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JANUARY 1987

PEARL CULTURE

CENTRAL MARINE FISHERIES RESEARCH INSTITUTE

(Indian Council of Agricultural Research)

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

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Edited by: K. ALAGARSWAMI

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PREFACE

The Central Marine Fisheries Research Institute made a significant achievement in developing indigenously the technology for pearl culture in the year 1973. The success was heralded as one which can lead to the establishment of a new industry for production of cultured pearls in the country. This hope materialised in later years and a joint venture commercial project by Tamil Nadu Fisheries Development Corporation and Southern Petrochemical Industries Corporation has been established in the year 1983.

The famous British marine biologist late James Hornell, as early as in 1916, remarked that pearl culture is the only way of making the pearl oyster resource of the Gulf of Mannar economically remunerative. Subsequently, starting from 1938, attempts were made in India to develop the technology for pearl culture. These efforts by the Department of Fisheries of Governments of Tamil Nadu and Gujarat, respectively at Krusadai and Sikka, did not result in the development of techniques for production of spherical cultured pearls, but important contributions on the pearl oyster biology were made. Against this background the CMFRI started an experimental research project on pearl culture in 1972 at Tuticorin which gave the early breakthrough in 1973. Since then, the Institute developed a strong research centre for pearl culture at Tuticorin and also collaborated with the Department of Fisheries, Government of Tamil Nadu, in the ICAR *ad hoc* Scheme on Pearl Culture during 1973-1978. Several lines of investigations on pearl oyster resource, biology, ecology, farming and pearl production were taken up simultaneously under expanded research projects which had yielded very valuable results. The most important of these is the success achieved in 1981 on the development of hatchery technology for production of pearl oyster which has the potential for solving the problem of non-availability of oysters from the natural beds. The technology has been tested repeatedly over the last five years and scaled up for large-scale production. This has also led to a new programme of sea-ranching of pearl oyster seed on the natural beds in the Gulf of Mannar for repopulating the beds as well as understanding the causes for the fluctuations of the resource.

A number of research papers on pearl culture have been published from time to time but these lie scattered in various journals. It was considered necessary to bring together all the information in one publication and this **Bulletin on Pearl Culture** was designed for the purpose. The chapters have been written by experts in the field and contain the latest information on pearl culture in India. The Bulletin contains 20 chapters covering all aspects of pearl oyster resources, pearl culture and hatchery production of seed.

The Bulletin gives a comprehensive coverage of pearl oyster resource and ecology of pearl oyster beds; morphology and physiology of pearl oyster; spat collection in the inshore areas including the harbour basins; methods of pearl oyster farming and farm management; techniques of cultured pearl production and quality of cultured pearls; technology of hatchery production of pearl oyster; sea-ranching; transfer of technology and problems and prospects of pearl culture in India. It also includes a chapter giving the results obtained by the Department of Fisheries, Govt. of Tamil Nadu under the ICAR *ad hoc* Scheme on Pearl Culture. Finally, the Bulletin gives an annotated bibliography of the Indian works on pearl oyster resource and culture.

There has been a constant flow of requests for information on the technology of pearl culture from several quarters including the industry, prospective entrepreneurs, scientists, academicians and scholars. I sincerely hope that this Bulletin will be found useful by all concerned.

Dr. K. Alagarswami has designed and edited this Bulletin. Dr. A. C. C. Victor did the difficult job of reading the proof of the chapters and Shri P. T. Meenakshisundaram helped in the printing of this Bulletin. To all the scientists and other staff of the Institute who have contributed the chapters and assisted in this publication I wish to record my deep appreciation of the good work they have done.

Cochin
January 1987

P. S. B. R. James
Director
Central Marine Fisheries Research Institute

1

INTRODUCTION

K. ALAGARSWAMI [1]

India is endowed with a pearl oyster resource which has been exploited for the natural pearls from time immemorial and, in the historical past, pearls have been one of the precious objects, along with spices, exported from the ports in the South. The Gulf of Mannar and Gulf of Kutch are the well known haunts of this resource and pearl fisheries had been organised in the past from Tuticorin and Jamnagar respectively. The 'paars' of Gulf of Mannar have yielded to very valuable fisheries in the past, the most successful of which has been the fishery series of 1955-1961. Since then the beds have gone back into a recessive phase without much of pearl oyster stock as has been the typical situation in the past. The 'khaddas' of the Gulf of Kutch, after yielding to a moderate fishery in 1966-67 season, have likewise, been unproductive since then.

The Central Marine Fisheries Research Institute, has been involved in the survey of the pearl banks, along with the chank beds, in the Gulf of Mannar since 1959 and the pearl oyster beds were chartered. The ecology of these beds has been studied in detail. The Institute started an experimental project in pearl culture in 1972 at Tuticorin with a field laboratory at Veppalodai. This project laid the foundation for multidisciplinary research in pearl culture which is being implemented with adequate infrastructure facilities. This chapter briefly reviews the developments in pearl culture research in India, the results of which are presented in the following chapters of this Bulletin.

Early attempts in Tamil Nadu and Gujarat

Late James Hornell who took the responsibility of investigating the prospects of the Gulf of Mannar pearl fisheries along the Indian as well as Ceylon coasts in the nearly part of the present century for the purpose of improving the pearl oyster resources and conditions of fishing grounds came to the conclusion that 'the only economically sound way of making the Indian and Ceylon pearl fisheries permanently and regularly remunerative is to concentrate upon the inducement of pearls by artificial means in comparatively limited numbers of cultivated pearl oysters....' Following this recommendation, the erstwhile Madras Fisheries Department commenced experiments on pearl culture at Krusadai island at the head of the Gulf of Mannar in 1938. This work continued intermittently over a period of about three decades and resulted in giving valuable information on some aspects of the biology of the Indian pearl oyster, farming and ecological conditions. However, success in respect of pearl culture technology was limited to obtaining 'two imperfect pearls' away from the site of implantation and 'mother-of-pearl ball' attached to the shell and coated with nacre.

Similar early attempts have been made in Gujarat. Presumably based on the advice of late James Hornell, stone enclosures with sluices were constructed near Sikka for farming pearl oysters. Experiments on pearl culture which commenced in 1956 did not result in developing the technology.

Breakthrough in technology

Against this background, the Central Marine Fisheries Research Institute started a research project on pearl culture in 1972 at Tuticorin with a field laboratory at Veppalodai. An early breakthrough was achieved and the first spherical cultured pearl was produced on 25 July 1973, heralding the development of pearl culture technology in India. The technology

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for farming of pearl oyster in the open sea adopting raft culture and production of cultured pearls has been developed.

Scheme on pearl culture

In the immediately following period, directed pearl culture research was organised by the CMFRI in collaboration with the Department of Fisheries, Government of Tamil Nadu under an *ad hoc* scheme on pearl culture of the Indian Council of Agricultural Research which was implemented from October 1973 to September 1978. During this period multiple production of cultured pearls was achieved ; surgical equipments for nucleus implantation were developed indigenously ; the growth of cultured pearls was studied ; the problems of biofouling and boring organisms in the farm were elucidated ; pearl oyster resource of the Gulf of Mannar was studied with reference to insurgence of non-*fucata* component in the paars and inshore areas ; growth of pearl oyster in the farm was observed ; the ecological conditions of Veppalodai farm were investigated ; and certain physiological experiments were carried out. Concurrently, the Department of Fisheries, Government of Tamil Nadu gained expertise in the field of pearl culture and re-established a pearl oyster farm at Krusadai island.

Experimental work at Vizhinjam

Chance occurrence of pearl oyster spat on the ropes used in mussel culture in Vizhijam Bay enabled the Institute to build up a pearl oyster stock through farming and subsequently trial production of cultured pearls. The Department of Fisheries, Government of Kerala subsequently executed a pilot project on pearl culture for a period. Monitoring the spat fall in the bay was continued and it was noticed that as the bay was being developed as a fishing harbour, the spat fall became reduced year after year as also the *fucata* component of pearl oyster. Increase in suspended silt made it more and more difficult to raise oyster stock. However, the programme gave valuable data on the biology and farming of pearl oyster.

Further research on pearl culture

The ecological conditions of the experimental farm at Veppalodai were found to deteriorate with the commencement of operation of fishing trawlers in the area resulting in poor growth, weakening and higher rate of mortality of pearl oysters. Farming was shifted to the Tuticorin harbour basin and better results in terms of growth and survival of oyster were obtained. Continued monitoring of pearl oyster beds showed that some of the northern shoreward paars had moderate populations but the age composition was static in any given season. An interesting feature observed in the beds was the heavy mortality caused by predatory gastropods. Emphasis was given to control of fouling and boring organisms for which simple methods were evolved. The pearl oyster resource potential of Andaman and Nicobar Islands was surveyed in 1978.

Development of hatchery technology

Having realised that all the success achieved in pearl culture will be of no avail in establishing an industry unless steady supplies of pearl oysters are assured, top priority was given from 1978 to the project on development of hatchery technology for production of pearl oyster spat. Techniques for induced spawning of pearl oyster were developed and the early developmental stages of pearl oyster larvae were described. The progress was at standstill at the straight-hinge larval stage for a considerable period until the flagellate *Isochrysis galbana* became available for culture as food of the pearl oyster larvae. The breakthrough came in 1981 when the first batch of pearl oyster spat was produced in the laboratory. This signified yet another important development leading to the establishment of a moderate hatchery for large-scale production of pearl oyster spat.

Juvenile rearing

At this stage, rearing the spat from about 0.3 mm to the minimum size of about 45 mm when the oyster can be used in surgery for pearl production had to be accomplished. This needs a period of a little more than a year. Considering the space, volume of sea water and the food requirements, it is not practicable to rear the pearl oyster in the hatchery for more than the absolute minimum period. The spat can be transplanted at about 3 mm and reared in the farm in special rearing baskets to ensure that they do not drop out through the meshes, a free flow of water is maintained and that they are protected against predation. Growth and survival are two important factors in juvenile rearing. Pearl oysters produced in the hatchery have been grown over a period of three years, employed in surgery for pearl production and used as brood-stock for raising further generations.

Sea-ranching

With the above technology, it has become possible to reverse the flow of pearl oyster from land to the sea for certain investigations. Commencing from the end of 1985 a sea-ranching programme was taken up to study the possibility of replenishing the natural stock on the beds and to understand the factors responsible for the fluctuations of the wild populations. Monitoring is a major technical and logistic problem in this effort. If successful, revival of pearl fishery may become possible. It can also supply grown oysters suitable for cultured pearl production.

Commercial pearl culture

The developments in pearl culture research have led to the establishment of a commercial pearl culture project in the country. The Tamil Nadu Fisheries Development Corporation Ltd and Southern Petrochemical Industries Corporation Ltd started a joint venture project in 1983 with a collection base at Tuticorin, farm at Kursadai and surgery at Mandapam. This is a laudable pioneering effort on the part of the Government and Industry.

Technology transfer

In an effort to transfer the technology of pearl culture and pearl oyster hatchery, the CMFRI has organised training courses for the benefit of the fisheries departments in the maritime States and Unioh Territories. This has been taken advantage of by Gujarat, Karnataka, Kerala, Tamil Nadu, West Bengal, Andaman & Nicobar Islands and Lakshadweep, besides Konkan Krishi Vidyapeeth. In order to instil confidence in the technology, consignments of pearl oyster spat produced in the hatchery have been presented to some of the programmes in the States/UTs.

Thrust areas

As the dictim goes, research should aim either at improving the trontiers of knowledge or at increasing the frontiers of production, ideally both. The CMFRI has so far had a good measure of success in both the frontiers in the field of pearl culture. However, there are several areas of research which need to be taken up. Some of the major priority areas in pearl culture would be identification of sites, site-specific farming technology, critical ecology of pearl culture grounds, identification and control of disease, species-specific technology for *Pinctada margaritifera* and possibly *P. maxima*. Andaman & Nicobars and Lakshadweep as special areas for pearl culture, shell-bead technology which is an engineering problem, improvement of oyster quality through genetic studies, increase in production, improvement of quality of cultured pearls through selective breeding and mantle tissue culture. On the hatchery front the thrusts would be on control of reproduction enhanced larval survival, synchronous larval growth and spat setting, economic nursery rearing and higher assured survival of spat in mother-oyster culture. Besides, an area which is totally open for future is freshwater pearl culture though this will not be within the mandate of CMFRI.

The Bulletin on Pearl Culture has been designed to present information on the several aspects of pearl culture briefly outlined above. Primarily,the results of research carried out at CMFRI since 1972 have been incorporated under different chapters. This includes results already published and those which are given for the first time. The chapters have also reviewed the relevant literature from outside India, particularly the publications from Japan.

2

MORPHOLOGY AND ANATOMY OF INDIAN PEARL OYSTER

T. S. VELAYUDHAN[1] AND A. D. GANDHI[1]

INTRODUCTION

In India, great strides had been made in the technology of culture pearl production from the Indian pearl oyster *Pinctada fucata* (Gould). For achieving satisfactory results in the production of culture pearl, it is absolutely essential to have a precise knowledge of the morphology and anatomy of the animal in view of the fact that the mantle and the gonad play a pivotal role in the production of good quality pearls. Herdman (1904) has given an excellent and detailed account of the anatomy of the Indian pearl oyster. Hynd (1955) and Kuwatani (1965 a, b) have also contributed to our understanding of the morphology of the pearl oysters from Australian and Japanese waters, in addition to throwing light on the functional role of the digestive and reproductive organs. Based on a number of dissections made on the oysters of the Tuticorin region, the present account on the anatomy of the most important systems of the pearl oyster is presented in the paper.

PTERIDAE AND ASSOCIATED FAMILIES

The Indian pearl oyster *Pinctada fucata* belongs to the family Pteridae. It differs from other bivalves in possessing a lorg and straight hinge. The long axis of the shell is not at right angle to hinge. The left valve is usually deeper than the right. There is a byssal notch on each valve at the base of the anterior lobe. The colouration of the periostracum varies; often brownish with radial markings (Rao and Rao, 1974).

In the genus *Pteria*, a member of the family Pteridae, the shell is much longer than high, the outer surface smooth and conspicuously scaly and the hind angle is always definitely prolonged, often greatly so. This prolongation usually appears as a definite wing-like expansion marked off from the rest of the shell by an oblique elevated area extending from the umbo to the hind lower margin.

The species belonging to the family Ostreidae are generally characterised by very much reduced foot. Byssus gland is absent. Gills are fused to the mantle and the shells are fixed to the substratum by the left valve which is larger than the right one.

In Pinnidae, the *Pinna* shells are broadly triangular in shape. The posterior margin is truncate or convex-rounded. The valves are very high and thick or rather thin or fragile. Valves are translucent and of light horn-brown to dark purplish brown colour. 8 to 17 radial ribs, which are sometimes scarcely visible, are present.

In Mytilidae the shell is inequilateral with umbo situated either terminally at the anterior end or subterminally, very close to it. The anterior adductor muscle is always much less strongly developed than the posterior (anisomyarian condition). *Modiolus* spp. (weaving mussels) usually 11 to 70 mm in length, attach themselves to substratum by means of byssus threads. The shell is thin, transparent, semitransparent or opaque; margins elevated, arched or straight and colouration with hairy periostracum.

SPECIES OF PEARL OYSTERS

Pinctada chemnitzii (Philippi)

The anterior and posterior ears are well developed and the convexity of the valve is much less. The valves are yellowish-brown with about a few or more

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whitish cream yellowish markings from the umbo to the margin of the shell and the growth processes are rather broad. The non-nacreous border is brownish without any conspicuous blotches.

P. sugillata (Reeve)

The hinge is very much shorter than the widest anterio-posterior axis of the shell. The convexity of the right shell valve is moderate. The colouration of the shell is dark grey with a tinge of brown. Posteriorly the nacreous border as it meets the hinge line, presents a wavy course.

P. margaritifera (Linnaeus)

Teeth are entirely absent from the hinge margin. Anterior border of the body of shell extends far in advance of the anterior ear lobe. Shell valves are moderately convex. The concentric laminae on the external surface of the shells are conspicuous in young animals. The nacreous layer is iridescent, silvery and distally sooty black in colour. Because of the dark marginal colouration this species is called 'black-lip' pearl oyster.

P. anomioides (Reeve)

The posterior ear and posterior sinus are absent. The right valve is nearly flat but the left is moderately convex. Externally the valves are translucent. Faint radial markings are present. The nacreous region is well developed and its posterior border meets the hinge at right angles.

P. atropurpurea (Dunker)

This species is distinguished from the previous species by its copper red colouration, thinner and more translucent valves and the posterior nacreous border meeting the hinge at an acute angle.

P. maxima (Jameson)

This species does not possess denticles on the hinge. The valves are more flat and less hollowed out than in *P. margaritifera*. The hinge is larger than in *P. margaritifera*. However, in the adult, the posterior portion of the hinge is not prominent as in *P. chemnitzii*. The valve is less rounded than in *P. margaritifera*. The cardinal portion may be coloured in a dense manner, dark brown, or purple, sometimes with spots of the same colours, but mostly deeper shades.

P. fucata (Gould)

The left valve is deeper and more concave than the right. The valves are more or less rounded in outline with flattened dorsal edge ending in projecting wings or auricles in front and behind.

Description of the Shell of *P. fucata*

The shell is thin, about 1.5 mm thick over the greater part of its extent, and lired by an exceedingly brilliant layer of nacre or mother-of-pearl. The outer side of the shell is usually marked by 6-8 radial bands of reddish brown colour on a pale yellow background. The growth processes or projecting imbricating lamellae, which arise from the external surfaces of the shells are laid down by the animal at successive intervals at the distal border. The anterior ear is larger than in the other species. The non-nacreous border on the inner surface of the valves possesses brownish or reddish patches coinciding with the external rays. The nacreous areas of the ears relative to the rest of the shell decreases with age slightly.

Immediately below the hinge line, the posterior border is frequently indented by a sinus markirg of the area of the shell known as the posterior ear, where the sinus is deep ; the posterior ear is relatively large. The byssal groove is short, forwardly curved depression on the external surface of the right valve running from the umbo to the byssal notch.

The large adductor impression is placed subcentrally occupying $\frac{1}{5}$ to $\frac{1}{4}$ the diameter of the shell. The pallial line and scars caused by the insertion of the pallial muscles are fan-shaped bundles formed of fibres radiating outwards. Usually there are 12-15 insertion scars between the umbonal region. Besides these distinct scars, is a narrow continuous insertion band confluent with the posterior and ventral edges of the adductor scars. Its scar merges with that of the adductor scar. The hinge line is a narrow edge and runs along the greater part of the straight dorsal edge ; elongated narrow ridge-like lateral teeth are present as paired elevation of the nacre of the hinge line, posterior to the ligament.

The shell is composed of three layers, the outer, middle and inner. The very thin outer layer is uncalcified cuticular 'periostracum', an extremely delicate horny layer which allows the colour of the layer below to show through and becomes worn off in old shells. At free margin of the shell the periostracum is very thin, transparent and extends beyond the calcareous matter and reflected to join the surface of the ectoderm cells of the mantle edge in the longitudinal groove where it is secreted.

The middle or prismatic layer of the shell shows a cellular structure being formed of calcareous prisms or columns running transversely to the surface and appearing polygonal in section. The prismatic layer is deposited by the mantle epithelium near the free edge just behind the margin which forms the periostracum and many such layers of fusion may be formed successively, each new one inside the last, as the shell grows. The inner layer is the nacre formed of numerous delicate lamellae of the organic matrix conchiolin and calcareous matter. It is transparent under microscope having fine granular appearance in surface view.

General Organisation of the Animal

Mantle

The mantle secretes all parts of the shell. The free edge of the mantle lobes is thickened, pigmented and fringed with branched tentacles. The pallial edge of the mantle is attached to the shell, a little away from the margin. Each pallial lobe may be divided into three parts : the central, distal or muscular and marginal mantle. The central pallial area extends from the middorsal line to the pallial line, where the shell is marked with muscle scars. At the points of attachment of the adductor, the retractors, the levators and pallial muscles the tissue of this part of the mantle is soft, mucoid and opalascent white in colour. The distal or muscular area is translucent and capable of considerable contraction by its muscles and extension

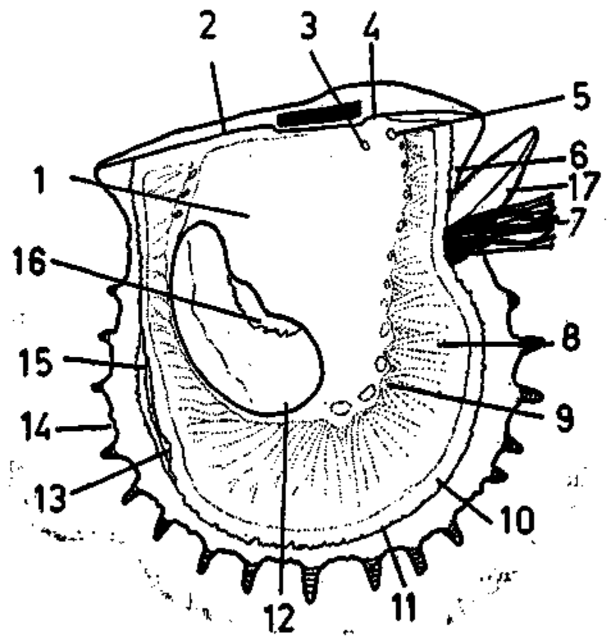

Fig. 1. *Pinctada fucata* with right shell remoed.

