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CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

(Indian Council of Agricultural Research)

P.B. No. 2704, Cochin 682 031, India

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# TECHNOLOGY OF CULTURED PEARL PRODUCTION

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## INTRODUCTION

In the recent years, there has been an increasing awareness on the possibilities of pearl culture in countries which had not hitherto shown any interest. To cite some examples, the Republic of China has already made inroads into the freshwater pearl market and the United States of America is getting into it (Ward, 1985). The traditional Japanese production of marine cultured pearls has declined since 1966 (Mizumoto, 1979). Production in countries in the Indo-Australian Archipelago from Burma to Australia has also declined. On the other hand, some of the island countries in the Western Pacific are concentrating on production of highly priced pearls. Nearer home, Bangladesh has a programme on freshwater pearl production (Ahmed, 1982). India has a moderate R & D project as well as a commercial venture arising out of the technological success in 1973 (Alagarswami and Qasim, 1973; Alagarswami, 1974 *a*). This paper reviews the recent developments in pearl culture technology in the world with emphasis on the Indian situation, and attempts a comprehensive presentation of the subject.

## HISTORICAL

The simple, yet undescribably beautiful, pearl was discovered by man of the earliest civilization even before 3500 B. C. The Vedas of India, the Bible and the Koran make several references to pearls as objects of adoration and worship, as also the barometer of wealth. On the other hand, pearls had also been used in the burial rites for the dead as found in the excavated coffins belonging to 2300 B. C. in Iran and in the crematory basins of the American Hopewell Indians (Ward, 1985).

The glory of pearl was at its zenith in the Roman empire and the historian Pliny the Elder had remarked that the coffers of the nation were being emptied for the import of pearls. The story of Cleopatra dissolving the pearl of one of her ear-rings in wine and drinking it on a wager with Mark Antony has gained wide currency when one talks of pearls. There has been international trading in pearls several centuries ago among countries such as Rome, Greece, Egypt, Persia, China and India by sea as well as land routes. Persian Gulf was one of the most popular centres of pearl production, as also the Gulf of Mannar. Bombay developed as a financial and marketing centre for the pearl trade of the Orient.

## ORIGIN OF PEARL

People believed that pearl was conceived by the oyster when it received a drop of rain or dew. Pliny, and later Columbus, shared this commoner's belief. One of the Vedas stated that 'when the ocean roared against Paranjaya with lightning, therefrom was born this golden drop (of pearl)'. Beginning from the 16th century, certain theories with scientific orientation were put forward. These theories stated that the pearls were the 'gallstones' of the oyster; surplus 'fluid' developed by the oyster but not discharged formed into pearls; they were undischarged eggs of the oyster; sand grains got into the shells and formed pearls; and that parasites or their eggs or other organic matter formed the core of the pearls. From the dawn of the present century, the theory that the larval cestodes formed the nucleus of pearls gained wide acceptance. Herdman (1903-1906) has made an extensive review of the origin of pearls.

In 1907, Tokichi Nishikawa gave the most plausible scientific explanation on the origin of pearls (Cahn, 1949; Alagarswami, 1970). His theory which has come to be known as the pearl-sac theory explains

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*that* a *pearl* is formed when the pearl-secreting cells of the mantle migrate into the body of the oyster under the stimulus of a foreign body and form a pearl-sac by cell division around the foreign body ; the pearl-sac secretes nacre which gets deposited on the foreign body and in course of time a pearl is produced.

## Cultured Pearl

The pearl produced by the pearl oyster in the manner described above is a natural pearl. These pearls are produced either within the mantle, or in other soft tissues of the oyster, or between the mantle and the interior of the shell. Such production is accidental during the life of the oyster and, therefore, rare in occurrence. They are generally small in size and irregular in shape, and larger and shapely ones are still rarer to find.

