest has been expressed by some countries in the use of flesh from bivalves whose shells are normally used in the shellcraft industry, e.g., *Placuna placenta* (windowpane oyster).

*Block and individually frozen mussels.*

## *ECONOMICS*

In many countries of the region, bivalve culture has not been a significant aquaculture enterprise in terms of size, food produced, resources employed in production, or net income received by producers. Perhaps the reason is that, until fairly recently, few attempts were made to research existing tropical bivalves and, thus, to increase the scientific and technical knowledge for their culture. However, there are now culture systems in commercial operation, and several others are being scientifically studied in the hope that they will be suitable for commercial application.

In many cases, detailed information on the biological and technical input–output relationships of specific kinds of bivalve culture is not yet available, and the full range of alternatives in culture techniques has not been developed. The scarcity of information is particularly critical for economic analyses. Financial data on bivalve culture and fishing are few, and little documentation exists about markets for inputs, quantities and combinations of inputs in production, or markets for the product.

The major economic concerns involve markets, production techniques, use of labour and capital, hatchery development, experimental vs commercial operations, comparative resource use, licencing, postharvest technology, levels of culture, and private vs social production:

- Market. The limited market for edible bivalves other than cockles harvested from natural stocks and cultured supplies is a powerful economic deterrent to increased bivalve production. Bivalves are relatively low priced and are in the preliminary stages of acceptance as food. Although there is a long-term, increasing demand for protein in Asia, research should focus first on species with known market acceptance. Increasing the culture and improving the acceptability for bivalve species now consumed are the best way of improving long-term production and utilization of a wider range of bivalve species.
- Production techniques. In addition to a variety of species that could be considered, there are a wide variety of culture techniques. More important for economic purposes, there is a wide range of alternatives in terms of material input, labour, sequence of operations, and engineering design for particular culture techniques. In the development of culture practices, one should con-

sider the costs and returns from all alternatives possible for each major component in the total culture or fishery practice.

- Use of labour and capital. Given that relatively limited markets exist for some bivalves, that they have low (relative to finfish) local-market prices, and that the cost of labour is generally lower than that for capital in Asia, culture practices that depend on intensive capital use would probably have less chance of being economically viable than those involving relatively more labour. This will depend, of course, on the biological environment, the relative prices of capital and labour, and the competition from other production activities for the inputs (particularly water).
- Hatchery development. Seed supply is a serious constraint in a number of countries (Table B), and establishing government or commercial hatcheries has been considered as a means to guarantee supplies. However, the costs of establishment and of measures to protect the spat during transport from the hatchery to the culture site should be weighed against the costs of identifying alternative sources of natural seed. Thus far, the spawning sites and the period and duration of spatfall are only broadly defined for some species and need further study.
- Experimental vs commercial operation. In countries where a commercial culture already exists, its economic efficiency in resource use should be assessed. Such an assessment would involve economic (rather than a simple, financial) analysis of the earnings from the use of water, labour, and capital in the culture operation compared with potential or actual earnings from alternative uses. If commercial culture is just being introduced in a country, researchers should monitor the operations and record deviations from those recommended in the experimental design. Any gap in production between the private commercial operator and experimental practice should be examined, and production improved with applications of new or existing technology not used by the commercial operator.
- Comparative resource use. In the development of bivalve-culture systems and the encouragement of their practice, the economic returns from resources used (water, capital, and labour) compared with those from alternative-production activities will be an important factor in commercial adoption. Polyculture may be a means for maximizing both biological and financial returns, but the potential from investments in polyculture systems must be weighed against that from the same investments in the expansion of the existing monoculture.
- Licencing. Licencing fees for bivalve culture vary widely in the region (Table C), ranging from no fee to S$250/0.5 ha annually. The fee allows the state to realize some return from its resource — the production site. From an economic viewpoint, the fee should equal the amount that the site contributes to production. The principle underlying the licencing fee is similar to that for wages or rent. However, the fee should not be so high initially that it deters new entrants into bivalve culture. This is particularly true for sites that are not used for other purposes.
- Postharvest technology. Given the often limited local market for fresh bivalves, some postharvest handling and processing seem to be required, and the operations should be as simple and low cost as possible, while allowing for reasonable productivity. However, they should ensure a relatively high standard of quality. There is a potentially high payoff from research that develops appropriate technology for postharvest operations, particularly depuration, and that also improves traditional methods of shucking, boiling, roasting, and drying. Production of a high quality, sanitary product would help to remove a market bias against bivalves as human food and therefore allow a relatively low-cost source of protein to compete with other, relatively high-cost, sources.
- Levels of culture. The economics of a relatively capital-intensive operation, as exemplified by Singapore, need to be compared with those for an intermediate type of culture emphasizing low capital costs and a significant use of labour. Such a comparison, along with market studies, could assist potential producers in determining the feasibility of the two levels of cultural practice in areas where bivalve culture has not yet been introduced.
- Private vs social bivalve production. In some areas, governments may consider bivalve culture as a means to fulfill social objectives — for example, to produce protein for a specific group of people in a society. Economic analyses could assist the policymakers to determine the least-cost method of achieving a particular objective.

Although the social objective may preclude profitable production, an attempt should be made to minimize its costs.

The priorities for economic research on bivalve culture are studies to define potential local, regional, and international markets for various species. These studies should also help to define the marketing cost for different species, the major factors behind the demand for different species, and, therefore, their potential market growth over time. Such studies are particularly important for species whose culture is being researched or planned but for which the market is not readily apparent.

# *Country Reports*

# *Bangladesh*

***Masud Ahmed*** *Ministry of Fisheries and Livestock, Government of the People's Republic of Bangladesh, Dacca, Bangladesh*

Bangladesh is blessed with many natural resources; among them are bivalves, which produce protein-rich flesh, calcium-rich shells, and pearls. Because Bangladesh is a riverine country, it has many ponds, lakes, canals, and rivers containing freshwater mussels, thousands of which are being harvested annually. According to a survey conducted by the East Pakistan Small Industries Corporation (now the Bangladesh Small Industries Corporation), in 1964 about 165 kg of natural pink pearls were produced, with a value of about Tk 1.4 million (Tk 19 = US$1). The number of pearl and mussel collection centres in 1964 in Bangladesh was 98: 8 in Bogra, 4 in Rajshahi, 9 in Pabna, 7 in Faridpur, 3 in Dacca, 40 in Mymensingh, and 24 in Sylhet.

Windowpane oyster beds near Cox's Bazar cover an estimated 220 ha. Although the pearls from these oysters are generally white and inferior, the shells are used for various purposes. The flesh of these and other oysters is eaten by local peoples and may have potential for export. Edible oysters are found mainly in the Maiskhali channel (Bay of Bengal) and in the Bakkali and Nāf rivers in the Chittagong district. The largest bed (33 ha) is in Gotibhanga in the Maiskhali channel. The commercial species of edible oysters available near Cox's Bazar belong to the genera *Crassostrea* and *Ostrea*.

In the early 1960s, the government realized the potential of pearl and mussel culture and launched a project to investigate windowpane oyster fisheries and the artificial culture of pearl oysters at Cox's Bazar. At the same time, a malacological unit was set up under the Freshwater Fisheries Research Station at Chandpur in the Comilla district, and, during 1975–80, a pilot project on the culture of pearl-bearing mussels was set up in Tangail district. The research to date has produced essential information on the biology, ecology, and population dynamics of the bivalves. Useful findings have related to:

- The culture of pearls and mussels. For example, freshwater mussels (variety Obesa) were sorted by length: 5 cm, 5–7.5 cm, 7.5–10 cm, and >10 cm; those belonging to the first three groups were reared in enclosures made of 0.9-m bamboo pegs that were pushed 15 cm into the mud. This system proved to be very efficient; it allows water circulation and navigation between the enclosures, and mature mussels can be collected and harvested quickly. Those larger than 10 cm are harvested for pearls.
- The cause of pearl formation. In about 6% of the mussels, natural pearls are produced, and research suggests that the tension at the points of attachment of adductor muscles causes powder-like substances or shell particles to dislodge from the shell and fall on the mantle. It is from these granules that pearls are produced.
- The frequency of seed-pearl formation in freshwater mussels. An examination of 1791 freshwater mussels revealed that 6% contain seed pearls.
- The taxonomy of freshwater mussels. Studies on mussels in five districts found seven different types or varieties. (These results have not been confirmed.)
- The fecundity and longevity of mussel larvae. The female mussel has been found to produce more than 100 000 eggs, and the larvae remain alive in pond water for fewer than 45 h.
- Induced or forced pearl culture. In efforts to force pearl formation, spherical pearls, the eyes of small fishes, and small pieces of mantle were tried as nuclei, but only cut pieces of mantle produced pearls, and the mortality of the mussels was very high (about 90%).

Because of the limited progress so far on the artificial culture of pearls in freshwater mussels and marine oysters, a consultant on shellfishes was brought in and is working in the country now.

# CHINA [1]

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China has about $1.8 \times 10^4$ km of coastline, large islands, and many archipelagoes (in the East China and South China seas). The main coastline extends from the temperate zone in the North to subtropical and tropical zones in the South. There are intertidal beaches and flats and shallow seas all along the coast, which provide about $2 \times 10^6$ ha suitable for mariculture.

Bivalve culture in China has a long history and an important position in modern mariculture. Oyster culture began in the Han Dynasty about 2000 years ago and may have equaled European oyster culture during the ancient Roman period. *Yelikou* (Manual for Oyster Culture), written by Zhen Hongtu in the Ming Dynasty (1368–1644 AD), gave systematic, practical information on oyster culture. Other species of bivalves, such as cockles and razor clams, also have long histories of culture. For example, the *Compendium of Materia Medica* written by the famous medical man Li Shizen in the Ming Dynasty records razor-clam culture.

Under the government of the People's Republic of China, aquaculture has received attention and strong support. Experimental stations have been established, and scientists have been encouraged to join workers' teams to develop the field. More than 10 species of bivalves are now cultured successfully along the coast. The major groups are oysters, mussels, razor clams, short-necked clams, pearl oysters, scallops, and hard clams. The area used for culture was about $1.48 \times 10^5$ ha in 1978: $6.5 \times 10^4$ ha for intensive culture and $8.3 \times 10^4$ ha for extensive culture. The yield of bivalves in 1978 was about $2.0 \times 10^5$ t, 44% of the total mariculture yield.

This production included $3.0 \times 10^4$ t of oysters (fresh flesh), $9.0 \times 10^4$ t of mussels, $4.0 \times 10^4$ t of razor clams, $4.0 \times 10^4$ t of cockles, and a small amount of small-necked clams and hard clams (fresh flesh).

Bivalve culture is not extensively developed in Fujian, Guangdong, Zhejiang, Shandong, or Liaoning provinces. However, the culture of pearl oysters was started recently in Guangdong and Guangxi provinces, and the coastal waters of Liaoning and Shandong are used for mussel and scallop culture. Mussel culture has been conducted there for about 20 years but scallop culture only recently. In the South, oysters, razor clams, cockles, and small-necked clams are called "the four well-known cultured bivalves." A great deal of knowledge and skill in their culture has been accumulated over the years.

The traditional culture method in the South is bottom culture in the intertidal zone. In the North, mussels and scallops are cultured on floating rafts, and the culturists mainly depend on natural spat. These bivalves are reared and harvested with little effort.

## OYSTERS

The most commonly cultivated oyster species are *Crassostrea plicatula* and *C. rivularis*. There is also small-scale culture of *C. talienwhenensis* in Liaodong and Shandong peninsulas. The *C. plicatula* culture is mainly in Fujian and Zhejiang, and the *C. rivularis* in Guangdong. The *C. plicatula* yield is very high and accounts for about five-sixths of the total yield of cultured oysters.

*Crassostrea plicatula* is a common species along the coast. It grows rapidly and has a short culture period. It produces spat all year, with spatfall peaks in May and September. Typical culture methods are the bamboo-stake method in the northern and eastern parts of Fujian and the

[1]This country report is based on two papers presented during the workshop. The main report was presented by Mr Nie. The appendix on oyster-culture techniques in Guangdong was presented by Mr Qiu Li-Qiang, South China Sea Fisheries Research Institute, Singanglu, Hai Zhu Qu, 2389 Canton.

stone-bridge method in the southern part of Fujian. The former is good where the bottom is soft. Bamboo stakes, 1.2 m long and 1.5 cm in diameter, are planted in midtidal flats before spatfall peaks, with 4-5 bamboo stakes in a bundle. The bundles are spaced regularly in rows. About $1.5-1.8 \times 10^5$ stakes/ha are used as spat collectors, and these are thinned once or twice during the growth period, so that there are about $1.2-1.5 \times 10^5$ stakes/ha at harvest. The spat settling in May require 11-15 months to grow to harvestable size and those in September, 16-18 months. The average yield is 60 t/ha, but yields sometimes reach 110 t/ha. The harvesting season is winter and spring.

The stone-bridge method is used in sandy mud bottoms. Bridges made of stone bars (80 cm × 20 cm × 8 cm in diameter) collect spat on midtidal flats in May and June. During the growth period (7-12 months), the bridges are moved periodically as a means to ensure abundant food supplies for the oysters. Fifteen thousand stone bars can be put in 1 ha, and the average yield is 30 t/ha, although yields sometimes reach 80 t/ha.

*Crassostrea rivularis* lives in estuaries of low salinity and is cultivated mainly on the bottom. Gravel, oyster shells, and cement plates (17-24 cm × 14-19 cm) or bars (40-80 cm × 6 cm × 4 cm in diameter) are used to collect spat. The last two, introduced in the 1960s, are reinforced, with bamboo being embedded in the cement. They are lighter than other collectors, have a larger surface area for spat settlement, and are not as easily covered by silt. The culture cycle has three phases: spat collection, adult rearing, and fattening. The peak of spatfall occurs in June-August, when salinity is at its minimum and temperature at its maximum for the year.

*Stone-bridge method of culture.*

Since the early 1960s, fisheries scientists have successfully helped the oyster farmers predict the best time for putting out the collectors. The criteria used are the numbers of pelagic postlarvae in the water and the hydrographic conditions (salinity 7.0-17.5 ppt and temperature 26-29°C). The postlarvae settle during low tide, to a depth of 10 m, with a maximum density within 0.4 m of the lowest tide line. This method of forecasting has ensured a stable yield.

The culture area is usually divided into rectangular blocks, and the spat collectors are lined up in rows. There are usually $3.0-3.8 \times 10^4$ cement bars or $1.0-1.4 \times 10^5$ cement plates/ha. The growth period of *C. rivularis* is 3-4 years. Before harvest, the oysters are moved to fertile waters for a few months of fattening. The yield is 45-110 t/ha.

Because of the potential damage by typhoons, oyster culture in the South has been limited to traditional bottom culture. Recently, however, experimental raft culture, which gives a higher yield in a shorter period than bottom culture, has shown potential. An 84-$m^2$ raft produces the same yield in 2 years that 667 $m^2$ of bottom culture does in 4 years. In addition, the rafts withstand typhoons better than expected.

## *MUSSELS*

There are three commercial species of mussels in China: the common mussel (*Mytilus edulis*), the black mussel (*M. crassitesta*), and the green mussel (*M. smaragdinus*). The common mussel occurs in Liaodong and Shandong peninsulas in the North, and the black mussel from the Bohai and Yellow seas to the East China Sea. The natural stocks of the black mussel are historically quite abundant, especially in Zhejiang and northern Fujian. The green mussel is distributed in the southern part of the East China Sea and in the South China Sea. The black mussel is the largest (shells 20 cm long), and the common mussel the smallest (shells 12 cm long). The common mussel is the most widely cultured species, whereas the green mussel is cultured in Guangdong on a much smaller scale.

Mussel culture in China began in the late 1950s. Mussels grow quickly, have a short culture cycle, and produce a high yield. At first, spat were quite sparse, but, as the scale of mussel culture increased, the numbers of natural spat quickly increased. The major culture areas are in Shandong and Liaoning. Artificial culture has spread

*Mussels under culture.*

successfully to Zhejiang and, in the South, to the northern part of Fujian.

Mussel culture uses the same floating racks that are used for *Laminaria* (kelp) culture. The rack is made of a rope 60 m long and glass or plastic floats 28 cm in diameter. It is anchored by large cement blocks or wooden stakes. Each floating rope is a culture unit and about 100 mussel strings are hung from each line. The strings used for rearing adult mussels are about 1.5–2.0 m long.

Mussel culture is simpler than other types of bivalve culture and can be divided into two stages: seeding and rearing. Seed mussels are collected from nature. The two major spawning seasons are April and late September. The spring spawning produces many more eggs than the fall and, hence, is the main source of seed. The production from the autumn spawning depends on the temperature during the following winter. In the coastal area of the North, the thousands of ropes used for *Laminaria* and mussel culture are good collectors for seed mussels. In some productive areas (e.g., inside a bay), new rafts and ropes are used to collect the spat.

The shells of seed mussels from spring spat can grow to more than 1.5 cm by July or August, when they are transplanted to the rearing rack and wrapped around the mussel strings with pieces of net. The net pieces can be removed after 1–2 days.

There are two culture cycles. One is about 8 months — from summer to March — by which time the mussel shells are just over 4.5 cm long, and the other is about a year — from summer to August — when the mussel shells are just over 6 cm long. Most culturists adopt the shorter cycle and harvest in the spring when the density should be about 1000–1200 individuals/m of string. In summer, harvest densities are 600–700/m. The densities affect total yield and quality, and yields vary considerably among sea areas with different productivities. However, the yield from spring harvesting is generally about 0.6 t/rope, and, in some regions, it reaches about 1.5 t. The yield from summer harvesting can be as much as 66% more but is vulnerable to summer storms or typhoons.

Because natural seed mussels were scarce during the early stage of mussel culture in China,

*Harvesting razor clams.*

fisheries scientists worked to develop practical techniques for artificial spat rearing. In 1973, one of the experimental tanks produced $2.8 \times 10^6$ spat/$m^3$ of seawater. Spat rearing, feeding, and managing techniques were studied, and much useful information was accumulated. With the tremendous increase of natural spat in the northern areas, artificial rearing is now important only in Zhejiang, Fujian, and Guangdong.

## RAZOR CLAMS

*Sinonovacula constricta* (razor clam) is found only in the cold waters of China and Japan, in bays where there is an input of fresh water. The clams inhabit the middle and low intertidal mud flats and can be found in all parts of China. They are the major species of cultivated bivalves in Fujian and Zhejiang and account for more than half the total yield of cultivated bivalves in the two provinces. These clams are an important source of income, and intensive culture techniques have been developed.

For a long time, development of razor-clam culture was limited by natural seed production. In the late 1950s, Chinese fisheries scientists developed a procedure to predict the best time for natural spat collection, and this development has greatly increased the production of seed clams. The forecasting procedure is based on observation of the time of intensive discharge of the sexual products by the parent stock and examination of the seawater in an attempt to determine the number of postlarvae nearly ready to settle (the pelagic larva stage lasts for 6–10 days). Just before the postlarvae settle, the spat beds are loosened and flattened on the site. The spawning season is from late September to January, with the peak from mid-October to mid-November. The intensive discharge of sexual products usually occurs at the end, but sometimes at the beginning, of a spring tide.

Seed clams are harvested and sown into rearing beds from January to March of the next year. The number to be sown depends on the size of the clams, the condition of the substrate, the tide level, and the season. Generally, $9–18 \times 10^6$ 1-cm long seed clams/ha are suitable. With proper management, they can be harvested in August of the same year. Marketable size is about 5 cm in shell length. The average yield is 15–22 t/ha. Sometimes, the clams are allowed to grow until March or April of the following year. Then they yield, on average, 30–37 t/ha; yields as high as 82.5 t/ha have been recorded.

## COCKLES

*Arca (Anadara) granosa* — cockles — are one of the major cultivated species in Shandong, Zhejiang, Fujian, and Guangdong and are the preferred seafood in many coastal parts of south

*Sieving and washing cockle spat.*

China. Cockles inhabit soft, muddy flats in estuaries and bays where winds and waves are weak and tidal currents as well as inflow of fresh water are unimpeded. The spawning season is July–September. The spat settle on fine, sandy mud flats where there is little wave action — usually in the middle and low intertidal zones.

The culture cycle for cockles is longer than that for other bivalves cultured in China. Cockles possess no siphons and can only live in the shallow surface layer of the mud flat; therefore, both freezing temperature and exposure to the sun can kill them. Also, carnivorous predators are quite numerous. These hazards demand careful management. In traditional culture, seed cockles are raised from natural spat and then reared in enclosed water pools. They are thinned several times, transplanted in rearing grounds in the lower tidal zone.

It takes about 1 year for the seeds to grow into young cockles (800 cockles/kg), and another 2–3 years to attain 2 cm, marketable size (120 cockles/kg). The yield is 22.5–60 t/ha. Harvest is usually in winter to meet the market demand created by the Chinese spring festival.

In the last decade, cockle culture has rapidly declined, mostly because of the great changes in the condition of the coastal mud flats. Many traditionally productive areas for seed rearing have been lost, especially in Guangdong, Fujian, and Zhejiang, and, therefore, artificial seed-rearing experiments are now in progress.

## *Small-Necked Clams*

The small-necked clam (*Tapes philippinarum*) occurs in China, Japan, and the Philippines and inhabits muddy, sand beaches in intertidal zones and the bottom of shallow waters near estuaries. The natural stocks are abundant in some areas of the Liaodong and Shandong peninsulas, and they support a local fishery. The small-necked clam is one of the important cultivated bivalves in Fujian. Its spawning season is in October–November. The pelagic larvae live in the water for about 2 weeks and then sink to the bottom to metamorphose. Settling sites are beaches in the lower tidal zone of water passages in clam bays.