1. Mantle lobe, 2. Mid-dorsal line, 3. Right levator of foot, 4. Left anterior levator of foot, 5. Right anterior levator of foot, 6. Oral aperture, 7. Byssus, 8. Pallial muscles, 9. Converged end of pallial muscles, 10. Outer end of pallial margin, 11. Papillae of middle lamellae of pallial margin, 12. Adductor muscle, 13. Pallial fold, 14. Exhalent orifice, 15. Left mantle lobe, 16. Right retractor of foot, and 17. Foot.

by the influx of blood into the large sinus it contains. It is formed of a thick layer of loose connective tissue traversed by nerves and blood space and by the radiating fan-like bundles of pallial muscles (Fig. 1, 8). This region is sensitive to foreign particles.

The marginal region or mantle edge is chiefly a thickening which ends in two thin membranous folds with pigmented papillate edges (Fig. 1, 11). The outer fold bearing digitate papillae is in the same place as the inner surface of the shell and forms the true pallial edge. The inner fold which bears the flattened palmate papillae, which may be called the pallial veil or velum projects inwards at right angles from the mantle edge, so that the veil of one pallial lobe stretches towards that of the other. The inhalent aperture is somewhere about the middle of the ventral surface, while the exhalent aperture is at the posterior end opposite the opening of the anal funnel and suprabranchial chamber. The exhalent aperture is broadly ovoid or almost circular. Along the posterior margin of the body, from the pallial fold (Fig. 1, 14) upwards to the posterior end of the hinge, the papillae of the veil become greatly reduced in size and simpler in form and in the region of the posterior auricle of the shell, they approach in character those of the pallial margins (Fig. 1, 10). The free pallial margin together with the velum, is in most cases deeply pigmented, dark grey and the degree of pigmentation varies in yellows and browns.

The ciliated pallial path

The inner surface of the pallial lobe is ciliated, but at the ventral truncate edge of the labial palps, a specially marked ciliated path begins which passes to the base of the velum, parallel with which it runs until it reaches the anterior wall of the pallial fold where it passes over the velar edge by means of a slight folding of the latter. The cilia of this pathway are in continuous motion, by which means the unsuitable particles collected by gills are sent forwards but rejected by the palps and conveyed away and passed out from the pallial fold.

The inner surface of the outer mantle fold

The free surface of the columnar epithelial cells of the outer mantle fold is provided with numerous microvilli.

The outer surface of the middle fold

Large numbers of ciliary epithelial cells with microvilli are arranged zonally or in a cluster along the longitudinal line over the middle region of the mantle fold.

Foot

The foot (Fig. 2, 1) is a highly mobile, tongue-shaped organ capable of great elongation and contraction. It arises from the anterior region of the visceral mass nearly midway between the mouth and the intestinal lobe and the anterior branchiae flanking it on either side. The major part of its bulk is composed of network of

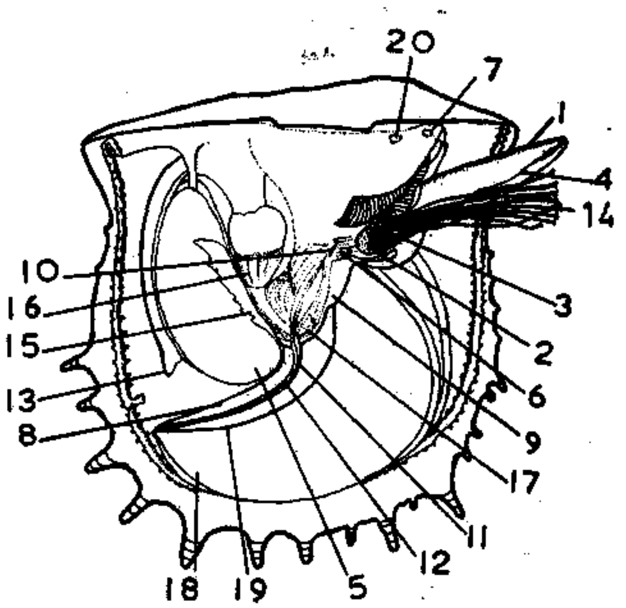

FIG. 2. Respiratory excretory and rerpoductive systems of *Pinctada fucata.*

1. Foot, 2. Byssus gland, 3. Root, 4. Pedal groove, 5. Adductor muscle, 6. Retractor, 7. Left anterior levator, 8. Muscular ctenidial axis, 9. Gonad, 10. Reno-genital aperture, 11. Efferent branchial vein, 12. Afferent branchlia vein, 13. Anal process, 14. Byssus, 15. Retractor, 16. Pericaidial gland, 17. Nephridium, 18. Gill, 19. Ctenidial axis and 20. Right posterior levator.

fibres running in various directions thus ensuring a wide range of movement and it is so extensively penetrated by blood spaces that the organ is highly controllable.

Byssus gland

The byssus gland organ (Fig. 2, 2) is lodged at the proximal end of the foot upon the ventral aspect. The byssal gland lodges the common root (Fig. 2, 3) of a bundle of stout laterally compressed bronze green fibres, the byssal threads. Each fibre of the byssus anchors the pearl oyster to rocks and other objects by means of a discoid attachment at the distal extremity. The anterior edge of the mouth of byssal gland passes into the pedal groove (Fig. 2, 4) extending medially along the whole of the remaining length of the ventral surface of the foot.

MUSCULAR SYSTEM

The pearl oyster is monomyarian, possessing only the posterior adductor (Fig. 2, 5) the largest and the most important muscle in the body.

Adductor muscle

The adductor muscle stretches transversely across the body from valve to valve. It is a massive wedge-shaped bundle. The narrow end points upwards and lies immediately behind the ventricle of the heart. The terminal part of the rectum runs in the middle line along the posterior surface. Two distinct regions of the muscles are obvious ; one, a narrow tendonous strip made up of white glistening fibres forming the posterior border and the other, broad and massive semitranslucent fibres occupying the remainder of the mass .The power exerted by the adductor in bringing the valves together by its contraction is very considerable with rapid action resembling ratchet mechanism.

The retractor

The retractors of the foot are a pair of symmetrically disposed muscles lying in the horizontal plane of the body (Fig. 2, 6). The V-shaped muscles originate from the byssal gland. The ends are attached to the right and left valves without making a separate scar on the nacre.

Levators

The levators of the foot are four, two anterior and two posterior (Fig. 2, 7). Each of the anterior pair has its insertion at the apex of the umbonal recess of its respective valve passing vertically downwards on either side of the mouth spreading laterally, fan-like as they go. The left anterior levator is stronger and by contraction of the strong cord of fibres, the food is drawn over the left side of the valve which is convex and more spacious. The posterior levators are two short insignificant bundles (Fig. 2, 20) which originate high upon the anterior levator, exactly on level with the mouth passing through the visceral mass to be attached to the valves behind the anterior levator scar. The contraction of the anterior levator (Fig. 2, 7) causes the foot to be retracted and dorsally raised. The intrinsic muscles of the foot are diffused forming a muscular enveloping sheath in the foot, with ill-defined muscle bundles passing from side to side, providing a framework wherein ramify the tubules of the digestive glands. The branchial muscles cause the shortening of the gills and withdrawl of their posterior extremities. They run within each ctenidial axis (Fig. 2, 8) from end to end, close to the dorsal edge. There are also muscle bundles running longitudinally down each side of the principal filaments.

Pallial muscles

The pallial muscles (Fig. 1, 8) are all retractors, and together constitute the orbicular muscle of the mantle. They are a series of fan-shaped muscles radiating towards the mantle edge from a number of insertion centres (15-18) of various sizes arranged semicircularly. Together these form the well marked pallial line of scars on the shell. With the exception of heart and the somewhat indistinct appearance of striation on the larger portion of the adductor, the muscle fibres throughout the body are non-striped.

DIGESTIVE SYSTEM

The oesophagus (Fig. 3, 2), stomach (Fig. 3, 3) and the greater portion of the intestine lie within the viscero pedal mass. Two horizontal lips conceal the aperture of the mouth. The labial palps (Fig. 3, 4) are smooth on the surface, turned away from the mouth and grooved on the opposed faces enclosing the mouth aperture. The mouth (Fig. 3, 1) is a large, slit like depression placed transversely between the anterior

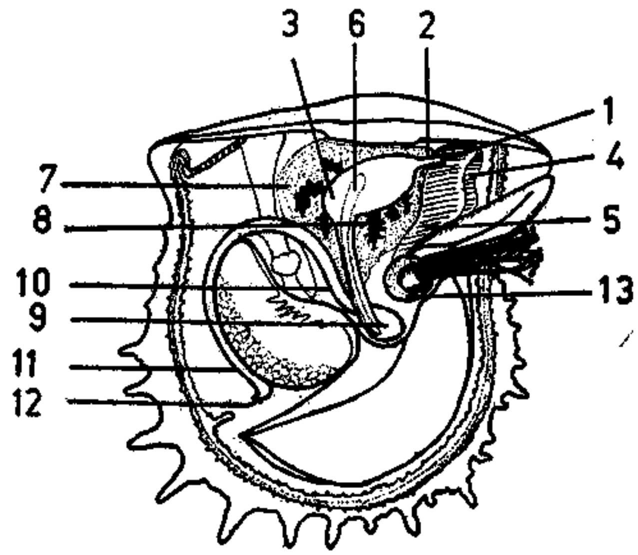

FIG. 3. Digestive system of *Pinctada fucata*.

1. Mouth, 2. Oesophagus, 3. Stomach, 4. Left outer labial palp, 5. Left inner labial palp, 6. Crystalline style, 7. Liver, 8. Digestive diverticula, 9. Descending portion of intestine, 10. Ascending portion of intestine, 11. Rectum, 12. Anal process and 13. Byssal gland.

levator muscles of the foot. The cavity contracts inwards to the narrow width of the short conducting tube, the so called oesophagus, which is straight, dorsoventrally compressed and ciliated. The hinder end opens into the anterior end of the stomach which is an organ of surprising elaboration. Folds and depressions diversify the walls and floor of the stomach and break them into definite areas. In life, it is too delicate and too intricately united with the surrounding tissues to be dissected free. The tissues consist largely of greenish brown masses often termed as liver (Fig. 3, 7) (which have no resemblance to that organ in the vertebrates) or better termed as digestive diverticula (Fig. 3, 8). Dense clusters of secreting alveoli open into ductules and these larger ducts lead into the cavity of stomach. The most conspicuous portion of the stomach is a slightly projecting vertical fold arising from the posterior wall marking out the cardaic stomach into a right and left chamber. This fold disappears towards the roof where it is smooth and unbroken, except for a well marked pit. The wide bipartite opening into the intestine and intestinal caecum marks the hinder end of the pyloric chamber. A peculiar (gelatinous) rod flattened and oblique occupies a subcentral position anterior to where the postero-ventral fold disappears midway along the floor. To the right of this area of the dendritic plate is a ridge with a furrow running up to the antero-lateral bile duct. A deep rugose-sub-oesophageal pit is well marked, anterior to the dendritic plate and high upon the right lateral wall. The posterolateral furrow leads from the posterolateral duct towards the intestinal aperture. On the left side, a short anterolateral fold lies between the preintestinal depression of suboesophageal pit.

There are eleven terminal ducts opening into the intestine—(*a*) anterolateral duct, (*b*) posterolateral duct opening in posterior third stomach, (*c*) the posteroventral duct, (*d*) three subventral ducts, (*e*) two preintestinal ducts opening within preintestinal depression and (*f*) three small suboesophageal ducts below the oesophageal aperture.

The head of crystalline style projects out of the sac where it is formed and across the cavity of the stomach where it bears against an irregular area of cuticle bearing a projecting tooth, known as the gastric shield. This area is not ciliated.

The intestine may be divided into three sections of approximately equal length namely the descending, the ascending portion and the rectum (Fig. 3, 9-11). The first portion passes ventrally through the posterior part of the visceral mass. Then it passes behind the base of the byssal gland and between the two pedal retractor muscles wherefrom it changes its direction curving forwards and downwards to the visceral mass passing on as ascending branch. A longitudinal fold projects inwards from the anterior and one from the posterior wall of the descending intestine. The apices of the two folds are so close together at the lower third so as to form two distinct tubes. The larger cavity is completely filled with a clear gelatinous solid cylinder, the crystalline style (Fig. 3, 6). The narrow tube on right side is the true intestine, the wider left being the sheath of the crystalline style which is imperfectly separated from the anterior portion of intestine with which it communicates by a longitudinal cleft. The upper end of the style certainly projects into the stomach.

The valvular folding of the intestinal ridge gives entrance to the ascending intestine which curves backwards along the base of the visceral mass to the left of the descending intestine (Fig. 3, 9). The ascending portion crosses to the right at the posterior extremity of the ventral surface of the visceral mass where the two intestinal divisions intersect. The intestinal loop thus formed is the visceral loop. From the point of intersection the ascending intestine turns sharply upwards, running parallel with and closely adjacent to the upper part of the descending portion (Fig. 3, 10). The portion of the intestine forming the second limb of the visceral loop is continued into it as a somewhat undulating ridge disappearing midway. At the point where this diversion of the intestine assumes a dual course, an increase takes place in diameter, side by side with the appearance of a long longitudinal fold-typhlosole, projecting from the anterior wall, curving over to the posterior side of the tube, then running vertically upward without further change of course. Longitudinal furrows channel the surface. As it approaches the level of the floor of the stomach, the typhlosole thins down rapidly to a low ridge, and the intestine itself then curves posteriorly in the direction of the heart. This change in direction and thinning of typhlosole marks the beginning of rectum.

The rectum (Fig. 3, 11) runs posteriorly through the upper part of the pericardium. Beyond this it curves ventrally and passes round the posterior aspect of adductor muscle in the median line, ending in an erectile ear-like process, the anus, situated opposite the exhalent orifice of the mantle. The anal process (Fig. 3, 12) is comparatively larger and slightly curved. It stands out at right angle to the last section of the rectum, and the tip is directed posteriorly. The anal aperture is situated at the base on the ventral aspect.

Respiratory System

The gills (Fig. 2, 18) consist of four crescent shaped plates, two half gills on each side which hang down from the roof of the mantle cavity like book leaves. They represent a series of ciliated sieves the whole constituting a feeding surface of utmost efficiency. Two rows of long delicate branchial filaments (Fig. 2, 19) are inserted at right angles along the whole length of the axis or vascular base which extends from the ventral border of the palps anteriorly curving round ventrally and posteriorly to a point opposite the anus with its convexity first forwards and then downwards. Where they terminate the mantle lobes of the two sides are briefly united by way of the inner mantle folds thus dividing the mantle cavity into a large inhalent chamber containing the gills and a much smaller exhalent chamber. Water enters by the one and leaves by the other. The outwardly directed parallel filaments of each series are folded upon themselves, so that they are V shaped, the folding being in such a way that that external filaments turn outwards and internal inwards. Consequently each branchial plate furrow of the double filaments, consists of two lamellae, the direct and the reflected, which enclose narrow interlamellar space.

The common base of each ctenidium is a vascular attached ridge reaching from the anterior end of gills. Hollow outgrowths, inter-lamellar junctions, containing branches from the afferent vessels convey blood from the axial trunk to the base of reflected lamellae. The blood enters certain of the individual filaments, flows outwards to the free margin, passing over to the direct filaments returning inwards to the branchial or ctenidial axis (Fig. 2, 19) where it joins the different vessel by openings along each side.

Neighbouring filaments are joined by continuous organic union mainly at the lower and the upper ends of the reflected filaments, where there are longitudinally running blood vessels. Elsewhere the filaments are joined chiefly by the interlocking stiff cilia of the large ciliated discs which occur at intervals, throughout their length. The normal function of the ordinary cilia on the branchiae is to create a current of water which enters the pallial chamber and passes over and through the branchial lamellae so as to purify the blood flowing in the filaments and to convey the food particles to the mouth. Yonge (1960) has elaborately dealt with the mechanism of the food movements to the palps from the water current thus set up.

Circulatory System

This consists of a heart with a series of arteries which lies above the adductor, being contained in a pericardium (Fig. 4, 1) and consisting of a single ventricle (Fig. 4, 2) and a pair of contractile thin walled auricles (Fig. 4, 3), one on each side. They receive blood from the body by way of the gills and the mantle, and pass it to the ventricle. Back flow is prevented by valves. There it is driven by contraction into the anterior and posterior aorta (Fig. 4, 5). The latter is short and serves the adductor, rectum and the anus ; the rest of the body is supplied by the anterior aorta which gives off a series of minor arteries (Fig. 4). These

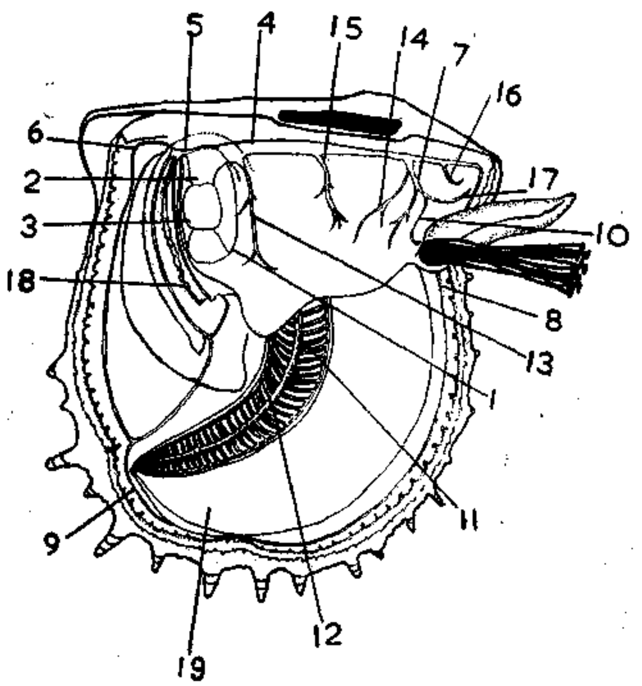

FIG. 4. Circulatory system of *Pinctada fucata.*

1. Pericardium, 2. Ventricle, 3. Auricle, 4. Anterior aorta, 5. Posterior aorta, 6. Posterior pallial artery, 7. Hepato pedal artery, 8 and 9. anterior pallial artery, 10. Pedal artery, 11. Efferent branchial vein, 12. Afferent branchial vein, 13. Visceral artery, 14. Anterior hepatic artery, 15. Posterior hepatic artery, 16. Upper labial artery. 17. Lower labial artery, 18. Right mantle lobe and 19. Gill.

open into the sinuses or blood spaces in which blood slowly circulates. The aorta finally communicates with a pair of large blood vessels that run around the margin of each mantle lobe. Deoxygenated blood is collected in veins (Fig, 4, 12) which carry it either into the gills or excretory organs. Blood flows round the organs and is purified by removal of waste products of metabolism. From the kidney it is pumped into the marginal vessel of the mantle by a pair of accessory hearts. Finally blood from the mantle together with that from the gills returns to the heart through efferent branchial vein (Fig. 4, 12) by way of auricles. The blood is colourless.

EXCRETORY SYSTEM

The excretory system consists of the paired nephridia and numerous small pericardial glands (Fig. 2, 16) projecting from the walls of the auricles. The nephridia (Fig. 2, 17) consist of two large symmetrical pouch-like sacs occupying either side of the hirder half of the viscero-pedal mass. Each opens into the pericardium by a wide duct and to the exterior by a minute pore. They intercommunicate by a wide channel beneath the auricles. In outlines each is roughly triangular, the apex passing into the channel under the auricle, while the elongated base looks towards and forwards coinciding with the base of the anterior third of the gill of that side, and thus conforming to the inclination of the gill.

The outer wall of the nephridium is thin and membranous ; it is fused with the body wall, as is also the most anterior portion of the inner wall, namely, that strip extending from the base of the gill to the visceropedal mass. From this line it runs back, overlying and in contact with the hinder part of the gonad, gradually narrowing as it approaches the auricle.