'Cultured' pearl is caused to be produced in the pearl oyster by human interference. Gaining the insight into the cause of pearl formation, it was elucidated that the pearl-secreting cells of the mantle and the foreign body are the two components that *in vivo* set the process in motion. It was found that cut pieces of the mantle epithelium would provide the pearl-secreting cells and that processed shell beads would be accepted by the oyster as the foreign body. Through careful surgery, the mantle piece (graft tissue) and the shell bead (nucleus) are implanted into the gonad of the oyster to lie in contact and in proper orientation. On return to the sea, in a short while, the outer epithelium of the graft tissue spreads over the shell bead and covers it forming the pearl-sac. This epithelial tissue, deriving its energy needs from the surrounding tissue, begins to perform its routine function of secretion of mother-of-pearl or nacre which gets deposited on the nucleus in the form of concentric microlayers, leading to the formation of a pearl. The quality of nacre being the same between the pearl formed in nature and the one produced through human manipulation, the difference lies only in the nucleus. This pearl has come to be known as the 'cultured' pearl to specifically denote the process of culture by which it is produced. Due to a deliberate choice, based on economic and market considerations, large, round pearls are produced by the culture techniques by using appropriate nuclei. The generic term 'cultured pearl' was used for the first time in 1920s for the pearls produced in the Japanese pearl oyster 'akoya gai' and marketed in Europe. The term 'artificial pearl' does not denote a cultured pearl, but would refer to cheap imitations made of plastics, glass etc, with an artificial shine.

## Pearl producing Molluscs

Pearls derive their origin from the composition of the shells of the molluscs which produce them. The pearl generally has the same structure as that of the innermost layer of the shell, called the nacreous layer, except that the nacre is deposited in concentric layers around the core substance in the former but on the flat surface of the shell in the latter. Therefore, any mollusc with an external shell is capable of producing a pearl but the quality of the pearl is defined by the quality of the nacre. Thus a pearl produced in the clam *Donax faba* which is entirely composed of prismatic layers of calcite crystals or organic material has no value as gem and is at best referred to as a shell concretion or a gall (Alagarswami, 1965). Also the pearl as large as a golf ball occasionally found in the giant clam *Tridacna* will not be considered as gem. The mussels *Mytilus* and *Perna* produce small pearls but not of quality. They are more a nuisance to the people who eat the meat. Windowpane oyster *Placuna placenta* harbours many tiny pearls which are valued as a source of pharmaceutical use in the indigenous system of medicine than as gems (Sriramachandramurty, 1978). The fan-shell *Pinna*, the wing-shell *Pteria*, the pink conch *Strombus* and the abalone *Haliotis* occasionally produce pearls of some value (Abbott, 1972). The freshwater mussels *Hyriopsis, Cristaria, Parreysia, Unio, Tritogonia, Amblema, Quadrula, Megalonais* and *Pleurobema* produce pearls of gem quality (Alagarswami, 1970). At the end of this scale of quality and value are the pearls produced in the marine pearl oysters *Pinctada fucata, P. margaritifera* and *P. maxima*.

## Techniques of Culture of Freshwater Pearls

The Chinese were the first to practise a sort of pearl culture in freshwater mussels in Lake Tahu in Central China in the 12th century A.D. As reported by Abbott (1972), 20-cm long mussels were reared in bamboo cages. With a forked bamboo stick, small pellets of hardened clay and small outlines of Buddha made of tin were placed either in the centre of the mussel or between the inner shell and the mantle. The cages of mussels were suspended in the canals for about a year after which they were opened. The tiny nacre-coated images of Buddha were sawed off the shell, hung on necklace strands and sold in the temple markets.

The Chinese themselves did not make any further progress in terms of technology and production until the 1960s. Freshwater pearl culture *per se* was developed in Japan in Lake Biwa in 1935 using the mussel *Hyriopsis schlegelii*. Later it was extended to Lake Kasumigaura in 1963. The Japanese freshwater pearl production reached 4.0 t in 1967, 7.2 t in 1971 and 5.5 t in 1977 (Kafuku and Ikenoue, 1983). The Japanese technique involves implantation of graft tissues cut from the mantle of a donor oyster into the mantle of the recipient oyster. No nucleus is used in this operation. The inner epithelium and the connective tissue of the graft disintegrate into a tiny mass around which the outer epithelium builds up the pearl sac. The nacre secreted by this sac gets deposited inward on the disintegrated mass which serves as the core around which the pearl is formed. Since, no shell bead nucleus is used, the freshwater pearls of this kind are irregular in shape and marketed as 'natural' pearls. More recently nucleation technique similar for the *Pinctada* pearl has been developed, although with less percentage of success, for the freshwater pearls (Kafuku and Ikenoue, 1983 ; Ward, 1985).