The culture beds are loosened and smoothed shortly before spat settlement. The spat grow to juveniles (0.5 cm) by April or May, and they are collected and cultured for another year to produce 1.4-cm seed clams, which are sown in the culture beds. The number of seeds sown is about $1.8 \times 10^6$/ha. It takes up to a year for the clams to grow to marketable size (3.5 cm). Harvesting takes place in spring or summer, and the yield is about 18.7 t/ha but is sometimes as high as 45 t/ha.

Before 1975, the development of small-necked clam culture was hindered by a sparse seed supply, but fisheries scientists in Fujian have developed a technique for the artificial rearing of spat, which has increased production. The rearing work is done in the field, in the lower intertidal zone. Shallow ponds with several hectares of smooth bottom are used. Pests, enemies, and seaweed are removed, and then the pond water is fertilized and inoculated with *Chaetoceros mueller*, a good food organism for bivalve larvae. Sperm and eggs are obtained from mature clams, which are artificially induced to discharge their sexual products, and then introduced into the ponds. Soybean milk is sometimes added as a supplement to allow the larvae to complete their early development and to metamorphose. Each pond can rear two or three batches in a breeding season. About 7.5–15.0 $\times$ $10^6$ seed clams (0.5 cm long) can be harvested from a 1-ha pond.

## *SCALLOPS*

The adductor muscle of the scallop, known as gan-bei, is considered a luxury among seafoods in China. It is usually dried and sold. The most important species of scallop in China is *Chlamys farreri*, which occurs naturally in Liaodong and Shandong peninsulas. It inhabits the sea bottom in areas with swift currents and high salinity, from the low tide line to a 20-m depth. Adult scallops have shells 6–9 cm high. Sustaining a regular fishery is becoming increasingly difficult as natural stocks decline.

Scallop culture in China began only a few years ago but has developed rapidly. Usually, floating racks and plastic-screen cages are used. The racks are similar to those used for *Laminaria* and mussel culture. Some people prefer to drill holes in the ears of the shells, string the scallops together, and hang them from the racks. Each rack (or rope) yields about 750 kg of marketable scallops. Mixing cultures of scallop and *Laminaria* — hanging scallop strings between the *Laminaria* strings — has proved successful, increasing the total yield of organic products from a given area of sea.

The optimum temperature for growth of *C. farreri* is 12–20° C. Temperatures lower than 5° C halt growth. The culture cycle from spat to marketable size (6–7 cm) takes about 1.5–2 years.

At present, most scallop culture depends on spat artificially reared by techniques developed in 1974. The scallop spawns in May–June and in late September. Usually, the larvae can be reared indoors to a size of 600 $\mu$m, with a yield of 3.0–4.0 $\times$ $10^5$ spat/$m^3$ of seawater. They are then transferred to the sea in screened cages to grow into seed scallops (1 cm high). The survival rate of this stage is low (10–50%).

With the rapid developments in scallop culture, natural spat have increased in some areas. For example, in Changdao county of Shandong, each polyethylene spat-collecting bag (35 cm $\times$ 23 cm) suspended from a floating rack yields 300–500 juveniles. If natural seeds continue to increase, artificial rearing may be unnecessary.

Another species of scallop (*C. nobilis*) has recently been cultured in south China. It is larger and grows faster than *C. farreri* and can reach shell height of 12 cm. It has been commercially cultured in southern Fujian and Guangdong. Spat are artificially reared and the production, as for *C. farreri*, is about 3.0–4.0 $\times$ $10^5$ spat/$m^3$ of seawater. The culture cycle lasts about 1.5 years, and the scallops are marketable size when their shells are 7 cm high. The yield is about 750 kg/rope, and all of the scallops cultured in Guangdong can be exported directly to Hong Kong.

Racks and methods used for *C. nobilis* culture are similar to those used for other scallops in the North. The main difference is that, to prevent typhoon damage during May–October, the culturists tie stones to the ropes to lower them 2 m below the surface. This anchoring is similar to measures taken in a few areas of northern China to protect kelp from freezing during winter.

## *PEARL OYSTERS*

Pearls, used for ornaments as well as a rare Chinese medicine, occur only in Guangdong and Guangxi. Among the few commercially important species, *Pteria (Pinctada) martensii* is the most abundant and is probably what is known as the mother of pearl in Chinese history. Although the artificial culture of this bivalve is recent, many pearl farms are now run by the state and collectives in Guangdong and Guangxi. Great achievements have been made in the artificial rearing of spat, the culture of adults, techniques for inducing pearl formation, and the direct utilization of pearl nacreous substance.

*Pteria (Pinctada) maxima* of Hainan Island is the largest of the pearl oysters. Its shells are widely used in handicrafts, and, recently, techniques for artificial spat rearing and nucleus insertion for pearl production with this species have been studied.

*Meretrix meretrix, Mactra antiquata, Brachydontes senhousei,* and *Aloidis* sp. are also cultured in some regions. *Meretrix meretrix* is broadly distributed along the coast of China in fine sand beaches. Its natural stocks are abundant, and culture has been extensive in some areas. It is a good seafood product for export.

In conclusion, bivalve culture in China has a long history. There are numerous species suitable for cultivation and the potential culture area is vast and diverse. However, less than one-tenth of this area is currently exploited. Because the importance of mariculture is now more widely recognized, it is expected that bivalve culture will expand at a greatly accelerated pace and that the yield will greatly increase.

## *APPENDIX: OYSTER CULTURE IN GUANGDONG*

### *SEED COLLECTION*

One year after attachment, at sexual maturity, oysters begin to reproduce. In the annual gonadal cycle, a large number of the original sex cells formed in February are differentiated in March. Sex cells mature and are discharged from April to October with a recovery stage in November. Small quantities of spat appear in April, but spatfall peaks in May–June and gradually decreases from June to September.

The seed-collecting ground is generally an internal bay receiving river water. For good seed collection, there should be an abundant oyster population and tidal water circulation. The intertidal zone between midtide and 1 m above the low tide line is the seed-collecting ground. From June to August, under normal oceanographic conditions, when the water salinity is 5–20 ppt and the water temperature is 27-31°C, the fertilized eggs metamorphose into larvae at a density of about 60 individuals/$m^3$ water, and, when they begin to settle in sufficient numbers, the collectors (cultch) are set out.

The traditional types of cultch are 3–8-kg stones, ceramic pieces, tiles, or large oyster shells. All are inexpensive and are easy to handle. Their disadvantages are that they provide only small surfaces for spat attachment, they sink in soft mud, and they have a low unit yield. From seed collection to oyster harvest requires 3-4 years, and the yield of flesh is 500–700 catties/mu (~3750–5250 kg/ha). Since 1965, most of the traditional types of cultch have been replaced by a cement cultch, and yields have increased to 1000–1200 catties/mu (~7500–9000 kg/ha). The advantages of the cement cultch are that it remains on the surface of the mud and extends the spat-attachment areas. There are two types — the cement bar and cement tile.

Immediately before seed collection begins, bamboo sticks are placed in the collecting grounds to outline the area in which the cultch are to be set. Collectors are shipped to the marked grounds at high tide and are thrown uniformly over the area from slowly moving boats. Cement bars are placed at a density of 3000/mu ($4.5 \times 10^4$/ha) and cement tiles at 3000–3500/mu (4.5–$5.3 \times 10^4$/ha). At low tide, the collectors are arranged in blocks. Between the blocks, a space of 3–4 m is left for boat navigation. Within the blocks, collectors are arranged in rows 10–12 m long. In each row, pairs of cement bars are crossed to form an "X" at intervals of 0.3 m. The space between the rows is 1–1.5 m. The cement bars are inserted 0.3–0.5 m into the mud so that they will stand straight and firm.

### *MANAGEMENT*

Between being collected as seed and reaching marketable size, the oysters need good management for growth and survival. The collectors are frequently checked and adjusted. During fall and winter each year, the collectors are lifted by hand and stripped of the oysters. Then they are reinserted in the mud in a different position so that the oysters have sufficient food and space for growth. During this time of year, the water temperature is at a minimum and the salinity is increased. The reproductive period is completed, and the oyster begins to recover and grow rapidly. After 3–4 years, when the length of the shell has reached 12–18 cm and the height is 6–8.5 cm, the oysters are transferred to the fattening ground.

### *FATTENING*

Most seed-collecting grounds in Guangdong can be used as both growing and fattening grounds. Oyster fattening is important for high yield. Three-year-old oysters are transferred to the fattening grounds at the river mouth and are arranged in the same pattern as earlier. About 11–15 $m^3$ of cement bars or 11 $m^3$ of cement tiles are used per mu (1/15 ha). The fattening season begins in August–September and continues until April of the following year. The oceanographic conditions are important:

- At the beginning of the fattening season, the salinity near the river mouth rises in 1 month from 4–10 ppt to 14–20 ppt;
- Mean temperature of the water is 28°C in August–September, 24°C in October, 21°C in November, 19°C in December, 15°C in January and February, 18.5°C in March, and 23°C in April;
- The $NO_2$-N content is more than 60 mg/$m^3$ and that of $PO_4$-P is more than 6 mg/$m^3$; and
- The pH value is stable, between 7.9 and 8.4.

## *HARVESTING*

The percentage flesh of the oyster is calculated by the formula: weight of dehydrated flesh/total weight of oyster in shell × 100. When the percentage has reached 12–16%, the oysters can be harvested. The age at harvest is usually 4 years. There are two steps in harvesting: collecting the oysters and shucking the flesh from the shell. The oysters are collected in low tide in one of two ways:

- When the water is 0.5 m or shallower, a boat is anchored over the harvest ground and the oysters are dredged with bamboo tongs; or
- When the fattening ground becomes an exposed beach, the oysters are harvested by a specially made wooden horse that supports the collector in the soft mud and carries the oysters to the boat.

Oysters are shucked by hand with a special knife. Oyster flesh may be sold fresh or dried or canned with a by-product (oyster sauce).

# *Fiji*

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Trials on the culture of green mussels (*Perna viridis*) in Laucala Bay near Suva were carried out by the Fisheries Division from 1979 to 1981. The spat were obtained from the Centre national pour l'exploitation des océans (CNEXO), Tahiti. Earlier attempts (appendix) had been made to introduce the Philippine green mussel (*Mytilus smaragdinus*) to Fiji, and the results were encouraging. They prompted this latest series of trials.

## *Culture Practices*

Soon after the spat arrived, they were spread evenly on perforated (shellfish) trays, which were tied together and suspended 0.5 m below the water surface. After 4–6 months, the spat were picked out and trained for attachment onto culture ropes, made of natural fibre. Training takes about 10–14 days. The mussels were thinned to 250/m of rope and then transferred either to bamboo rafts or mangrove racks for maturation.

In the rack system, wire-mesh cages were placed on mangrove racks constructed in the intertidal zone and raised 20 cm from the sea bottom. The mussels were exposed during low tide and submerged about 1 m at full tide. In the raft system, the bamboo rafts were anchored in water 6 m deep. The mussel ropes were placed inside cylindrical mesh cages and suspended from the rafts about 1–3 m below the surface. Thus, the mussels were submerged throughout the culture period.

Most trials were carried out in the shallow (3–5 m), turbid waters close to shore. Salinities ranged from 26 ppt to 36 ppt and temperatures at the surface of the water from 26° to 28° C. On arrival, the spat were 3–12 mm in shell length. The mussels on the rafts grew faster than those on the racks, reaching an average shell length of 90 mm after 18 months and a wet-flesh weight of 10–12 g. After 3.5–4.0 years, the average maximum shell length was 136 mm and the wet-flesh weight was 40 g. Unfortunately, the quality of the flesh was not very good.

Management included repairing racks and rafts, providing protection from predators and fouling organisms, and cleaning the cages.

Predators — crabs, mangrove eels, fish, shell borers, etc. — were a major problem for the mussels at all stages of development. Fouling organisms were also troublesome, clogging the mesh of the protective cages and making regular cleaning necessary for good water circulation. These problems, however, are probably surmountable; however, another problem may be less so: there has been no evidence of natural spatfall of this introduced mussel species in Fiji.

## *Conclusion*

Growth of the introduced species of mussels compared poorly with that in other countries, although the reason is unclear. Whether the poor performance reflects inappropriate management, improper site selection, or some other factor is a question beyond the scope of the trials. Nevertheless, the trials did show that the predator problem is significant and the lack of natural spawning is a major constraint to the future of mussel cultivation in Fiji.

## *Appendix: Preliminary Bivalve Culture Trials*[1]

Natural populations of the mangrove oyster *Crassostrea glomerata* are abundant in Fiji, but

[1]This appendix was abstracted from a 1977 FAO report on oyster culture prepared by T.P. Ritchie for the government of Fiji. The report was circulated at the workshop as background information and its general conclusions are summarized here. The conclusions are those that were considered appropriate when the original report was prepared.

the species is small, seldom longer than 50 mm, and appears to survive only in the intertidal zone. Experimental attempts to rear this species to marketable size have been unsuccessful. Data from observations indicate that, under the conditions found in Fiji, the species dies after it has grown a maximum 50 mm. It grows in subtidal conditions but survives only a short time. Commercial culture methods would probably not appreciably alter the basic growth characteristics of this species and, therefore, would be futile.

Natural populations of *C. echinata* are rare in Fiji, but there is one substantial population in a lagoon on Mago Island. This species appears to be the only indigenous *Crassostrea* species that has potential for commercial culture in Fiji. It has evolved the ability to survive and grow past marketable size. Although its growth rate is slow compared with that of other, experimentally introduced, species, its survival rate is likely to be much higher than that of nonindigenous species. Its hard, thick shell affords adequate protection from most predators and many shell-boring sponges; a uniform size and shape should be obtainable through special commercial-culture techniques.

In the Mago Island lagoon, dense populations of *C. echinata* spat settled on the hull of a fiberglass boat, and several hundred single spat were easily removed without damage. The owner of Mago Island is conducting additional experiments with artificial setting substrates to obtain single seed oysters for tray-culture experiments. Growth and survival of *C. echinata* are currently being monitored by oyster project staff in Laucala Bay.

Although the prospects for commercial culture of *C. echinata* in Fiji look good, the experiments and observations so far are not definitive.

### *Nonindigenous Oysters*

Most commercial oyster-culture experiments in Fiji have been conducted with the Pacific oyster *C. gigas*, which was introduced to Fiji in 1969. Although information on this species' survival and growth is still being collected and is essential for definitive conclusions, data thus far suggest that *C. gigas* spat survive and grow exceptionally well during the first 8 months of culture in Fiji but their survival and growth rate decrease rapidly thereafter. The presence of wild *C. gigas* has been recorded and indicates that the species reproduces naturally under the conditions found in the country.

The Australian or Sydney rock oyster (*C. commercialis*) was experimentally introduced to Fiji in 1973. Data accumulated over 7 months indicated that growth and survival rate of cultchless spat of this species in Fiji were not sufficient for commercial-culture attempts. It was tentatively concluded that seawater temperatures in Fiji are too warm for the successful culture of the species.

The Philippine oyster *C. iredalei* was experimentally introduced into Fiji in April 1975. Its commercial-culture potential cannot be estimated yet because observations are continuing, but the data are encouraging. *Crassostrea iredalei* is a tropical species and should be more genetically capable of surviving and growing in Fiji than many oysters already experimentally introduced. If progeny can be obtained from this species, they, and successive generations, should be even more acclimated to survival and growth in Fiji.

### *Nonindigenous Mussels*

The green mussel (*Mytilus smaragdinus* or *Perna viridis*) was experimentally introduced into Fiji in April 1975. Although growth and survival observations were only conducted for 1 year, the results were encouraging. The total survival rate was relatively high and the growth rate appeared adequate for commercial culture. Preliminary market surveys indicated that mussels could be readily marketed in Fiji. Commercial mussel-production costs should be less than those for commercial oysters. Many *Mytilus* species are commercially cultured in high-salinity areas, and oyster project staff are currently conducting experiments in such areas in Fiji. It is tentatively concluded that *M. smaragdinus* has commercial-production potential in Fiji.

## *AQUACOP (Aquaculture Team of the Centre océanologique du Pacifique), Tahiti*[1]

Two research and development agencies are focusing on bivalve culture in French Polynesia. At present, they are involved in a spat-production program for pearl oysters (*Pinctada margaritifera*) and are searching for edible species capable of withstanding the peculiar conditions of the Polynesian environment. The Centre national pour l'exploitation des océans (CNEXO), a French agency, through its laboratory at Tahiti (the Centre océanologique du Pacifique, COP), is studying spat production in a hatchery, and the Service de la pêche, a French Polynesian agency represented in many of the islands, is working on spat collection, culture problems, and implantation techniques.

The area with potential for bivalve culture is located in the trade-wind belt 15–25° S and 135–155° W. The superficial seawater typifies ocean water, with an annual temperature range of 25–30°C; an annual salinity range of 34–36 ppt; and poor nutrient content. The two island groups considered here are the Tuamotu-Gambier Archipelago, for pearl-oyster culture, and the Society Islands for edible-bivalve culture.

The Tuamotu-Gambier Archipelago is composed mainly of atolls, with some volcanic islands, like the Gambiers. The atolls have large lagoons, some of which — generally the closed ones — shelter natural populations of *P. margaritifera*. These lagoons have potential as sites for pearl-oyster farms composed of floating or fixed, underwater-culture platforms.

The Society Islands are composed of the Windward and Leeward islands, most of them being high — of volcanic origin — and surrounded by barrier reefs delimiting lagoons. The lagoons are fed by ocean combers swelling over the reefs. The water flows back out to the ocean through passes, and the renewal rate is generally rapid. Thus, the water inside the lagoons typifies oceanic characteristics and precludes bivalve culture in most of the sites. However, some of the islands have deep, sheltered bays that receive river water and harbour natural beds of *Saccostrea cucullata*. The bays are rich in nutrients leached from surrounding basaltic soils. Some, like Tatutu Bay in Tahiti Island, have been separated into two parts by roadway dikes, the parts being connected by pipes. Water exchange is by means of the tide. At Tatutu Bay, the tide amplitude is 0.4 m, the mean depth 0.6 m, and total area 3.5 ha, the pond having been used for 10 years for experimental culture of oysters, mussels, and clams. In such a pond, the equilibrium of environmental factors is fragile, and great variations in physicochemical parameters have been recorded, especially after the heavy rains in December–March and during periods when the tide amplitude is low and water renewal minimal. In Uturoto Bay (Raiatea Islands), a similar setup was improved by the addition of a second dike to channel fresh water. Thus, the salinity can be controlled, although increases in temperature during the periods of low seawater renewal remain a problem.

Except for the culture of *P. margaritifera*, which is adapted to the natural environment, bivalve culture in French Polynesia faces difficult environmental conditions: the suitable sites are limited to the furthermost part of some shallow bays and are subject to great variations in salinity, temperature, and nutrient content.

### *PEARL OYSTERS*

The black-lip pearl oyster (*P. margaritifera* var. *cumingi*) has long been fished for the mother-of-pearl industry and has recently been collected for culture farms involved in black-

[1]This report was presented at the workshop by D. Coatanea, Centre national pour l'exploitation des océans, Centre océanologique du Pacifique, B.P. 7004, Toravao, Tahiti. The data concerning pearl-oyster culture were kindly contributed by Martin Coeroli, Service de la pêche, Papeete, Polynesie française.

pearl production. Natural populations of *P. margaritifera*, which are limited to some atolls and islands of the Tuamotu-Gambier Archipelago, have been overfished and are dwindling rapidly. Obtaining 3-year-old pearl oysters for implantation is increasingly difficult — a fact that has prompted CNEXO and the Service de la pêche to investigate spat production by hatchery rearing and by collection in atolls with natural populations.

Hatchery experiments have been carried out at COP. Spawnings were obtained from broodstock native to surrounding atolls and islands, but larval-rearing experiments with different combinations of temperature, food, and light were unsuccessful in promoting growth beyond the 10th day (Millous 1980). Only a few larvae developed normally to the attachment stage, and no explanation based on rearing conditions could be given for the mortality.

Spat collection was studied by the Service de la pêche in Takapoto atoll (Mizuno and Coeroli 1980). Collectors made of polyethylene sheets and protected against predators by plastic net bags gave best results. The collecting period lasts from November to January, and collectors that are placed in October are recovered 6 months later. In June and July, a secondary spatfall peak occurs. Collectors are recovered and spat are put into polyethylene net baskets; when they reach 9 cm, they are drilled, put on strings suspended from underwater platforms, and left to grow 3 years. The average yield is 50 spat/collector. Sufficient spat have not yet been collected to supply farms with 3-year-old oysters for implantation.

The 3-year-old oysters are implanted with spherical nuclei by Japanese experts. Implantations are made in or around the gonad. Oysters are then returned to underwater platforms and remain there 2 more years — the time required to obtain a mother-of-pearl deposit of about 1.5 mm. Only 30% of implanted oysters will produce a marketable pearl 9–12 mm in diameter. Further studies at the Service de la pêche will focus on implantation techniques and growth control of oysters and pearls. In 1980, about 280000 oysters were implanted. Most of these came from the natural population.

Fourteen cooperative societies and eight private companies, directly or indirectly employing 200 persons, are involved in pearl-oyster culture in French Polynesia. Pearl exports yielded US$1 million in 1980 and are expected to have earned more than US$2 million in 1981. Pearls have become the second largest export product, copra being the largest.