The external renal aperture is a minute oval opening with a sphincter muscle. It opens immediately below the genital aperture within an inconspicuous lipped slit placed at the junction of the inner plate of the inner gill with the visceral mass at a point about midway between the ventral border of the latter and the base of the foot.

Each nephridium consists of a glandular and non glandular portion. By separating the right and left ctenidia and reflecting each, the glandular region is seen as narrow, elongated coloured strip, yellow or pale brown or even dark dull red, bordering the anterior part of the inner base of each gill. It consists of spongy tissue, occupying the anterior angle formed by the meeting of the inner and outer walls of the organ, and the secretion passes from the cavernous chambers of the glandular region directing into the spacious cavity of the main or non-glandular portion.

The passage connecting the right and left nephridia lies beneath the auricles. It is a wide tunnel with thin membranous walls, bounded behind by the lower part of the pericardium. While in front its wall lies against the visceral mass below it fuses with the body wall and so forms part of the root of the adductor embayment of the suprabranchial chamber. The renopericardinal tubules are a pair of wide lateral prolongations of the precardiac part of the pericardium, thinwalled and membranous and directed forwards. Each gradually narrows towards the anterior end where it opens into the nonglandular part of nephridium of its own side. The aperture is a curved slit, with the concavity facing towards the ventral aspect. It has but one lip, the tube opening at a very acute angle. It is situated upon the inner wall of the nephridia. A small area around is tinted with brown pigment. The presence of accessory pericardial glands on the walls of auricles is said to have excretory function. These glands are dark brown in colour. The lower or auricular end of the pericardium is also glandular. Its epithelium is thrown into folds formed of granular vacuolated cells of the same character as those of the nephridium.

Nervous System

The laterally symmetrical nervous system has three pairs of galglia (1) the cerebral ganglia at the sides of the oesophagus, (2) the pedals joined to form a single ganglion at the base of the foot and (3) a pair of large visceral or parieto-splanchnic ganglia lying upon the anterior surface of the adductor.

The stout paired cerebrovisceral connectives (Fig, 5, 1) link the cerebral with the parieto-splanchnic ganglia, while a pair of cerebro-pedal connectives (Fig. 5, 4) join the cerebral with the pedal nerve mass. The cerebral ganglia are supra-oesophageal in position, and a nerve cord or commissure passing over the oesophagus connects the two cerebral ganglia (Fig. 5, 2). A single stout transverse visceral commissure forms the two parieto-splanchnic ganglia (visceral ganglia) (Fig. 5, 6).

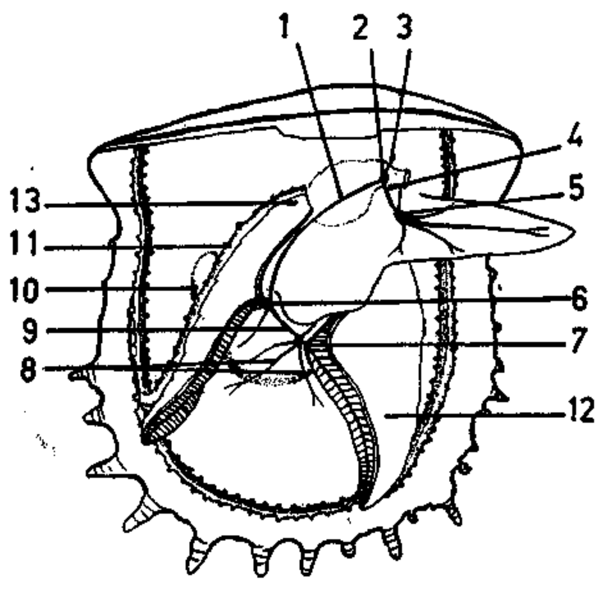

Fig. 5. Nervous system of *Pinctada fucata*.

1. Cerebro-visceral connective, 2. Cerebral ganglion, 3. Cerebral commissure, 4. Cerebropedal connective, 5. Pedal ganglion, 6. Visceral ganglion, 7. Branchial nerve, 8. Posterior pallial nerve, 9. Visceral commissure, 10. Adductor muscle, 11. Right mantle. 12. Left inner gill and 13. Right inner gill.

The cerebro-visceral connectives taking their rise at the posterior end of the cerebral ganglion, each passes backwards and downwards bound within the visceral mass till it merges opposite the upper angle of the base of the foot. Then it passes ventrally over-laid by the renal sinus entering the tissue at the base of the gills. It turns slightly forwards still passing ventrally and ends in its respective parieto-splanchnic ganglion. The cerebral ganglion of each side gives off anteriorly a stout nerve, the anterior common pallial. This passes forwards, bifurcating. The outer branch (external pallial nerve) runs along the pallial edge, uniting and anastomosing with the corresponding external pallial branch of the postetior common pallial trunk. The lateral palps and otocysts are innervated by the cerebral ganglia.

The cerebro-pedal connectives arise from the posterior and outer sides of the cerebral ganglia and run downwards within the visceral mass just behind the levator muscles of the foot to the pedal ganglion. They lie close together in their course. Three principal nerves arise from the pedal ganglion (Fig. 5, 5) which innervate the foot and the byssal gland. Each of the visceral or parieto-splanchnic ganglia receives from above the stout cerebro visceral connective, the two ganglia being themselves united by a single transverse visceral commisure (Fig. 5, 9). Each ganglion also gives off two stout distributory nerves an anterior lateral and a posterior lateral. Each branchial nerves (Fig. 5, 7) leaves the ganglion at the anterior lateral corner, turns down into the base of the gills and then backwards to the posterior tips following the afferent vessels. The posterior pallial nerves (Fig. 5, 8) emerge from the posterior end of the visceral ganglion; from the base of each, a stout nerve passes straight back till it reaches the pigmented pallial sense organs of its respective side, a little anterior to the anus.

The common pallial trunk passes backwards and outwards bifurcating; the external branch, the larger, is the external pallial nerve. The inner branch follows a median course but divides. The outer of the resultant nerves becomes the median pallial nerve; the inner internal pallial nerve. By the ramification of these three nerves in the muscular marginal region of the mantle and by their anastomosing a complex network of nerves termed 'pallial plexus' is formed.

Reproductive System

The sexes are separate except in occasional cases. The gonads are paired but asymmetrial; they form a thick envelop covering the stomach, liver and the first two sections of the intestine, connecting a greater part of the outside of the proximal portion of the viscero-pedal mass (Fig. 3, 9). The gonads do not hide the byssal gland. When the viscero-pedal mass is viewed from the right side of the byssal gland it is seen as a broad band reaching from the base of the foot backwards to the right retractor muscle. This band appears to divide the right gonad into a larger part dorsally and a ventral smaller portion. No portion of the reproductive glands extends into the foot proper or into the mantle.

The male and female gonads are practically indistinguishable. Both are creamy yellow in colour. The male gonad in some cases is rather paler than the female. The gonads, testes or ovaries as the case may be, consist of branched tubuli with myriads of succate caeca, the alveoli. The spermatozoa and ova develop in these. The accumulated ripe gametes fill these alveoli and tubuli and later pass into three trunks which converge into one just within the external genital aperture (Fig, 2, 10). This opens immediately dorsal to the renal aperture of the same side.

References

Herdman, W. A. 1904. Anatomy of the pearl oyster. In: *Report on the pearl oyster fisheries of the Gulf of Mannar, with Supplementary reports upon the Marine Biology of Ceylon*, Royal Society, London, Part II: 37-76.

Hynd, J. S. 1955. A revision of the Australian pearl shells, Genus *Pinctada* (Lamellibranchia). *Aust. J. Mar. Freshw. Res.*, 6 (1): 98-137.

Kuwatani, Y. 1965a. A study on the feeding mechanism of Japanese pearl oyster *Pinctada martensii* (Dunker) with special reference to passage of charcoal particles in the digestive system. *Bull. Japanese Soc. Sci. Fish.*, 31 (10): 789-798.

Kuwatani, Y. 1965b. On the anatomy and function of stomach of the Japanes pearl oyster *Pinctada martensii* (Dunker). *Bull. Japanese Soc. Sci. Fish.*, 31 (10): 174-186.

Prasad, B. and J. L. Bhaduri. 1933. Pearl oysters of the Indian waters. *Rec. Indian Mus.*, 35: 167-174.

Rao, K. Virabhadra and K. Satyanarayana Rao. 1974. Pearl oysters. In: The Commercial Molluscs of India, *Bull. Cent. Mar. Fish. Res. Inst.* 25: 84-105.

Wada, K. 1970. Cultured pearl and its structure. *Proc. Symp. Mollusca*, Mar. Biol. Ass. India, Part III: 972-974.

Yonge, C. M. 1960. *Oysters*. Collins. London: 209 pp.

3

BIOLOGY OF PEARL OYSTER *PINCTADA FUCATA* (GOULD)

A. CHELLAM[1]

INTRODUCTION

Comprehensive account on the biology of the Indian pearl oyster, *Pinctada fucata* (Gould) has been wanting. Age and growth of pearl oysters of the Gulf of Mannar was studied by Herdman (1903), Hornell (1922), Devanesen and Chidambaram (1956), Chacko (1970) and Chellam (1978). The age and growth of the pearl oysters of the Gulf of Kutch was studied by Gokhale *et al.* (1954), Narayanan and Michael (1968) and Pandya (1975). Chellam (MS) has traced the growth of the pearl oyster from the settlement of the spat in the hatchery, whose day of spawning is known, to the age of three years, reared in the farm at Tuticorin Harbour.

Study on the food and feeding habits of the pearl oysters in Indian waters is scanty excepting the work of Herdman (1903) and Chellam (1983). Ota (1959 a b, c, d) has studied in detail the feeding habits of *Pinctada martensii* from Japan with particular reference to seasonal changes, nuclear insertion and different conditions of culture grounds. Kuwatani (1965 a, b) has traced the anatomy and function of the stomach of the Japanese pearl oyster and the feeding mechanisms with reference to passage of charocal particles in the digestive systems.

Not much is known about the reproductive biology of the pearl oysters in the Indian waters excepting the work of Herdman (1906), Hornell (1922 a) and Chacko (1970). Cahn (1949) and Uemoto (1958) have found a relationship to exist between temperature and spawning in oysters of the Japanese waters. Tranter (1958 c, d) observed biannual spawning in the Australian pearl oysters.

MATERIALS AND METHODS

The study on the growth of pearl oyster was based on periodic measurement of pearl oysters under culture (Chellam, 1978). Chellam (MS) has used spat produced in the hatchery to trace growth over a period of three years. The dorsoventral measurement indicated the length, taken monthly, on the averages of 30-50 oysters. The weight was the averages of 30-50 oysters belonging to different batches grown in the Harbour farm, whose day of spawning was known.

Chellam (1983) had preserved the pearl oysters immediately after collecting them from the natural beds and farms, in 5% formalin and the stomach and intestine were examined qualitatively for their contents. He had fed experimentally with the laboratory reared pearl oyster larvae to find out the fate of the larvae ingested.

To study the reproduction of pearl oysters in the farm at the Tuticorin Harbour (Gulf of Mannar), monthly samples of at least 30 animals were collected and analysed during the period January 1980 to December 1981. The length (DVM), thickness and weight were recorded. The left valve of the oyster was removed by cutting the adductor muscle of the side along the shell. After nothing the colour and fullness of the gonad visually, the stages of maturity were confirmed through smear. The gonad follicles were anastomising in nature, covering most of the dorsal and ventral surfaces, penetrating into the visceral mass extending upto the labial region when fully mature. The viscera was removed from the right shell and preserved in Bouin's solution for 48 hours. The gonad was trimmed from all other tissues and transferred to 70%

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(V/V) ethanol for storage. It was then dehydrated, embedded in paraffin, sectioned at 7 microns and stained with Delafield's haematoxilin and counter stained with eosin.

AGE AND GROWTH

At the farm at the Krusadai Island, Devanesen and Chidambaram (1956) have found the rate of growth of spat of five months and above to be 5%. As the age increases, the rate of growth decreases. The growth was 45 mm at the end of one year, 55 mm at the end of two years, 60 mm at the end of three years, 65 mm at the end of four years and 70 mm at the end of five years. The weight of the oyster was 10 g, 30 g, 45 g, 60 g and 70 g at the end of first, second, third, fourth and fifth years. Chacko (1970) came to similar conclusions by observations on natural populations in the pearl banks of Tuticorin during 1954-57. Chellam (1978) has found the growth of the pearl oysters to be moderate in the shallow water farm at Veppalodai. The growth increments were greater from September to January when the quarterly mean temperature was 28.47°C and salinity 31.48‰.

The age and growth of pearl oysters of the Gulf of Kutch, based on the number of growth rings on the shells, was studied by Gokhale *et al.* (1954), Narayanan and Michael (1968) and Pandya (1975). In the Gulf of Kutch, the pearl oysters, *Pinctada vulgaris* (Schumacher) (= *P. fucata*) grew vigorously in winter months when the temperature varied from 23°C to 27°C and growth ceased in summer (Gokhale *et al.*, (1954). The relative increase between age and linear measurements was studied by Narayanan and Michael (1968) and the growth in length (height) was found to be 44.05 mm, 61.68 mm, 76.20 mm, 81.62 mm, 85.15 mm and 86.65 mm at the end of first through sixth year.

Chellam (MS), while tracing the growth of *Pinctada fucata* produced in the hatchery and grown in the farm at Tuticorin Harbour, found the spat to attain a mode of 47.0 mm at the end of first year, 64.5 mm at the end of second year and 75.0 mm at the end of third year. The estimated von Bertalanffy growth parameters were $L\infty = 79.31$ mm, $K = 0.07557$, $t_0 = 0.44$ months. The corresponding weights at ages 1 to 3 years were 8.3 g, 31.6 g and 45.4 g respectively. The length-weight relationship was found to be a curvilinear one and was different for the first, second and third year groups of oysters. The equations derived were :

$$\text{Log } Y = -2.5430 + 1.9477 \text{ Log } X \text{ — I Year}$$
$$\text{Log } Y = -7.0902 + 4.7532 \text{ Log } X \text{ — II Year}$$
$$\text{Log } Y = -2.5827 + 2.2629 \text{ Log } X \text{ — III Year}$$

where X = dorsoventral measurement (length) in mm and Y = weight in g.

The observations on the increase in length (dorsoventral axis) is in conformity with the growth observed in oysters of the Gulf of Kutch (Narayanan and Michael, 1968). The increase in weight is in agreement with that observed at the farm at Krusadai Island, Gulf of Mannar by Devanesen and Chidambaram (1956) and the observations at Tuticorin (Chacko, 1970).

FOOD AND FEEDING

Herdman (1903) noted unicellular organisms including infusorians, foraminifers and radiolarians to form largely the food of pearl oysters. Inclusion of minute embryos, larvae of various animals, algal filaments, spicules of alcyonarians and sponges was also seen in the stomach of pearl oysters. Ota (1959 d) has seen bivalve larvae in the stomach content of the Japanese pearl oysters which were similar in size to that of the swimming bivalves in summer months. Chellam (1983) has reported the presence of diatoms, flagellates, larvae of lamellibranchs, gastropods, heteropods, crustacean nauplii, appendages and frustules of copepods, spicules of sponges and unidentified spores, algal filaments, detritus and sand particles in the stomach and intestine of *P. fucata* collected from the farm. The oysters collected from the natural beds were also found to contain the same organisms in their stomach and intestine. The size of the straight-hinge larvae found in the stomach measured 57.5 to 115 μ in length and that of the umbo larvae ranged in size from 162.5 to 232.5 μ in length. The sizes of the planktonic lamellibranch larvae present in the farm area were close to those of the larvae found in the stomach of the pearl oysters.

By experimental feeding of starving pearl oysters with straight-hinge larvae, Chellam (1983) found that within 45 minutes all the larvae in the water had been filtered and ingested. The larvae, ejected as pseudofaeces, were found entangled in mucus. The faecal matter extruded within 2 hours contained larvae alive. The trochophore larvae of 5 hours old, when fed, passed through the pseudofaeces and faeces and, if separated from the mucus and reared, developed further. The larvae retained in the stomach for more than two hours were either dead or feeble and inactive.

Korringa (1952) after studying the feeding methods of lamellibranchs, concluded that they are a wasteful feeder. Only part of the material ingested can be digested. No evidence of selection of food is found

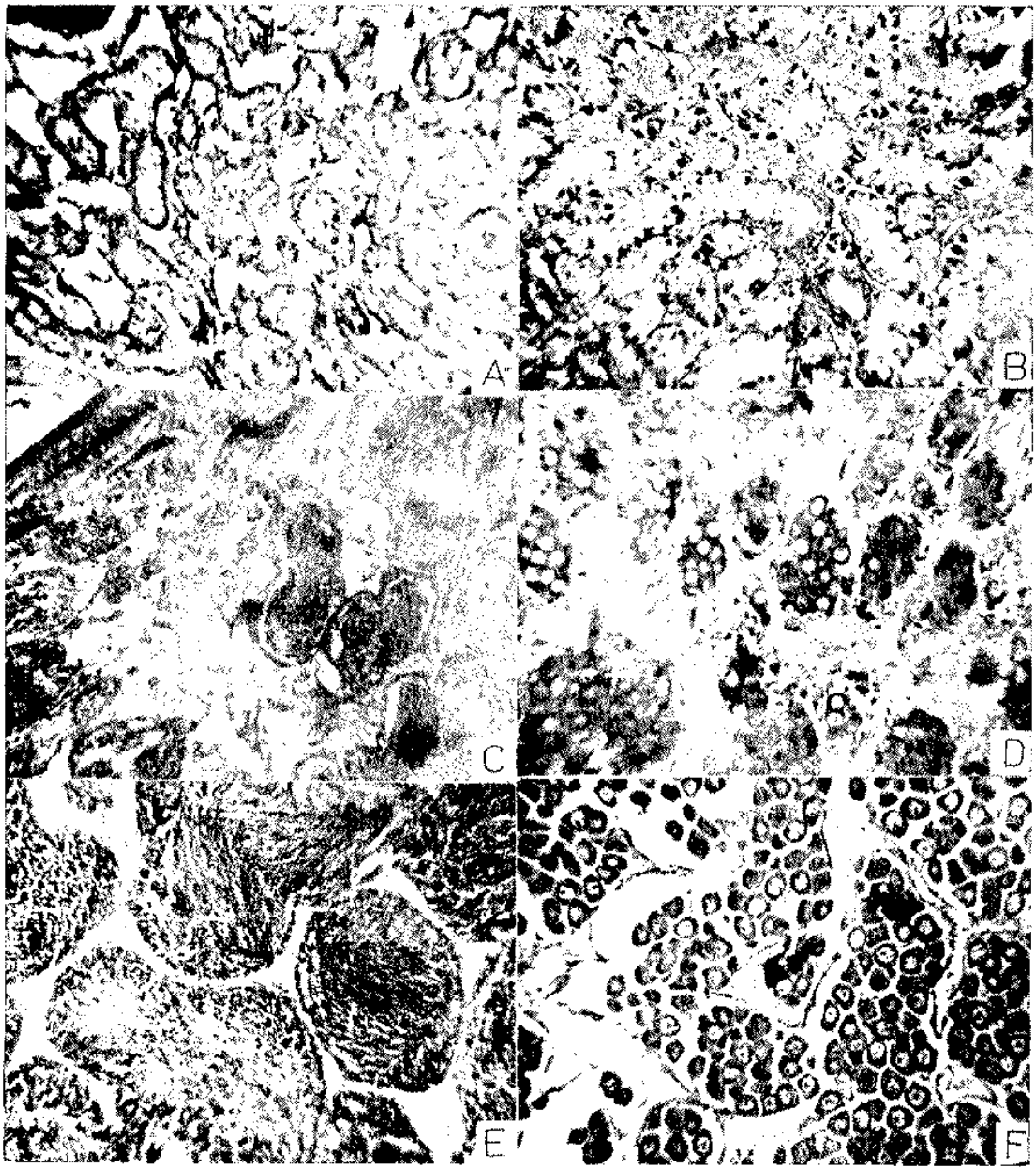

Plate I. A. Inactive gonad ; B. Undetectable minimal gonad development ; C. and D. Developing male and female gonads ; E and F. Mature male and female gonads.

and the actively feeding oyster appears to ingest anything that it can take in. Some micro-organisms found in the stomach are not digested and emerge from the oyster unchanged, often alive. These larvae very rarely succeed in freeing themselves from the mucus and organic detritus they are wrapped in and therefore are doomed to perish.