The Republic of China has made inroads into the freshwater pearl market since interest in pearl culture was revived in the 1960s. As reported by Ward (1985), China leads the world in freshwater pearls, producing 50-80 t a year as against the Japanese production of about 5 t in 1984. To quote Ward (1985) : '...... the Government-controlled Chinese industry works to improve culturing methods and has built an artificial lake for research 60 kilometers southwest of Shanghai. Low-tech labour-intensive operations characterize China's pearl business'.

Bangladesh, during 1975-80, established a pilot project on the culture of pearl-bearing mussels *Parreysia corrugata* and *Lamellidens marginalis* (Ahmed, 1982). The same author reported that, in 1964, the natural pink pearl production from 98 mussel collection centres was about 165 kg.

Ward (1985) reports of U.S.A. entering into freshwater pearl production based on the mussel resources of several species in River Mississippi.

Although no interest has as yet been evinced in freshwater pearl culture in India, with the vast riverine and lacustrine water resources it should be within reach for the country to develop a project for a proper survey of the freshwater mussel resources and a production programme.

## TECHNIQUES OF PEARL OYSTER FARMING

Pearl culture in the sea is carried out on three major species of pearl oyster, namely *Pinctada fucata*, *P. maxima* and *P. margaritifera*. Other marine species employed to a very limited extent are the abalone *Haliotis discus* and the wing-shell *Pteria penguin*. The latter two species form subsidiary culture to the major species in some centres and production is not of much significance.

An attempt has been made to schematically represent the different systems involved in pearl culture. Fig. 1 represents the five major subsystems, namely pearl oyster stock (arrivals), mother-oyster culture, surgery, post-operative culture and pearl harvest. In Figs. 2-5, each of these subsystems has been elaborated, combining mother-oyster culture and post-operative culture as the farming operations are similar for both. These have been drawn to represent the general practices of pearl culture in different parts of the world.

### *Rafts*

From the on-bottom farming adopted by Kokichi Mikimoto in the early phase of pearl culture in the 1890s, the system has developed into raft culture which has enabled the use of the water column for growing the pearl oysters. The method of raft culture for the Japanese oyster, *P. fucata* has been described by several authors (Cahn, 1949, Alagarswami, 1970 ; Wada, 1973 ; Mizumoto, 1979 ; Kafuku and Ikenoue, 1983). The same has been adopted in India with some modification, using single rafts with independent moorings, to suit the sea conditions of the experimental farm area at Tuticorin (Alagarswami and Qasim, 1973). While the basic structure of rafts has remained the same, developments have been towards achieving greater buoyancy of rafts and more durability of the floats. While bamboo and logs continue to form the frame, the wooden barrels which were common in the 1960s in the Japanese farms have been totally replaced by styrofoam floats. More recently, steel pipes have been used instead of logs but it is not yet common (Mizumoto, 1979). The depth of farms ranges from 10-20m in the Japanese bays, with a general oyster suspension depth of 2-6 m which is varied for specific purposes.

The Australian pearl culture farms for *P. maxima*, as also the farms in Papua New Guinea use similar raft culture system in the bays. The tidal amplitude in this region is a maximum of 34 ft and hence the rafts are moored by iron anchors of special design. (Hancock, 1973).

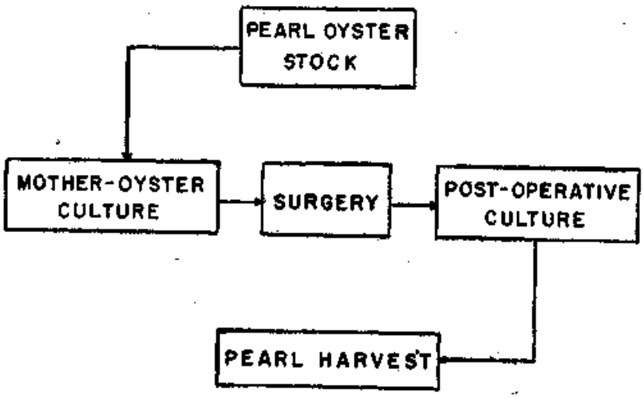


FIG. 1. The five major subsystems of pearl culture system.