## *Edible Bivalves*

Edible-bivalve culture is not well developed in French Polynesia. The few available sites are located in some of the Society Islands, and *S. cucullata* is the only traditionally cultured species able to withstand the hard and unstable environmental conditions. Spat are collected on *Tridacna* shells or laths that also serve as growing structures. Oysters reach 6–8 cm after about 2 years (Millaud 1971). In 1975, because of efforts of the Service de la pêche, oyster production reached a maximum of 22 t in Raiatea and Tahaa islands, compared with 55 t of oysters imported from New Zealand, Australia, and France. Since then, production has continually decreased because of the development of *Polydora* sp. in the culture sites. To overcome this problem, researchers have experimentally introduced other species of bivalves into the Polynesian environment.

*Crassostrea gigas* was introduced in 1975, and spat were produced in the COP hatchery (AQUACOP 1977). Growing experiments were carried out in Tahiti, Raiatea, and Tahaa islands by the Service de la pêche. After 3 years of experiments, this species was abandoned because it could not adapt to local conditions. Poor phytoplankton production, plus a generally high water temperature, resulted in very thin and fragile shells and made *C. gigas* extremely sensitive to *Polydora* attack.

*Saccostrea echinata* was introduced in 1978 from New Caledonia and proved better adapted to tropical conditions. More than 2 million spat have been produced in the COP hatchery, and growth has been studied. This oyster is able to withstand the environmental conditions and is less sensitive to *Polydora* attack than is *C. gigas*. Marketable size is obtained within 2 years, and an experimental production of hundreds of kilograms was realized in 1981. However, this oyster is not well liked by Polynesian consumers because of its harsh taste, and the larvae are difficult to rear. To solve these problems, researchers are attempting to cross *S. echinata* with *S. cucullata* to obtain a resistant oyster with a less harsh taste.

*Perna viridis* was also introduced in 1978, and spat are now produced by the COP hatchery (AQUACOP 1979, 1980). Two culture sites are used by the Service de la pêche: Tatutu Bay and Uturoto Bay. The 10-mm spat are allowed to attach to iron bars that are then hung in the bay.

The culture area is enclosed by wire net and, thus, is protected from predators (mainly *Scylla* *serrata*). During the growth period, the culture bars are moved up or down according to temperature and salinity conditions. Marketable size is obtained within 1 year of culture. Experimental production of about 9 t has been obtained. Culturists hope to satisfy the local market (i.e., 30–50 t/year) once the Uturoto Bay culture site is in full production.

*Venerupis semidecussatus*, a clam known as palourde in France, was introduced 2 years ago. The first experiments gave good results, and commercial size was obtained in less than 1 year. However, this species is very sensitive to the drop in salinity common in the rainy season (December–March). To overcome this problem, culturists have relegated the rainy months to hatchery and nursery purposes so that the 8–12-mm spat are then available in March for direct sowing on the culture site. The palourdes are harvested in early December before the environmental conditions deteriorate.

## *Conclusion*

Only pearl-oyster culture plays a significant role in French Polynesia at present because natural conditions are generally unfavourable to edible-bivalve culture, with extreme variations in salinity, temperature, and food being common. The rainy season causes the variations and is the principal obstacle to bivalves that take longer than a year to reach marketable size. Mussels and palourdes show some potential because they are quick growing: the spat can be produced in controlled conditions during the rainy months, seeded on sites later, and harvested before the next rains. Future prospects are uncertain, but it is hoped that at least the local market can be satisfied through culture operations.

# INDIA[1]

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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.

## PRODUCTION

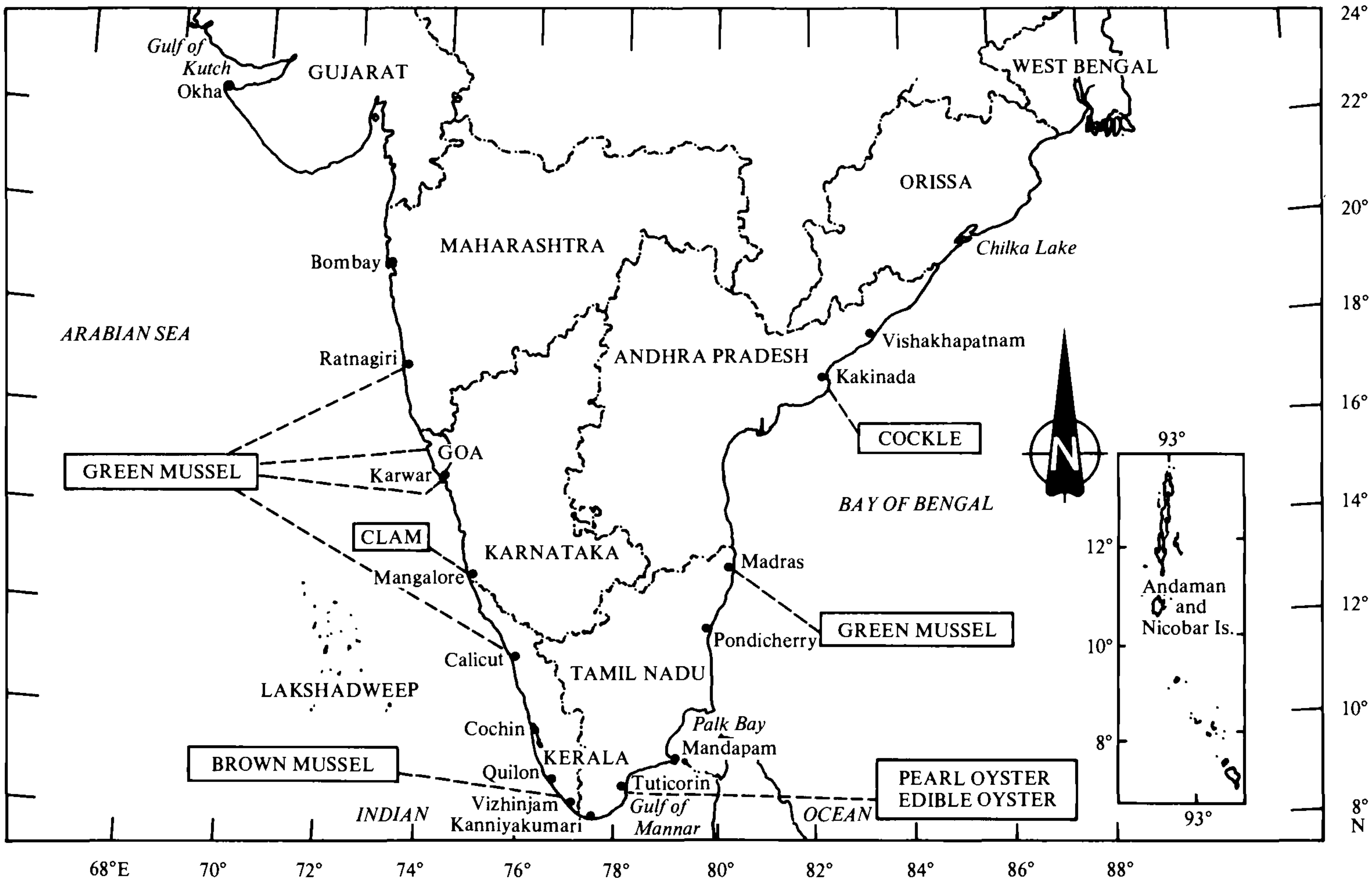
A number of oyster species occur in Indian waters (Rao 1974); those that are exploited are *Crassostrea madrasensis, C. gryphoides*, and *C. discoidea*, which occur in estuaries, backwaters, and creeks. *Crassostrea cucullata* is found on intertidal rocks but is not exploited.

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

[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.




*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 $2.6 \times 10^3$ 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 $3.1 \times 10^3$ 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 $2.0 \times 10^3$ 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 $1.1 \times 10^3$ 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 $3.0 \times 10^3$ 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 $2.0 \times 10^5$ t of lime shells are exploited annually (1968) from Vembanad Lake alone, and live *V. cyprinoides* constitute about $2.7 \times 10^4$ 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 $4.0 \times 10^3$ 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 km², 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/m² and 175/m² (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/m²). 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 $\mu$m × 330 $\mu$m. 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).

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.

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 | |

Bivalves have been exported on a trial basis since 1970 when $6.0 \times 10^3$ 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.

# *INDONESIA*[1]

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Indonesia has about 5.8 × $10^6$ $km^2$ marine coastal waters and is richly endowed with shellfish (molluscs) of economic importance. Shellfish production was 5.1 × $10^4$ t in 1979, and the total marine-fisheries production was 1.3 × $10^6$ t. Shellfish are gathered mostly from natural beds, and mariculture production is negligible. Blood cockles (*Anadara* spp., kerang darah) are most important, followed by clams (various species, remis), oysters (tiram), and scallops (simping) — all harvested from wild stocks (Table 1).

The Malacca strait of North Sumatra and the waters north of Java, especially in the northeast, are important sources of blood cockles. In 1979, 2.8 × $10^4$ t of blood cockles were taken from the Malacca strait and 2.1 × $10^3$ t from the area north of Java. Asian moon scallops are caught by shrimp trawlers using Danish seines (dogol) in Central Java, and production was 377 t in 1979. Clams were gathered mainly from the Malacca Straits, and production was 2.0 × $10^3$ t in 1979. The small venerid-clam (*Gafrarium tumidum*) is reportedly common in Teluk Bintan, Bintan Island.

Bivalve culture in Indonesia is largely experimental at present, although five companies in eastern Indonesia are in the business of producing pearl oysters, using Japanese technology. The native rock or mangrove oyster is also being cultured, but on a limited scale, at Kanyan (Bangkalan) in Madura Island, East Java. Its culture at Marunda, in the eastern part of Jakarta, has ceased because the sand has been taken away for construction material.

Recently, the experimental culture of green mussels (*Perna viridis*) has begun at Ancol (Jakarta Bay), Mauk-Tangerang (West Jakarta), and Banten Bay. Production at Ancol, with the bamboo-stake method, is 100 t/ha in 6 months, whereas, with the hanging method, yields of 200 t/ha and 578 t/ha have been obtained at Mauk-Tangerang and Banten Bay, respectively.

The culture of blood cockles (*A. granosa*), practiced by local people at Mauk from 1950 to 1969, consisted only of gathering seed and spreading it in beds. Production was 5 t/ha. Unfortunately, this activity was halted in 1975 because of lack of seed.

## *INSTITUTIONS INVOLVED IN BIVALVE WORK*

Institutions involved in bivalve work include research establishments, management authorities, and teaching institutions: the Research Institute for Marine Fisheries (Balai Penelitian Perikanan Laut, BPPL); National Institute of Oceanology (Lembaga Oceanologi Nasional, LON); Muzeum Zoologi Bogor (MZB); Gelanggang Samudera Ancol (GSA, an oceanarium); Directorate General of Fisheries; and Faculty of Fisheries of the Bogor Agricultural University. All, except GSA, are government institutions.

[1]Paper presented by Retno Andamari.

Table 1. Commercial landings of molluscs in Indonesia (Direktorat Jendral Perikanan 1981).

| Name | Species | Landings ($10^3$ t) | | | |
|---|---|---|---|---|---|
| | | 1976 | 1977 | 1978 | 1979 |
| Cupped oyster | *Crassostrea* spp. | 0.62 | 1.27 | 0.19 | 0.91 |
| Asian moon scallop | *Amusium* sp. | 0.08 | 0.08 | 0.45 | 0.48 |
| Clams | Various | 1.17 | 2.70 | 4.32 | 2.56 |
| Blood cockles | *Anadara* spp. | 22.98 | 31.36 | 40.98 | 32.18 |

BPPL is under the Agency for Agricultural Research and Development of the Ministry of Agriculture and has two branches involved with bivalve culture: Sub BPPL Ancol and Sub BPPL Serang-Banten. It is also the implementing agency for a mariculture research and development project based in Banten Bay, which receives technical assistance from the Japan International Cooperation Agency.

LON and MZB are under the Indonesian Institute of Sciences (LIPI). Experimental programs on bivalve culture are conducted by LON, and the study of bivalve distribution, classification, and ecology is done by MZB. LON and LIPI have successfully cooperated with GSA, with support from the government of Jakarta, in the experimental culture of green mussels. The Faculty of Fisheries, Bogor Agricultural University, has a department of aquaculture that is engaged in bivalve work. The Directorate General of Fisheries under the Ministry of Agriculture is the management authority and has emphasized the development of sea farming in Indonesia.

## *CULTURE PRACTICES*

Several methods of culture are being explored in Indonesia. In 1973–76, a raft or floating method of oyster culture was tried in Banten Bay, and the rack method was used in estuarine waters of Pamanukan. At Marunda, Jakarta, fishermen collected seed on shell cultch in February–March, grew the oysters in beds, and harvested after 6 months.

Green mussels are grown either on bamboo stakes (6–8 m long) or on ropes. The first system has been used mainly by GSA with the cooperation of LON-LIPI in Jakarta Bay and the second by BPPL at Mauk-Tangerang and Banten Bay. Also, the mussels attach to bamboo bagans (light, bamboo fishing traps used by local people) and are gathered as a subsistence food, especially during the west-monsoon season.

A bivalve-culture experiment is being conducted in Banten Bay by BPPL. This bay, about 90 $km^2$, has potential for shellfish culture and is far from sources of pollution. *Perna viridis, Anadara* spp., *Pinctada vulgaris* (pearl oyster), *Musculita arcuatula* (kupang), and *Crassostrea* sp. (oyster) are found in the bay.

Bivalve spat are collected when their numbers are judged to be at a peak. To determine the best time and place for collection, researchers rely on surveys of planktonic larvae; April–May and August–November have proved to be peak times for shellfish larvae in Banten Bay. This finding is supported by observations of gonad maturity of oysters.

Experiments have been conducted on inducing the spawning of the green mussel and on its egg development as a basis for methods of artificial seed production. It has been found that one can easily induce *P. viridis* to spawn by adding sperm media to the water and raising the water temperature from 27° to 35°C.

As there is no commercial farming of bivalves near Jakarta and the Riau Islands, there is no practical experience to provide a basis for selection of culture methods. Bivalve-culture trials are needed to determine site selection and the best methods of spat collection and growing. Some trials have already begun in Ancol (Jakarta Bay), Mauk-Tangerang, and Banten Bay. In Riau Island, trials are needed to establish oyster culture and introduce mussels.

If the trials confirm the potential for sea farming, the government should:

- Establish a demonstration farm and a national shellfish sanitation program;
- Develop a legal framework for aquaculture;
- Invest in the training of aquaculture specialists and sea farmers; and
- Provide an extension service for sea farmers.

Several kinds of cultch are used for the collection of spat. For example, the fishermen at Marunda use oyster shells, which are a traditional collector. Collectors made from cement-coated tiles are effective and have been reported to be better than plain tiles for oyster-spat collection. Bamboo cultch was successfully used to collect green-mussel spat at Ancol-Jakarta and Banten Bay, and a net-type collector has been used at Ketapang Bay.

BPPL has identified Banten Bay as a grow-out ground and Mauk-Tangerang, which is becoming increasingly polluted, as a spat-collection ground; some experiments applying this concept to green mussels have been carried out. Mussel seed (1 cm long), gathered from bagans or net collectors hung from rafts in Mauk, were transplanted to Banten Bay, bundled to ropes by a fine net and hung from a raft. Preliminary observations indicate that the mussels grow to 8 cm long within 10 months in this bay and that the oyster *Saccostrea cucullata* can reach 5 cm in length within 12 months. However, there is a species of oyster in Pamanukan that reaches a shell length of 7.7 cm within 6–7 months.

Along the shore of Ketapang Bay, clumps of young seed mussels are gathered from the bagans and attached to grow-out ropes, with a bamboo dowel (30 cm long and 2 cm in diameter) being inserted every 50 cm to prevent the growing column of mussels from sliding off.

## *PROBLEMS AND CONSTRAINTS*

Many of the constraints to bivalve culture in Indonesia derive from the fact that it is still in the preliminary stages of development within the country. Statistics, knowledgeable personnel, market demand, and sanitary regulations are limited if they exist at all. Some steps to relieve the constraints include:

- Collecting statistics on bivalve landings so that potential areas for bivalve production can be identified;
- Hiring, or providing current, government employees with special knowledge and experience in mariculture so that they can formulate plans for mariculture development as well as carry out government programs.
- Promoting bivalves and their products as nutritious and palatable food items;
- Instituting extension programs for sea farmers; and
- Beginning now to plan shellfish sanitation programs — for example, certifying clean areas as suitable for harvesting of shellfish and prohibiting harvests from polluted waters.

## *FUTURE PLANS*

Projecting the profitability of bivalve culture in Indonesia is difficult because figures on production and marketing are not available. Nevertheless, several factors suggest a focus for production. For example, Singapore reportedly could absorb all the oysters produced from several 100-ha farms (Glude et al. 1981), so the development of bivalve culture in the Riau Archipelago might well be economically feasible. Jakarta consumed 0.5 t of bivalves/day in 1971. As consumption has probably increased since, small-scale bivalve farming near Jakarta (Banten Bay) would also probably be economically feasible, at least in terms of demand.

# *MALAYSIA*[1]

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Total production of molluscs in Peninsular Malaysia in 1979 was about $7.7 \times 10^4$ t, which constituted approximately 11% of the overall fisheries production that year. Of the total mollusc production, $6.3 \times 10^4$ t was cockles (*Anadara granosa*) and the rest was other molluscs (oysters, mussels, and clams). The production of molluscs from the eastern states (Sabah and Sarawak) in 1979 was low. In Sabah, about 0.17 t of oysters were produced for export (the majority from wild stocks), and, in Sarawak, about 4 t of razor clams (*Solen* sp.) were sold in the local market. Although production of oysters and mussels in Peninsular Malaysia was not precisely documented in the annual fisheries statistics for 1979, it was estimated that about 13 t of oysters (*Crassostrea belcheri*) were taken from the Muar River, Johore (Ng 1979), and that about 198 t of mussels were taken from around the Johore region (Choo 1979). No figures are available for the production of other bivalves (*Placuna* sp., *Gafrarium* sp., *Geloina* sp., *Pinna* sp., *Paphia undulata, Modiolus* sp., etc.), although they are sold in local markets.

## *INSTITUTIONS INVOLVED IN BIVALVE WORK*

The Fisheries Research Institute, Penang, the Department of Fisheries, Sabah, and the Inland Fisheries and Aquaculture Branch, Department of Agriculture, Sarawak, are involved in studies on the biology and culture of cockles, oysters, and mussels. The Fisheries Authority of Malaysia (Majuikan) is now actively involved in organized culture of cockles in Peninsular Malaysia.

## *CULTURE PRACTICES*

No organized oyster culture was carried out until very recently. The earliest record of oyster culture was the experimental raft-culture studies carried out by Okada from 1960 to 1963 (Okada 1963). Oysters are now being propagated on a part-time basis in the Muar River, Johore, with on-bottom culture methods, oyster shells being used as collectors. The Fisheries Research Institute is presently carrying out research on raft culture of a flat oyster (*Ostrea folium*) using polyethylene nets and ropes as collectors at Pulau Langkawi, Kedah (Ng 1979).

In Sabah, experimental oyster culture was started in 1970 in Sandakan and later in Tawau and Labuan. Two species of oysters have been used: *C. belcheri* and *Saccostrea cucullata*. In addition, an experimental station for cockles (*A. granosa*) is being set up. The initial stocking seed will be from a commercial source in Peninsular Malaysia. Experiments on the artificial establishment of brown-mussel (*Modiolus philippinarum*) beds were carried out in 1973 along with the oyster-culture project. There were no further trials on mussels because of the lack of technical personnel and funding, but the mussel project is expected to be revived in the Fourth Malaysia Plan.

Oyster culture is carried out experimentally in Sarawak by the Department of Agriculture. Three culture methods are used. The raft or floating method is employed for oysters grown in riverine conditions where siltation is comparatively heavy and the tidal range is often as high as 5.5 m. The raft method is also suitable in areas where the water level remains high during low tide. The pole and rack methods are intertidal,

[1]This paper is an edited compilation based on three separate papers presented by the individual authors during the workshop. The cooperation of the authors in preparing this country paper is gratefully acknowledged.

fixed-culture methods used in both spat collection and grow out, generally in places where the gradient is gradual, siltation less serious, and the time that oysters will be exposed minimal. A combination of pole or rack and raft methods has proved most effective: the spat are transferred, either together with the collectors or detached from them, and grown in boxes or trays suspended from the raft.

The Fisheries Research Institute has successfully demonstrated the culturing of mussels in the Johore Straits using the raft-culture method, with polypropylene ropes as collectors (Choo 1979).

Cockle culture first began about 1948 by a village leader in Bagan Panchor, Perak; since then, it has spread rapidly and developed into the most important aquaculture industry in Malaysia. Today, it is the most organized culture system developed in Peninsular Malaysia. Currently, mass culture of cockles is being practiced by Majuikan or through cooperatives along the west coast of Peninsular Malaysia, and, on the east coast, some small areas (lagoons) have been utilized by Majuikan for the culture of cockles.

In Sarawak, wild-seed cockles are sown in prepared coastal mud flats. From 1954 to 1967, there was considerable cockle farming at the delta of major rivers in southwest Sarawak (Harrisson 1970). Most plots were bounded by natural landmarks, but, where these were lacking, the boundaries were marked by other means. The sowing density was between 2 kg and 6.5 kg of seed/$m^2$.

Sites suitable for oyster and mussel culture need to be sheltered from strong winds and wave action, free from predators and fouling organisms, accessible to nearby populations because local participation is required, and free of excessive pollution.