Reproductive Biology

In *P. albina*, Tranter (1958 c) has divided the gonadial stages into stages of development and stages of regression. The stages in development is subdivided into five stages and the stages in regression into three. This was felt to be too elaborate and overlapping for the oysters of the Gulf of Mannar and hence the modified version of Alagarswami (1966), Walter (1982) and Brousseau (1982) is followed in the classification of gonad stages in *P. fucata*, in this paper. Based on the external appearance and also microscopic examination of smear and gonad sections, gonad development in pearl oyster, *P. fucata* is divided into five stages. The stages are described below based on the gonad development in the female.

Stage 1 : *Inactive/spent resting*

The gonad shrinks completely and becomes translucent. In some case, it is pale orange in colour. Large vacuolated yellow (fat) cells present in the interfollicular space. The sex is mostly indeterminate. Undetectable minimal gonad development may start in this stage (Pl. I A, B).

Stage 2 : *Developing/maturing*

The transparent nature of the resting gonad is lost. The gonad becomes distinguishable from other visceral tissue. Gametogenetic materials begin to appear in the gonad. As the stage advances, the gonad begins to branch a little along the posterior side of the retractor muscle and advances to the anterio-dorsal region. The gametes begin to proliferate along the follicle wall. In advanced stages, the interfollicular space becomes reduced and in females, the lumen of the follicle may contain some free eggs also. Most of the oocytes (78%) are irregular in shape and without germinal vesicle (nucleus). The average size of the oocyte is 60.0 × 47.5 μ and the germinal vesicle, if present, is 20.0 μ (Pl. I D).

Stage 3 : *Mature*

The gonad spreads on to most of the visceral tissues. It is mostly yellowish cream in females. A little prick on the gonad makes the gametes to ooze profusely. In females, the lumen of the follicle is filled with free and enlarged oocytes. Some of them are attached to the follicular wall. Majority (65%) of the oocytes are pyriform in shape. The average size of the oocyte is 68.0 × 50.0 μ with a well defined germinal vesicle. The average size of the nucleus is 25 μ (Pl. I E).

Stage 4 : *Partially spawned*

The gonad becomes loose and the visceral epithelium becomes dull. The follicle shrinks with the reduction of the gametes in the lumen. The oocytes are free and found along the follicular wall. Most of the oocytes (62%) are spherical and nucleated. The average size of the oocyte is 51.7 μ. Externally, this stage has similarity to stage 2 (Pl. II B).

Stage 5 : *Spent*

The gonad shrinks further with a few left over gametes in the lumen of the follicles. Ruptured follicles are seen in some cases and the lumen some times contain ruptured cellular materials. The oocytes, if present, are few and 98% of them are spherical. The average size of the oocyte is 54.5 μ (Pl. II D).

The foregoing description of the spent stages applies to the animals which have recently undergone oogenesis only. Otherwise they will transform to the spent resting stage quickly. In males also the same pattern of reproductive activity takes place. In stages 2 and 3, the colour of the gonad is pale cream (Plate 1, Fig. C, E). In other stages of oogenesis, the gonads of males and females appear similar externally (Pl. II A, C).

Seasonal distribution of Maturity Stages

Table 1 gives the monthwise percentage distribution of the maturity stages of pearl oyster in the Tuticorin Harbour farm for the period from January, 1980 to December, 1981. The development of gonad appears a continuous process and there does not seem to be any time lag in transformation from stage to stage. Analysing the data, it was seen that the seasonal distribution of different maturity stages can be better expressed by combining the five stages into three categories. The developing/maturing and mature stages are combined to represent gonad development, the partially spawned and spent gonads to represent gonad regression and the spent resting/inactive gonad. Fig. 1 depicts the gametogenic activity of the oysters in the Harbour farm based on the above categories of classification.

In the farm, the inactive, maturing and mature gonads were represented almost in all the months of the year. The partially spawned and spent gonads were present throughout, excepting a break in February and May, 1980 and April-May and September 1981. The percentage of resting/inactive gonads was less during March-May and September-October (1980) and April-June and September (1981). For the years 1980 and 1981, peaks of spawning were noted in January, July-September, December-February, June-August and November. During February-May, October-November (1980) and March-May and September-October (1981), most of the oysters were in the active gametogenic stages with more percentages of developing and mature gonads.

Sex Ratio

The distribution of sex among the different size groups of pearl oysters farmed at the Tuticorin Harbour is given in Table 2. In the smallest size group (16-20 mm) with developed gonads, 63.2% were females. But in the group 16-25 mm, the sexes were equally distributed. Only in the large size groups examined (56-65 mm), the females dominated (57.2%). In size groups 26-55 mm the males dominated (62.7%). On the whole, the male-female distribution among the 452 pearl oysters ranging in length from 16-65 mm was 57 : 43.

The gonad differentiation began in the spat (produced

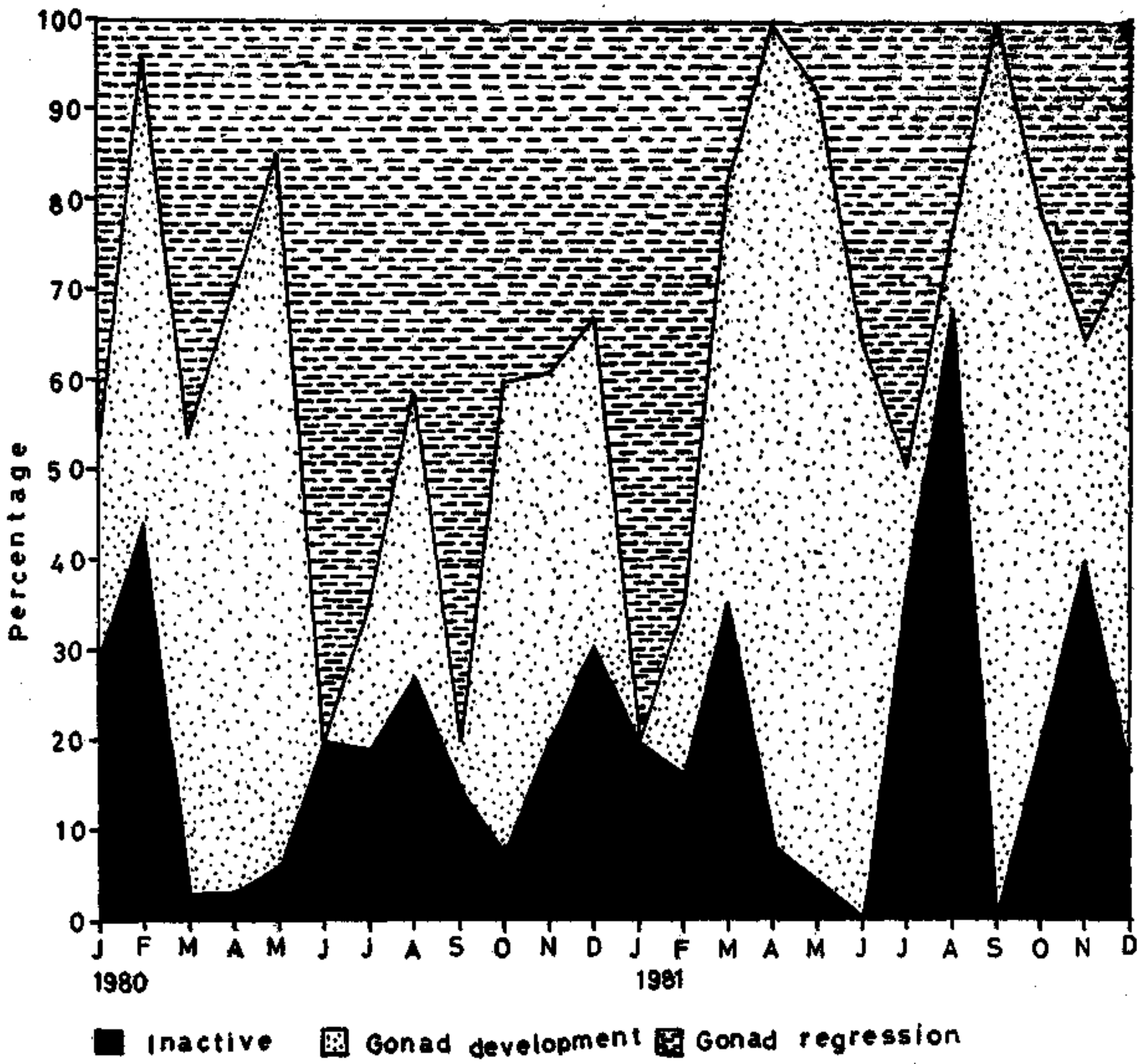

Fig. 1. Gametogenic activity of the pearl oyster *Pinctada fucata* (Gould) at the Tuticorin Harbour farm (1980 and 1981).

in the hatchery and reared in the farm) of seven months old and in another month the gonad was sexually mature. They spawned when they were nine months old.

TABLE 1. *Percentage frequency of gonad stages in oysters of Tuticorin Harbour farm for the period* 1980 *and* 1981.

Year/month	Percentage frequency of gonad stages				
	(1)	(2)	(3)	(4)	(5)
1980					
January ..	29.8	15.3	8.7	6.2	40.0
February ..	43.6	42.8	10.0	..	3.6
March ..	2.3	7.0	44.0	12.0	34.7
April ..	2.5	18.0	49.5	6.0	24.0
May ..	5.3	12.0	69.0	3.7	10.0
June ..	20.0	..	..	60.0	20.0
July ..	18.9	10.0	5.4	30.0	35.7
August ..	26.5	3.0	28.0	7.0	35.5
September ..	14.3	..	5.7	8.0	72.0
October ..	6.8	43.2	9.5	30.3	10.2
November ..	20.3	10.2	30.5	17.0	22.0
December ..	30.5	7.8	28.7	9.0	24.0
1981					
January ..	20.0	..	..	75.0	5.0
February ..	16.0	3.5	16.0	50.0	14.5
March ..	36.0	22.0	24.0	8.0	10.0
April ..	8.0	16.0	76.0	..	..
May ..	4.0	56.0	32.0	8.0	..
June ..	—	4.0	60.0	30.0	6.0
July ..	37.0	13.0	—	—	50.0
August ..	68.0	4.0	4.0	..	24.0
September ..	—	16.7	83.3	—	—
October ..	20.8	33.3	25.0	20.8	—
November ..	40.0	16.0	8.0	6.0	30.0
December ..	16.0	8.0	50.0	—	26.0

TABLE 2. *Sex distribution among different size groups of pearl oysters in the Tuticorin Harbour farm.*

Length range (mm)	No. of oysters	No. of males	%	No. of females	%
16—20 ..	19	7	(36.8)	12	(63.2)
21—25 ..	31	18	(58.3)	13	(42.0)
26—30 ..	23	13	(56.5)	10	(43.5)
31—35 ..	34	22	(64.7)	12	(35.3)
36—40 ..	33	22	(66.7)	11	(33.3)
41—45 ..	44	27	(61.4)	17	(38.6)
46—50 ..	72	46	(63.9)	26	(36.1)
51—55 ..	84	53	(63.1)	31	(36.9)
56—60 ..	62	27	(43.5)	35	(56.5)
61—65 ..	50	21	(42.0)	29	(58.0)

SEX REVERSAL

The mature males and females were separated through smear examination and reared separately for a period of 10 months. The oysters were narcotised to observe the gonads. Periodic examination of the gonads of these oysters showed that there was sex reversal in these oysters (Table 3). The reversion from male to female was noted on three occasions and from female to male on one occasion. One male reverted its sex twice.

TABLE 3. *Sex reversal in pearl oysters.*

Date	No. of males	No. of females	Male—females	Female—male	Dead
28-2-1980 ..	48	26	—	—	—
11- 6-1980 ..	36	26	11	—	1
5- 8-1980 ..	33	23	3	—	14
7-10-1980 ..	27	20	—	2	10
3-12-1980 ..	21	19	5	—	4

INFLUENCE OF ENVIRONMENTAL PARAMETERS ON REPRODUCTIVE CYCLE OF PEARL OYSTERS

Table 4 gives the environmental parameters that prevailed at the Tuticorin Harbour farm during 1980 dnd 1981. In Fig. 2, the temperature, salinity and pH during the years is depicted. From the Figs. 1 and 2, a relationship is found to exist between the temperature and the gametogenic activity (gonad development) and spawning (gonad regression) in oysters of the Harbour farm. During 1980, the percentage frequency of the spawning and spent gonads (gonad regression) was high in January, (46%), June (80%), July (65.7%), August (42.5%) and September (80%). In December, oysters with gonad development and gonad regression were somewhat equal, ie, 33 per cent and 36.5 per cent respectively. During 1981, higher percentages of gonad

TABLE 4. *Environmental data of the Harbour farm* (1980 *and* 1981).

Year/month	Temp. (°C)	Salinity (ppt)	Clarity (m)	pH	Rainfall (mm)
1980					
January ..	25.2	31.84	1.00	8.15	—
February ..	26.0	33.30	1.50	8.50	—
March ..	28.8	34.02	1.50	8.20	—
April ..	30.5	34.89	1.75	8.17	74.4
May ..	31.4	35.38	2.00	8.15	—
June ..	29.0	35.48	0.50	7.75	—
July ..	26.7	34.92	1.50	7.82	—
August ..	27.0	34.55	1.00	7.90	1.2
September ..	28.1	34.10	1.00	8.00	17.9
October ..	29.7	34.36	0.40	7.65	88.8
November ..	29.2	34.11	1.25	7.85	240.5
December ..	26.4	32.53	0.75	8.05	203.1
1981					
January ..	26.1	31.93	1.25	8.10	0.3
February ..	27.2	32.10	2.87	8.12	20.2
March ..	29.48	32.93	2.28	7.93	16.3
April ..	31.40	33.35	2.23	8.10	18.5
May ..	30.60	33.94	2.30	8.00	24.6
June ..	27.33	34.17	2.05	7.94	13.8
July ..	27.84	33.89	2.78	8.03	3.4
August ..	26.75	33.85	1.94	8.07	—
September ..	29.05	33.99	2.78	8.04	41.5
October ..	29.10	33.76	3.12	8.07	58.7
November ..	28.13	32.71	3.64	7.79	34.0
December ..	26.47	31.16	4.89	8.01	28.2

regression was noted in January (80%), February (64.5%), July (50%) and November (36%). During the period of gonad regression in the years 1980 and 1981, a corresponding lowering of water temperature (Table 2) was also seen. Majority of the gonads were in the developmental stages during February (51.7%), March (51%), April (67.5%), May (81%), October (51.7%) 1980 and April (92%), May (88%), June (64%), September (100%), October (58.3%) and December (58%) 1981. During the corresponding months,the surface temperature was found to be high (Table 2).

The salinity range in the Harbour was not much (Table 2). Like temperature, though not pronounced, biannual peaks were noted (Fig. 2). The major peak was during May-June (1980 and 1981) and the minor one during October-November (1980) and September-October (1981). The salinity may also play a combined role with temperature in the gonad development and spawning. In both the years, the peaks fell more or less close to that of temperature. The pH ranged from 7.65 to 8.50. However, no relationship could be noted for this parameter in pearl oyster reproduction or other environmental conditions. A rainfall of 240.5 mm and 203.1 mm was recorded in November and December, 1980 at the Harbour area with a continuous rain in low intensity till December, 1981 which was responsbile for the comparatively low saline condition in that year.

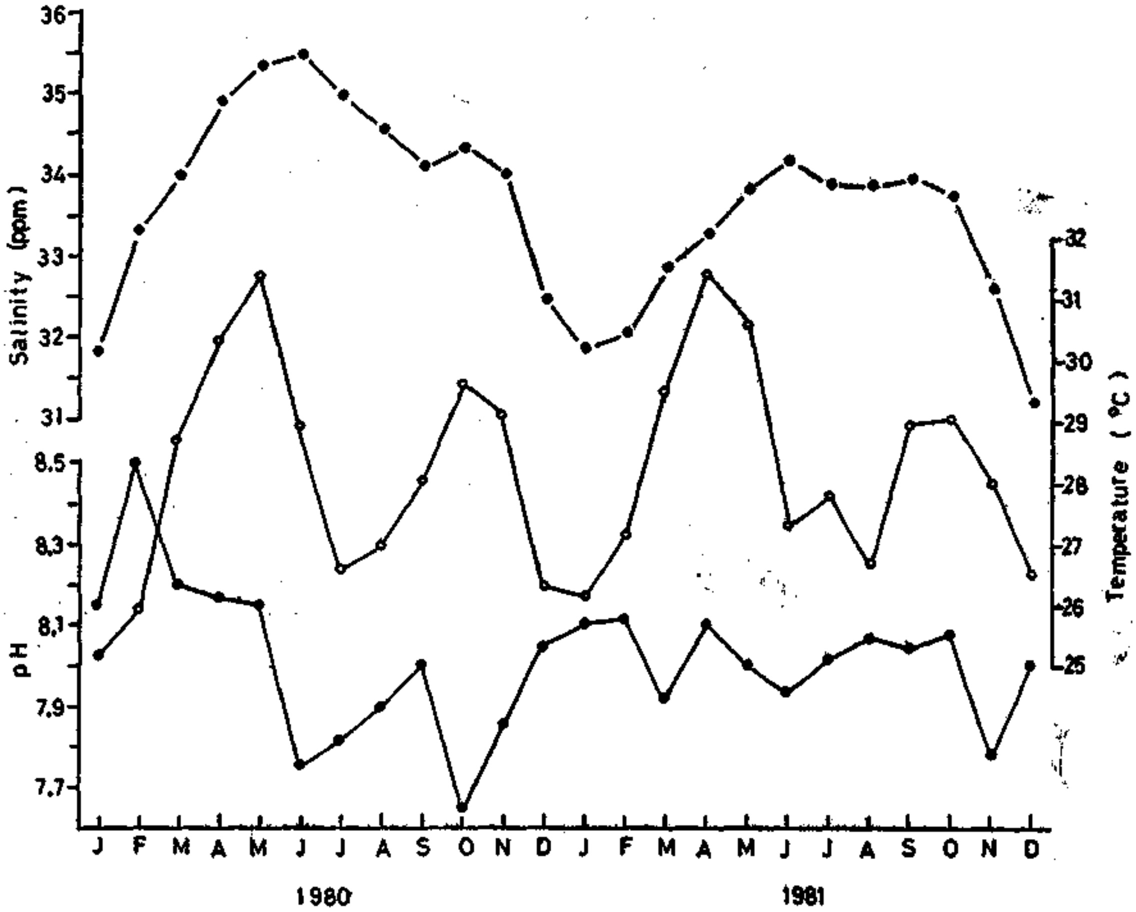

FIG. 2. Monthly averages of salinity, temperature and pH in the Tuticorin farm (1980 and 1981).

DISCUSSION

Earlier works on pearl oyster reproduction from different parts of the world confirm Orton's Rule that 'if temperature conditions are constant or nearly so and the biological conditions do not vary much, animals will breed continuously'. Herdman (1906) and Hornell (1922 a) have reported two peaks of spawning in Sri Lankan and Indian pearl oysters; during May-July and November-January in the former and April-May and September-October in the latter. The peaks of spawning coincided with the southwest and northeast monsoon periods. According to Chacko (1970), spawning takes place in all the months of the year. In Japan, the spawning occurs when the water temperature reaches 25°C and pH 7.8 (late June to early

August) (Cahn, 1949). In the Ago-Bay (Japan), it continues from June to middle of July (Uemoto, 1958). In Australian waters also, the *P. albina* breeds continuously throughout the year but most activey in April-May when the sea temperature begins to fall (Tranter, 1958 c). In *P. margaritifera* the major spawning was in early January and late July and the lesser spawning in other months (Tranter, 1958 d).

In the Tuticorin Harbour (Gulf of Mannar), two peaks of spawning, during June-September (1980) and December (1980) February, July-August and November (1981) were observed. A slight reduction in temperature had triggered the spawning in both the years of observations. The increase in water temperature had resulted in gonad development. The range in salinity and pH was not much in the farm area and their influence on the maturity and spawning of the farm oysters, if any, was not known. Tranter (1958 b) has noted highest frequency of ripe gonads in warmer months and highest frequency of spent gonads in cooler months. Most rapid decrease in gonad ripeness (spawning) coincided with the decreasing sea temperature. Lesser spawning occurred during other months of the year. Ripe gonads were present throughout and therefore spawning was possible throughout the year.

The sex ratio of 604 animals of 3 and 4 years old was 56 : 44 in Japanese waters (Uemoto, 1958). In the Harbour farm, among the 452 animals ranging in length from 16-65 mm, males dominated when they were below 55mm. The overall sex ratio was 57 : 43.