*Long lines*

The long line is practised in the open sea such as the Seto Inland Sea of Japan and the system is stronger than the rafts under rough sea conditions. It consists of lengths of ropes attached to spherical plastic floats at intervals. These are interconnected and moored appropriately to keep the distances between the rows of ropes and floats.

*Underwater platforms*

Culture of *P. margaritifera* in the lagoons of Tuamotu Archipelago of French Polynesia is carried out on underwater holding systems erected at depth of 40 ft (AQUACOP, 1982; Ward, 1985). This follows the method developed by FAO (1962) for the same species in the Dongonab Bay of Sudan. Underwater growing trays using galvanised wireweld mesh were erected at depths of 1.8—6.0 m and supported off the bottom by concrete blocks (FAO, 1962). William Reed who had been responsible for this work on *P. margaritifera* in Sudan has subsequently shown interest in developing similar on-bottom culture of *P. maxima* in the Australian waters.

*Pearl oyster baskets*

The pearl oyster, being a sedentary organism, can be held in place using appropriate holding systems. In raft culture the oysters are held in baskets or their variations in form which are suspended from the rafts at the required depths. The simplest of the holding systems was the 'pearl string' in which pearl oysters were individually strung along the length of ropes which were suspended from the rafts (Alagarswami, 1970). The practice is still in vogue for the small *P. maxima* in Australia (Hancock, 1973) and for 9-cm long *P. margaritifera* in French Polynesia (AQUACOP, 1982).

The variations of holding baskets are too many for any brief description. Some of them are: typical bamboo baskets; cuboid baskets with metal frame and webbed with synthetic twine; wire net baskets; book-type frame nets with partitions; multilayered collapsible nets with partitions; plastic covered wire mesh with partitions for vertical suspension; and lantern-nets for spat rearing. The factors governing the choice of suitable types and sizes are essentially the size of oyster (type of basket changes with growth of oyster), the density of oysters (density is reduced with growth), individual or bulk care of oysters as required, free flow of water, current velocity, protection from predators

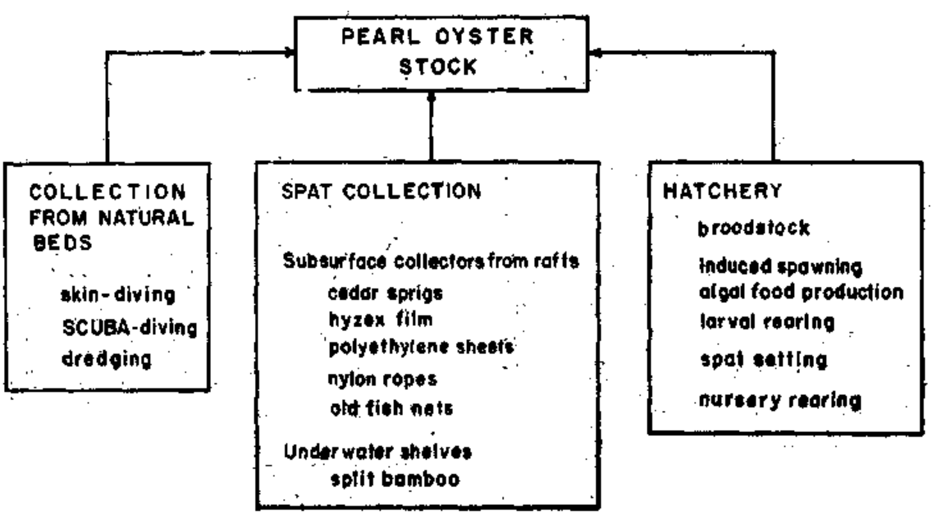


FIG. 2. Steps/methods for raising pearl oyster stock.

facility for easy examination, cost and durability, and maintenance requirements.