Cockle culture can be carried out in coastal mud flats with soft flocculent mud at least 45–75 cm thick. The culture area should be free from predators (e.g., boring molluscs such as *Natica maculosa* and fish such as skates) and free from excessive industrial and domestic pollutants; the salinity of the water should be between 18 ppt and 30 ppt.

## *Nursery Aspects*

In the Muar River, Johore, oyster shells have proved to be the most suitable cultch for the collection of spat from *C. belcheri*, whereas, in Sabah and Sarawak, various cultch materials were tested, and corrugated roofing asbestos was found to be best. In Pulau Langkawi, polyethylene ropes and nets were found to be the best collectors for *Ostrea folium*. For the culture of mussels in the Straits of Johore, polypropylene ropes have proved to be the most effective cultch.

Forecasting the best time to set out the cultch for oysters and mussels depends on meteorological conditions and confirmation by quantitative analysis, from plankton hauls, of the numbers of oyster and mussel larvae in the water.

In Malaysia, oyster and mussel spatfalls occur throughout the year, but there are two main peaks. In Pulau Langkawi, in the northwestern part of Peninsular Malaysia, the first peak for oysters is in March–May and the second in September–December. In Sarawak, the first peak is also in March–May but the second is in November–December. In Sabah, the first is in April–June and the second in October–November. Heaviest spatfall occurs 2–3 weeks after a sudden, heavy rainfall and lasts 2–3 days. The first peak for mussel spatfall in Selat Tebrau, Johore, is in November–February and the second in May–June. Cockle spatfall occurs in definite areas and seasons, generally from late June to late November with a peak in September and October.

## *Grow-Out Aspects*

The bottom-culture method practiced for oysters in the Muar River requires no special grow-out grounds. The same ground is used for collection and grow out. The raft-culture method for *O. folium* using polyethylene materials as collectors also requires no grow-out grounds, and spat are left on the collectors to grow to marketable size. Thinning is only carried out when the oysters become too crowded. In Sabah, where the rack-and-raft-with-tray method is used, spat are collected from tributaries of Cowie Bay. They are retained in boxes on racks for about 4 months and later transferred to higher intertidal racks for hardening. After hardening for 2 months, they (3–5 cm) are removed from the cultch and grown in trays suspended from rafts.

In Sarawak, collectors are usually transferred for grow out from the spat-catching ground to another area. Because the Sarawak coastline is exposed, the only suitable grow-out areas are estuaries or brackish-water mangrove swamps. Not only are these areas sheltered from strong wave action, but the lower salinity of the water minimizes barnacle fouling. The mussels grow on the cultch until they reach marketable size but are thinned to new collectors when they become too crowded.

Cockle seeds taken from natural areas are transferred to culture areas and scattered evenly over the culture beds. Wire scoops with long handles are used to gather spat and to move the cockles. As the spat grow, the beds are thinned, the cockles being transplanted to other areas. This approach results in rapid growth.

*Crassostrea belcheri* raised in Sabah grows to about 14 cm long, with a flesh weight of about 14–21 g, after 1 year. The condition factor ranges between 115 and 135 points on the standard 50–150 condition scale for oysters. *Ostrea folium* cultured in Pulau Langkawi attains a length of about 6–7 cm (marketable size) in 10–12 months, with an average flesh weight of about 4–5 g. *Mytilus viridis* cultured in the Johore Straits reaches marketable size (7 cm) in about 5–6 months. Cockles grow to more than 2.5 cm long (marketable size) in 6–8 months.

In Sarawak, the growth rates of two species of oysters (*C. cucullata* and *C. rivularis*) have been examined under experimental conditions, and *C. cucullata*, a small species, attained an average size of 45 mm in 1 year, starting from 5-mm spat. This rate is comparable with that of the same species found in Singapore's waters where the mean growth is reported to be 26.96 mm in 10 months (Tham et al. 1970); *C. rivularis* showed much faster growth and easily attained an average length of 7.5 mm in 1 year. Unfortunately, the spat of this species are not available in sufficient quantity.

The racks and rafts used for oyster culture in Sabah and Sarawak are supported by belian (a heavy hardwood, *Eusideroxylon zwaferi*) and other suitable timber. All materials are coated with a layer of bituminous compound to protect against marine borers and to prevent rusting of metal parts. Oil drums and synthetic floats provide buoyancy for the rafts.

In the raft culture at Pulau Langkawi and in the Straits of Johore styrofoam blocks and plastic jerry cans are used for buoyancy. The rafts are normally made of meranti wood, coated with antifouling or tar paint.

## *Management and Production*

Oyster and mussel culture is currently being conducted on a small scale, particularly in Peninsular Malaysia, on a part-time basis. Bottom culture of oysters in the Muar River involves about 20 fishermen in an area of about 16 ha. The fishermen gather the oysters by diving during low tide. Mechanical devices (dredges) have not been introduced because of the possibility of damaging the oyster bed. The oysters are collected and shucked, and the empty shells are immediately thrown back into the river. Only oysters of marketable size are kept; immature oysters are thrown back. A hard-working fisherman can get an average of about 1–2 kg of oyster flesh/day. However, when oyster production is poor, the fishermen devote more time to fishing, and this allows the oyster population to recover. It is estimated that more than 12 t of oysters (shucked)/year are produced from this system.

In Pulau Langkawi, oysters 4–5 cm long are harvested daily during low tide by women. The quantity taken and the number of people involved are unknown. Experimental culture of oysters carried out by the Fisheries Research Institute indicates that there is potential for oyster culture, and feasibility studies are in progress. It is anticipated that raft culture of oysters on a part-time basis can be carried out by local people.

In Sabah, oysters are being commercially cultured by cooperatives. Productivity from the rack-and-raft-with-tray system is estimated to be about 18 t/ha each year (Kamara et al. 1976).

Fish culturists farm mussels in the Johore Straits on a part-time basis, but it is anticipated that farming will be by family units in future. With raft culture, an estimated 315 t/ha can be produced in a year.

Cockle culture can be carried out on a full- or part-time basis. The beds are maintained by a few people working in shifts. Two full-time people are needed to oversee the culture beds day and night throughout the culture period. Casual workers are recruited on a part-time basis during sowing and harvesting. Harvesting is normally carried out by fishing personnel paid $1.20–$3.00/sack of cockles collected (payment depending on experience). An average bed of about an acre (0.4 ha) would produce an estimated 16 t yearly; in well-managed and fertile beds, the yield could easily be doubled.

## *Problems and Constraints*

The main problems affecting oyster culture in Peninsular Malaysia are the fouling from other sedentary organisms and algae, predation by xanthid crabs (*Myomenippe granulosa*) and starfish, siltation, and poor spatfall. Oyster culture in the Muar River is affected by poor spatfall (perhaps because of siltation) and fouling by algae. In Pulau Langkawi, there has been a drastic decline in spatfall during the last 2 years. Predation by xanthid crabs and starfish and competition from other sedentary organisms (bryozoans, sponges, and barnacles) have seriously affected culture efforts by the Fisheries Research Institute.

In Sabah, the high cost of culture, especially collectors, may become the main constraint. In the past few years, there were two mass mortalities of oysters (*C. belcheri* but not *S. cucullata*) at the culture station. Causes of the first incident are not known, but sudden environmental changes may have caused the one, later, in May 1981. Extensive tree cutting and burning near the culture station, coupled with heavy rainfall, caused a sudden change of pH and temperature and heavy siltation on the site.

Lack of technical personnel is affecting the promotion of oyster culture by the Department of Fisheries, Sabah. The basic technique of oyster culture has been established, but it now needs to be introduced to the interested public. To initiate and encourage oyster farming, the agencies involved need to introduce basic training on oyster culture, ensure a supply of oyster spat, and advise on the suitability of sites for culture. Information about general production and management skills, harvesting, and oyster handling should also be provided. Subsidies to reduce the initial development cost to the individual farmer would greatly assist in establishing oyster farming. In addition, applied research must be carried out to improve profitability.

In Sarawak, the main problems are a limited supply of desirable oyster seed and difficulties in locating suitable grounds for cultivation. Although several species of oyster are found in Sarawak, only the spat of *C. cucullata* are abundant. Sarawak has extensive mangrove swamps and a long coastline that has potential for aquaculture development, but large and sheltered areas suitable for commercial culture of oysters have not been identified.

Most of the estuaries and rivers are subject to heavy siltation and have low densities of plankton — food essential to oysters. In addition, sheltered bays are lacking, and the coastline is subject to strong wave action, especially during monsoons. The excessively high tidal range (more than 5.5 m) is also a disadvantage. Other problems are fouling from barnacles and aquatic growths and predation from crabs and oyster borers. Areas selected for small-scale oyster culture are not affected by pollution at present.

The main constraint affecting mussel culture in Malaysia is poor consumer acceptability.

Cockle culture in Peninsular Malaysia is not affected by serious problems, although failures in culture beds have been recorded occasionally. These failures may have been the result of poor site selection or delays in transport of seed to the culture beds. Other problems include the pilfering of cockles at night in Perak and the illegal culture and export of seed to Thailand. Seed supply will likely become a problem if culture increases and large quantities of seed continue to be exported. However, the most pressing problems in the future will be the increase in industrial and domestic pollutants, as major towns and cities develop and more heavy industries locate along the west coast of Peninsular Malaysia.

In Sarawak, the main sources of pollution are sawmills and woodchip and sago factories. Antipollution measures have already been introduced, but many natural cockle beds may already have been destroyed. Cockle farming has been going on intermittently in Sarawak since about 1954, but it has never become an established part of coastal life, mainly because seed are difficult to obtain and the harvest is inconsistent. Currently, shortage of seed and difficulties in locating suitable sites are the main constraints. At present, because of high market demand, the cockles are harvested long before they reach the legal size (31.8 mm) adopted in Peninsular Malaysia. If growers can be persuaded to delay harvest until the cockles reach reproductive size, seed will be produced. At present, seed must be imported from Peninsular Malaysia, and delivery from the seed bed to the culture site usually takes several days, during which there is usually high mortality.

## *Postharvest Handling*

In many countries with oyster or mussel industries, sanitary and pollution surveys must be carried out before permission to cultivate in an area is granted. Fortunately, Malaysia is not affected as much by pollution as some other countries. Oyster and mussel culture is still in its infancy, and most culture areas are not affected by industrial and domestic pollutants. Hence, sanitary control is not practiced at present. Likewise, cockles are generally cultured in areas unaffected by pollutants. However, as industries and population increase, the concentration of pathogenic bacteria as well as heavy metals (copper and zinc) will require monitoring. The Fisheries Research Institute has recently acquired equipment to monitor heavy metals and in future may be able to undertake regular surveillance of coastal waters.

Oysters harvested from the Muar River are shucked by hand. They are usually opened with a knife. The shucked oysters are weighed and sold to intermediaries who sell to retailers or to oyster-sauce factories. Oysters produced in this region are intended for local consumption, but some are sent to Singapore. Refrigeration is not necessary, but crushed ice is normally used to keep the flesh fresh. Likewise, oyster flesh harvested by local people in the Pulau Langkawi region is sold directly in open markets or dispatched by boat to the mainland.

Mussels are sold in the shell in the open market in Johore Baru.

Processing of mussels and oysters by drying or canning is not carried out yet in Peninsular Malaysia, but cockles are processed in soybean sauce and canned by factories for export. Cockles harvested from culture beds are sold locally in gunny sacks or exported to Thailand.

## *FUTURE PLANS*

Quayle (1975) asserted that the biological problems of oyster culture in the tropics are more complex than those associated with culture in cooler waters (temperate countries), and, therefore, quick solutions are unlikely. The high cost involved in the production of oysters in Pulau Langkawi and the poor market price do not justify commercial production at present. Oyster culture in Pulau Langkawi would require considerable financial and labour inputs and the advantages over collecting oysters from the natural environment are not great enough to warrant the investment.

The Fisheries Research Institute is carrying out research to improve the culture techniques, to solve problems like predation by crabs and starfish, and to locate suitable areas — areas with little predation and competition from other sedentary organisms.

The Institute has already demonstrated that mussel culture in Malaysia has good potential as a low-cost source of protein. Raft culture is very productive in the Straits of Johore, and possibly other suitable areas could be found along the coast. The poor market for this bivalve is a constraint, but, as the prices of fish, prawns, and meat continue to increase, there may be an increase in demand for mussels. Therefore, the rate at which mussel culture develops will depend largely on demand and the market price. It is anticipated that both the demand and the price for mussels can be raised if the culture techniques are given wide publicity through the media. Biological and ecological conditions in the Johore Straits are very favourable for mussel culture, and, if 10 ha of the Tebrau or Johore Straits could be developed for mussel culture in the coming decade, the production of minced flesh would amount to about $3.0 \times 10^3$ t/year (Ong 1981).

Cockle culture is already established and is rapidly expanding in Peninsular Malaysia. Currently, about $1.6 \times 10^3$ ha of mud flats along the west coast are used for cockle culture. The potential area is probably at least double this amount.

Production could be increased not only by the opening of new sites or the introduction of new systems for mollusc culture but also by the control, on existing sites, of pests, predators, and diseases. With the existing potential for cockles, mussels, and possibly oysters, production of molluscs in Malaysia could be doubled within the next few years. The Fisheries Division of Malaysia is currently promoting aquaculture development through research and extension. Already major research findings on the biology and culture of cockles in Malaysia have helped the cockle industry. Although the larvae of cockles have been identified (Pathansali 1963), only recently has any attempt been made to breed cockles and raise larvae to spat. This has been carried out in the Fisheries Research Institute, which is also intensifying its efforts to identify new culture sites for cockles, mussels, and oysters and to upgrade existing culture techniques. Moreover, the Institute is providing training and technical advice to culturists on mollusc-culture techniques.

To date, the Department of Fisheries, Sabah, has been providing advice on the suitability of sites for oyster culture, information on basic production techniques, and free oyster spat for the initiation of such ventures. The Department hopes to increase oyster production by encouraging small-scale, family-run oyster farming, which would benefit coastal inhabitants in rural areas. Initially, these ventures would be practiced predominantly part time, but, when sufficient skill and experience have been acquired, the farmers would be encouraged to expand into full-time operations. This strategy is in line with the objectives of the Fourth Malaysia Plan to increase food production and to raise living standards in rural sectors. Although the long-term strategy would aim toward an export-oriented industry, small-scale, family-run farming operations must first be promoted.

In Sarawak, studies are currently concentrated on further development of culture techniques and on the economic aspects of oyster culture. The

Department of Agriculture assists interested coastal people to establish oyster plots through an oyster-subsidy scheme. In view of the difficulties in obtaining large species of oysters, however, attention will be directed to determining the culture potential of *C. cucullata*. With regard to cockle culture, the Department plans to continue its restocking program, which is aimed at producing seed locally.

# PAPUA NEW GUINEA

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Bivalve culture has been relatively unimportant in fisheries development in Papua New Guinea. At present, only the culture of pearl oysters is under way, and it is confined to a few small, village farms — remnants of a larger pearl-farming operation that existed in the early 1970s.

Plans have been proposed to revitalize the pearl fishery, mainly among village artisans, and a program may soon be implemented. The government is emphasizing development of artisanal and subsistence fisheries, and, as pearl farming has been successfully run at the village level, it is a logical choice for future development of the inshore fishery.

## PAST DEVELOPMENTS AND FUTURE PROSPECTS

In the early 1970s, two centres of pearl farming existed — the only commercial attempts at bivalve culture. In Fairfax Harbour, Port Moresby, an Australian-Japanese enterprise operated from 1965 to 1975 and produced some 40 000 pieces/year from gold-lip oysters (*Pinctada maxima*). It imported seeds from Kuri Bay in Western Australia because local supplies were not considered sufficient. High mortality among the stocks, possibly resulting from pollution in the harbour, forced the shutdown of operations.

Of more interest to Papua New Guinea's future plans was the development of a pearl-culture centre in the Milne Bay area at the eastern end of the country. Here, in 1966, an experienced pearl culturist selected a site on Dagadaga Island (later renamed Pearl Island) as the centre of a private farm. By 1972, the farm was operating on a technically sound basis. Both black-lip (*P. margaritifera*) and gold-lip oysters were bred, and spat collection of black-lip oysters on plain nylon rope was extremely successful. The next step was to involve local islanders by setting up small farms adjacent to a number of villages. In 1975, 15 farms handling a total 20 cultivating rafts had been established on four islands. The farmers formed the Milne Bay Pearl Farmers Association, with 250 active members. A school was established to train personnel in pearl farming. The course included such subjects as establishment and management of pearl farms, pearl-cultivation techniques, and the processing and handling of pearls. All village production was based on half pearls. Nuclei and glue were supplied by the expert culturist, and pearls were sent to him for processing. Pearl buttons, rings, earrings, pendants, and other costume jewelry were made on Pearl Island and later also by jewelers in Port Moresby.

Unfortunately, because of financial and other problems, the activities of the Pearl Farmers Association have now virtually ceased; only a small number of farmers and the expert are still producing. Nevertheless, the experience pointed the way for future programs, and, given adequate financial backing, pearl cultivation on an artisanal level is considered feasible. The villagers are enthusiastic about reestablishing pearl culture because it provides a source of cash without substantially altering their way of life.

Experiments on the exploitation of edible oysters (Ostreidae) have been done, but no commercial production has yet been undertaken. At least eight oyster species or varieties occur around the Papua New Guinea coastline. Of these, the large black-lip (*Crassostrea amasa*) and the milky oyster (*C. echinata*) could be considered for farming. Both form dense clusters in intertidal zones in harbours and bays. Studies of settlement and gonad condition indicate that, in the Port Moresby area, they do not possess a clearly defined reproductive cycle and probably spawn sporadically throughout most of the year. The fact that gonad condition appears to vary may make the rock oysters unreliable for some overseas markets. A further constraint to the development of an oyster industry is the occurrence of seasonal red tides (*Pyrodinium bahamense*) and the associated risk of paralytic shellfish poisoning in many areas. To overcome this, it would be necessary to ban sales of oyster for specified periods during and after red-tide seasons or to locate oyster farms in red-tide-free zones. The latter would restrict oyster farming to the mainland west of Port Moresby on the south coast and west of Lae on the north coast.

The possibility of spat collection as a first step to initiating commercial edible-oyster culture has been investigated. As early as 1955, mangrove poles were set out in Port Moresby Harbour and nearby sites, but the results were not encouraging. Around Port Moresby, silt caused mortality among spat, and the experiments at other sites, such as Yule Island in the Gulf of Papua, also failed. In 1960–63, extensive experimentation took place in Milne Bay, and spat were plentiful. Although the project was discontinued, it indicated that the coast is capable of providing oysters in sufficient quantities for commercial bivalve culture. The warm water around Papua New Guinea ensures rapid growth rates, and oysters could well reach marketable size within 18 months. In addition, the quality of oysters sent to Australia from Milne was found to be acceptable.

Research relevant to bivalve culture has been undertaken by the Zoology Department of the University of Papua New Guinea. Tridacnid clams have been studied for a number of years, and findings indicate that *Tridacna gigas* is suitable for mariculture. Weights of 29 kg can be attained in 6 years, and, although mature clams exhibit a high degree of autotrophy, the juveniles may filter-feed to meet their nutritional requirements. Induced spawning and mass culture of larvae and juveniles of *T. gigas* have not been achieved in Papua New Guinea but are not considered major obstacles because they have been done elsewhere (Beckvar 1981). From about 1 cm long, juveniles could probably be reared in floating trays until large enough to be reared in suitable habitats. As there is a high demand for dried adductor muscles, and, as the flesh of the mantle and internal organs is eaten by coastal peoples in many parts of the Pacific, marketing should not be a problem. Thus, there is potential for culturing tridacnid clams in Papua New Guinea, and, after research is completed, a pilot mariculture project should be launched to investigate the commercial potential.

# PHILIPPINES[1]

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Natural populations of oysters and mussels have long been gathered for food by coastal communities in the Philippines, and bivalve farming began in early 1900. The first farms were no more than a series of bamboo poles inserted in the muddy bottom of Manila Bay in Bacoor Cavite. In May 1934, the Bureau of Fisheries and Aquatic Resources (BFAR) established a pilot oyster farm in Binakayan, Cavite Province, Luzon, and a lucrative industry soon grew up. By 1950, about 200 ha of private farms existed in Bacoor Bay, but, in the late 1950s, mussels appeared on the farms and threatened the industry. The response of BFAR was to initiate farms for mussels, and the results prompted the establishment of a mussel industry that proved to be at least as lucrative as the oyster industry.

Farming of windowpane oysters (*Placuna placenta*) began in the late 1940s in the tide flats of Bacoor Bay, the delicate, translucent *Placuna* shells being used for window glazing and shellcraft. In the early 1970s, however, the bay became increasingly polluted, the stocks could not survive, and they are still not found in the waters of the bay.

## PRODUCTION

In 1979, bivalves produced for food comprised green mussels (*Perna viridis*) $2.95 \times 10^3$ t; blood clams (*Anadara* sp. and *Arca* sp.) $1.95 \times 10^3$ t; oysters (*Crassostrea iredalei* and *Saccostrea* sp.) 799 t; scallops (*Amusium pleuronectes*) 62 t; and clams (*Paphia* spp.) 47 t. Total production had increased from $5.9 \times 10^3$ t in 1976 to $9.0 \times 10^3$ t (Table 1).

There are 22 commercially important species in the country (Table 2), but, of the species marketed domestically, only the green mussel (*P. viridis*) and the slipper oyster (*C. iredalei*) are farmed commercially. Nevertheless, commercial farms — ranging from 100 m$^2$ to 2 ha in size —account for 75% of green-mussel production and 60% of oyster production. Most other bivalves are collected from the wild. Pearl oysters are collected more for their shell and pearls than for food. The nutrient composition of green mussel, slipper oyster, and windowpane oyster has been investigated (Table 3).