Pinctada albina sexually matured within the first 6 months (Tranter, 1958b). In the Tuticorin farm, the *P. fucata* was mature within 8 months and spawned in the ninth month. From the natural bed, the smallest oyster with mature gonad was 15.5 mm in length.

Cahn (1949) reported the maximum sex change in *P. margaritifera* to be 73%. Tranter (1958c) has observed 17 sex changes, 7 protandric and 10 protogynic, within a period of 15 months in *P. albina*. He observed that protandry dominated the sexuality of all oysters and that the succession of phase continued season by season. Uemoto (1958) noted 13 hermaphrodite animals having spermatozoa in the ovaries which were in the process of sex reversal. In the oysters from the Harbour farm, in a period of 10 months, 19 protandric and 2 protogynic reversal of sex was observed. A maximum of 30% of them changed the sex on one occasion.

REFERENCES

ALAGARSWAMI, K. 1966. Studies on some aspects of biology of the wedge-clam, *Donax faba* Gmelin from Mandapam coast in the Gulf of Mannar. *J. mar. biol. Ass. India*, 8 : 56-75.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301.

BROUSSEAU, J. D. 1982. Gametogenesis and spawning in population of *Geukensia demissa* (Pelecypoda : Mytilida) from the west port, Connecticut. *The Veliger*, 24 (3) : 247-251.

CAHN, A. C. 1949. Pearl culture in Japan. Published by Gen. Supreme Commandant for the Allied Forces. *Nat. resources Section Report* No. 122, Tokyo. 91 pp.

CHACKO, P. I. 1970. The pearl fisheries of the Madras State. *Proc. Symp. Mollusca*, Mar. biol. Ass. India, Pt. III, 868-872.

CHELLAM, A. 1978. Growth of pearl oyster, *Pinctada fucata* in the pearl culture farm at Veppalodai. *Indian J. Fish.*, 25 (1 & 2) : 77-83.

CHELLAM, A. 1983. Study on the stomach contents of pearl oyster *Pinctada fucata* (Gould) with reference to the inclusion of bivalve eggs and larvae. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Pt. II : 604-607.

CHELLAM, A. (MS). Growth and biometric relationship of hatchery produced pearl oyster *Pinctada fucata* (Gould) in the farm at Tuticorin Harbour, Gulf of Mannar.

DEVANESEN, D. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oyster farm, Krusadai Island, Gulf of Mannar, and their application to problems relating to pearl fisheries in the Gulf of Mannar—I. Contribution from the Marine Fisheries Biological Station, Krusadai Island, Gulf of Mannar, No. 4, 89 pp.

GOKHALE, S. V., C. R.E ASWARAN AND R. NARSIMHAN. 1954. Growth rate of the pearl oyster (*Pinctada pinctada*) in the Gulf of Kutch with a note of the pearl fishery of 1953. *J. Bombay nat. Hist. Soc.*, 52 (1) : 124-136.

HERDMAN, W. A. 1903. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar*. Royal Society, London, 1 : 1-307.

HERDMAN, W. A. 1906. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar*. Royal Society, London, 5 : 1-452.

HORNELL, J. 1922. The Indian pearl fisheries of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, 16 : 1-188.

KORRINGA, P. 1952. Recent advances in oyster biology. *Ouart. Rev. Biol.*, 27 : 266-308 and 339-365.

KUWATANI, Y. 1965a. On the anatomy and function of stomach of Japanese pearl oyster *Pinctada martensii* (Dunker). *Bull. Japanese Soc. Sci. Fish.*, 31 (10) : 174-186.

KUWATANI, Y. 1965b. A study on feeding mechanism of Japanese pearl oyster *Pinctada martensii* (Dunker), with special reference to passage of charcoal particles in the digestive system. *Bull. Japanese Soc. Sci. Fish.*, **31** (10) : 789-798.

NARAYANAN, K. A. AND M. S. MICHAEL. 1968. On the relationship between age and linear measurements of the pearl oyster *Pinctada vulgaris* (Schumacher) of the Gulf of Kutch. *J. Bombay nat. Hist. Soc.*, **65** (2) : 441-452.

OTA, S. 1959a. Studies on feeding habits of *Pinctada martensii.* II. Seasonal changes in amount of faeces. *Bull. Natl. Pearl Res. Lab.*, **5** : 429-433 (in Japanese).

OTA, S. 1959b. Studies on feeding habits of *Pinctada martensii.* III. Difference of the amount of faeces due to nuclear insertion in pearl culture. *Bull. Natl. Pearl Res. Lab.*, **5** : 434-438 (in Japanese).

OTA, S. 1959c. Studies on feeding habits of *Pinctada martensii.* IV. Difference of the amount of faeces due to different conditions of culture raft and culture ground. *Bull. Natl. Pearl Res. Lab.*, **5** : 439-442 (in Japanese).

OTA, S. 1959d. Studies on feeding habits of *Pinctada martensii.* V. Number and size of swimming bivalve larvae fed by pearl oyster in summer. *Bull. Natl. Pearl Res. Lab.*, **5** : 443-449 (in Japanese).

PANDYA, J. R. 1975. Age and growth of pearl oyster *Pinctada vulgaris* (Schumacher) of the Gulf of Kutch. *J. Indian Fish. Ass.*, **2** (1 & 2) : 47-54.

TRANTER, D. J. 1958b. Reproduction in Australian pearl oyster (Lamellibranchia) II. *Pinctada albina* (Lamarck). Gametogenesis. *Aust. J. Mar. Freshw. Res.*, **9** (1) : 144-158.

TRANTER, D. J. 1958c. Reproduction in Australian pearl oysters (Lamellibranchia) III. *Pinctada albina* (Lamarck). Breeding season and sexuality. *Austr. J. Mar. Freshw. Res.*, **9** (2) : 191-216.

TRANTER, D. J. 1958d. Reproduction in Australian pearl oysters (Lamellibranchia). IV. *Pinctada margaritifera* (Linnaeus). *Aust. J. Mar. Freshw. Res.*, **9** (4) : 509-525.

UEMOTO, H. 1958. Studies on the gonad of pearl oysters, *Pinctada martensii* (Dunker). II. Histological observation with regard to the seasonal variation and change during the course of the artificial spawning (with English summary). *Bull. Natl. Pearl Res. Lab.*, **4** : 287-307.

WALTER, CHAD. 1982. Reproduction and growth in the tropical mussel *Perna viridis* (Bivalvia) ; Mytilidae. *Kalikasan, Philipp. J. Biol.*, **11** (1) : 83-97.

4

SOME ASPECTS OF PHYSIOLOGY OF PEARL OYSTER

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INTRODUCTION

Pearl oysters of the genus *Pinctada* occur in different environments, from the intertidal zone to shallow coastal waters as well as at depths of 12-23 m as on the pearl banks of Gulf of Mannar. A knowledge of the physiological characteristics of pearl oyster is necessary for successful rearing in the farm as well as for production of quality pearls. Realising this, several studies have been carried out on the physiology of *Pinctada fucata* of the Japanese seas. Itoh (1976) has studied the relation of oxygen consumption and ammonia nitrogen excreted in the adult oyster to body size and water temperature. Cahn (1949) has reported the role of oxygen during conditioning of the pearl oyster *P. martensii*. The influence of low saline water on growth and mortality of *P. martensii* and quality of cultured pearls has been studied by Katada (1959). In India there have been only a few studies on the physiological aspects of pearl oyster. Variation in the metabolic rate of *P. fucata* and *P. sugillata* collected from two different environments has been studied by Dharmaraj (1983). Alagarswami and Victor (1976) have reported the salinity tolerance and rate of water filtration in *P. fucata*. Seasonal variation of biochemical constituents of pearl oyster in the Gulf of Kutch has been reported by Desai *et al.* (1979). The results on oxygen consumption and salinity tolerance already published (Dharmaraj, 1983; Alagarswami and Victor, 1976) are briefly summarised. Other observations are reported for the first time in this paper.

MATERIAL AND METHODS

For the biochemical investigations pearl oysters (45-60 mm in dorso-ventral measurement) were collected from pearl banks of Gulf of Mannar. The soft parts were dried immediately in oven at 80°C to constant weight, and the water, glycogen, lipid and protein contents were determined. Glycogen was estimated by the method of Oser (1954) and followed by Umbreit *et al.* (1959), lipid by extraction with a mixture of methanol chloroform (Bligh and Dyer, 1959) and protein by semimicrokjeldahl method (Bock and Benedict, 1915). The biochemical constituents of the homogenised animal (without shell) and also of specific organs such as the gonads, hepatopancreas, adductor muscle and mantle in different phases of reproduction were estimated.

Pearl oysters for the experiments on salinity tolerance and rate of filtration were obtained from the natural beds off Tuticorin coast in the Gulf of Mannar (Alagarswami and Victor, 1976). Seawater of experimental salinities was prepared by adding freshwater to normal seawater for dilution and adding fresh common salt collected from the salt pans for increasing the concentration. In all, 16 experiments were carried out in the salinity range of 14.01‰ to 57.99‰ with larger intervals of about 4‰ to 5‰ nearer the normal salinity and smaller intervals of about 1‰ to 2‰ nearer the extremes. The neutral red technique of Cole and Hepper (1954) was employed to study the rate of filtration. The optical density of the solution was read out in a photocolorimeter (Alagarswami and Victor, 1976).

The rate of oxygen consumption was estimated by Winkler's method and expressed in terms of μl of O_2/hour. The post-exposure rate of oxygen consumption was estimated based on wet tissue weight in varying temperature from 26.0°C to 29.4°C (mean 27.9°C). *P. sugillata* from pearl banks (21.8-54.0 mm) and *P. fucata* from pearl culture farm (30.0-54.5 mm) were used for anaerobic study (Dharmaraj, 1983).

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Biochemical Changes in *Pinctada fucata* Associated with Reproduction

Water

The water content in the pearl oyster *P. fucata* was more than 70% in the total tissue as well as in individual organs like gonad, hepatopancreas, adductor muscle and mantle. The mantle had a high percentage of water, being 81.99% wet weight in immature stage, 86.39% in maturing stage, 85.37% in ripe stage, 84.16% in spent stage and 85.85% in resting stage (Table 1).

Table 1. *Percentage of water content in tissues of* Pinctada fucata

Organ	Water content (%)				
	Immature	maturing	ripe	Spent	resting
Total tissue ..	81.13	79.94	79.50	82.10	81.41
Gonad ..	75.41	76.05	77.79	77.69	75.95
Hepatopancreas ..	76.90	73.91	70.88	70.42	70.76
Adductor muscle ..	79.10	79.14	73.55	74.90	74.01
Mantle ..	81.99	86.39	85.37	84.16	85.85

Glycogen

The glycogen level increased sharply from 2.64% to 22.51% in the total tissue and from 6.99% to 22.79% in the adductor muscle from maturing to spent stage. It declined in the resting stage to 13.93% and 12.23% in the total tissue and adductor muscle respectively indicating low metabolic energy demand. During gametogenesis glycogen level rose in gonad from 2.63% to 11.65%, in hepatopancreas from 3.91% to 10.34%, in adductor muscle from 6.99% to 22.79% and in the mantle from 1.91% to 9.97%. In all the organs the glycogen content declined after spawning. The data show accumulation of glycogen reserves in all the organs during gametogenesis and utilization during spawning. Accumulation of glycogen and lipid showed similar trend in the gonad, hepatopancreas and mantle. Biochemical changes during reproductive cycle in *P. fucata* are shown in Fig. 1.

Lipid

In the case of lipid the individual organs did not show wide variation in different stages of reproduction. The level increased gradually in the organs till ripe stage. In the gonad it increased from 3.61% to 8.65%, in the hepatopancreas from 4.97% to 8.22% and in the mantle from 3.18% to 5.60%. In the adductor muscle the lipid level remained almost constant. There was a close relationship between the levels of glycogen and lipid during the reproductive cycle both showing similar trend except in the adductor muscle.

Protein

The protein content was over 50% in the individual organs during maturation of gonads. It declined sharply in the total tissue from 93.43% in immature stage to 66.81% in spent stage and increased in resting stage. In hepatopancreas the level came down to 51.22% from 79.65% between the immature and spent stages and increased to 78.02% in resting stage. In contrast, the protein content of the mantle increased steadily from 60.69% in immature to 82.26% in spent stage and decreased to 76.67% in the resting stage. In gonad and adductor muscle the pattern of protein level was similar showing an increase from 62.91% to 66.67% in the former and 68.99% to 79.19% in the latter during maturation and a decline when the gonad was in fully ripe condition (56.10% to 59.20%) in the respective organs.

Energy Storage and Utilisation

Requirements of reproduction

Growth results when energy gain is in excess of energy expenditure. When the energy acquisition is less, endogenous reserve is used up for maintenance metabolism of the body. Bivalve molluscs may regulate individual components of energy balance in order to maximise net energy gain. Food availability fluctuates in nature with peaks and troughs. Therefore, a common response is to lay down reserves like carbohydrate, lipid or protein during the periods when food is abundant for later utilization. In most marine bivalves glycogen is the major carbohydrate storage reserve. The adductor muscle is a storage organ for glycogen. The steady increase in glycogen level in adductor muscle from 6.99% in the maturing stage to 22.79% in the spent stage is related to maturation and spawning processes. A similar rise noticed in the gonad from 2.63% to 11.65% might be attributed to the requirements of high gamete output. During gametogenesis glycogen in the hepatopancreas also increases from 3.91% to 10.34% which may be mobilised to other organs. The glycogen cycle in the mantle is similar and ranged from 1.91% to 9.97% which may be utilised for maintenance metabolism.

Lipid is another source of energy available for various metabolic activities. In all the organs the variations in lipid level closely resemble those of glycogen levels. Among the organs, the gonad showed high percentage of lipid (3.61% to 8.65%) during maturation which is mostly utilised for gametogenesis. In the case of adductor muscle, as it had high glycogen for its activity, the lipid level remained unchanged throughout the reproductive cycle. Storage and utilisation of lipid in the mantle

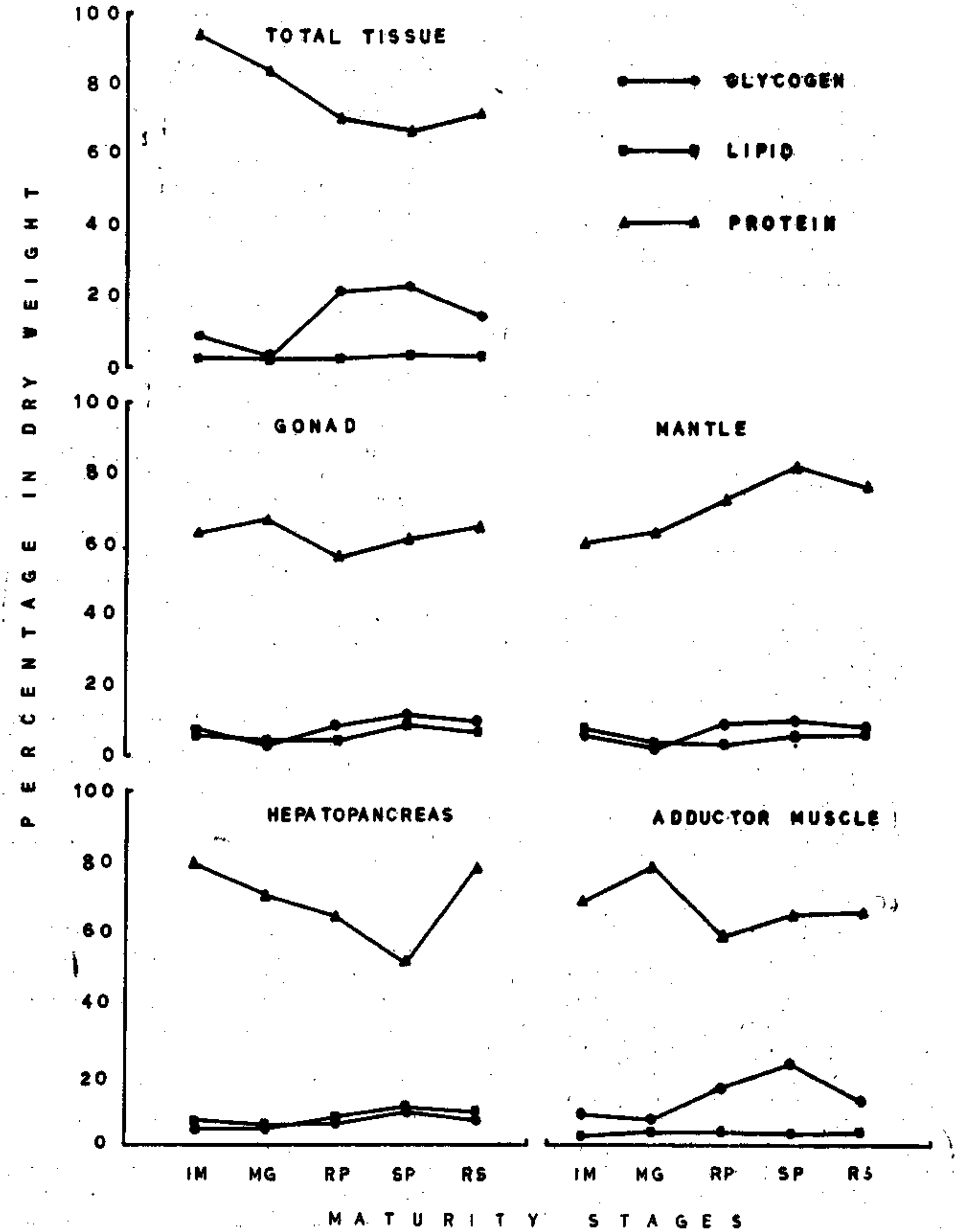

FIG. 1. Biochemical changes during different maturity stages in *Pinctada fucata*. IM—immature; MG—maturing, RP—ripe, SP—spent and RS—resting.

and hepatopancreas are associated with maturation of gonads. When the energy demands for gametogenesis are more, the maximum growth efficiency is less. In some molluscan species reproduction is not initiated until somatic growth ceases, while in others growth continues after the age of first maturity but an increasing proportion of surplus energy is utilised for gametogenesis (Bayne and Newell, 1983).

Glycogen utilisation during starvation

During the periods of starvation the metabolic energy demands must be met from endogenous reserves. Weight loss indicates utilisation of energy reserves for maintaining body metabolism. In *P. fucata* the glycogen content decreased considerably during different stages of starvation as shown below:

Starvation duration		Glycogen %
Day 0	..	25.23
Day 7	..	21.66
Day 14	..	8.07
Day 21	..	1.66
Day 28	..	1.32

The level of glycogen showed 14% reduction after 7 days of starvation, 68 % after 14 days, 76% after 21 days and 97.75% after 28 days of starvation. The study showed that *P. fucata* relies to a large extent on their glycogen reserves during starvation.

Oxygen Consumpion

The results of experiments on oxygen consumption as reported by Dharmaraj (1983) are summarised here. The rate of oxygen uptake of pearl oyster varies in accordance with the size, physiological state and environmental conditions. Oxygen consumption of *P. fucata* collected from the pearl banks at a depth range of 12-23 m and of *P. sugillata* from the pearl banks as well as from the nearshore waters (depth 0.5-1.5 m) was estimated. In *P. fucata* oxygen consumption of the size group 40-50 mm was 1,339 μl/h, 50-60mm 1,650 μl/h, and 60-70 mm 1,810 μl/h. The rate of oxygen consumption of *P. sugillata* (from pearl banks) of the size groups 20-30, 30-40, 40-50 and 50-60 mm was 255, 345, 588 and 1,045 μl/h respectively and *P. sugillata* (from nearshore waters) of the size groups 10-20, 20-30, 30-40, 40-50, 50-60 and 60-70 mm was 618, 828, 510, 879, 1,170 and 1,361 μl/h respectively. It has been noted that *P. sugillata* of similar size groups collected from two ecologically different conditions exhibited differences in metabolic rate.

Post-exposure rate of oxygen consumption

P. fucata tested for oxygen consumption were kept out of water for different durations such as 6, 9, 12, 18, 21, 24 and 30 hours and the post-exposure rate of oxygen consumption was estimated on wet tissue weight basis in varying temperature from 26.0°C to 29.4°C (mean 27.9°C). Oysters exposed for 9, 12 and 18 hours showed higher rate of oxygen consumption during the first hour on reimmersion and normal rate of consumption was observed from second hour. *P. fucata* exposed to 6 and 21 hours showed less rate of consumption during the first hour itself on reimmersion. On return to seawater after 21 hours of exposure the oysters closed their valves partially throughout the experiment.