*Environmental parameters*

Starting from surface winds to the amount of trace elements in the seawater, every environmental factor —physical, chemical and biological—influences the success of pearl oyster farming and pearl production (Matsui, 1958). These factors determine the techniques to be used in farming the oysters. The choice of raft, longline or bottom platform or any other method depends on coastal configuration, winds, tides and waves, protection from the preceding three factors, depth, and current direction and velocity. The natural phenomena such as monsoons, cyclones and typhoons put limitations on the techniques and allow only a narrow choice of farming methods in marine pearl culture in areas visited by these. In pearl culturing countries, bays or lagoons with adequate depths are generally chosen to establish farms as in Japan, Australia and Philippines. Archipelagic areas with chains of islands are also ideal situations. Inland sea, such as the Seto Inland Sea, is manageable within the present limits of technology. Open sea farming or offshore farming for pearl oyster is still not within techno-economic limits of pearl culture. In the Indian situation, the Gulf of Mannar though not ideal on the above terms, has sustained year-round pearl oyster farming with satisfactory results. Better results would be possible in the Andaman and Nicobar Islands (Alagarswami, 1983) and in Lakshadweep from the viewpoint of farming technology.

*Mother-oyster culture*

The phase of culture from spat to size when the oyster becomes suitable for nucleus implantation operation is generally referred to as mother-oyster culture (Alagarswami, 1970). The initial stock for rearing may come from various sources such as natural beds, spat collection on cultch materials in the subsurface waters and hatchery. The oysters that come from the natural beds are generally the best, but due to fluctuations in the resource and the effort required in collection the method is not dependable as a sole source. This is the only method available and practised in the case of *P. maxima* in the region of Indo-Australian Archipelago and, therefore, the pearl culture farms face shortage of oysters. The spat collection at subsurface waters has been very successful for *P. fucata* in Japan since the end of World War II, but recently the shift has been towards hatchery production. *P. margaritifera* stocks are raised by this technique in French Polynesia (AQUACOP, 1982), Papua New Guinea (Lock, 1982) and Sudan (FAO, 1962). Hatchery production of *P. fucata* in Japan is practised on a commercial basis and the technology is yet to be successfully adopted for *P. maxima* and *P. margaritifera*. Hatchery technology for *P. fucata* of India has recently been developed and has proved successful for large-scale production (Alagarswami *et al.*, 1983).

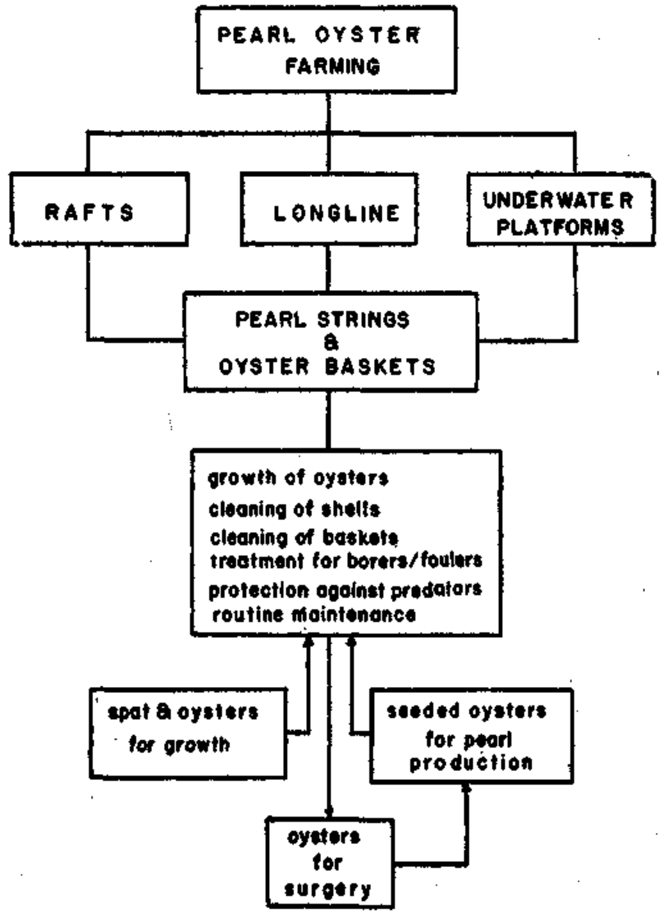


FIG. 3. Steps involved in pearl oyster farming (mother-oyster culture and post-operative culture).