Present culture practices are traditional but appropriate for local conditions. Bamboo poles serve both as substrates for mussels and oysters and as racks for suspension of other substrates. Bottom culture of oysters on rocks is practiced

Table 1. Bivalve production (t) in the Philippines, 1976–79.

| | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|
| Oysters | — | 33 | 84 | 799 |
| Mussels | | | | |
| Brown | — | — | 21 | 17 |
| Green | 415 | 1697 | 3220 | 2952 |
| Scallops | 4894 | 4 | 68 | 62 |
| Clams and shells | | | | |
| Hammer oysters | 105 | — | — | — |
| Giant clams | 243 | 664 | 1635 | 2861 |
| Blood cockles | 201 | 209 | 171 | 1947 |
| Marine clams | 1 | 37 | 1134 | 47 |
| *Placuna* | 81 | 1635 | 581 | 221 |
| *Pteria* | — | 485 | 457 | 53 |
| *Pinctada* | — | — | — | 63 |

[1]This country report is an edited version based on two separate papers presented by the authors during the workshop. The general introduction was drawn from both papers; the sections on mussels, windowpane oysters, and other bivalves were written by Adam Young, and Evelyn Serna wrote the sections on oysters, the economics of shellfish farming, and future prospects and recommendations. The cooperation of the authors in preparing this country report is gratefully acknowledged.

Table 2. Commercially important species of bivalve molluscs found in the Philippines.

| Species | Local name | English name |
|---|---|---|
| *Perna viridis* (*Mytilus viridis; M. smaragdinus*) | Tahong, amahong | Green mussel |
| *Modiolus metcalfei* | Abahong | Brown mussel |
| *Crassostrea iredalei* | Talaba, talabang, sinelas | Slipper oyster |
| *C. malabonensis* | Kukong kabayo | |
| *Saccostrea echinata* | Sisi | Denticulated oyster, |
| *S. cucullata* | | horse's hoof oyster, palm-root oyster |
| *Placuna placenta* | Kapis, lampirong | Windowpane shell |
| *Pinctada margaritifera* | | Black-lip pearl shell |
| *P. maxima* | | Mother-of-pearl Gold lip |
| *Pteria* sp. | | Wing shell |
| *Amusium pleuronectes* | Lampirong, Lupad-lupad | Asian moon scallop, sun and moon scallop |
| *Cyrtopleura costata* (*Pholas orientalis*) | Diwal | Angel wings, piddock |
| *Anadara granosa* | Batotoy, imbow | Blood clam, cockle, |
| *Arca* sp. | litab, hungkay-hungkay | Ark shell |
| *Protapes; Katelysia* (*Paphia* spp.) | Halaan | Sand clam |
| *Atrina* sp. | | Pen shell |
| *Pharella acutidens* | Tikhan | Razor clam |
| *Geloina striata* | Tuway | Mud clam |
| *Circe gibba* | Saropsaropan, bugaton | Venerid clam |
| *Mactra mera* | Katakao, punaw | Hen clam, mactrid clam |
| *M. maculata* | Kagaykay | Surf clam |
| *Donax radians* | Alamis, polopatani | Bean clam |
| *Corbicula fluminea* | Tulya | Little-neck clam (freshwater) |

Table 3. Nutrient composition of the green mussel, slipper oyster, and windowpane oyster by weight/100 g of flesh (edible portion).[a]

| | Fresh flesh | | |
|---|---|---|---|
| | *P. viridis* | *C. iredalei* | *P. placenta* |
| Moisture (%) | 40.8 | 85.5 | 70.2 |
| Food energy (cal) | 300 | 62 | 126 |
| Protein (g) | 21.9 | 5.9 | 23.3 |
| Fat (g) | 14.5 | 1.7 | 1.4 |
| Carbohydrate (g) | 18.5 | 5.2 | 3.3 |
| Ash (g) | 4.3 | 1.7 | 1.8 |
| Calcium (mg) | 151 | 147 | 110 |
| Phosphorus (mg) | 199 | 77 | 257 |
| Iron (mg) | 24.8 | 5.9 | 17.3 |
| Sodium (mg) | — | 882 | — |
| Potassium (mg) | — | 237 | — |
| Vitamin A (IU) | — | 365 | — |
| Thiamine (mg) | 0.5 | 0.21 | 0.02 |
| Riboflavin (mg) | 1.28 | 0.2 | 0.11 |
| Niacin (mg) | 3.1 | 1.7 | 1.4 |
| Ascorbic acid (mg) | — | 5 | — |

[a]Source: Food Composition Table, FNRC-NSDB Handbook (4th Revision) 1968, Manila, Philippines.

extensively, although the species caught are not always those desired. Blood clams are harvested wherever they occur. Obviously, there is much room for improvement, both in seed collection and in farming methods, and current research efforts are directed toward this goal.

## *INSTITUTIONS INVOLVED IN BIVALVE RESEARCH*

The institutions involved in research on bivalve culture and utilization are: the Aquaculture Department, Southeast Asian Fisheries Development Center — larval biology of bivalves, spatfall forecasting, bivalve-culture technology, depuration, and sanitation aspects; the Marine Science Center, University of the Philippines — larval biology of bivalves and culture technology; the Biology and Zoology Department, University of the Philippines — depuration and uptake of mercury; the National Institute of Science and Technology (National Science

Development Board) — microbiology of bivalves and utilization; the Bureau of Fisheries and Aquatic Resources — culture technology and utilization; the Philippines Atomic Energy Commission — heavy metals in shellfish; the International Center for Living Aquatic Resources Management — transplantation of mussels in areas where they are not indigenous; the Freshwater Aquaculture Center, Central Luzon State University, Munoz, Nueva Ecija — freshwater bivalves; the Binmaley School of Fisheries, Pangasinan — oyster culture; and Bicol State University — general biology of bivalves.

## *Oysters*

Oysters are widely distributed in the Philippines in bays and estuaries that have some runoff from the land and, therefore, somewhat lower salinity than the open sea. They filter food from the water and grow best in areas that have moderate to high concentrations of phytoplankton.

The most desirable species for culture are the large *C. iredalei*, which are usually about 6–9 cm long when marketed and the moderately sized *C. malabonensis*, which are usually 4–5 cm long. Both have excellent appearance and flavour and are accepted equally in the market. The two species have similar environmental requirements and often occur together.

Table 4. Estimated potential for expansion of oyster farming in the Philippines (Glude et al. 1981).

| Location | Number of farms | Area now used (ha) | Potential area (ha) |
|---|---|---|---|
| Pangasinan | 386 | 16.8 | 300–5000 |
| La Union | 39 | 3.7 | 200–1000 |
| Ilocos Sur | 11 | 1.3 | 100 |
| Ilocos Norte | 19 | 0.7 | 20 |
| Cagayan | 32 | 9.5 | 28 |
| Bulacan | 145 | 18 | 17 |
| Cavite | 300 | 300 | 2 |
| Batangas | — | — | 50–100 |
| Quezon | — | — | 200–1200 |
| Sorsogon | 32 | 6.6 | 500 |
| Capiz | 160 | 50 | 500 |
| Aklan | 9 | 8.3 | 100 |
| Iloilo | 14 | 3.3 | 15 |
| Negros Occidental | 48 | 7.8 | 100 |
| Cebu | — | — | 100 |
| Bohol | — | — | 100 |
| Leyte | — | — | 2000 |
| Samar | 1 | 0.3 | 200 |
| Davao Oriental | — | — | 170 |
| Surigao Sur | 2 | 0.5 | 400 |

Several smaller species of oysters — all called sisi locally — are found in various locations and are utilized as food. However, because they are only 3–4 cm long, they are difficult to shuck — the task usually being undertaken by the grower's family before the flesh is sold to consumers or wholesalers.

*Crassostrea iredalei* and *C. malabonensis* occur in bays on the islands of Luzon, Panay, Negros, Cebu, Bohol, Leyte, Samar, and perhaps others. However, there are extensive coastal areas where natural populations of talaba oysters are not found and where they could probably be introduced (Table 4).

Many areas in the Philippines are well suited for oyster culture. Water temperature is ideal throughout the year (26–30°C), nutrients in the costal bays and estuaries are adequate, and food (phytoplankton) is abundant. The growth rate of oysters is excellent, and a marketable crop of medium-sized *C. iredalei* can be produced in 6–8 months. Large oysters take about 1 year, whereas, in many places in the temperate zone, 2–5 years are required. Thus, annual production in the Philippines is better than that in the temperate zone.

Rainfall, although seasonal, is sufficient to maintain the flow of the rivers that provide suitable salinity for growth and reproduction. There are many unused, shallow bays protected from surf and storms that would be excellent for oyster culture, especially by the stake or hanging method. In some locations, the sediment in shallow bays is firm enough to permit bottom culture by the broadcast method.

Oyster farms are located in 17 provinces, with major production in Cavite, Bulacan, Pangasinan, Sorsogon, Capiz, and Negros Occidental. Total production exceeds 10 000 t/year. Although farms average less than one-third hectare, oyster culture contributes significantly to the income of more than 1200 families in coastal villages (Glude et al. 1981). In areas where natural populations occur, they are usually gathered and sold by local people. Landings from wild stocks represent only a small portion of the total oyster production, but the low cost of harvesting results in a low price for the product, which reduces the profitability of oyster farming in those areas.

Reproduction of oysters is generally good, especially with off-bottom culture, which reduces or eliminates mortality from silt and crawling predators. Some mortality was noted at Calape, Bohol, and at Mona, Pangasinan, but much of this was attributed to high summer temperatures, especially during low tide when some oysters were exposed. In some areas, 4–5 of the 10–12 spat that attach to a single oyster shell survive to market size — a satisfactory survival rate.

### CULTURE PRACTICES

Four principal methods of oyster culture are used in the Philippines: lattice, broadcast (sabog), stake (tulos), and hanging (bitin or inhitin, sampayan or long line, horizontal, or bangsal) methods.

The broadcasting method is the most primitive and is used where the bottom is firm enough to support the collectors. Old oyster shells, stones, rocks (paringit), and tin cans are scattered on the bay bottom in areas where natural setting occurs. In Tinagong-dagat, Capiz, blocks, boulders, or logs are used as collectors. Areas without natural setting can also be used, collectors with attached spat or juvenile oysters being transplanted from areas where setting occurs. The oyster spat are left in place, attached to the collectors, for 8–12 months or until large enough to be harvested. Gathering is usually done by divers.

The principal advantage of the broadcast method is low-investment cost; the disadvantages are that it can only be used in shallow waters with a firm bottom; the production per unit of area is less than for off-bottom methods; mortality of oysters is higher than for off-bottom methods because of silt and predation; harvest is difficult, especially if stones are used as collectors, unless the beds are exposed at low tides.

The stake method is used in areas where the bottom is too soft for the broadcast method (the water is usually not more than 1 m deep at lowest tide); stakes, 5–9 cm in diameter, made of bamboo or other rigid materials are driven into the bottom. Usually, they are placed in rows and placed about 0.5 m apart during the April–July spawning season. The tip of the stake extends to the high-tide level because oysters, unlike mussels, can survive and grow in the intertidal zone. The stakes provide clean surfaces to which the oyster larvae attach after their pelagic stage. In some cases, culturists increase the attachment surface available by adding horizontal bamboo pieces or by attaching empty oyster shells or other hard materials to the stakes. This method is commonly used in Binakayan in Cavite, Binloc in Dagupan, Binmaley in Pangasinan, Sto. Tomas in La Union, and Abucay in Bataan.

The advantages of the stake method over the broadcast method are that mortality from setting is eliminated, growth rate is increased as is production per unit area. The disadvantages are that predators such as crabs, starfish, and oyster borers (snails) can crawl up the stakes and reach the oysters; bamboo is expensive if not available locally; bamboo usually lasts only 1–2 years; harvesting is difficult because the oysters must be removed from the stakes; the surface available for attachment of oysters is small in relation to costs; and bamboo collects fewer spat per unit area than do oyster shells.

The hanging method uses empty oyster or coconut shells as collectors. These are hung on synthetic twine or heavy, monofilament nylon line, held 10 cm apart by spacers — bamboo tubes or knots in the twine. In some places, the shells are strung without spacers for spat collection and then restrung with spacers for the grow-out phase.

Variations of the hanging method include:

- Bitin or inhitin, in which empty oyster shells are threaded on polyethylene rope (no. 4) and are hung on a bamboo platform or fence with bamboo posts attached horizontally near the high-tide level. The strings of oyster or coconut shells are spaced about 25 cm apart. String length depends on the depth of the water, but, if the lower end is allowed to touch the bottom, some of the oysters will die from siltation and predation.
- Sampayan or long line, in which the cultch consists of a long line of threaded oyster-shell valves held apart by tubes 12–15 cm long. Four parallel lines, approximately 20 m long and 20 cm apart, are strung between two bamboo posts. Oysters grown by the line method are not crowded and, thus, can grow fatter and larger in 10 months than those grown by other methods.
- Horizontal, in which horizontal pieces of bamboo are replaced with synthetic rope or, in deep water, the bamboo fence or platform is replaced by an anchored raft. The framework, which is usually 1 m × 10 m, consists of heavy bamboo horizontal stringers and 20 small-diameter bamboo cross pieces 0.3–0.7 m apart. The whole frame is driven 1.0–1.3 m into the bottom. It is partly submerged during low tide. The cultch of threaded shells is prepared in June and July. In Pangasinan Province, round strips of rubber tires are used as collectors and are hung from horizontal poles.
- Tray, which is practical in still waters with firm bottoms where silt is minimal. A bamboo tray (1.5 m × 1 m) with 15-cm sides is used to hold the collectors. These trays rest on horizontal supports, and oyster seedlings are left in them to grow to marketable size.

The hanging method, which was patterned after Japanese techniques, has several advantages over other methods: high productivity per unit area; no mortality from silt; no mortality from crawling predators; the oysters grow rapidly with thin shells; the quality of flesh from the mature oysters is excellent; the method can be used in shallow water where the sediment is too soft for culture by the broadcast system as well as areas where the oysters do not occur naturally; and harvesting is easy and economical. Disadvantages include: cost of materials, including ropes, strings, and bamboo (although less bamboo is needed than for stake culture); and the requirement of floats, anchors, and anchor line, and weights in the raft-culture system.

In the lattice method, bamboo trunk splits are woven into a lattice and tied with galvanized wire (no. 14) or monofilament nylon twine. The splits are spaced about 15–30 cm apart, and, on average, a lattice comprises 10–16 splits, which can be handled easily by an individual.

The lattice can be positioned horizontally or vertically; the setups include: fence style — either stuck on the bottom or supported by bamboo posts; tent formation in rows; mounted on rocks; flotation style (mounted on long bamboos and empty drums); suspended (three pieces of lattice assembled in a triangle and supported by long bamboos and empty drums); etc.

The advantages of the lattice method are that the device is usable alone or in groups; losses of collectors are eliminated; harvesting is simple; the oysters do not touch the bottom; the method is practical for collecting, growing, and fattening oysters; production is increased per unit area, especially in three-dimensional setups; and the placement of oysters can be controlled for abundant food, favourable water temperature and salinity, etc., and, hence, maximal oyster growth.

## *Postharvest Handling*

The flesh of *C. iredalei* and *C. malabonensis* is excellent. Both species reach prime condition shortly before spawning, and the yield (weight of flesh compared with live weight in the shell) is highest at that time. Both species recover rapidly after spawning, reaching marketable condition within about 1 month. The flavour is also excellent, at least as good as, and perhaps better than, temperate-zone oysters. Although the oysters harvested at 6–8 months are small for consumption raw on a half shell, they are ideal baked, smoked, or in stew or soup.

Paralytic shellfish poisoning evidently does not occur in the Philippine islands. However, research is needed to verify this, especially in areas where red tide has been observed. The major deterrent to wider use and increased demand for Philippine oysters is the fact that most are grown in waters contaminated by domestic wastes. Although this kind of pollution usually does not adversely affect the growth rate or survival of oysters, the product must be cooked thoroughly to avoid the transmission of diseases and cannot be exported as it does not meet the sanitary standards of most countries.

Harvesting procedures vary with the culture method. In the stake method, the bamboo stakes are usually lifted from the water, the oysters removed on shore or in the boat, and the stakes discarded. If the stakes are strong enough to be used again, the oysters are scraped or pulled off by divers, put into the boat, and brought ashore for separation of clusters. When grown by the hanging method, oysters are lifted from the water on the strings and brought ashore where they are removed. When stones or logs are used, the oysters are usually removed at low tide and the stones or logs left on the bottom.

Although oysters may be harvested at the grower's convenience, the quality is best when the glycogen content of the oysters is high, usually just before or 3–4 months after the peak of spawning. If spawning is continuous, with no clearly defined peak, the grower must experiment to determine the best time.

Most oysters are transported in the shell; they are put into loosely woven plastic-coated sacks that hold about 37 kg. They withstand shipping well because their shells are tight enough to retain moisture. However, when they are shipped in the shell, they are bulky and are more expensive to transport than are shucked oysters. They are sent to market in jeepneys, trucks, tricycles, buses, boats, etc. If the growing area is close to the market, intermediaries or even retailers provide their own transportation as well as containers — often 5-gallon (~20-L) vegetable oil or kerosine cans. When markets are nearby, shucked oysters are packed (with or without fresh water) in polyethylene bags, bottles, or in evaporated milk cans.

Oysters, as filter-feeders, extract microscopic food particles from the water they inhabit. In sewage-contaminated areas, they digest, retain, and discharge sewage bacteria. To be purified, they must be placed in clean water for 7 days, where they rid themselves of impurities naturally before being marketed fresh.

Oysters are usually retailed in the shell; however, if they have been transported for some distance, they are shucked at the market in an effort to avoid discarding the weak ones. The flesh is packed in polyethylene bags, fresh water is added, and the bags are iced until sold. Also, live oysters are shucked and sold at roadside stalls close to or at the growing sites.

Oyster flesh, which spoils quickly, can be preserved simply if packed in bottles with salt (bagoong, or salted oyster). Other methods of preservation include pickling, smoking, canning, freezing, and cold storage. Storing the flesh at -23° C for 7 days has been found effective in limiting contamination.

Oysters in the shell are protected naturally from external contamination as long as the valves are tightly closed. However, the growth of bacteria in the liquid within the shells is enhanced if the oysters are kept alive in ambient temperature.

Shucking under unsanitary conditions at the market adds to the bacterial load of the product, and, although the bags of flesh and water are usually put into pans of ice while being offered for sale, the pans are shallow and the ice level rarely rises to the warm water in which the flesh is bathed. Oysters shucked and stored in this way have a shelf life of about 1 day.

Shucking at the growing sites is even more contaminating. It is usually done over a wet cloth on the ground, often by children who interrupt their work to play and then resume shucking with dirty hands. The flesh is deposited in a pan on the ground and is, thus, exposed to dust, dirt, and insects.

The best initial means of retarding bacterial spoilage and avoiding associated dangers is to maintain careful sanitation during processing and preparation. Cooking is indispensable, as it minimizes bacterial growth. Rapid cooling, and storage as close to 32° F (0° C) as possible, also prolongs storage life. Spoiled, uncooked oysters develop a sour odour. If they are cooked long enough for the enzymes to get hot, a rancid odour prevails.

Wholesalers prefer the Manila market to other areas because it absorbs large quantities of oysters at prices higher than smaller markets. The price to growers from sales to wholesalers is generally related to the distance between growing areas and Manila and to the complexity of transportation. In the Cavite area, close to Manila, the growers get 2–2.5 pesos/kg and in Sorsogon, Luzon, and Jiabong, Samar, about 1 peso/kg; oysters from Tinagong Dagat, Capiz, destined for Panay markets are sold to wholesalers for 60–70 centavos/kg. In some parts of Pangasinan, Luzon, growers get only 30–40 centavos/kg.

Retail prices of oysters in the shell in Manila vary between 4 and 5 pesos/kg, and markups in other cities are also about twice the price to the producer. The retail price includes transportation costs, and, in some cases, the cost of containers. There is no transport equipment designed and built to deliver perishable products while maintaining quality.

As there is little oyster processing in the Philippines, distribution channels from producer to consumer are relatively simple. Some conveniently located producers attempt to sell as much of their production as possible directly, through roadside stands or wholesale–retail booths at landing sites. Most of the production, however, is sold at landing points to wholesalers who transport the product to markets and sell it to other wholesaler–retailers and institutional (hotel and restaurant) buyers or sell it wholesale–retail themselves in one or more urban markets.

Prices are monitored weekly by the statistical division of BFAR through representatives in producing and marketing centres throughout the Philippines. In April–May 1981, oysters in the shell were selling wholesale at about 3 pesos/kg and retail at 4 pesos/kg in Manila markets. Thus, when the local demand is satisfied, wholesalers must buy at a price that includes the cost of transportation to another market.

Oyster exports are small, but, in 1980, some $1.8 \times 10^5$ kg of frozen oyster flesh was shipped to Singapore. The value to the shipper was 2.5 million pesos. Singapore is the only significant importer of Philippine oyster products, and export data show fairly regular increases since 1976. From 1976 to 1980, oyster flesh was transported by air as chilled (iced) products; however, outbreaks of gastroenteritis in Singapore in 1979 were reportedly traced to Philippine oysters, and, subsequently, Singapore authorities have required that the bacterial levels of imports be certified and that products be frozen during transportation.