Conditioning time and shell activity

The conditioning time, i.e., the time taken by the shellfish to open valves on immersion, in the case of freshly collected pearl oysters ranged from 2 to 65 minutes, whereas the oysters exposed to air for 9 to 21 hours took 0 to 15 minutes. The amplitude of shell activity of nonexposed oysters was accelerated below ambient oxygen concentration. A minimum shell activity was recorded in normoxic conditions. At lower oxygen level the shell opened to a maximum extent, thus exposing the gills fully to the medium. The oysters in well aerated seawater kept their valves open only narrowly.

Tolerance limit in anaerobiosis

P. fucata was found to be less tolerant to anaerobic condition than *P. sugillata*. Mortality of the former in anaerobic medium set in early from 19th hour. In the case of *P. sugillata* from nearshore water the mortality began from 24th hour. *P. sugillata* from the pearl banks were found to tolerate upto 27 hours of anaerobiosis.

Exposure to air

P. fucata exposed to air for 21 hours showed 100% survival at the end of the period but at the end of 24 hours they showed very little shell movement and died. During exposure, oysters showed shell activity upto a period of 18 hours and it ceased on further exposure.

Salinity Tolerance and Rate of Filtration

The results of study on salinity tolerance and rate of filtration reported by Alagarswami and Victor (1976) are summarised here. The pearl oyster, a truly marine form, has been found to tolerate a wide range of salinity from 24‰ to 50‰ for short durations of 2-3 days under experimental conditions. The estuaries and adjoining marine realms along the Indian coast are influenced by the enormous discharge of river water during the monsoons and are subject to salinity fluctuations.

Experiments on salinity tolerance were conducted in the following salinities (‰) 14.01, 15.03, 15.95, 16.99, 19.02, 24.03, 26.05, 29.03, 34.05, 38.05, 42.97, 45.00, 50.07, 52.08, 55.09 and 57.99. In normal seawater with 34.05‰ salinity all the oysters opened immediately on immersion. In dilutions the average conditioning time showed variations from 16 min. in 26.05‰ and 22 h 10 min in 14.01‰. The oysters opened within the 1st hour in the salinities of 29.03, 26.05 and 24.03‰, during the 6th hour in 19.02‰ and in 19th hour in 15.03 and 16.99‰. On the other hand, in higher concentrations the conditioning time showed a narrow variation from 12 min in 50.07‰ and 4 h 45 min in 57.99‰. In the lowest salinity of 14.01‰ the oysters did not open during the first day but remained open for considerable period during the second day. In dilutions of salinity from 15.03‰ to 16.99%° the oysters remained open only for a short time during the first day, but for a longer duration on the second day. Between salinities of 19.02 and 29.03‰, the oysters remained open for 47 to 93% of the duration on the first day itself. In the immediate higher salinity concentration of 38.05 to 45.00‰ the oysters remained open for 58 to 99% of the time on the 1st day itself. In the salinity range 50.07-57.99‰ the oysters showed a decrease to 27.33% of the time during the first day and in 52.08‰ the duration was 72%. In this higher range of salinity the oysters remained open for 78 to 100% of the time during the second day. Shell activity was maximum in the normal seawater. In dilutions and in higher salinities the shell activity decreased gradually.

The rate of mortality was 100% among the oysters kept in the salinity of 57.99, 55.09 and 14.01‰, 67% in the salinity of 52.08‰, 50% in the sainity of 15.03‰ and 10% in the salinity of 15.95‰.

The rate of filtration was studied in the salinities of 13.98, 19.90, 24.10, 34.23, 43.97, 49.90 and 56.96‰. Filtration was maximum in normal seawater being 33.7% at the end of 1 hr, 52.1% at the end of 2 hrs, 76.1% at the end of 4 hrs and 92.6% at the end of 8 hrs. In the two salinities of 13.98 and 19.9‰ the rate of filtration was poor, being 13.7% and 22.9% respectively at the end of 4 hrs. In the salinity of 24.1‰ filtration was 51.3% at the end of 4 hrs. In the higher salinity of 56.96‰ the removal of neutral red was 41.8% at the end of 4 hrs and in 43.97‰ it was 49.5% for the same duration. At 49.9 ‰ the removal was 53.7% at the end of 4 hrs.

The mortality rate at the end of 48 hrs was 3 out of 5 oysters in the salinity of 19.90‰ and was total in the salinities of 13.98‰ and 56.96‰. In other salinities there was no mortality.

Byssus Formation

Byssus is secreted by the byssal gland and assembled by a specialised region of the foot. It consists of three parts : the root, stem and disc. The root is deeply embedded in the base of the foot and resembles an artist's paint brush. It consists of small fibres of flesh colour which emerge from different points and converge to form a single stem. The arrangement of small fibres facilitates better anchorage. Attached to the root is a tanned acellular stem which is thick green in colour and forms a thread. The disc at the end of the thread is meant for adhesion to the substratum.

When a new thread is formed, the foot is extended out of the shell with the tip touching the substratum. During this quiescent period, components of the thread are secreted into the byssal groove and moulded there in the form of a thread by muscular contractions. After a brief time in this position the animal withraws the foot allowing the new thread to remain attached.

Formation of byssus thread in the spat and adults upto 30 mm in size (DVM) was rapid. When the byssus threads were detached, immediate extrusion of foot was seen leading to the formation of new byssus thread, even during day time. In the oysters of 30 mm and above, though their threads were detached they did not extrude the foot during day time. Movement and attachment of these oysters took place mostly during night.

Some oysters with byssus threads *in situ* first ejected the existing threads and developed fresh threads. In other cases attachment was seen even before the old byssus threads were cast off. Byssal attachment takes place always with the right valve down to the substratum. Among oysters of 20.0-25.3 mm, 30.0-36.7% attached within 5 hrs during day time and the rest during night. But among those of 33.5-54.2 mm, none attached during day and 78.8-93.8% attached during night. The number of byssus threads in oysters ranged 10-28.

Discussion

In most marine bivalves the major biochemical components such as glycogen, lipid and protein are chiefly related to reproductive cycle. In *Mytilus edulis* the seasonal cycle of storage and utilisation of glycogen is closely linked to reproduction (Bayne, 1976). The biochemical components of the pearl oyster *P. fucata* showed a definite pattern of changes in the individual organs during different reproductive phases. The trend in glycogen levels indicated a uniform pattern in the gonad, hepatopancreas, adductor muscle and mantle. The increase in the glycogen content during gametogenesis was kept up till spawning time. Vahl (1981) reported that mature individuals store more glycogen and this is done at the expense of rapid growth. Desai *et al.* (1979) reported that in *P. fucata* of Gulf of Kutch glycogen and lipids are stored during prespawning period and they decline in postspawning season. Presence of high glycogen content in the adductor muscle showed its glycolytic nature. According to Suryanarayanan and Alexander (1971) the slow muscle of *Lamellidens corrianus* has a low glycogen and high lipid content than the fast muscle and it may utilise lipids as the main fuel for oxidative metabolism.

Mane and Nagabhushanam (1975) attributed the low lipid content in several bivalves to their sedentary way of life and their capacity to survive anaerobic conditions. In the present study the lipid in the adductor muscle of *P. fucata* was low and was maintained almost constant. Probably the high glycogen content in the muscle may provide energy for oxidative metabolism during activity. Zandee *et al.* (1980) suggested that in *Mytilus edulis* lipids are the main source of energy production in growing mussels and may be utilised during gametogenesis. Voogt (1972) found that all bivalve species investigated by him are able to synthesise fatty acids from acetate. Teshima and Patterson (1981) showed that the American oyster, *Crassostrea virginica* is able to synthesise sterols from acetate. In *P. fucata* the trend of quantitative changes in glycogen and lipid was the same. It is probable that they are associated with the reproductive cycle.

Starvation experiments showed lipid to be the most important reserve in *C. gigas* (Riley, 1976). Nagabhushanam and Dhamne (1977) reported that in *Paphia laterisulca* lipid contents remained constant after starvation for twelve days, glycogen content decreased and water content increased. Small individuals with a relatively low glycogen reserve increase considerably their protein catabolism during starvation, whereas larger individuals rely to a greater extent on their relatively high glycogen stores (Bayne, 1976). In our study the glycogen content of *P. fucata* declined progressively during different stages of starvation. The reduction in the glycogen level has gone to the extent of 97.75% after starvation for 28 days.

The biochemical components of the byssus thread are derived from various exocrine glands in the foot. These glands are named as (1) white or collagen gland, (2) mucous gland, (3) phenol gland and (4) accessory gland (Brown, 1952; Allen *et al.*, 1976). From the functional point of view the collagen gland secretes the major fibrous components of the thread (Vitellaro-Zuccarello, 1980). The gland secretes a substance that may promote the function of a colloidal gel when mixed with other components (Tamarin *et al.*, 1976). The phenol gland produces the adhesive substance for the disc as reported by the same authors. The role of the accessory gland is not known.

The byssus of *Mytilus* and *Modiolus* appears to contain collagen as suggested by the high glycine content and presence of hydroxyproline. As the pearl oyster *Pinctada alba* has high glycine 242 residues per 1000, the presence of collagen in the fibres is indicated. Stary and Andratschke (1925) showed that the material in *Mytilus* and *Pinna* byssus threads was a sclerotised protein.

The average dissolved oxygen content in the bottom water of pearl banks was 4.37 ml/l and that of the pearl farm in harbour 4.77 ml/l. *P. sugillata* collected from these two areas showed variation in the rate of oxygen consumption. The oysters from the pearl banks exhibited low metabolic rate characteristic of benthic species. Further the oysters from the pearl banks withstood anaerobic condition for 27 hrs whereas the same species from nearshore waters could tolerate only for 24 hrs. *P. fucata* survived upto 19th hrs. in anaerobic medium. The species withstood 21 hrs of exposure to air. It is probable that in aqueous medium the metabolic end products might readily be released which in turn caused deleterious effect on the oysters. Korringa (1952) reported similar feature in *Gryphaea virginica*. In a practical situation, *P. sugillata* were transported to a distance of 1,896 km from Tuticorin to Dhauli in a duration of 43 h without mortality by covering them with wet jute piece but occasionally immersing them in seawater. The survival time of wedge clam *Donax cuneatus* exposed to air at room temperature (30° C) was found to be 69 h and that of *D. faba* in the same conditions 94 hrs (Rao and Kutty, 1968).

In *P. fucata* the oxygen consumption of the size group 40-50 mm was 1339 μl/hr of 50-60 mm 1650 μl/hr and of 60-70 mm 1810 μl/hr. Oxygen tension of the medium should be ascertained while conditioning the oysters before nucleus implantation for pearl production. The information on the relationship between the shell gaping and oxygen tension in the medium has much value in the controlled culture of oysters in the laboratory. The measure of shell gape has been recognised as an indicator of the level of oxygen in the medium and it is inversely proportional to oxygen level.

Experimental results on salinity tolerance and the low saline conditions observed in Veppalodai farm showed the range of salinity which the pearl oyster could survive (Alagarswami and Victor, 1976). The tolerance limit of *P. fucata* appears to extend over a wide range of 24 and 50‰ at least for 2-3 days. Katada (1959) found that the unoperated oysters remained unaffected in the density ranging from 6.53 to 21.90 during the first 24 hrs, whereas the operated oysters could remain so only for the first 12 hrs. He concluded that the density of 15.00 which is nearly equal to a salinity of 20.65‰ was the safe limit for the Japanese pearl oyster. According to Alagarswami and Victor (1976) a salinity of about 24‰ appears to be the safe limit in dilutions for *P. fucata* of Gulf of Mannar. The European mussel *Mytilus edulis* occurs in salinities ranging from 30 to 10‰ and even as low as 4‰ in some areas and the American oyster *Crassostrea virginica* lives for weeks at salinities just above freshwater (Gunter *et al.*, 1973).

In *C. virginica* a sharp reduction in salinity from 27 to 20, 15, 10 and 5‰ decreased the pumping rate to 24, 89, 91 and 99.6‰ respectively for approximately 6 hrs after transfer (Loosanoff, 1953). Decreased filtration rate has been observed in the pearl oyster in lower salinities and it is less than 25% in salinities of 14‰ and 20‰ even after 4 hrs. In *Meretrix casta* the rate of filtration was adversely affected both at low and high salinities (Durve, 1963). In the clam the filtration rate remained fairly high even at salinities of 45 and 56‰ and became erratic at 64‰. In *P. fucata* the rate of filtration was high in the higher salinity range.

REFERENCES

ALAGARSWAMI, K. AND A. C. C. VICTOR. 1976. Salinity tolerance and rate of filtration of the pearl oyster *Pinctada fucata*. *J. mar. biol. Ass. India*, **18** (1) : 149-158.

ALLEN, J. A., M. COOK, D. J. JACKSON, S. PRESTON AND E. M. WORTH. 1976. Observations on the rate of production and mechanical properties of the byssus threads of *Mytilus edulis*. *J. Molluscan Stud.*, **42** : 279-289.

BAYNE, B. L. 1976. *Marine mussels : their ecology and physiology*. Cambridge University Press, 233 pp.

BAYNE, B. L. AND R. C. NEWELL. 1983. The physiological energetics of marine molluscs. *In* : *The Mollusca, Physiology*, Pt. I (A.S.M. Saleuddin and K. M. Wilbur, Eds.), 4, pp. 472-497, Academic Press, London.

BLIGH, E. G. AND W. J. DYER. 1959. A rapid method of total lipid extraction and purification. *Can. J. Biochemistry and Physiology*, **37** : 911-917.

BOCK AND BENEDICT. 1915. Semimicrokjeldahl method of protein estimation. *J. Biol. Chem.*, **20** : 47.

BROWN, C. H. 1952. Some structural proteins of *Mytilus edulis*. *Q. J. Microsc. Sci.*, **93** : 487-502.

CAHN, A. R. 1949. Pearl culture in Japan. *U. S. Fish. Wildl. Serv., Fish. leafl.*, **357** : 1-91.

COLE, H. A. AND B. T. HEPPER, 1954. The use of neutral red-solution for the comparative study of filtration rates of lamellibranchs. *J. du Conseil*. **20** (2) : 197-203.

DESAI, K., G. HIRANI, AND D. NIMAVAR. 1979. Studies on the pearl oyster *Pinctada fucata* (Gould) : Seasonal biochemical changes. *Indian J. Mar. Sci.*, **8**(1) : 49-50.

DHARMARAJ, S. 1983. Oxygen consumption in pearl oysters *Pinctada fucata* (Gould) and *Pinctada sugillata* (Reeve). *Proc. Symp. Coastal Aquaculture*, Pt. 2 : 627-632. *Mar. Biol. Ass. India*.

DURVE, V. S. 1963. A study on the rate of filtration of the clam *Meretrix casta* (Chemnitz). *J. mar. biol. Ass. India*, **5**(2) : 221-231.

GUNTER, G., B. S. BALLARD AND A. VENKATARAMIAH. 1973. Salinity problems of organisms in coastal areas subject to the effect of engineering works. Gulf Coast Research Laboratory, Ocean Springs, Mississippi, Extract Report, H-73-3, 176 pp.

ITOH, K. 1976. Relation of oxygen consumption and ammonia nitrogen excreted to body size and to water temperature in the adult pearl oyster *Pinctada fucata* (Gould). *Bull. Natl. Pearl Res. Lab.*, **20** : 2254-2275.

KATADA, S. 1959. The influence of low salinity seawater on death and growth of the pearl oyster (*Pinctada martensii*) and quality of cultured pearls. *Bull. Natl. Pearl Res. Lab.*, **5** : 489-493.

KORRINGA, P. 1952. Recent Advances in Oyster Biology. *Quart. Rev. Biol.*, **27** (4) : 266-308 and 339-365.

LOOSANOFF, V. L. 1953. Behaviour of oysters in water of low salinities. *Proc. Nat. Shellf. Assoc.*, 1952 : 135-151.

MANE, U. H. AND R. NAGABHUSHANAM. 1975. Body distribution and seasonal changes in the biochemical composition of the estuarine mussel, *Mytilus viridis* at Ratnagiri. *Riv. Idrobiol.*, **14** : 163-175.

NAGABHUSHANAM, R. AND K. P. DHAMNE. 1977. Seasonal variations in biochemical constituents of the clam, *Paphia aterisulca*, *Hydrobiologia*, **54** : 209-214.

OSER, B. L. 1971. *Hawk's Physiological Chemistry*. Fourteenth edition, pp. 1472. Tata McGraw-Hill Publishing Company.

RAO, S. R. AND M. N. KUTTY. 1970. Resistance to desiccation and Oxygen debt in wedge clams. *Proc. Symp. Mollusca. Mar. Biol. Ass. India.* **3** : 595-606.

RILEY, R. T. 1976. Changes in the total protein, lipid, carbohydrate and extra cellular body fluid free aminoacids of the Pacific oyster, *Crassostrea gigas*, during starvation. *Proc. Nat. Shellf. Assoc.*, **65** : 84-90.

STARY, Z. AND I. ANDRATSCHKE. 1925. Bertrage zur Kenntniss einiger Skleroproteine. Hippe-Seyler's. *Z. Physiol. Chem.* 148, 83-98.

SURYANARAYANAN, H. AND K. M. ALEXANDER. 1971. Fuel reserves of molluscan mussel. *Comparative Biochemistry and Physiology*, **40** A : 55-60.

TAMARIN, A., P. LEWIS AND J. ASKEY. 1976. The structure and formation of the byssus attachment plaque in *Mytilus*. *J. Morphol.*, **149** : 199-221.

TESHIMA, S. I. AND G. W. PATTERSON. 1981. Sterol biosynthesis in the oyster *Crassostrea virginica*. *Lipids*, **16** : 234-239.

UMBREIT, W. W., R. H. BURRIS AND J. F. STAUFFER. 1959. *Monometric Techniques*. Burgess Publishing Company.

VAHL, O. 1981. Energy transformations by the Iceland scallop *Chlamys islandica* (O. F. Muller) from 70°N.1. The age-specific energy budget and net growth efficiency. *J. Exp. Mar. Biol. Ecol.*, **53** : 281-296.

VITELLARO-ZUCCARELLO, L. 1980. The collagen gland of *Mytilus galloprovincialis* : an ultrastructural and cytochemical study on secretory granules. *J. ultrastruct. Res.*, **73** : 135-147.

VOOGT, P. A. 1972. Lipid and sterol components and metabolism in Mollusca. In : *Chemical Zoology* (M. Florkin and B. R. Scheer, Eds.), 7 pp. 245-300, Academic Press, New York.

ZANDEE, D. I., H. KLUYTMANS, H. ZURBURG AND H. PIETERS. 1980. Seasonal variations in biochemical composition of *Mytilus edulis* with reference to energy metabolism and gametogenesis. *Neth. J. Sea Res.*, **14** ; 1-29.

5

ECOLOGY OF PEARL OYSTER BEDS

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INTRODUCTION

The importance of pearl fisheries in the Gulf of Mannar and the unpredictability of annual fishery due to the disappearance of oysters from beds or failure in oyster spat settlement over the banks have stimulated pearl oyster experts in the past to devote considerable attention to find out the probable causes. Kelaart (1859), Herdman (1903-1906) and Hornell (1905, 1913, 1916 and 1922) have contributed much to our knowledge about internal or external relationships of the pearl oyster with one kind of animal or other in the same habitat, besides some valuable information on the anatomy, reproductive biology and growth of oysters in the beds. Where observations on the associated fauna and flora, their distributional abundance and the topographical features of the banks are concerned Mahadevan and Nayar (1967, 1973, 1974 and 1976) have given useful data and information based on their direct underwater observations by SCUBA diving. Thus the main line of investigations had been to look at the problem from the angle of possible predation of oyster stock by bottom dwelling fishes, and other animals and competition for space and food by cohabiting organisms or seasonal settlers. The effect of sand-drift over the banks, the role played by water movement and current in the dispersal of the planktonic larvae of pearl oysters, the failure of oyster banks to reproduce on account of predominant homogenous populations during certain years were also advanced by earlier workers (Malpas 1929, Devanesan and Chidambaram 1956). Thus these studies on oyster tended only to touch the fringe of the problems of synecology.

It is now clear that studies on integrated ecology are necessary since the ecological set up of the pearl oyster habitat is intricately connected with a variety of factors or combination factors. Although some investigations had been done in previous years in selected segments of the Gulf of Mannar relating to the productivity, plankton and hydrography these have not been decisive enough to arrive at any conclusion about the extent of their exact influence on the pearl oyster biology and reproduction. Some of our knowledge on these factors relates to the Japanese and Australian species through the works of Kawamato and Motoki (1954), Kobayashi and Yaki (1952), Kobayashi (1940), Mori (1948a, b), Ogawa (1952) and Tranter (1958a, b, c, 1959). In recent years precise information on reproduction, larval development and spat settlement of the Indian pearl oyster *Pinctada fucata* has been provided as evidenced from the experimental studies of Alagarswami *et al.* (1983 a, b, c).