If one starts from spat produced by collection from the sea or raised in the hatchery generally the duration of mother-oyster culture is as long as the duration of post-operative culture for producing medium sized pearls of about 6 mm diameter. To minimise the problem of natural mortality due to various causes, including that caused by heavy biofouling and boring organisms and occasional predators, it becomes necessary to farm the oysters during the pre-operation phase in areas and in a manner which would provide optimum conditions for growth and survival.

In the Japanese farms the practice was to use oysters of about a year-and-a-half weighing, 30 g at the surgery (Alagarswami, 1970). Depending on needs, oysters of 25 g also have been used. In the more recent years, the size has come down still due to competition in pearl production. In the Indian work, oysters of about 20 g have been found the ideal size for surgery (Alagarswami, 1974) for production of pearls of medium size and for double implantation.

### TECHNOLOGY OF PEARL PRODUCTION

*Developments in implantation techniques*

Shell beads are used as nuclei for free, spherical cultured pearls in all the regions. These beads are made out of freshwater mussel shells from the Tennessee and Mississippi Rivers in U.S.A. The pigtoe, washboard, butterfly, three-ridge and dove shells, particularly the first two, have been found ideal raw material for production of nuclei (Alagarswami, 1970; Ward, 1985). The shells are imported into Japan and cut and processed into beads of different diameters with great accuracy. In India, preliminary experimental success has been achieved with the sacred chank shell (Velu *et al.*, 1973). Other potential species is the giant clam *Tridacna*.

Originally, the shell-bead nucleus was fully wrapped with the mantle tissue and implanted into the visceral mass of the pearl oyster. Later it was found that a small piece of mantle would serve the same purpose. The size of the mantle piece (or graft tissue) was progressively reduced and standard sizes of pieces were evolved for the different sizes of the nucleus. Generally pieces of 3 x 2 mm are adequate for medium size range of nuclei. So also the thickness of the epithelium was considered important in determining the quality of the pearl. If it is thin (2-10 $\mu$m), the surface of the pearl would be good. If it is more than 20 $\mu$m thick, the pearl would be dull and badly coloured (Shirai, 1970). On implantation, the inner epithelium and connective tissue of the mantle piece would disintegrate and get absorbed in the surrounding tissue, leaving the outer epithelial cells to proliferate and cover the nucleus fully, forming the pearl-sac. Generally, the graft tissue is inserted first in position after which the nucleus is implanted. But some do practise the reverse process depending on convenience. For a long time water soluble eosin was used in maintaining the mantle pieces from time of preparation to time of insertion which is normally less than 10 minutes