## *MUSSELS*

Mussel culture occurs mainly in Bacoor Bay, Cavite (about 134 farms, Glude et al. 1981); Sapian Bay, Capiz (about 300 farms); and Maqueda Bay, Samar (250 farms) (Table 5). Mussel farms range in size from 0.025 ha to nearly 1 ha, and their productivity is generally higher than that of oyster farms, ranging from 20–68 t/ha from stake culture to about 300 t/ha from the hanging method.

Table 5. Estimated potential for expansion of mussel farming in the Philippines (Glude et al. 1981).

| Location | Number of farms | Area now used (ha) | Potential area (ha) |
|---|---|---|---|
| Zambales | — | — | 23 |
| Bulacan | — | — | 10 |
| Mindoro Oriental | — | — | 10 |
| Palawan | — | — | 25 |
| Quezon | — | — | 200–1200 |
| Capiz | 300 | 15 | 200 |
| Iloilo | — | — | 10 |
| Aklan | — | — | 100 |
| Negros Occidental | 6 | 2 | 100 |
| Cebu | — | — | 50 |
| Bohol | — | — | 50 |
| Leyte | — | — | 100 |
| Samar | 250 | 200 | 5000 |

Not all areas in which green mussels occur are suitable for commercial farming; factors affecting site selection include:

- Availability of spat in the area;
- Protection from strong winds;
- Availability of natural food in the water; and
- Adequate tidal exchange.

## *Culture Practices*

Philippine mussel farmers generally grow the spat to marketable size on the same materials and site that are used for collection. Farming is commonly done with either the stake method or the hanging method, although recently the rope-web method was tried in Capiz Province.

In the stake method, bamboo (*Bambusa blumeana*) poles are sharpened at the base and driven into the muddy bottoms of bays and estuaries at water depths of 2–10 m. In shallower areas, a shorter variety of bamboo (*Schizostachyum lumampao*) known locally as buho is used, and, in areas where bamboo is in short supply, trunks from mangrove and palm trees are used. The stakes are spaced 0.5–1.5 m apart, with some lanes left open for regular inspection. A 0.25-ha farm would normally comprise about 5000 stakes, and, if the current is strong in the area, each row of stakes would be connected and reinforced by horizontal poles. The lower half of the poles are drilled full of holes so that water can enter and prevent the poles from floating.

A variation of the staking method is the wigwam method, where 7–10 poles are staked in a 2-m radius from a central pole; then the upper ends of the poles are tied to the central pole to form a wigwam, which withstands waves and currents better than do single stakes and, thus, is used in deeper waters and where currents are too strong for single stakes.

The bamboo poles serve as cultch for the settling mussel larvae, and no thinning or transplanting is done during the grow-out phase.

In Bacoor Bay, Cavite, the spatfall seasons are March–May and August–November, and the bamboo stakes are put out during these periods. If they acquire a lot of barnacles (*Balanus* sp.), a good set of mussels may be expected. Similarly, in Europe, mussel larvae like to settle on hydroids, which in turn like to settle on the calcareous shells of barnacles. A catch of 2000–3000 spat/m of pole is considered good. Poles staked in 12 feet (4 m) of water usually yield the most spat 4–7 feet (1.2–2.1 m) from the surface, with at least 600–1000 spat/foot (0.3 m).

In the hanging method, cultch made of empty oyster shells or coconut shells strung on wire or twine is hung on bamboo-pole racks. The cultch materials are kept about 10 cm apart by knots or loops on the wire. Recently, the Southeast Asian Fisheries Development Center (SEAFDEC) found that pieces of coconut husk could be used as cultch in the hanging method. These are inserted into polyethylene or polypropylene ropes (12–20 mm in diameter) at 50-60-mm intervals. Bamboo pegs 1.5 cm wide and 15 cm long are inserted into the rope between husk segments to prevent clusters of mussels from slipping off the ropes during bad weather or when the ropes are lifted for inspection. Such collector ropes are also hung on bamboo racks or rafts and spaced 0.5 m apart. The average farm using this method is 100 m × 25 m and has about 20 mussel plots. Each plot spans the width of the farm and consists of five parallel pairs of stakes spaced 5 m apart, with 2 m between parallel rows. The space between plots is 3 m for navigation purposes.

A new method using rope web was introduced in Sapian Bay, Capiz Province, by Bruce French, American Peace Corps. One unit of rope web consists of a parallel pair of 5-m ropes, positioned 2 m apart, and connected at intervals of 40 cm, in a zigzag pattern, by a 40 m rope. Bamboo pegs are inserted into the rope at 40-cm intervals. Each unit is strung across a pair of bamboo stakes spaced 5 m apart, parallel to the current and positioned 2 m deep at low tide. The rough, fibrous rope serves as cultch, and the mussel spat that settle on the ropes are left to grow to marketable size. Farms using the rope-web method have the same layout as those using the hanging method, with the rope webs spaced 5 m apart.

Usually, the whole length of the farm faces the current; however, in narrow tidal rivers, the farms are laid out across the current so that navigation lanes are kept open. Rope webs are usually parallel with the current.

In the Sapian Bay region, the peak spawning seasons are February–March and September, with peaks in February and in March. Peaks probably differ in other areas of the country.

## *Growth and Condition*

Philippine green mussels grow an average 10 mm/month and are marketed after 4–6 months when they are 40–60 mm long. After they reach 60 mm, they grow more slowly.

They are ideal for harvest when they are in the resting phase of their reproductive cycle, when large amounts of glycogen are stored in the mesosoma and mantle lobes. Condition-index studies on mussels grown in Himamaylan, Negros Occidental, from 1977 to 1978 indicated two periods when the mussels were in prime condition: July–September and January–March. Raw flesh constitutes about 55% of the total shell-on weight, and cooked flesh constitutes from 12% to 33% of the total shell-on weight, depending on the condition (gonadal) of the mussel.

## *Farm Management and Production*

On farms using the stake method, after spat have settled, little is done until harvest. If there is heavy settlement of spat on the poles, farmers sometimes dive and tie thin ropes or plastic straw around the mussel clusters to prevent the oversized clusters from falling. Regular management practices include inspection of the farm area so that floating debris can be removed and weak or rotten poles can be replaced or reinforced.

On most farms, whatever the culture method, there is a 24-h guard who lives in a small hut at the farm and who serves as farm caretaker. Near harvest, more guards are posted to prevent poaching. The stake method of culture on small farms (<600 $m^2$) requires about 54 work days (one work day is one person working 8 h) from farm layout to harvest. The figure for bigger farms is about 71 work days.

On farms using the hanging method, the growing ropes are lifted weekly for inspection. Poorly settled collectors are replaced with new ones to catch new sets of spat. During inspection, foulers are scraped from the ropes and loose or rotten bamboo pegs are replaced. If there are exceptionally large clusters, additional pegs are provided as support.

On farms using the rope-web method, the farmer inspects the rope web under water because the laden ropes are too heavy to lift; repairs of ropes and bamboo pegs are made under water. Where settlement of spat is heavy, additional bamboo posts are added.

Harvesting and selling begin when the mussels are 5 cm long, rather than at a fixed time. The quantity harvested depends on buyers' orders, the prevailing market price, and the monetary needs of the farmer.

In the stake method, harvesting is done when the sea is calm. The farmer usually hires 3–5 divers, depending on the size of the farm. Divers wear goggles or face masks and improvised flippers. The mussel-laden stakes are pulled on board a small boat (banca), and other hired workers strip the mussel clusters off the stakes with iron bars. The mussels are separated, sorted, and cleaned (placed in a nylon-net bag and shaken in the water until the dirt is removed).

Stakes with more undersized than marketable-sized mussels are not completely harvested, but partial harvesting can be accomplished by the divers, the large mussels being stripped from the stakes under water and deposited in a nylon basket tied around the diver's waist. After the harvest, the poles that are still sturdy are restaked. Mussel yields vary from 2.5 kg to 15 kg/m of pole. A 0.25-ha farm using the stake method can produce annually about 12–13 t of whole mussels; deeper, more productive farms in Sapian Bay, Capiz, produce as much as 5 t/250-$m^2$ plot each year. In good growing areas with regular spatfall seasons, two main harvests a year are possible.

In the rope-web method, the rope-web units are untied from the bamboo poles and hauled on a small boat or an improvised raft made from 9-m bamboo poles. Mussel clusters are detached, sorted, and cleaned as in the stake method. The rope-web units are cleaned of foulers and dried in the sun for a few days before they are restrung on the vertical poles for a new set of spat.

In Sapian Bay, mussels harvested from rope-web units are not always transported immediately to markets. Instead, the improvised rafts containing the mussels (sometimes packed in polyethylene sacks) are sunk (weighted down with rocks, water-filled barrels, and other heavy objects) and kept under water until needed.

With the rope-web method, a unit with a good catch of mussels produces an average 200 kg whole mussels. If the spatfall is heavy, the annual yield can be up to 300 t/ha.

### *PROBLEMS AND CONSTRAINTS*

The major problems in the mussel industry and the constraints to its expansion are:

- Irregular spatfall and lack of spatfall-forecasting services. Except in a few traditional culture grounds, spatfall seasons are generally irregular, and spatfall may occur in March and November one year and a month earlier or later the next year. The intensity of spatfall also varies from year to year, perhaps because of total harvesting by mussel farmers and harvesting regardless of gonadal stage. The Seafarming Project of the Aquaculture Department of SEAFDEC is initiating spatfall-forecasting programs in Himamaylan and Batan Bay; however, as forecasting schemes are geared toward the hanging method of culture, farmers who use the stake method might not benefit.
- Deterioration of prime farming areas. Reclamation of areas for housing and industry has been detrimental to some culture grounds. Even more devastating than reclamation is the increase in siltation caused by bamboo stakes being placed too close together and rotted poles being left to decay on the bottom. Putting new poles beside these rotting stumps results in slowed tidal currents, reduced mussel growth, increased mortality, and thin, brittle shells. In addition to biological deterioration, pollution from industrial wastes and heavy metals has increased and has adversely affected many mussel-culture areas.
- Lack of consumer demand because of unsanitary measures in the culture and harvesting of mussels and because of variable quality from year-round harvesting, regardless of how plump or thin the mussels are. At present, there are no sanitation programs for shellfish-growing waters or for shellfish. Many mussel-culture areas are heavily polluted with coliforms, and the mussels are not depurated before being sold. As mussels are generally eaten without much cooking, the consumers all suffer gastrointestinal disorders at some time or other.

Another factor contributing to the lack of popularity is the poor condition of mussels sold in the markets. Spent mussels shrink during cooking much more than do plump mussels and leave homemakers feeling short-changed. Low demand is the main constraint to the growth and expansion of the mussel industry.

### *POSTHARVEST OPERATIONS*

Little or no processing is involved after green mussels have been harvested. They are transported to market where they are cleaned, trimmed of their byssal threads, and sold live and unopened. The only processed mussel product is brined mussels (locally called bagoong), made of flesh of oversized mussels or of mussels that have died or weakened during transport.

## *WINDOWPANE OYSTERS*

The adult *Placuna* or windowpane is up to 16 cm in diameter and can be found in waters from 0.5 m to 100 m deep. If undisturbed, it prefers to live under a thin layer of mud that camouflages it from predators. Juveniles have been observed to dive into the mud by repeated (every 4–8 seconds), sharp contractions of the adductor muscle.

Unlike mussels or oysters, the windowpane has an extended reproductive cycle; at 8–12 months, it is sexually mature (about 70 mm diameter). Spawning usually occurs from February to May. When viewed against the light, the male *Placuna* is a dull, dirty-yellow hue, whereas the female is generally orange-yellow. Females release eggs with a sudden contraction of the adductor muscle, which forcefully expels the eggs through the posteroventral margin. Males release sperm in steady streams. Eggs are golden yellow and measure about 45 $\mu$m in diameter. Fertilization takes place in the water.

Developing larvae are planktonic for only about 10 days. Pediveligers settle at a size of 220–230 $\mu$m. Settling larvae either sink directly to the bottom or drift with the currents. Juveniles up to 8 mm long are capable of crawling on clean, hard surfaces (e.g., glass) and have been observed to float either horizontally or vertically on or near the water surface. They are capable of secreting thin byssal threads while floating or crawling.

The environmental limits of tolerance of the windowpane are (Rosell 1981): temperature 24.5–30°C; salinity 18–38 ppt; pH 6.4–7.7; and dissolved oxygen 2.65–6.06 ml / L.

*Placuna* thrives in soft muddy or sandy-muddy bottoms. Notable *Placuna* beds are located along eastern Manila Bay; Capiz; Iloilo; Talibon, Bohol; Hinigaran and Valladolid, Negros Occidental; Samal, Batan; Labrador, Pangasinan; San Jose, Mindoro Occidental; Misamis Oriental; and Sulu. In the late 1970s, the main collection grounds for the fishery were in Western Visayas, notably Leganes, Miag-ao, Guimbal, Tigbauan, Oton, Zarraga, La Paz, and Guimaras in Iloilo; Valladolid and Pontevedra in Negros Occidental; at the mouth of the Visayan Sea channel in northern Capiz; and Batan, Aklan. These beds range from 4 m to 20 m deep.

### *Culture Methods*

The usual gathering season in Panay and Negros islands is summer (February–May), when the water is clear enough for diving. Divers use goggles, improvised flippers, and stone weights. Instead of using standard scuba tanks, however, they breathe air from a thin rubber hose connected to an ordinary air compressor mounted on a nearby service boat. This hose is usually 20–30 m long to allow the diver to move around. At the sea bottom, the divers grope for shells with gloved hands and place the shells in net bags that are later pulled on board. Divers generally gather about 6000 pieces a day, diving eight times and remaining under water for up to 1.5 hours/dive.

*Placuna* farms consist of mud flats in protected bays or lagoons that the farmers enclose with fences made of bamboo poles and barbed wire. *Placuna* seed, 25–40 mm in diameter, are gathered from wherever they occur and stocked in these farms. In Bacoor Bay, stocking rate is 100–200 seeds/$m^2$; thus, a 1-ha farm is usually planted with 1 million pieces of seed. In Capiz Province, seeds, 30–35 mm in diameter, are stocked at a rate of 80 000–120 000/ha. Seeds planted in October–November are harvested in April–June the following year at an average length of 90 mm, whereas those planted in April become 80–100 mm long after 4 months, with a survival rate of 80–90%.

As *Placuna* shells more than 90 mm long become increasingly opaque and cannot be used for shellcraft purposes, most shells are harvested as early as possible after they reach this size, usually before they have had a chance to mature and spawn.

### *Processing*

The shells are shucked on shore and then cleaned (soaked overnight in fresh water and then brushed vigorously). They are then cut into rounded shells by a shell cutter that operates like a paper punch with hollow plungers. The shell-cutting machine cuts away the soft fragile edges, leaving a firm, translucent piece of shell. Cut shells are sorted by size and then rinsed in fresh water. A weak solution of acid (HCl) is applied to the adductor-muscle scar with a piece of soft rubber to remove the scar impression. The shells are again rinsed and then soaked in a solution of hydrogen peroxide to soften them so that they can be moulded into various shapes. Two layers of shells are used in the making of trays or plates so that only the smooth, lustrous shell interior is seen on each side.

Some shells are placed on a grill and exposed briefly to heated charcoal, which gives them a golden, mother-of-pearl lustre. The products are all coated with a layer of fiberglass to give them strength.

Processing is labour-intensive, providing employment and income for entire coastal villages. Processors who have enough capital purchase boats and hire divers to gather shells at the natural beds. Others, particularly the children and women, shuck, clean, cut, sort, soak, and shape the *Placuna* shells into various shellcraft items.

### *Problems*

In 1977–78, 42.5 billion *Placuna* bivalves, valued at 850 million pesos, were gathered in Capiz Province alone. Total production of *Placuna* shells in 1979 was 221 t, only 14% of 1977's production of 1635 t.

As *Placuna* shells become increasingly opaque with age and, thus, decreasingly desirable for shellcraft (for which translucent shells are required), they are harvested early. Because of this conflict between the demand for young, translucent shells and the need for maintaining older, sexually mature shells to replenish the stocks, the occurrence and yield of *Placuna* are very erratic.

## ***Other Bivalves***

Bivalves other than oysters, green mussels, and windowpanes are not farmed; they are simply collected wherever they occur. *Modiolus* spp., *Paphia* spp., *Arca* and *Anadara* spp. are gathered by divers using bare hands or simple digging blades. In some areas, blood clams or cockles are harvested in mud flats at low tide. *Paphia* is usually gathered by divers, but, in some places, people can gather it by wading through shallow waters and feeling for the clams with bare feet. *Modiolus* occurs in mats or carpets, composed of intertwined byssal threads, found on the bottom of many shallow bays, and is easily collected by divers.

The angel's wings shell *Crytopleura costata* of Negros Occidental Province lives in burrows up to 50 cm deep in sticky, soft sandy-muddy bottoms rich in silt and detritus. It displays a general tendency toward gregariousness. Natural beds of *C. costata* average 5–10 m in depth. Divers use an iron or wooden paddle-shaped implement or bare hands to dig the animal from its burrow. *Crytopleura costata* does not burrow again if taken from its original spot (Ablan 1938).

Pearl oysters, *Pinctada margaritifera*, *P. maxima*, and *Pteria* spp., occur in clear waters up to 40 m deep where the current is strong and the bottom sandy or gravelly. Juveniles and young adults up to 10 cm long attach themselves with byssal threads to rocks and other objects; however, when they become heavy enough to withstand the currents, they detach and live unattached or weakly attached on the sea bottom. The pearl shells are usually gathered by experienced divers.

## *Economics of Shellfish Farming*

At present, there are 1200 oyster farms and 700 mussel farms operating in the Philippines. The oyster farms occupy 500 ha of coastal waters and the mussel farms 300 ha. In 1980, the estimated combined annual production of these farms was $1.4 \times 10^4$ t: $1.0 \times 10^4$ t from oyster farms and $4.0 \times 10^3$ t from mussel farms. Recent studies reveal that $9.0 \times 10^3$ ha of coastal waters are suitable for expansion of oyster culture and $5.0 \times 10^3$ ha for expansion of mussel culture. A total 86 000 additional farms have been identified as suitable coastal areas for bivalve culture: 45 000 for oyster farms and 41 000 for mussel farms. For these additional farms, the projected average area per farm is 0.1 ha for mussels and 0.2 ha oysters. The projected area for mussels is smaller than for oysters because mussel farms have higher productivity. If fully utilized, this additional area could provide sea-farming opportunities for nearly 20% of the municipal fishermen in the Philippines.

Although Philippine oyster and mussel farms average less than 4 ha, they are profitable, earnings being dependent upon the culture methods and on the size of the farms. Some culture methods are more productive than others. In a study conducted by Ordoña and Librero (1976), total farm receipts for oyster culture were found to be P19 001/ha for the lattice method, P18 394/ha for the hanging method, P8942/ha for the stake method, and P1556/ha for the broadcast method (Table 6). Earnings for mussel farms were 76% of sales/ha for long line, 74% of sales/ha for rope web, and 53% of sales/ha for the stake-culture method (Table 7).

The expansion of oyster and mussel farming has been precluded in many areas by limited demand, low prices, the high cost of transporting the product, the uncertain sanitary quality of the oysters and mussels, and lack of capital.

## *Future Prospects and Recommendations*

The shellfish farms in Bacoor Bay, the first farms to be established in the Philippines, subsequently became the most productive. From 1935 to 1955, the farms produced an abundance of oysters and mussels in an environment relatively free from human and industrial wastes. The proximity of the farms to Manila and outlying urban areas made possible the distribution of fresh oysters and mussels to markets at low transport cost. These factors increased the area of shellfish farms

Table 6. Receipts, expenses, and measures of profitability for various methods of oyster and mussel culture (based on Librero et al. 1976).

| Item | Oyster-culture method | | | | Mussel-culture method |
|---|---|---|---|---|---|
| | Stake | Hanging | Lattice | Broadcast | Stake |
| Average farm size ($m^2$) | 1603 | 5968 | 472 | 3678 | 3242 |
| Capital investment | | | | | |
| (P/farm) | 400 | 800 | 203 | 111 | — |
| (P/ha) | 2495 | 1340 | 4301 | 302 | — |
| Total annual receipts (P/ha) | 8942 | 18934 | 19001 | 1556 | 12975 |
| Total annual expenses (P/ha) | 5711 | 4975 | 9559 | 1408 | 5765 |
| Net annual earnings[a] (P/ha) | 3231 | 13419 | 9442 | 148 | 7210 |
| Earnings on sales (%) | 36 | 73 | 50 | 10 | 56 |

[a]Includes unpaid family labour.

Table 7. Projected costs of, and income from, mussel farming at Samar by long-line, rope-web, and stake methods.

| Item | Culture method | | |
|---|---|---|---|
| | Long-line | Rope-web | Stake |
| Investment cost (P/ha) | 64663[a] | 31618 | 1617 |
| Annual operating cost (P/ha) | 28560 | 37808 | 102086 |
| Annual interest[b] (P/ha) | 33948 | 16600 | 849 |
| Total annual expenses (P/ha) | 127171 | 86026 | 104552 |
| Total annual receipts (P/ha) | 528840[c] | 333450[d] | 222300[e] |
| Net annual earnings (P/ha) | 401669 | 247424 | 117748 |
| Earnings on sales (%) | 76 | 74 | 53 |

[a]Amortized over 5 years.
[b]Based on 14% of 75% of the total investment.
[c]476 t/ha less 5% losses × 1.17 P/kg.
[d]300 t/ha less 5% losses × 1.17 P/kg.
[e]200 t/ha less 5% losses × 1.17 P/kg.

to 200 ha, with some of the farms producing as much as 50 t/ha annually. After 1960, demand and production declined because the water became contaminated by human and industrial wastes. Now, there are about 70 ha of shellfish farms left, and their output is steadily declining. It is expected that, within the next few years, shellfish farms in the area will disappear.