The present paper summarises and evaluates information of interest available to date on the response of pearl oyster to intensity variations of major abiotic and biotic ecological factors.

SEA-LAND FEATURES OF THE SHALLOW REGION OF THE GULF OF MANNAR

Substratum

Wadia (1975) refers to the peculiarity of the peninsular east coast of India which has a wide bed of alluvial margin in addition to the deltaic deposits of the mouths of all major east coast rivers. Along the Gulf of Mannar the sea-land boundary is almost uniform and regular but for a few indentations in places where it is intercepted by rivers forming 'Concave crescents' or tidal inlets. The coast is gently sloping. There are no major estuaries in the Gulf of Mannar except for Tambaraparni, Vembar and Vaipaar which are of seasonal nature and categorised as minor ones. A deep

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muddy gully off Tambaraparni river mouth (depth upto 40 m) meanders a few miles in the sea and is considered as a repository of silt and organic sediments brought down by the river while in spate, during October-December. The deposition of sediments by these rivers is only next in importance to those from other rivers of the Coramandel coast since a general spreading of alluvial deposits upto 20 m depth zone in the Gulf region by major rivers is reported by geologists. The rocky bottom within this zone is therefore subjected to an overwash of sand and mud. The intensity and nature of sediments depend on direction and velocity of prevailing current apart from the effects of wave action and swell. The result of the interaction of the natural forces at work determines the extent and contour of the rocky exterior, season after season.

The 8-10 m depth zone nearer the coast all along the Gulf of Mannar from Tiruchendur to Tuticorin, a distance of nearly 25 nautical miles is characterised by a narrow belt of submerged dead coral block formation gradually emerging as a fairly broad fringing live coral reef towards the windward side of 20 islands or 'Sand Cays' located between Tuticorin to Pamban, a near distance of 150 nautical miles north of Tuticorin. The coral reefs are mostly hermatypic and serve as a barrier against wave action, getting the brunt of pounding waves. Majority of the broken branches in this process, forming the spit and wash are pushed to the leeward shallow areas and intertidal flats. The outer reef edge areas also get strewn with fragments and these get pushed away by bottom swells and current forces to the deeper seaward region accumulating and getting consolidated under coarse sand and coral grains forming pits and hollows on the sea floor.

Patches of hard ground of very low profile known as 'Paar' are characteristic of the depth zone from 16 m-23 m. These lie roughly in line parallel with and at a distance of 10-16 nautical miles from land. Majority of them are located between 8°-20' N Lat. and 9°-00' N Lat. within 78° 15' E long and 78°25' E Long. There are formations north of 9°-00' N. Lat. but are considered not very important from the point of view of pearl oyster settlement. From 8°-35' N. Lat. an inner series is recognisable at 15-17 m depth whereas the outer series is located at 20-23 m depth, the intervening stretches being coarse and fine sandy sea floor.

There is no strict line of demarcation between the paar and sandy region. The surface of paar consists of rock which appears in many areas of recent origin formed of corals and shells to certain extent and to a great extent by 'Calcrete'-compound of sand and neighbouring organic remains cemented to a continuous mass by calcium carbonate. The character of rock varies considerably partaking usually the character of the circumjacent sand. The latter is made up principally of calcium grains formed from the comminuted remains of shells and corals thus giving the true character of limestone. Where it is not calcrete it is of coarse sand, wholly inorganic containing quartz grains derived from 'granulitic rock' brought by rivers. Elsewhere shells of foraminifers (*Heterostigina*, *Orbitolites* and *Amphistigina*) mixed with calcareous remains of many animals form rocky mass. The Indian pearl oyster, *Pinctada fucata*, settles down in large numbers on the rocky substratum of this type and attains harvestable size at the end of the third year of its growth when pearl formation also reaches exploitable proportions. The rocky bed supports a variety of marine plant and animal assemblages, which are characteristic of the region constituting well recognisable and defined pearl bank biota. Mahadevan and Nayar (1974) have described in detail the characteristic fauna and flora of the pearl banks in the Gulf of Mannar.

Variety and abundance of bottom fauna greatly depend on the physical and chemical structure of the substratum. The type of substratum is said to play a pivotal role in modifying the pattern and rate of reproduction of animals living on it in addition to settling and metamorphosis of pelagic larvae of benthic forms (Bacescu, 1972). A widely discussed problem is that of the factors which determine the settling of the pearl oyster larvae, their distribution and completion of life cycle. Recent observations at the Tuticorin Shellfish Hatchery Laboratory on the fertilised pearl oyster eggs indicate that these eggs initially settle down on the bottom and only when the cleavage advances do they rise up and become pelagic (Dharmaraj-personal communication). If the substratum is sticky or loose or soft there is every possibility of the fertilised eggs being locked up or covered by soft sand without allowing them to float up for completing the pelagic larval phase. The macrophytic algae which grow in the pearl banks and whose thallus is often covered with calcareous algae also serve as substrate for very small molluscan spat which may later on migrate to a more agreeable hard substratum. The size of granules, kind and amount of organic matter associated with the substrate, degree and mobility of substrate, degree of hardness of solid substrates and the total area of a given type play a key role in the prosperity of pearl oysters in the natural beds. The reasons for the record of irregular oyster settlement in these areas may be due to possible effects of the change in the nature of sediment and silt covering the substratum and thus modifying it.

Primary Production

Galathea expedition reports give out a value of 0.01 to 2.16 gC/m²/day (Seeman Nielsen and Jenson, 1957, quoted by Qasim, 1979) for the shelf region of the Bay of Bengal. Nair *et al.* (1973) state that the primary production of Tamilnadu coastal areas lying in less than 50 m depth zone averaged 1.33 gC/m²/day. But the Gulf of Mannar area, particularly the zone where pearl oyster beds are situated is rich in coral reefs. The productivity in this zone has been observed to reach 7.3 gC/m²/day (Nair and Pillai, 1972) which appears to be fairly high compared to the values obtained in other areas of east coast nearshore waters. Nair (1970) estimated that the near inshore regions where the euphotic zone is 6 m deep, the column production amounted to 1.2-1.5 gC/m²/day due to turbidity and annual gross production was 450 gC/m²/. But just outside the zone where turbidity is not high enough to affect light penetration the euphotic zone extends from 15-40 m depending on depth and distance from shore. A daily production of 3.5 gC/m² is met with thus indicating the highly productive nature of this region.

Wind, Water movement and current

Wind velocity shows a trimodal oscillation with maximum in June, August-September and December and minimum in March-April. The velocity is greater in southwest monsoon period.

The importance of water movement as an ecological factor is frequently underestimated. Gessner (1955) states that this is a potent factor as it is in the case of temperature and light. Very little is known with reference to the various parameters of water movement over Paar area excepting extrapolation from local current and tide conditions. There is a general drift of water over pearl banks from south to north between April to September and from north to south during height of northeast monsoon with intermittent periods of calm and variable movement from February-April. Many days in late April to early June there is a bottom swell, of water in east-west direction over the Paar area. These are critical months for oyster reproduction. Population replenishment might depend upon conditions of water movement. Devanesan and Chidambaram (1956) state that the water drift and current over the pearl banks of Ceylon and India may carry the larvae of pearl oyster from one coast to the other, thus holding the view of interdependence of the pearl banks of Ceylon and India for getting replenishment of oyster population. There is another possibility also. Depending on the direction and rapidity of water movement the pearl oyster larvae, at the plantigrade stage, might reach such areas in the sea with unsuitable sea bottom where they perish after settlement. All these factors thus play a vital role.

Light

It is a recognised fact that throughout euphotic and littoral regions the various modalities of light modified by the time of the day and year and latitude, the presence or absence of water movement and the depth and clarity of water exert effects upon functions and structure of marine invertebrates. The periodicity and the width of shell opening is said to be influenced in natural beds by alternating light and darkness. The width is narrower in light but broader in darkness, due to the effect of light on adductor muscle. Hence the rate of filtration of water is likely to be affected during day time in areas where light penetration is greater. This is more frequent in depths beyond 20 m and less so in shoreward banks during the months from December to April.

Turbidity

Not much has been done to study the turbidity in various seasons of the year except the observations by Malupillai (1962 a) who recorded that visibility over pearl banks varies from 6.0 m in July to 19.0 m in November to February. The pearl oyster larvae are photopositive in the veliger stage and metamorphosis proceeds normally under favourable light. There is a view that turbidity during metamorphosis is desirable, shielding the larvae against ultraviolet radiation in shaded areas. Conditions in nature, over the pearl banks in May-July satisfy this requirement.

Flood water discharged from east coast rivers during the northeast monsoon rains in October-November, carry with it considerable silt which creates great turbidity over the pearl beds, particularly over the shoreward lying banks. This introduces a new dimension to the problem of growth and survival of oyster population met within 12 m-15 m depth range.

Temperature

There are a few general records of long-term studies on temperature variations. Sewell (1927) and Herdman (1903-1906) gave a general picture. Chacko *et al*, (1954), Prasad (1957), Malupillai (1962 b) Freda Chandrasekaran *et al.* (1967) and Freda Chandrasekaran and Sudhakar (1967) are the major studies relating to Gulf of Mannar. Herdman (1903-06) stated that the general temperature of the sea-water in the paar varies from 27°C (January) to 32.5° C (May). Freda Chandrasekaran *et al.* (1967 a) found a general uniformity in the temperature pattern ranging from 25.6°C30.-6°C. Chacko and Sambandamurthy (1969) observed an annual range of 2.7°C for 1962-63. Alagarswami *et al.* (1983 b) were able to induce mature *P. fucata* to spawn by increasing the temperature from 26.5°C-28°C to 32°C-35°C. In the case of Japanese pearl oyster, Kobayashi (1948) found that the optimum temperature for fertilisation was 28°C-30°C. In the Indian pearl oyster fertilisation in laboratory tanks was noticed to take place in the 27°C-28°C range.

There appears to be some correlation between temperature and the breeding behaviour of the pearl oyster. The breeding season is more restricted in higher latitudes and occurs during warmer months. In lower latitudes there is a less restricted breeding sason, and major spawning occurs outside warmer months (*Pinctada fucata* : 7-10 N ; *P. margaritifera* : 17 S). Orton (1920) states that in those parts of the sea where temperature conditions are constant or nearly so and where biological conditions do not vary much, animals breed continuously. Tranter (1958 d) states that there is a particular threshold temperature which, when exceeded all the year round, permits continuous breeding and, when exceeded only in summer, restricts breeding intensity to summer months.

Uuder laboratory conditions temperature variations appear to affect the larvae of pearl oyster at the time of settlement. Alagarswaml *et al.* (1983a) state that the 'larval set' was achieved after 24 days in temperature range of 28.2°C-29. 8°C whereas it took 32 days to settle when the temperature range was 24.3°C-27.2°C. The lower the temperature the greater the time taken for completing metamorphosis and settlement.

Salinity

Sewell (1927) stated that the salinity in the Bay of Bengal is high in the southwest monsoon period and low during the northeast monsoon months. In the Gulf of Mannar, according to Malupillai (1962 b), the salinity reaches 35.19‰ in September. Freda Chandrasekaran *et al.* (1967) found low salinity in January increasing upto June, dropping in July (30.2‰) and increasing again in August (33.5‰). This was maintained till November when there was a lowering in December. The highest average salinity was 35.9‰ in November and the lowest was 27.40‰ in December. The annual range in the value was 7.9‰. Jayaraman (1954) noted a salinity range of 28.35‰ in January to 36.4‰ in May. The mean annual range was 7.4‰. Alagarswami and Victor (1976) found the average values of salinity in the oyster farm at Veppalodai (near Tuticorin) ranging between 32.15‰-33.50‰ during 1974-1976. The lowest value recorded was 31.26‰ in January, 1974.

The above data would indicate the pattern of salinity variations that can be normally encountered in the pearl oyster beds. Although the pearl oyster lives within this range, seasonal fluctuations in conjunction with other environmental factors are known to exert influence on the physiological functions and reproductive activity of the oyster. By and large the pearl oyster being truly marine form in its entire life cycle is not known to tolerate great variations in salinity. However, some pearl oyster farms in Japan are known to be located in areas which are subject to the influence of freshwater discharge from rivers.

Lower salinities have a depressing effect on filtration rate of bivalves (Cole and Hepper, 1954). Alagarswami and Victor (1976) found that in the laboratory experiments the rate of filtration was generally higher in high concentrations than in the dilution. In salinities of 13.90‰ and 56.96‰ mortality was total after 48 hrs, whereas 3 out of 5 oysters died in the salinity of 19.90‰ in the same period. Katada (1958) stated that low saline waters of 14.35‰ did not cause mortality in the spat and 2-3 year old oysters in Japan during experimental duration of 72 hrs. In one case of extreme lowering of salinity to 15.69‰ observed in the Veppalodai farm during November, 1977 on account of the admixture of flash flood freshwater, the oysters did not suffer mortality for 24 hrs as the very next day the salinity was restored to 26.53‰ (Alagarswami and Victor, 1976). Malpas (1929) stated that changes in temperature and salinity induce the pearl oyster to spawn. He contended that low salinity in December-January and high salinity in July-August acts as breeding stimulus. This can be considered only as one of the probable factors influencing the spawning. Hornell (1910), Moses (1928) and Rao (1951) correlated spawning maxima with changes (dilution) in salinity for *Crassostrea madrasensis.* Detailed assessment of salinity effects and tolerances is difficult in natural conditions because the effects may be increased, decreased or masked by other simultaneously effective environmental factors like light, temperature, water movement and interactions between co-existing organisms.

Dissolved oxygen

Values ranging from 6.84 ml/l in October to 3.4 ml/l in September appear to be common in pearl oyster beds. A trimodal curve has been noticed with distinct peaks in June, October and January with a decline in April, September and November. It looks as though the oxygen saturation is greater in northeast monsoon months and less in southwest monsoon months. The oyster is not stressed much due to limited range of high and low concentrations. It is a known fact that the metabolism of many molluscs is independent of ambient oxygen tension until some low oxygen tension is reached. Dharmaraj (1983) observed that the oxygen consumption was 1,339 µl/h for oysters of 40-50 mm size; 1,650 µl/h for 50-60 mm and 1,810 µl/h for 60-70 mm. After conducting exposure experiments it was found that *Pinctada fucata* withstood exposure upto 21 h, and mortality started from 19th hour in anaerobic medium, when the 'oxygen debt' crossed the safe level.

Silicate and Phosphate

Jayaraman (1954) recorded phosphate content of 0.16 µg at p/l (October) to 0.27 µg at P/l (February). The silicate content showed wide fluctuations from 9.0 µg/l in March to trace in October and January. June-July, November-December, February-March seem to be silicate rich months. Jayaraman (1954) reported values of 3.7 µg at Si/l in September to 7.0/µg at Si/l in February in Mandapam area of the Gulf of Mannar.

Associated Fauna and Flora

The very fact that the fauna and flora of the pearl banks comprise the whole assemblage of more than 2,700 species of animals and 200 species of plants (Herdman, 1906), small and large, makes the study of interrelationship among them very complicated although it is well recognised that the nature and density of such animate surroundings have a profound effect on the well being of the stock of oysters in the beds. Mahadevan and Nayar (1967) have added more information about the density and distribution patterns of the pearl oyster bed biota in different depth zones. Sponges, starfish, molluscs (gastropods particularly), crustaceans, annelids, coelenterates and fishes among the fauna and the luxuriant growth of different species of algae belonging to Rhodophycea, Phaeophycea and Chlorophycea dominate the pearl oyster beds.

Characteristic of the area is the dense growth of sponges, especially in the northern Vaipar area. *Aulospongus tubulatus* (Bowerbank). *Phakellia donnani*, *Siponochalina communis* (Carter), Iotrochota spp., *Clathria procera* (Ridley), *C. indica* Dendy, *Mycale grandis* Gray, *Zygomycale parishii* (Bowerbank), *Phyllospongia* spp., *Spongionella* spp. and *Suberites* spp. are abundant. Dense forest-like growth of the gorgonid *Juncella juncea* Pallas and *J. gemmacea* (Valenciennes) is noticed in the northern area.

The growth of the coral *Heteropsammia* sp. is characteristic of the inner series. *Montipora* sp. and *Echinopora* sp. are the other corals in addition to *Porites* sp.

The molluscan fauna is mostly represented by myriad numbers of *Modiolus* spp. spreading like mattress on the bottom. Large *Pinna* spp. are found in good numbers rooted in this layer of sand covering the rock in many places. *Cypraea tigrinus* are seen in rocky pits. *Oliva* spp., *Conus* spp., *Nassa* sp. and *Bulla ampulla* are the other common shells.

Among the echinoderms *Lamprometra palmata palmata* (J. Muller) and *Comanthus* (*Comanthussis timorens*) (J. Muller) are the most common under rocky crevices and over the gorgonids and sponges. *Holothuria edulis* Lesson, *Protoreaster lincki* (Blainville) and tests of *Clyspeaster humilis* (Leske) are the other common species.

The fish fauna is fairly rich and consists of *Scolopsis bimaculatus* Rüppell, *S. vosmeri* (Bloch), *Abalistes stellaris* (Bloch), *Upeneoides* spp., *Chaetodon* spp., *Pomacanthodes annularis* (Bloch) and *Lutjanus lineolatus* (Rüppell). Large fishes like *Gaterin* spp., *Ennaeacentrus miniatus* (Forsk.), *Epinephelus* spp., *Lethrinus* spp. and *Siganus* spp. are abundantly seen.

The flora is poor in the southern area but in the Vaipar area *Gracilaria* spp., *Hypnea* spp. and *Sargassum* spp. are common.

Compared to the inner series, the outer series is richer in fauna and flora qualitatively and quantitatively. The formation of the outer series runs in a southeast to northwest direction, generally between 15-25 m depth range. The formations are fairly extensive stretches of rock whose outcrops differ greatly from tubular fragments, rock of a metre or two across, to great areas of a km in extent. Fine grained sand covers the rock filling up the hollows and crevices occasionally cutting off the continuity of paars to give the impression of sandy bottom. Actually the hard core of the bottom can be easily detected by removing the engulfing sand of 5-10 cm thickness. Live corals are seen as a low fringe running along the 18-19 m depth on the eastern side of the paar. Broken and worn out fragments of pearl oyster shells, cockles, *Pecten* spp., *Conus* spp. etc. are scattered about in great profusion. Balls of *Porolithon* sp. from the size of a nut to that of a lime are seen on the edges of the rocky expanse. All through the length and breadth of the paar are a number of pits ranging from 0.5-1 m diameter and of equal depth. Such pits are inhabited by a number of small and large fishes, eels and lobsters. The general set-up of the area appears ideal for the settlement of oysters as the horizontal clarity at the bottom exceeds 15 m on most days and because of the variety of fauna and flora inhabiting the area.

The concentration of sponges is very high especially in the upper (northern) regions of the paar. The predominant species are *Petrosia testudinaria* (Lamarck), *P. similis* Ridley, *Aulospongus tubulatus* (Bowerbank), *Axinella donnani* (Bowerbank), *A. symmetrica* Dendy, *Spirastrella inconstans* (Dendy), *Suberites* spp., *Cliona vastifica* Nancock, *Clathria indica* Dendy, *C. procera* (Ridley), *Mycale grandis* Dendy, *Raspailia hornelli* Dendy, *Myxilla arenaria* Dendy, *Iotrochota purpurea* (Bowerbank), *Pachychalina subcylindrica* Dendy and *Phakellia donnani* (Bowerbank). There are other species of *Auletta, Spongionella, Hippospongia, Phyllospongia* and *Hircinia* met with in the 25 metre depth line also.

The area is rich in coelenterates with a conspicuous growth of anemones, alcyonarians and gorgonids. Some of the fleshy alcyonarians that are common are *Sarcophytus* spp., *Lobophytum* spp. and *Sclerophytum* spp. *Spongodes rosea* Kukenthal, *Nepthya* sp., *Solenocaulon tortuosum* Gray, *Suberogorgia* sp., *Acanthogorgia* sp., *Lopohogorgia* sp. and the gorgonids. *Juncella juncea* Pallas and *J. gemmacea* (Valenciennes) harbouring many commensals are noticed commonly.

Octopus (*Polypus* spp.) are common in pits and holes. Great numbers of dead, empty broken shells are found in crevices and faults in the rocks haunted by the octopus. Pearl oysters are particularly preyed upon by them thus posing the question as to whether they are the chief enemies of the pearl oysters. On many occasions the octopus has been noticed to open the shell valves of the oysters and eat the flesh.