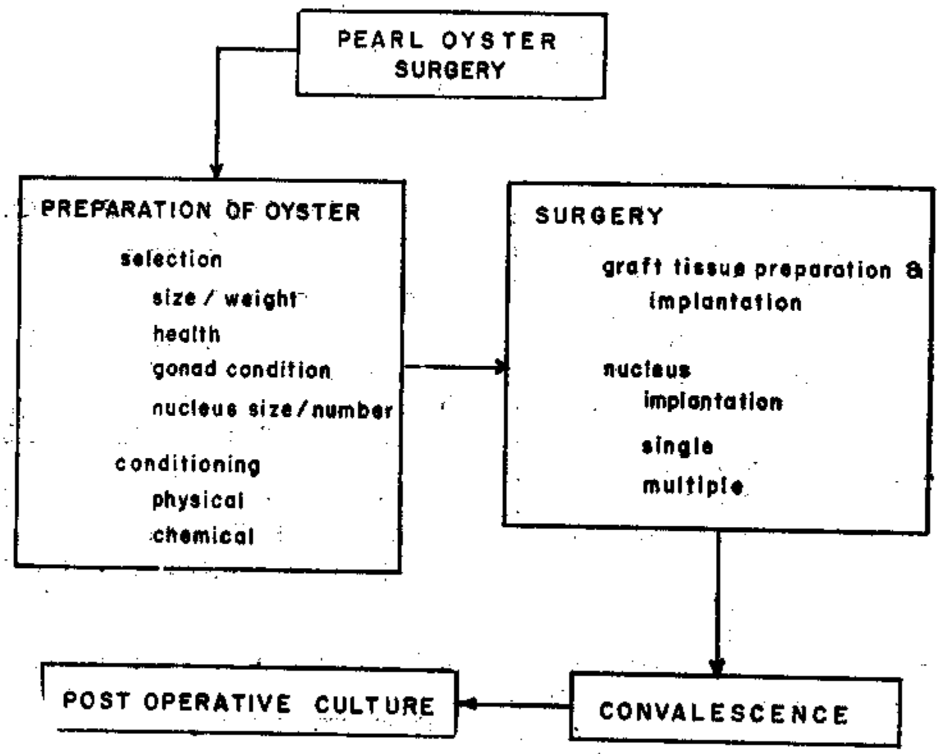


FIG. 4. Steps involved in pearl oyster surgery.

(Alagarswami, 1970). Eosin has a sterilising effect and also enables visual observation of the passage of the piece during insertion in many cases. Now mercurochrome or other antibiotic solution is used for the purpose (Kafuku and Ikenoue, 1983).

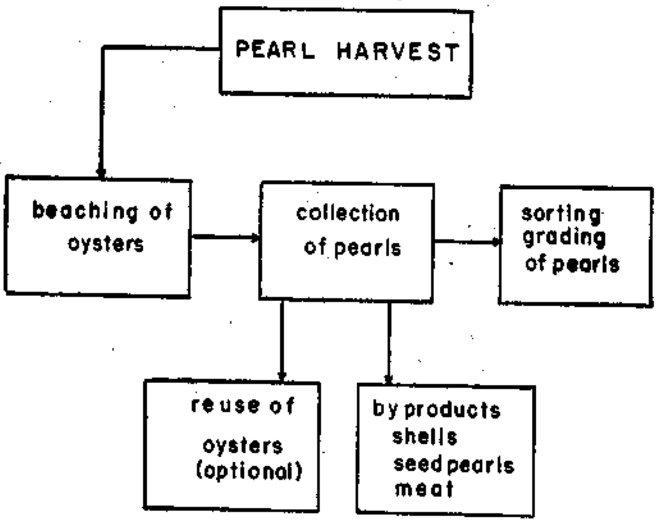


FIG. 5. Steps involved in pearl harvest.

*Conditioning*

Pre-conditioning of pearl oyster for surgery is an essential process in pearl culture. It is aimed at discharge of gametes and lowering the metabolism of the pearl oyster (Alagarswami, 1970). The visceral mass is largely occupied by the gonad during the active reproductive phase. Gonad takes the major nucleus load. Hence it is necessary to discharge the gametes for getting the required space for the nuclei to be implanted and also to avoid oozing of gametes through the surgical incision. Lowering of metabolism is done to reduce the reaction of the oyster during surgery, particularly the reaction of adductor and retractor muscles. Thermal stratification in the temperate waters enables achieving the above two processes through maintenance of oysters for short durations in different temperature regimes at different depths. At the higher surface temperatures the oysters spawn naturally. Crowding and suspending in low productive areas for starving the oysters are common practices. In the tropics where such thermal stratification is not present in the inshore waters, this is achieved through narcotisation using menthol crystals. Discharge of gametes of mature oysters has become possible with the development of physical or chemical stimulation techniques (Morse *et al.*, 1976 ; Alagarswami, 1980).

*Techniques for different species*

Pearl production techniques differ from species to species and also on the types of cultured pearls aimed for production. The most common one employed on *Pinctada fucata* (Gould) is for production of free, spherical pearls of diameter range about 2—10 mm. This species being the smallest (maximum about 8 cm dorsoventrally) among those employed in pearl culture, it is not suitable for production of half-pearls. Hence all the pearls are grown inside the gonad. About 1-5 pearls can be produced in a single oyster depending on its size (Alagarswami, 1974 *b* ; Mizumoto, 1979).