The growth and the decline of shellfish farming in Bacoor Bay indicate that the potential for bivalve farming depends crucially on some factors affecting demand for, and supply of, oysters and mussels. The factors affecting demand include: the nearness of the farms to the markets; the cost of transporting the product from the farms to the markets; the palatability and cleanliness of the product; the price; the existence of consumers who have the income to buy the products, and the presence of good market outlets for the product. Major factors affecting supply include farm productivity; production and operating costs; prices; availability of suitable (unpolluted) culture areas; and government support. These factors should be considered when plans are made to develop potential oyster and mussel seeding, culture, and cleansing areas. The opportunity for developing a potentially profitable business must be demonstrated so that the municipal fishing families can be convinced that integrating culture fishing with their capture fishing will make them economically productive members of their community.

## *Recommended Action*

To expand oyster and mussel farming, the government must intervene to protect the public health through sanitary regulations; increase the demand for oysters and mussels through promotional measures; increase production through innovations in existing techniques and incentives for expansion of farming.

### *Protecting Public Health*

Philippine oysters and mussels are harvested from waters of unknown sanitary quality, transported and processed under conditions that may be unsanitary, and stored at temperatures that encourage the growth of bacteria. There is, at present, little or no effective control by government. The government must protect the health of its citizens, visitors from other countries, and residents of other countries who consume Philippine products.

Shellfish, and other foods, should be produced, processed, and transported under conditions that ensure safe products. Achieving this goal will require a series of actions over several years, including:

- Sanitary surveys of areas for oysters and mussels. BFAR or other appropriate government agencies should conduct or commission sanitary surveys of all waters that are sources for bivalves used as food; the surveys should include periodic determination of total and fecal coliforms in waters and in shellfish from productive waters for at least 1 year and from waters proposed for expansion of oyster and mussel farming.
- A shellfish sanitation and health program. BFAR should design and implement a system for approving areas and methods (including depuration where necessary) for shellfish harvest as well as the means for

enforcing the regulations. Control procedures should be consistent with the requirements of countries that might import Philippine molluscs — for example, the USA, whose Food and Drug Administration has laid down requirements for imported shellfish.

- A system for natural cleansing of shellfish grown in contaminated waters. A series of shellfish-cleansing stations should be established in clean areas near contaminated growing areas, beginning with three stations, probably at Pangasinan, Capiz, and Quezon. Shellfish would be held for 1-3 weeks at stations before being marketed. It is recommended that these stations be operated by BFAR in conjunction with other appropriate government agencies.
- A pilot-scale, shellfish-depuration plant. A plant for depuration should be located near Manila and operated by BFAR to develop and test procedures for cleansing shellfish in areas where no uncontaminated waters are available for natural cleansing. If practicable, depuration plants could be established in several areas and operated by government or by private industry under government supervision.
- A pilot-scale, shellfish-processing plant. BFAR should also operate a plant to demonstrate sanitary methods for shucking shellfish; for processing, packaging, storing, and shipping shucked flesh; and for the training of plant operators. Such a plant should be located in an area where production outstrips local demand and where transport costs preclude shipment in the shell. Possible sites are Roxas (Capiz), Bacolod (Negros Occidental), and Dagupan (Pangasinan). Another possibility is the Manila area, in combination with a government-operated shellfish-depuration plant. In this case, shellfish from a variety of sources could be cleansed, shucked, and processed at a single location.

### *Increasing Demand*

Limited demand is frequently cited as a major reason for the failure of oyster and mussel farming to expand rapidly, and it is an area in which government can intervene effectively to:

- Ensure the availability of clean, safe products. The lack of assurance that shellfish produced in the Philippines are safe to eat limits sales in major markets. The lack of an approved shellfish-sanitation and health program providing an acceptable certification of wholesomeness precludes even the sale of processed shellfish in most world markets.
- Develop better systems for packing and shipping to improve product quality. Shellfish from outlying areas such as Capiz, Samar, Negros, and Pangasinan require 6–24 hours to reach Manila, the principal market. Oysters in the shell can live about 3 days out of water but a significant portion of green mussels die within a day. Therefore, the product reaching the Manila market may already be in poor condition, leaving an extremely short time for distribution to retailers, sale, and consumption. It is recommended, therefore, that BFAR evaluate the existing methods of packing and shipping and develop systems that will reduce mortality en route and extend the safe marketing time in Manila. These systems should be tested and demonstrated to industry.
- Introduce processing, for items that must be shipped, to reduce bulk and ensure quality. Oysters shucked under sanitary conditions and marketed in sealed containers kept on ice retain high quality for up to 10 days and are only 8–18% of the weight of oysters in the shell. A system based on this observation would provide employment in local processing plants and would retain oyster shells near the farms where they are needed as collectors. Likewise, mussels should be opened by steam and the flesh frozen for shipment to population centres in the Philippines and to export markets. Other products that might be processed and packed at various places in the Philippines include shucked or steamed oysters or mussel flesh frozen in blocks and packed in various-sized containers for shipment to world markets. Canned products include smoked or boiled oysters and mussels, and oyster or mussel stew or soup; dried products are also a possibility. Government efforts should intensify the development and testing of procedures for preparing products in various forms for domestic use and for export, training industry personnel in their use.
- Ensure continuity of supply. Because oysters and mussels are grown on farms, it should be possible to schedule harvests so that fresh oysters and mussels are available to consumers throughout the year. BFAR should

assist the sea farmers with analysis of the market and advise them on the best time to harvest their crops.

### *Increasing Production*

There are good opportunities for expanding production: more than $9.0 \times 10^3$ ha in shallow bays are suitable for oyster culture, although fewer than 500 ha are now in use. Likewise, nearly $5.0 \times 10^3$ ha are suitable for mussel culture, and fewer than 300 ha are now being used. To increase production, the government should:

- Evaluate and modify high-productivity methods used elsewhere.
- Establish training programs, expand sea-farming extension services, and operate demonstration farms to encourage expansion of oyster and mussel farming.
- Contract or conduct research to solve biological problems (uncertainty in spatfall forecasting, predator attacks and other causes of mortality, etc.) limiting oyster or mussel farming.
- Help municipal fishing families to become sea farmers. There are enough suitable areas in the Philippines to provide space for more than 45 000 additional oyster farms and about 41 000 additional mussel farms. Such expansion could benefit nearly 20% of the municipal fishing families, including 100% in Samar, 50% in Pangasinan, and more than 5% in Quezon — the priority provinces. Government actions to encourage municipal part- or full-time farming might include allocating space for oyster and mussel culture (restricting plots to a size large enough to provide substantial increases in the income of municipal fishing families but small enough to make them unattractive to wealthy individuals or corporations); establishing training programs and expanding sea-farming extension services through BFAR in cooperation with other appropriate government agencies, universities, or organizations; providing funding to fishing families who wish to become sea farmers through assistance programs like Biyayang Dagat; operating and making available, without charge, shellfish-cleansing services; and offering business-management services for sea farmers. BFAR-operated cleansing stations and demonstration farms should perform the management functions of cooperatives until the sea farmers are able to operate without government assistance. The services should include assistance in marketing and bulk purchasing of supplies and equipment. The BFAR cleansing stations would receive payment from buyers of cleansed shellfish, so loan payments could be deducted from returns due the sea farmers.

# *SINGAPORE*[1]

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The green mussel (*Perna viridis*) is cultured in Singapore; however, other bivalves, such as oysters (*Saccostrea cucullata*) and brown mussels (*Glauconome rugosa*), are collected mainly from the wild. Mussel production is derived from artisanal fishermen who harvest from fishing stakes during low tide or from farmers operating raft culture in coastal areas. Annual production is estimated at 500 t, with half derived from the wild and half from culture.

Basic research on bivalves is conducted by the National University of Singapore, and, in late 1975, the Primary Production Department of the Ministry of National Development initiated studies on the intensive culture of mussels in Singapore's coastal waters.

## *CULTURE PRACTICES (FOR GREEN MUSSELS)*

Grounds suitable for mussel culture (in both the nursery and the grow-out phases) are those with phytoplankton concentrations ranging from 17 $\mu$g to 40 $\mu$g Chl.a/L seawater, currents ranging from 0.17 m to 0.25 m/second at flood tide and 0.25 m to 0.35 m/second at ebb tide, and primary hourly productivity ranging from 73 $\mu$g to 100 $\mu$g carbon/$m^3$. The estuaries of Sungei Serangoon, Sungei Ponggol, and Sungei Seletar at the East Johore Strait and Sungei Kranji and Sungei Sarimbun at the West Johore Strait have natural stocks of mussel beds and are suitable for farming.

A modification of the raft method employed in Spain is used (Cheong and Lee 1982, unpublished), and mussels grow on culture ropes suspended from rafts. The rafts are basically wooden pontoons with cross beams for culture ropes. They are anchored parallel to the flow of the tides so that wave resistance is minimized, and they are arranged in rows to maximize utilization of water space and to reduce the problem of rope entanglement, which is often encountered with individually anchored rafts. The minimum plot area is 0.5 ha, and the effective culture area is about 20–30% of this, the remaining space being used for anchoring purposes.

### *NURSERY ASPECTS*

In early studies at the Primary Production Department, ropes used for spat collection (Cheong and Chen 1980) were 4 m long and 40 mm in diameter, were made of unoiled coconut-coir fibres, and were different from those used in the grow-out phase. However, later, studies showed that spat-catching and grow-out phases could both be done on a polycoco rope (Cheong and Lee 1981) consisting of a main, 14-mm diameter, polyethylene rope with pieces of 40-mm coconut-coir rope attached at the middle of each metre of the main rope. Farmers also use polyethylene netting for spat collection and grow out.

About 2 weeks after the rope has been immersed, the spat settle, usually first along the lay of the rope and later along the entire rope surface. On an ordinary 4-m coconut-coir rope, spat tend to settle more densely on the upper 2 m of rope, whereas, on polycoco ropes, settlement is more uniform.

A simple and effective technique for inducing spawning of mussels is to raise the water temperature rapidly; this method has been tested by Lim et al. (1982, unpublished) and has proved better for mussels conditioned in tanks for a few days than for freshly collected ones.

In spatfall forecasting, test ropes are monitored once every fortnight, and the appearance of spat, 0.5 mm long, on them signals the time to

[1]In total, five presentations were made during the workshop on aspects of bivalve culture in Singapore. These contributions are listed in appendix 2. The cooperation of the individual authors in agreeing to a single country report is gratefully acknowledged.

immerse more culture ropes. Farmers sometimes use the colour of the mantle to ascertain the onset of spawning. When the majority of the mussels have a reddish-coloured mantle, the mussels are considered ready for spawning, and spat settlement will occur in 1–2 weeks. Spatfalls occur throughout the year, with peaks (seasons) about February–May and October–November in the East and June–August and November–December in the West Johore Straits. However, the seasons vary from year to year and have been observed to occur as often as once every 2 months. Each spatfall within the season normally lasts 2–3 weeks. Usually, if 5000 spat/ $m^2$ are collected at any one time, the resource is considered sufficient for commercial farming. (The combined surface area of the culture portion of the polycoco rope is 0.164 $m^2$ for the 2-m rope and 0.328 $m^2$ for the 4-m rope.)

### *Grow-Out Aspects*

Mussels collected in the nursery ground either remain there for grow out or are transferred to areas that do not have broodstock. In areas where only grow out is possible, i.e., where spat are not found, the current can be slightly faster than in the nursery ground.

Monthly growth increments for shell length average 1.06 cm and for shell width, 0.4 cm. Mussels attain a marketable size of 6–7 cm after 6 months when the flesh-condition index is about 80.

For nursery ropes made entirely of coconut coir, thinning is necessary prior to grow out. This is done 2 months after the spat have collected on the nursery ropes and involves binding the spat on production ropes made of polyethylene. Each rope is 14 mm in diameter and 4 m long. The operation is time-consuming and laborious and is one of the major constraints to large-scale mussel production.

Farmers using polycoco ropes don't need to thin because the spat that have settled on the coconut-coir rope pieces of the polycoco rope distribute themselves naturally along the entire rope length during grow out. Where polyethylene nets are used as culture materials, thinning is also unnecessary.

Ropes are immersed at 8 ropes/ $m^2$ for spat collection and spread to 4 ropes/ $m^2$ for grow out. They are checked occasionally in case they have become tangled. Double immersion, i.e., immersion of new spat-collecting ropes between grow-out ropes, would help increase production as well as stagger harvesting time. Studies have shown that shading is not necessary for the nursery or the grow-out phase.

The mussels are harvested after 6 months. From a 4-m polyethylene production rope, a yield of 40 kg of mussels can be expected. The 2-m and 4-m polycoco ropes yield 25 kg and 42 kg respectively. In other words, based on a stocking density of 4 ropes/$m^2$, production, every 6 months, from polycoco ropes would range from 100 kg to 160 kg/ $m^2$.

### *Problems and Constraints*

To date, sea farmers in Singapore have not reported major problems in the culture of mussels. Constraints lie in the handling of the large quantity of fresh shell-on mussels that are harvested at any one time. The current method is time-consuming and labour-intensive, and the Primary Production Department is looking into the possibility of mechanizing the operation.

## ***Postharvest Handling***

Acceptable bacteriological limits for imports of frozen, shucked oysters in Singapore are: aerobic plate count, $\leqslant$500000 MPN/g; *Escherichia coli*, $\leqslant$20 MPN/g; *Vibrio parahaemolyticus*, $\leqslant$100 MPN/g; *Salmonella, Shigella*, and *V. cholera*, nil in 25 g.

The Primary Production Department monitors the heavy metal and bacteria levels in the water and mussels of the farm areas and, to date, has found that the levels fall within acceptable limits.

Studies have been conducted on the use of an ultraviolet, recirculating seawater system for high-density depuration of bivalves, and the findings are that highly polluted mussels (>2400 *E. coli*/ $m^2$) can be depurated to acceptable limits ($\leqslant$20 MPN *E. coli*/g flesh) within 48 h. The system uses a stocking density of 100 kg shell-on mussels/ $m^3$ of water at a water flow of 6 $m^3$/h (Cheong and Syed 1982). The mussels are placed in shallow trays that are stacked in tiers and hosed down every 24 h. The water is drained, and fresh, sterilized seawater is then added for a further 24 h depuration. This method is feasible for both small- and large-scale operations and could be used to improve the quality of live mussels when they are to be eaten raw or semicooked.

Postharvest processing machines for declustering, washing, debearding, and deshelling mussels have been made locally under the joint supervision of the department and a quasi-government engineering firm, the M/S Applied Research Corporation. Designs based on those developed by farmers in Holland were modified to suit local conditions. The declusterer-cum-washer separates the mussels from each other and can handle approximately 1 t/h, with about 10% breakage and 80% efficiency. The debearder removes the byssal threads from individual mussels and can handle 1 t/h, with about 15% breakage and 30% efficiency. The desheller dislodges the flesh from the shell and handles cooked mussels — again about 1 t/h — with almost no breakage and about 60% efficiency. The mussels have to be cooked under pressure for the flesh to be dislodged.

Because these machines are still being tested, farmers currently enlist their families to carry out the operations: the mussels are usually cooked in a metal drum, shucked by hand, and sauteed on a metal plate. They are then sun dried and sold. About 5 persons can handle 300 kg of fresh mussels in a 6-h day, i.e., 10 kg shell-on/person-hour.

The shelf life of the mussel depends on the state in which it is sold. Fresh, shell-on mussels can stay alive for only 2 days under normal room conditions. They should be kept in a wet gunny sack but not immersed in stagnant water. Studies have shown that shelf life can be increased to as much as 4 days if the mussels are placed in shallow trays supplied with a flow of sterilized water.

Processed mussels have longer shelf lives. Cooked mussels can be kept in a refrigerator for 1–2 weeks and in a freezer for as long as 2–3 months. If blast frozen, they can be stored for as long as 1 or 2 years, and the texture of the flesh is still comparable with that of freshly cooked mussels. Glazing of individually frozen mussels helps to retain their shape so that they can be easily handled during thawing. The shelf life of dried-mussel flesh depends on moisture content. After sun drying, the moisture composition is usually about 10% of the dried-flesh weight, and the flesh can be stored for 4 months if kept in air-tight containers.

Shell-on mussels can be frozen whole for storage and plunged directly into boiling water before being eaten. If they are allowed to thaw before being cooked, the flesh tears and becomes unsightly. Cooked flesh can be brined or smoked, and the product canned, as is done in Europe.

The protein composition of local mussel flesh averages 67.8 g/100 g dry weight. This value compares favourably with beef, pork, mutton, chicken, and eggs. The amino-acid composition is comparable with that of high-quality fish meal and shrimps, as it is fairly rich in essential components. The flesh also contains minerals such as calcium, phosphorus, iron, iodine, copper, and small amounts of thiamine, riboflavin, and niacin. The shell contains 90% calcium, which could be directly incorporated into feed suitable for productive hens. Also, it has been reported from overseas that the flesh of green mussels has an antiarthritic effect.

There is no industry involved in mussel processing in Singapore. However, there is a local cannery that cans sambal (curry) cockles. Studies have been conducted by the department on block freezing of cooked-mussel flesh; glazing and quick freezing of individual mussels; and smoking, brining, and drying of mussel flesh.

## *FUTURE PLANS*

The economics of farming green mussels in Singapore with various culture methods (raft, long line, pole, and bouchot) were examined by the department, based on extrapolations from research findings, and raft culture was found to be the most feasible. Operations that don't involve thinning and that use 4-m polycoco ropes suspended either from a single 150 $m^2$ raft or a group of rafts located in a farm (0.5 or 0.75 ha) are economically feasible. Better profits are possible, however, through highly mechanized, large-scale operations.

There is a need to ensure that bivalves are available in Singapore and that they are wholesome and of good quality. Further studies on a high-density depuration system suitable for other bivalves, especially oysters and cockles, are needed, and studies to improve machines used in postharvest operations should continue.

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Bivalve resources are considerable in Sri Lankan waters, and some have been described by Fernando (1977) and Pinto and Wignarajah (1980). Present exploitation is far below the level of natural production and is confined to wild stocks, as bivalve culture is not practiced in the country.

Bivalve species commonly found in Sri Lanka are: oysters — *Crassostrea belcheri* and *Saccostrea cucullata*; mussels — *Pérna perna, P. viridis,* and *Modiolus auriculatus*; cockles — *Anadara antiquata* and *Larkinia rhombea*; and others — *Pinctada vulgaris, Pinna bicolor, Geloina coaxans, Gafrarium tumidum, Meretrix meretrix, Marcia opima,* and *Donax faba.*

## *Present Utilization*

To date, the demand for bivalves has been limited, being confined to subsistence purposes in areas where the resources are plentiful. Local fishing families turn to bivalves during the monsoon seasons when they are unable to go out to sea and when fish are scarce.

Fresh clams and cockles are cooked with condiments and made into curries; small quantities, sun dried, are occasionally sold in the markets during and immediately after the monsoon period. Clam shells are used for the manufacture of lime on the west coast. With the recent increase of tourism in the coastal areas, utilization of wild stocks of oysters has increased considerably at some locations.

## *Future Prospects*

The rich resources of bivalves, especially oysters and mussels in certain coastal areas and lagoons, indicate suitable environmental conditions for culture, although studies on chemical, physical, and biological parameters in these areas are a prerequisite for culture projects. A low tidal range (on average, $<0.5$ m) and heavy barnacle infestations are common in these areas. As well, most of the large lagoons support heavy fishing activity and have dense populations and heavy boat traffic. Therefore, decisions on, and selection of, sites, methods, and times of spat collection will have to be carefully made.

Preliminary studies on oyster culture will begin next year in Putlam lagoon on the west coast. Currently, trained personnel and technical knowledge are lacking because mariculture is not traditional in Sri Lanka, as it is in many Southeast Asian countries.

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# *THAILAND*[1]

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Thailand ranks among the top 10 fishing nations of the world, with a reported production of about $2.0 \times 10^6$ t. Marine products account for more than 90% of this figure and include a modest production of molluscs. There is potential for even greater production, and the Government of Thailand, through the Department of Fisheries, is emphasizing coastal aquaculture development as one component of the Fifth National Economic and Social Development Plan (1982–86). This development activity is the responsibility of the Brackishwater Fisheries Division (BFD) of the Department of Fisheries, which is assisted by several foreign agencies including the Food and Agriculture Organization of the United Nations (FAO), the UN Development Programme (UNDP), the Japan International Cooperation Agency (JICA), the Asian Development Bank (ADB), and the World Bank.

Thailand has $2.6 \times 10^3$ km of coastline on the Gulf of Thailand and the Andaman Sea. The total area of intertidal flats, based on 2 km width from the shoreline, is about $3.25 \times 10^6$ rai ($5.2 \times 10^5$ ha). The intertidal flat can be utilized for mollusc culture, fish-cage culture, and shrimp-pen culture. In addition, the use of some deteriorated mangrove areas would provide about $3.0 \times 10^5$ ha of coastal land for development as shrimp and fish ponds. The shellfisheries of Thailand have been reviewed by Rabanal et al. (1977).

## *PRESENT PRODUCTION*

Bivalves have been captured and cultured in Thailand for several decades. The people of the maritime provinces have traditionally collected edible molluscs and have been increasingly turning to mollusc culture as the deterioration of the coastal environment has reduced production from natural beds.

Oysters (*Crassostrea commercialis, C. lugubris*)[2], mussels (*Mytilus smaragdinus*), and cockles (*Anadara granosa*) are cultured for human consumption; species collected as food from natural beds include horse mussel (*Modiolus senhausenii*), carpet shell or short-necked clam (*Paphia undulata*), piddock (*Pholas* spp.), razor clam (*Solen abbreviatus*), Jackknife clam (*Ensis malaccensis*), surf clam (*Mactra* spp.), wedge

[1]This report includes some information on the reproductive cycle of mussels from a paper presented by Tanittha Chongpeepien, who is also with the Department of Fisheries. The cooperation of the authors in agreeing to the publication of a single country paper is gratefully acknowledged.

[2] Editor's note: *C. lugubris* may be a similar species to *C. belcheri* found in Malaysia; *C. commercialis* may likewise be similar to *C. cucullata*.

Table 1. Present and potential production of cultivable shellfish in Thailand (Rabanal et al. 1977).[a]

| | Production | | | Estimated potential | |
|---|---|---|---|---|---|
| | Area (ha) | Unit (t/ha) | Total (t/year) | Area (ha) | Production[b] (t/year) |
| Mussels | 2626 | 39.5 | 103727 | 34994 | 1382263 |
| Horse mussels | 300 | 40.6 | 12180 | 4600 | 186760 |
| Ark shells (cockles) | 500 | 8.9 | 4450 | 11300 | 100570 |
| Oysters | 1430 | 13.4 | 19162 | 13190 | 176746 |

[a]Based on estimates by the Brackishwater Fisheries Division, Department of Fisheries, 1970.

[b]Based on present rates of production. Another way to increase production is to improve techniques, a possibility not considered here.

Table 2. Catch (t) of economic mollusc species, 1974–79.

| | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 |
|---|---|---|---|---|---|---|
| Blood cockle | 3130 | 6201 | 12729 | 16646 | 16326 | 19263 |
| Green mussel | 13478 | 46916 | 72542 | 81855 | 49868 | 48266 |
| Oyster | 4398 | 5456 | 6963 | 15889 | 14594 | 9832 |
| Horse mussel | 12887 | 29681 | 43233 | 15711 | 17313 | 12553 |
| Short-necked clam | 13806 | 14307 | 23275 | 17360 | 10654 | 21098 |
| Hoi tok | 4320 | 2532 | 600 | 420 | 225 | 75 |
| Jackknife clam | 36 | 270 | 326 | 336 | 360 | 108 |
| Hoi-lod | 40 | 1 | 1 | 4 | 86 | 158 |
| Venus shell | — | 648 | 255 | 90 | 491 | 550 |
| Other shell | 13 | — | — | 58 | 12 | 32 |

shell (*Donax faba*), and top shell (*Trochus* sp.). The shells of some species are used for decorations. These include top shell (*Trochus* sp.), turban shell (*Turbo* sp.), windowpane oysters (*Placuna placenta*), and *Mytilus*. Species cultured for pearls are *Pinctada margaritifera, P. maxima,* and *Pteria penguin*.

Thailand has substantial areas available for mollusc culture. In 1976, the activity occupied $4.9 \times 10^3$ ha, but the potential area is $6.0 \times 10^4$ ha (Table 1), according to a field study by the BFD.

Mollusc production has fluctuated widely. It gradually increased from $5.0 \times 10^4$ t in 1958 to a peak $2.9 \times 10^5$ t in 1971, and then abruptly declined. It increased again from $5.0 \times 10^4$ t in 1974 to more than $1.0 \times 10^5$ t in 1979 (Table 2). The total value in 1977 was 264 million baht (US$1 = 22.5 baht) and in 1978, 342 million baht (Table 3).

## *Institutions Involved in Bivalve Work*

Coastal land in Thailand is composed of the mangrove forest zone and the muddy or sandy mud flats off the mangrove forest. Coastal aquaculture on these areas is the responsibility of BFD. Generally, shrimp and fish ponds are constructed where the mangrove forest has been destroyed, whereas mollusc culture is usually practiced on muddy or sandy mud flats. In some places, floating-cage culture is also practiced.

Other government agencies directly concerned with mollusc fisheries include six Brackishwater Fisheries stations and the Songkhla Coastal Aquaculture Center. They are responsible for management and development of both fisheries and shellfish. Several universities also work closely with the staff of the Department of Fisheries (DOF) in research and training. At present, the Faculty of Fisheries, Kasetsart University, and the Department of Marine Science, Chulalongkorn, are working on bivalves and related fields. Other universities, including Sri Nakharinwirot and Songkhla, participate to some extent.

In 1982, the International Center for Living Aquatic Resources Management (ICLARM) began to support a project on technical assistance for applied research on coastal aquaculture. This agency will implement the project by means of a special agreement between the Government of Thailand and the German agency for technical cooperation (GTZ).

It is not known when bivalve culture started in Thailand; however, the present systems have been operating for several decades.

Table 3. Catch and value of mollusc production for Thailand (1977, 1978).

| | 1977 | | 1978 | |
|---|---|---|---|---|
| | Quantity (t) | Value (1000 baht)[a] | Quantity (t) | Value (1000 baht) |
| Blood cockle | 16646 | 47135 | 16326 | 59666 |
| Green mussel | 81855 | 90041 | 49868 | 69815 |
| Oyster | 15889 | 88978 | 14594 | 154113 |
| Horse mussel | 15711 | 15711 | 17313 | 19044 |
| Short-necked clam | 17360 | 19096 | 10654 | 31962 |
| Other shellfish | 976 | 2928 | 2670 | 7120 |

[a]22.5 baht = US$1.

## *OYSTERS*

Oyster culture was first attempted in Chantaburi province about 35 years ago and has, since, been introduced to other sandy mud intertidal flats, mostly on the east side of the Gulf of Thailand, particularly in Cholburi Province. Traad, Chantaburi, and Rayong on the east coast and Chumporn and Surajthani on the west coast also have moderate amounts of oyster production from farms. Two species of oyster can be captured from natural beds and cultured: *C. commercialis* and *C. lugubris*. The first, a small species, is commonly cultured along the east coast. On the west coast, the larger *C. lugubris* is produced naturally and on farms in Surajthani Province; it is more expensive than *C. commercialis* and is in great demand for consumption fresh. The spat have been observed along the east and west coasts as well as on the Andaman Sea coast. Spawning peaks in May–July and October–November.

Sites for oyster culture are usually on the hard, stable bottom of intertidal flats, which will support heavy collectors such as cement blocks, stones, or rocks for spat attachment. The collectors should not be exposed for more than 3–4 hours during low tide and should be submerged during high tide so the oysters can feed. Sufficient plankton, provided by mild water movement, in moderately clear water is essential for oyster growth.

Methods of culture in Thailand range from traditional to semitraditional, and the most suitable for a particular area depends on bottom conditions. There are basically four types: those that use stones or rocks as the substratum, those that use wooden stakes, those that rely on concrete blocks, and those incorporating trays. The first method used in Thailand was large stones or rocks, placed on hard, sandy or sandy-mud bottoms. The spat attaching to these materials would be left for 1–1.5 years before being harvested.

Date-palm and bamboo stakes are also used as collectors, in certain areas of Rayong, Ranong, and Surajthani provinces. The stake method is usually practiced on soft or muddy bottoms, and the stakes are pushed into the ground about 0.6 m apart. The spat settling on these collectors are allowed to grow for up to 1 year when they are harvested.

Several kinds of artificially made concrete blocks, such as pegs, rods, and tubes, are employed as spat collectors. A pair of pegs is pushed into the bottom to fix and hold a rod off the bottom, with about 0.6 m between pairs so that there is space for passage and for management of the farms.

The shallow-bottom-tray method is used for parent oysters transplanted to new areas or for young, small oysters. Young oysters, approximately 2–4 cm, are put in a shallow-bottom tray, consisting of a wooden frame with a nylon-net bottom. The trays may be covered with small-mesh nylon net to prevent losses caused by the waves. The trays are held above the bottom by posts.

Oyster farmers need a simple way to determine the best time to place collectors, avoiding attachment of barnacles and maximizing spat collection. BFD staff suggest placing a few collectors several months before spatting season and monitoring them for occurrence of oyster spat, especially in relation to barnacles, which are mostly found before spatfall, gradually decreasing with increasing oyster spat. When suitable numbers of spat are found on the test collectors, the remainder of the collectors can be placed.

## *MUSSELS*

Mussels are a popular and inexpensive protein source for Thai people as well as a feed for poultry, shrimp, and fish. The history of mussel culture in Thailand is not documented, but, at one time, fishing families harvested mussels from fishing gear such as bamboo-stake traps and from rocks or stones in natural beds. As the human population increased, so did the demand for mussel products. Therefore, several culture methods are being investigated, although the ones in common use employ rocks or stakes as spat collectors. Bamboo or date-palm stakes are driven into the intertidal muddy area along the Thai coast, especially in Chachoengsao Province.

Hanging ropes and long lines, which have proved successful in Spain and in Singapore for mussel culture have recently been tried in Thailand, Manila rope being used as a collector (Choncheunchop 1979). After 8 months, about 359 mussels were attached per metre of rope, whereas about 900 pieces attach to 1.4-m bamboo stakes, according to Anant et al. (1980). Thus, the method is not practical in Thai waters at present, but further experiments should be carried out with different rope materials. Both ropes and stakes have one serious drawback: although attachment of mussel spat is usually high during spatfalls, less than half of the initial numbers of spat are harvested because of the competition for space among the growing mussels. Anant et al. (1980) reported that the number of mussels attached to 1.4-m bamboo stakes was reduced from 4000 to 500 after 11 months of growth and that on 1-m Manila rope, the number was reduced from 850 to 350 after 8 months. These figures indicate that at least some of the crowded, young mussels should be transplanted to new substrates for resettlement.

In one experiment, young mussels, 1–2 cm long, were removed from bamboo stakes and placed in a 0.3-m diameter by 1-m long cylindrical net. The net was stretched with iron rings so that the mesh allowed the passage of water and plankton but not the mussels. After 1 month, all the young mussels were attached to the mesh of the net. At this time, the thread holding the net in a cylindrical shape was removed and the net was allowed to hang in the water. This method reduced competition for space and should be studied further so that the findings can be confirmed and methods can be developed that are profitable for the farmers.

Transplanting parent mussels has also been attempted in areas where limited numbers of mussels exist. Usually the spatting season occurs after the rainy season, in July–September and October–March. However, the periods of spawning vary with locality. Detailed studies, by Tanittha (1982), of the reproductive cycle of mussels, carried out on specimens collected from mussel farms at Samaekao, Chachoengsao Province, revealed two spawning periods there: one in July–September and another in November–February. The development of the mussel gonad can be divided into four stages: indifferent; active; ripe; and spawning. This development cycle requires about 1–3 months. Determining the sex of the mussel by the colour of the mantle can be accurate if the gonad is orange or creamy white but is difficult if the colour is deep yellow or between pale orange and creamy white. No hermaphrodite condition was found during the investigation (Tanittha 1982).

Hatchery propagation is not practiced in Thailand, so farmers depend on the availability of wild spat. Two places are considered as nursery grounds: culture beds where collectors are used for culture purposes and natural beds where mussel seeds attach to submerged rocks or stones. In July 1979, transplanted small mussel seeds (2.4–4.1 cm long) were experimentally introduced to Ban Koa Mak Noi, Phang Nga Province. After 70 days, they attained a shell length of 7–8 cm. This rapid increase in size was of interest to the villagers.

Plans are to introduce mussel culture to suitable sites in 23 maritime provinces. At present, several maritime provinces in the inner gulf are the main centres for mussel production. Cholburi, Chachoengsao, and Samutprakarn provinces on the east coast and Samutsakorn and Petchaburi provinces on the west coast of the gulf have suitable mud flats for mussel farms. These areas are usually adjacent to dense and well-developed mangroves. The bottom must be mud or muddy-sand and must not be exposed during the lowest tide. The size of the farm depends on management ability and purpose. Farms range in size from one-third hectare to several hundred.

## *COCKLES*

Cockle culture in Thailand has a 70-year history at least (Amatayakul 1957). Fishing families in Bangtabun district, Petchaburi Province, where natural beds exist, first practiced culture over the intertidal flats. Since then, cockle culture has spread along the west coast of the Gulf of Thailand and the Andaman Sea coast. At present, cockles on farms are said to be semicultured because the seeds are collected from natural spatfall areas and then sown on prepared grounds. Cockle farms of maritime provinces along the west coast of the inner gulf depend on cockle seeds collected from adjacent areas; however, cockle farms in Satul Province on the Andaman Sea coast depend on seeds imported from Malaysia.

The highest cockle production is currently in Satul Province; however, farmers in Petchaburi and Samutsongkarm provinces also culture cockles. The size of farms is generally 1–5 ha for family operations and 30–100 ha for commercial operations.

Cockle culture in Thailand could be expanded if the broadcast or sowing method were used more widely not only on natural intertidal mud flats but also on elevated central areas of shrimp ponds. The former commonly extend along the coastline of tropical countries, especially where mangrove forests exist. The extent of intertidal mud flats depends on geographic conditions and sedimentation. The thicker and denser the mangrove forest, the wider the intertidal mud flats (Anant et al. 1980). The areas already under cockle culture are fenced by the farmers with 50-cm long bamboo stakes to prevent the escape of cockles from the culture beds. A guard house is also sometimes necessary to prevent losses to nearshore trawling and dredging operations.

Also, shrimp ponds have an elevated central portion, surrounded by a ditch, and shrimp farmers can use this central area for cockle culture (Chomdej and Anant 1978). The elevated area is fenced with 50-cm bamboo stakes. Cockle seeds, 2–3 cm, are sown in the area and then harvested after 5–6 months along with the shrimp. This method has been practiced for about 5 years in the Klongkone district, Samutsakorn Province. The seed used is larger than that for cockles cultured on natural intertidal flats (usually about 300–400 pieces/L), but yields receive a higher price because of better consumer acceptance.

The bottom substratum for cockle culture must be muddy-silt, that is, high in organic matter and nutrients, and the topsoil must be soft and grey. Cockles must be able to move freely to a deeper layer of the bottom to escape enemies, avoid desiccation during low tide, and avoid unsatisfactory environmental conditions. An excess of empty shells should not be left on the culture grounds because these obstruct the movement of the cockles. Cockle farms that have been used for a long time have many empty shells, and these should be removed. At harvest, farmers can gather empty shells as well as marketable-sized cockles. Amatayakul (1957) described conditions that indicate suitable sites for cockle culture: a layer of soft grey mud 15–30 cm thick; moderate water movement; water 2.0–2.5 m deep during high tide; and bottom exposed during low tide.

## *Management*

For each method of oyster culture, two or three workers are usually hired to remove fouling animals, especially barnacles, from the collectors. Also, some sedimentation of small particles and blue-green algae must be cleaned from the collectors for good oyster growth. Market-sized oysters are removed piece by piece at harvest. An average of $3.0 \times 10^3$ kg/rai (19 t/ha) is harvested annually. Thailand still has a large potential area of intertidal flats suitable for oyster culture — reportedly 80 000 rai ($1.3 \times 10^4$ ha).

In the common stake method of mussel culture, bamboo poles are driven into the bottom 0.5–1.0 m apart. On a 1-rai farm, about 1600 poles are used (10000 poles/ha). When long bamboo poles are used, spaces between farms are needed for navigation. After the spat settle, the farmers pay little attention to management and simply wait until harvest. However, some farmers harvest part of the crop of mussels early (2–4 cm long) for poultry feed. One diver wearing goggles or a face mask dives to the bottom and cuts the bamboo poles, leaving 1 m of pole with attached mussels to reach market size. A worker in the boat lifts the upper portion, with the young mussels attached, into the boat and removes the mussels with a type of shovel. Mussel production varies from $1.4 \times 10^3$ kg to $6.0 \times 10^3$ kg/rai (8.6–37.7 t/ha) annually. The variation in production results from differences in the depth, monsoon season, and amplitude of tides, all of which affect spatfall on the poles. However, mussel production in Chumporn Province once reached $3.1 \times 10^4$ kg/rai (19 kg of mussels/pole).

The broadcast or sowing method is practiced only for cockle culture, and the management or layout of farms has already been mentioned. However, areas where cockle farms have long been located should be improved, as some areas have had problems with increased silt and sedimentation and the accumulation of broken twigs and mangrove leaves. Moreover, after dead cockles rot, empty shells accumulate on the bottom. These should be removed. Traditional methods of cockle culture yield $5.0 \times 10^3$ kg and $17.5 \times 10^3$ kg/rai (31 t/ha and 109 t/ha) annually for small-scale and commercial-scale farms, respectively.

## *Problems and Constraints*

Attention to coastal aquaculture by fishing nations, such as Thailand, has increased as capture fishing has increasingly become less feasible. The prices of oil-based fuels have risen rapidly, and the coastal nations of the world have all declared exclusive economic zones, charging fees for access to their waters and, in some cases, excluding other nations entirely. Development of mollusc culture is one method of increasing coastal animal-protein production. Different traditional methods for the culture of economic mollusc species have been improved and developed by the introduction of modern techniques. However, the most important factor is the ecology of the area. Several culture areas are now polluted by industrial and domestic wastes, and, to some extent, highly turbid waters have resulted from mining activities. Therefore, in addition to farm management, government assistance is required to improve environmental conditions.

Intertidal zones are the only habitats suitable for mollusc culture. Coastal waters are also the productive zone where nutrients, phytozooplankton, and larval and juvenile stages of coastal animals, as well as true coastal species, exist. These areas — nursery grounds or natural cradle for young stages of aquatic animals — are often adversely affected by human activities, which also affect mollusc culture.

Except for sales under moderately hygienic conditions at the Fish Marketing Organization (FMO), there are no mollusc markets that handle the product with a high degree of sanitation. The molluscs from culture beds are harvested from the farms and then transported without ice to local markets. They are only kept moist during transportation.

Molluscs are sold either fresh or cooked. Mussels and cockles are commonly sold in their shells in local markets. Shucked molluscs may be boiled and dried for preservation. Oysters, mostly *C. commercialis*, are usually shucked and frozen, and then sent greater distances. However, *C. lugubris* is commonly sold in the shell for consumption. There is little sanitary control because at present molluscs are not markedly affected by industrial and domestic pollutants. Heavy industries are starting in certain provinces, and, thus, monitoring of pathogens and heavy metals will be needed.

## *Future Plans*

The mollusc-culture development plans of the Royal Thai Government aim at creating greater employment opportunities and increasing production. Many potential areas should be developed for coastal aquaculture to improve the socioeconomic conditions of the fishermen. To accomplish these objectives, BFD under the Ministry of Agriculture and Cooperatives was set up with full responsibilities for promotion and extension of coastal mollusc-culture development.

Oyster culture is one of the inexpensive coastal protein sources. Annual *C. commercialis* production is reported to range from 16.7 t/ha to 21.5 t/ha. The annual investment in oyster culture with cement blocks is about 8000 baht/ha, which could give a net income of 59000 baht to the farmer (Chomdej and Poocharoen 1979). Although fishermen are interested in oyster culture, supplies from farms are still insufficient to meet the market demand.

Among bivalve culture operations, commercial cockle culture could yield the highest income. But only certain areas far from industrial and domestic wastes, such as the intertidal flats of the outer gulf and the Andaman coast, are suitable for development, and lack of cockle seeds is a problem. At present, cockle farmers, especially in Satul, must import cockle seeds from Malaysia.

Mussels are consumed locally because of their low market price. The mussel farmers may harvest young mussels as feed for poultry and leave some to grow to marketable size for human consumption. Because of space competition between mussels on collectors, methods should be sought to maintain a proper density of mussels throughout the growing cycle.

# APPENDICES

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# 2. PAPERS SUBMITTED AT THE WORKSHOP

These papers were presented for discussion purposes. Edited versions of some of these papers have been included in the proceedings. Where more than one paper was presented per country, the papers have been combined by the editors into a single country report.

*Status of Bivalve Culture in Thailand* **Anant**
*High-Density Depuration Trials on Green Mussels* Perna viridis *(L) Using Ultraviolet Radiation* **Cheong**
*Bivalve Culture in Singapore* **Cheong**
*Manual on Mussel Farming in Singapore* **Cheong**
*Preliminary Report on the Induced Spawning of the Green Mussel,* Perna viridis *(L) in Singapore* **Lim**
*Bivalve Culture in Papua New Guinea* **Lock**
*Bivalves and Bivalve Fisheries in Bangladesh* **Masud**
*Report of Trials on Culturing Green Mussels* (Perna viridis) *in Laucala Bay near Suva* **Navakalomana**
*Bivalve Culture in Eastern Canada* **Newkirk**
*Status of the Mollusc Cultures in Malaysia* **Ng**
*Artificial Cultivation of Bivalves in China* **Nie**
*Present Status of Bivalve Production in Sarawak, Malaysia* **Pang**
*Oysterculture Techniques in Guangdong* **Qiu**
*Bivalve Exploitation* **Sadacharan**
*Bivalves in the Philippines: Oysters and Mussels* **Serna**
*Present Status of Marine Bivalve Culture in India* **Silas**
*The Tolerance to and Uptake of Lead in the Green Mussel* (Perna viridis) *(L)* **Tan**
*Status of the Sabah Shellfish Culture* **Tang**
*Reproductive Cycle of Mussel* (Mytilus smaragdinus) *at Samaekao, Chachoengsao Province* **Tanittha**
*Present Status of Bivalve Culture in Indonesia* **Unar**
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