The largest among the pearl oysters is the goldlip *Pinctada maxima* which produces the South Sea pearls of size up to 20 mm. Both spherical pearls and half-pearls are produced in this species. The latter are from nuclei glued to the inner aspects of both the right and the left valves. These oysters are used for a second or even a third crop of pearls because of their size and longevity (Hancock, 1973).

The blacklip pearl oyster *Pinctada margaritifera* is emerging as a species of considerable importance in pearl culture because of the fine free, black pearls of 10-16 mm produced by them (Ward, 1985). The species was considered 'more difficult to obtain, to raise, and to use for culturing purposes' (Shirai, 1970). However, in the recent years, techniques are continuously being upgraded on implantation and growth control of oysters and pearls in French Polynesia (AQUACOP, 1982).

## MODERN TRENDS IN PEARL CULTURE TECHNOLOGY

*Freshwater pearl culture*

Due to increasing realisation of the potential of pearl production in the freshwater mussels, there has been an expansion of this industry, particularly in the Republic of China. As stated by Ward (1985), the U.S.A. is entering the field. Bangladesh, with vast reverine resources, has started a programme (Ahmed, 1982). In terms of technology, nucleated pearl production is gaining momentum with advances made in surgical and post-operative procedures in the recent years (Kafuku and Ikenoue, 1983). Pollution is the major problem in freshwater pearl culture.

*Marine pearl culture*

The trend in Japan is clearly one of stabilization of production and improvement of quality. Pearl production which reached a peak of 127 tonnes in 1966 had fallen to 34 tonnes in 1973 and the number of management units in the same period came down from 4710 to 2526 (Mizumoto, 1979). Wada (1973) remarked that the cultured pearl industry in future will try to establish greater control over the colour and lustre of pearls by a combination of the management of the physiological and inherited qualities of molluscs in natural beds or by tissue culture of the outer epithelial cells. Mizumoto (1979) concluded that for the prosperity of pearl farming, besides improving culture techniques, simultaneous studies should be made in various areas and under different environmental conditions to resolve problems of pearl qualities and that steps should be taken to secure good culture grounds and preserve them from environmental deterioration. These statements clearly indicate the directions in which technological improvements are being made.

Improvement of quality of cultured pearls, thereby its value, is receiving the highest priority in Japan. Having faced the pearl crash after 1966 caused by over production and poor quality, the Japanese scientists are very conscious on this aspect. Application of genetics has received due recognition. It has been confirmed by selective breeding experiments that pearls without yellow pigments can be produced more effectively (Wada, 1975, 1984, 1986). Results of the genetic experiments would lead to improvement of pearl oyster stocks through hatchery production, resulting in stocks yielding pearls of desired quality, resistant to microbial diseases, adaptable to environmental stress, having high growth potential and other desirable characteristics.

A good deal of research has been carried out on mineralisation and spectral characteristics of pearls to understand the formation of organic matrix and crystalline microlayers, ultrastructure of nacre and the causes of colour, lustre and iridescence of pearl (Wada, 1972, 1983). The nature and function of extrapallial fluid secreted by the outer epithelium of the mantle, the root cause of pearl formation, is under detailed investigation. These studies are bound to improve the quality of pearls through application of biotechnology.

Tissue culture of pearl oyster mantle has been pursued for many years with the object of isolating and culturing the cells responsible for the secretion of fine aragonite crystals of calcium carbonate which gives the gem quality to the pearl. *In vitro* culture of mantle epithelium of *P. fucata* resulted in sheet-like accumulations of a large number of migrated cells derived from the explant consisting of roundish epithelial cells, pigmented epithelial cells, spindle-shaped muscle cells or string-like muscle cells and deposition of organic substances has clearly been seen (Machii, 1974). Colonies derived from epithelial-like cells have been established for *P. fucata* and *Haliotis discus* (Machii *et al.*, 1985). It has been recently reported that the following process has been developed: a fraction of cell suspending liquid, arising out of mantle epithelial tissue culture, is injected around the nucleus implanted in the gonad of the pearl oyster, and the cells in suspension would form the pearl sac (*Technocrat*, 18 (4) 1985). Success on these lines will open up possibilities, of controlling the quality of pearls.

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