The echinoderm fauna is found to be lacking in abundance as a whole. By far the crinoids are the most abundant, found attached to the gorgonids, under coral blocks or on sponges. *Lamprometra palmata palmata* (Muller) and *Comanthus annularis* (Bell) are the most common. Among holothurians, *Holothuria edulis* Lesson is the most common. The synaptid *Chondrocloea striata* (Sluiter) is common in deeper waters. Of the sea stars, *Protoreaster lincki* (Blainville) is the most abundant although *P. affinis*. (Muller and Troschel) and *P. australis* (Lutken) are also seen rarely. The southern areas are more thickly populated whereas in the north and shoreward areas there are only 2 per 100 sq. metre. The other sea stars are *Pentaceraster multispiralis* V. Martens, *Linckia laevigaeta* (Linnaeus) and occasional specimens of *Culcita schmideliana* (Retz), *Protoreaster nodosus* (Linn.), *Astropecten indicus* Doderlein and *A. monocanthus* Salden are also seen.

Of the cake urchins *Clypeaster humilis* (Leske), *Echinodiscus auritus* (Leske) and *Laganum depressum* Lesson are common. Of the heart urchins *Echinolampus ovata* (Leske) and *E. alexandri* de Lorial appeared here and there. Among sea urchins *Salmacis bicolor* Agass, and *Salmaciella dussumieri* (L. Agassiz) occur wherever dead coral blocks are covered by coarse sand. In the crevices of the coral stones and under the boulders live many numbers of ophiuroids of which *Astrob clavata* (Lyman), *Ophiocnida echinata* (Lungman), *Ophiocnemis marmorata* (Lamarck), *O. cataphracta* (Brock) and *Ophiocnermis dubia* (Muller & Troschel) are more common. All over the rocky bottom, fishes are found abundantly. Numerically *Abalistes stellaris* (Bloch), *Sufflamen capistratus* (Shaw), *Odonus niger* (Rüppell), *Scolopsis bimaculatus* Rüppell and *S. vosmeri* (Bloch) are the most abundant. But wherever the area is rugged with boulders and pits fishes like *Gaterin* spp., *Lethrinus* spp., *Enneacentrus* sp., *Epinephelus* spp., *Pomacanthodes annularis, Lutjanus sebae* (Cuvier), *Pterois miles* (Bennet), *Chaetodon* spp., *Zanclus cornatus* (Linn.) and *Heniochus acuminatus* (Linn.) live in large numbers.

Throughout the rocky expanse studied the density of algal vegetation seems to be moderate especially on the eastern edge between 17-25 m line. The flora on the southern areas seem to be luxuriant with *Sargassum* spp., dominating in most of the areas. Among the red algae *Gracillaria edulis* and *Hypnea valentiae* are common. The other common species in the pearl banks of the outer series are *Caulerpa* (3 species), *Codium* sp., *Halimeda* spp., (2 spp.), *Dictyota* (3 spp.), *Padina* spp., *Porolithon* sp., and *Spathoglossum* sp. It has been remarked by Varma (1960) that the algal flora of the pearl beds is mostly of the types found in coral beds or rocky regions of Indian coast, irrespective of depths. In other words there appears to be no selectivity for algae with regard to depth.

Many of the below mentioned animals have been identified by pearl fishery workers as important enemies of pearl oyster either by direct aggressive action or indirectly in the struggle for existence. In order of importance in causing pearl oyster destruction they are :

Modiolus spp. (Weaving mussel)—by completion and smothering oyster spat settlement.

Octopi—Predation ; by killing and preying on flesh.

Fishes—Predation by *Balistes*, serranids, rays and skates—by crunching the shells and eating the meat.

Boring polychaetes—by drilling the shell valves after setting on them (*Polydora* sp).

Boring sponge—by riddling the shell valves with minute holes for gaining substratum for living.

Seastars—by tearing the shell valves apart and feeding on oyster meat.

Boring gastropods—by gyrating holes on shell valves and feeding on the meat (*Nassa* spp., *Sistrum* spp., *Murex* spp. and *Cymatium* spp.).

Crabs and lobsters—by destroying byssal threads and killing the oysters.

In a vast environment like the sea-bed, control would be impossible. Large-scale colonisation of oyster spat in the rocky area might help to offset the effects since it is likely that considerable percentage of stock might survive after what would be destroyed by enemies. The oysters are often found in clusters piled together in such profusion so as to interfere with one another's growth and stunting many. Except for parasitic infestations by cestodes and trematodes which do not necessarily kill the oysters, very little knowledge exists as regards microbial diseases. Understanding these may provide one of the vital clues for the disappearance of oyster stock from densely populated beds.

REFERENCES

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983a. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, **34** : 287-301.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM AND A. C. C. VICTOR. 1983b. On controlled spawning of Indian pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture.* Mar. Biol. Ass. India, Pt. **2** : 590-597.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM AND A. C. C. VICTOR. 1983 c. Embryonic and early larval development of pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture*, Pt. **2** : 598-603.

ALAGARSWAMI, K. AND A. C. C. VICTOR. 1976. Salinity tolerance and rate of filtration of the pearl oyster *Pinctada fucata. J. mar. biol. Ass. India*, **18** (1) : 149-158.

BACESCU, M. 1972. *Marine Ecology* 7. Substratum 7. 3. animals. Wiley—Interscience, London, Vol. 1 Pt. 3. 1291-1322.

CHACKO, P. I., A. P. VALSAN AND C. MALUPILLAI. 1954. Meteorology and hydrography of Kundugal Gut in the Gulf of Mannar. *Contr. Mar. Biol. St., Krusadai*, **1**: 1-20.

CHACKO, P. I. AND P. S. SAMBANDAMURTHY. 1969. Conditions of existence in twenty pearl banks in the Gulf of Mannar off Tuticorin during 1962-1963. *Madras J. Fish.*, **5** : 94-99.

COLE, H. A. AND B. T. HEPPER. 1954. The use of neutral red solution for the comparative study of filtration rate of lamellibranchs. *J. du Conseil*, **20**(2) : 197-203.

DEVANESAN, D. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oysters farm, Krusadai Island, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar—Part I. *Contr. Mar. Biol. St., Krusadai*, **4** : 1-89.

DHARMARAJ, S. 1983. Oxygen consumption in pearl oysters *Pinctada fucata* (Gould) and *Pinctada sugillata* (Reeve). *Proc. Symp. Coastal Aquaculture*, Pt. **2** : 627-632.

FREDA CHANDRASEKARAN AND K. SUDHAKAR. 1967. Observations on the hydrography and planktology of pearl banks of Gulf of Mannar. *Madras J. Fish.*, **4** : 28-33.

FREDA CHANDRASEKARAN, A. D. ISSAC RAJENDRAN AND C. MALUPILLAY. 1967. Salinity and temperature variations over pearl and chank beds of Tuticorin. *Madras J. Fish.*, **4** : 21-27.

GESSNER, F. 1955. *Hydrobotanik*, Ed. I, Energiehanshalt. Dentscher Verlag der Wissenschaften, Berlin.

HERDMAN, W. A. (1903—1906) *Report to the Government of Ceylon on the Pearl oyster Fisheries of the Gulf of Mannar (with supplementary reports upon the Marine Biology of Ceylon by naturalists).* Royal Society, London : **1** : 1-307 ; **2** : 1-300 ; **3** : 1-384 ; **4** : 1-326 ; **5** : 1-452.

HORNELL, J. 1905. Report to the Government of Madras on the Indian pearl fisheries in the Gulf of Mannar (Madras Govt. publication).

HORNELL, J. 1910. Note on an attempt to ascertain the principal determining factor in oyster spawning in Madras backwaters (Madras Fish. Investigations, 1908). *Madras. Fish. Bull.*, **4** : 25-31.

HORNELL, J. 1913. A preliminary note on the preponderant factor governing the cyclic character of the pearl fisheries of Ceylon and South India. Commun. to 9th Congr. Intern. Zool. Monaco. Ser. 2 : 35-36.

HORNELL, J. 1916. Marine Fishery Investigations in Madras, 1914. An explanation of the cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, **8** : 11-12.

HORNELL, J. 1922. The Indian pearl fisheries of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, **16** : 1-188.

JAYARAMAN, R. 1954. Seasonal variations in the surface temperature of sea water at Mandapam from January 1950 to December 1954. *Indian J. Fish.*, **4**(1) : 20-31.

KATADA, S. 1958. The influence of low salinity sea water on the pearl oyster *Pinctada martensii* (Dunker). *Bull. Natl. Pearl. Res. Lab.*, **4** : 308-314.

KAWAMATO, N. Y. AND E. MOTOKI, 1954. Influence of diluted sea-water on the pearl oyster *Pteria (pinctada) martensii* (Dunker). *Rep. Fac. Fish. Univ. of Mie.* 1(3) : 346-354.

KELAART, E. F. 1859. Report on the natural history of pearl oyster for season 1858-1859 : 16-20 (Govt. publiction).

KOBAYASHI, S. 1948. On the study of pearl culture 1. On development of *Pinctada martensii*, collection and breeding., 10(9) : 267-268.

KOBAYASHI, T. 1940. Report of ecological investigation of silver lip pearl oyster in the vicinity of the northern Australia and the East Netherlands Indes for 1938. (J) Fisheries Experimental Station of the South Seas Administrative Government.

KOBAYASHI AND R. YAKI. 1952. Artificial breeding of pearl oyster *Pinctada martensii* in tanks (Je). *Bull. Jap. Soc. Sci. Fish.*, 17 : 175-282.

MAHADEVAN, S. AND K. N. NAYAR. 1967. Underwater ecological observations in the Gulf of Mannar off Tuticorin. 7. General topography and ecology of the rocky bottom. *J. Mar. biol. Ass. India.*, 9 (1) : 147-163.

MAHADEVAN, S. AND K. N. NAYAR, 1973. Pearl oyster resources of India. *Proceedings of the Symp. on Living Resources of the Seas around India* : 659-671.

MAHADEVAN, S. AND K. N. NAYAR. 1974. Ecology of pearl oyster and chank beds. In : The Commercial Molluscs of India. *Bull. Cent. Mar. Fish. Res. Inst.*, 25 : 106-121.

MAHADEVAN, S. AND K. N. NAYAR. 1976. Underwater observations on the settlement of spat of pearl oyster on the paars off Tuticorin. *Indian J. Fish.*, 23 (1 & 2) ; 105-110.

MALPAS, A. H. 1929. Age and growth rate of the pearl oyster in the pearl fishery of 1925. *Bull. Ceylon. J. Sci.*, C 3 : 62-74.

MALUPILLAY, C. 1962a. A survey of the martime meteorology and physico-chemical conditions of the Indian pearl banks off Tuticorin in the Gulf of Mannar from December 1958 to May 1959, *Madras J. Fish.*, 1 (1) : 77-95.

MALUPILLAY, C. 1962b. A review of the physico-chemical environmental conditions of the pearl banks and chank beds off Tuticorin in the Gulf of Mannar during April 1960-March 1961. *Madras J. Fish.*, 1(1) : 102-104.

MORI, S. 1948a. Daily rhythmic activities of 'Martens' pearl oysters (*Pinctada martensii*) Dunker) (Je) *Jap. J. Malac.*, 15(1-4) : 46-51 (Reprinted in Bull. Nippon Inst. Sci. Res. Pearls (1) 1953.

MORI, S. 1948 b. On the respiration of *Pinctada martensii* (Dunker) in the sea water of lower oxygen tension. A preliminary note (Je). *Jap. J. Malac*, 15(1-4) : 52-54 (Reprinted in Bull. Nippon Inst. Sci. Res. Pearls (1) 1953).

MOSES, S. T. 1928. A preliminary report on the anatomy and life history of the common edible backwater oyster, *Ostrea madrasensis*. *J. Bombay Nat. Hist. Soc.*, 32 : 548-552.

NAIR, P. V. R. 1970. Primary productivity in the Indian seas. In : *Bull. Cent. Mar. Fish. Res. Inst.*, 22 : 1-54.

NAIR, P. V. R. AND C. S. G. PILLAI. 1972. Primary productivity of some coral reefs in the Indian Seas. *Proc. Symp. Corals and Coral reefs.* Mar. Biol. Ass. India. : 33-42.

NAIR, P. V. R., S. SAMUEL, K. J. JOSEPH AND V. K. BALACHANDRAN. 1973. Primary production and potential fishery resources in the seas around India. In : *Proc. Symp. on Living Resources of the Seas around India.* Special publication of CMFRI, Cochin : 184-198.

OGAWA, Y. 1952. Mortality of pearl oyster as influenced by low temperature in sea water (J). *Medicine and Biology*, 24 (5) : 174-179.

ORTON, J. H. 1920. Sea temperature, breeding and distribution of marine animals. *J. Mar. Biol. Ass., U.K.*, 12 : 339-366.

PRASAD, R. R. 1957. Seasonal variations in the surface temperature of sea water at Mandapam from January 1950-December 1954. *Indian J. Fish.*, 4 (1) : 20-31.

QASIM, S. Z. 1979. Primary production in some tropical environments. In : *Marine pollution Mechanisms* (M. J. Dunbar, Ed.) Camb. Univ. Press, pp. 31-69.

RAO, K. VIRABHADRA. 1951. Observations on the probable effects of salinity on the spawning, development and setting of the Indian backwater oyster, *Ostrea madrasensis* Preston. *Proc. Ind. Acad. Sci.*, 33B : 231-256.

SEWELL, R. B. S. 1927. Geographic and oceanographic research in Indian waters III. Maritime meteorology. *Mem. Asiat. Soc. Bengal*, 9 : 53-129.

TRANTER, D. J. 1958a. Reproduction in Australian pearl oyster (Lamellibranchia) *I. Pinctada albina* (Lmk.) Primary gonad development. *Aust. J. Mar. Freshw. Res.*, 9 : 135-143.

TRANTER, D. J. 1958b. Reproduction in Australian pearl oyster (Lamellibranchia), II *Pinctada albina* (Lmk.) Gametogenesis. *Aust. J. Mar. Freshw. Res.*, 9 : 144-158.

TRANTER, D. J. 1958c. Reproduction in Australian pearl oyster (Lamellibranchia), III. *Pinctada albina* (Lmk.) Breeding season and sexuality. *Aust. J. Mar. Freshw. Res.*, 9 (2) : 191-216.

TRANTER, D. J. 1958d. Reproduction in Australian pearl oysters (Lamellibranchia). IV. *Pinctada margaritifera* (Linn.) *Aust. J. Mar. Freshw. Res.*, 9 : (4) : 509-525.

TRANTER, D. J. 1959. Reproduction in Australian pearl oysters (Lamellibranchia). V. *Pinctada fucata* (Gould). *Aust. J. Mar. Freshw. Res.*, 10 (1) : 45-66.

VARMA, R. PRASANNA. 1960. Flora of the pearl beds off Tuticorin. *J. mar. biol. Ass. India*, 2(2) : 221-225.

WADIA, D. N. 1975. *Geology of India.* Tata McGraw Hill Publishing Co., Delhi, 508 pp.

6

PEARL OYSTER RESOURCES OF INDIA

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Distribution

The pearl oysters belong to the genus *Pinctada* Roding under the family Pteriidae. They enjoy a world wide distribution occurring in almost all the seas of the tropical belt and also in the subtropical region. Six species of pearl oysters occur in the Indian waters viz., *Pinctada fucata* (Gould), *P. margaritifera* (Linnaeus), *P. chemnitzii* (Philippi), *P. sugillata* (Reeve), *P. anomioides* (Reeve) and *P. atropurpurea* (Dunker), of which *P. fucata* alone has contributed to the pearl fisheries in the Gulf of Mannar and Gulf of Kutch. *P. fucata* is distributed in the Red Sea, Persian Gulf and the Indian and Pacific Oceans. In the Indian waters, these oysters are found in large numbers on 'paars' in the Gulf of Mannar which extend from Kilakarai to Kanyakumari. In Palk Bay the pearl oysters are found on coarse sandy bottom and in the Gulf of Kutch on intertidal reef known as 'khaddas'. In the southwest coast of India (Vizhinjam, Kerala), *P. fucata* spat are collected in large numbers on mussel culture ropes. The black-lip pearl oyster *P. margaritifera* is confined mostly to Andaman waters. From Lakshadweep, settlement of spat of *P. fucata* and *P. margaritifera* are found on the ridges of rocks and corals.

Topography

The pearl oysters are always found attached by byssus to some hard substratum such as rocks, dead coral outcrops or sand grit covered with marine organisms. In the Gulf of Mannar, the areas of occurrence of pearl oysters are known as pearl banks or 'paars'. The Gulf has about 65 such pearl banks located between Kanyakumari and Rameswaram (Hornell, 1922). These banks lie at a distance of about 12 to 20 km away from the coast at depths of 15 to 25 m. Hornell (1922) divided these paars into three divisions viz., Northern or Kilakarai Division extending from Adam's bridge to Vaipar, the Central or Tuticorin Division extending from Vaipar to Manapad and the Southern or Kanyakumari Division extending from Manapad to Kanyakumari. Of these, the central division is the most productive one in view of the fact that out of the 40 fisheries that had taken place between 1663 and 1961, 39 fisheries had been in the paars located in this division. A notable feature of these fisheries is their irregular character, fishing sometimes being conducted after long intervals. This is due to the periodical decline of fishable quantities of pearl oyster population in the pearl banks for a number of years. The probable factors responsible for the decline of oyster population are failure of spatfall, pests like weaving mussels and boring worms, predation by gastropods, octopi, sharks, rays and sea breams, overgrowth of algae, changes in the oceanographic conditions, occasional silting and non-availability of sufficient number of breeding population (Hornell 1916, Mahadevan and Nayar, 1973). In the Gulf of Kutch, the pearl oyster reefs are scattered along the southern part of the Gulf of Kutch. There are about 42 known pearl oyster reefs covering an area of 24,000 ha located between Sachana on the east and Ajad on the west. These beds are located in the intertidal region and are exposed at receding tides (Pandya, 1974).

History

From time immemorial, the pearl oyster resources along the Indian coast have been exploited and the fishing rights passed on in succession from one ruling power to another. Hornell (1922) gives the history of the pearl fisheries of the Gulf of Mannar. During

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the 16th century, the history of pearl fisheries is intricately connected, on the one hand, with the 'ruling power' (the Nayaks of Madura, Nawab of Carnatic and the Portuguese with their battles for controlling the land and sea of that region) and on the other with the 'Paravas' who traditionally exploited the fisheries and the 'moors' who had an interest in pearl fishing largely for trade (Hornell, 1922). With the independence of the country in 1947, the rights over the pearl fishery are being fully exercised by the Government of Tamil Nadu. Similarly the pearl fishery of the Gulf of Kutch was under the control of the Jam Saheb of Nawanagar and the fishery was conducted under unique rules (Hornell, 1909). In 1926, a separate department called 'Moti Khata' was organised to manage the fisheries and finally, with the merger of the Nawanagar State with the Indian Union in 1948, the pearl fishing came under the control of the Government of Gujarat.

Pearl Fishery Series 1955-61

Chacko (1970) and Mahadevan and Nayar (1973) have given vivid accounts of the pearl fisheries of the series 1955-61. Oysters of the central sector including Tholayiram paar and the zone south to that which includes Kudamuthu paar, Karuwal paar, Poonthottam paar, Kuthadiar paar, Sayathonpathu paar and Rajavukku Chippi Sothitha paar were fully exploited during the fishery. From the account of the paars fished, number of oysters fished and the effort spent, it is evident that oysters ranging in length from 55-75 mm, in the age group 3-3½ years, formed the fishery. During the entire period of fishery, Tholayiram paar was fished in all the years of the series. A maximum number of 26,679 oysters per diving unit were collected in the year 1958.

Post-fishery Condition of the Pearl Banks

Baschieri-Salvadori (1960) during December 1958 to May 1959 had seen in the pearl banks of the northern sector (Pernandu, Nagara and northern and central parts of Tholayiram), 132 oysters per square meter. In the central sector (southern part of Tholayiram paar, Kuthadiar, Melonpathu, Vadaonpathu, Sayathonpathu, Pulipundu, Kudamuthu and north Karwal) the number per square meter was 74 while in the southern sector (Tiruchendur and Manapad) large quantities of both adult and young oysters were found. About the post-fishery condition of the pearl banks, Mahadevan and Nayar (1968) report that 'the pearl oysters were very few, almost absent, most of them having been fished and the remaining either perished or eaten away by predators.'

The oyster population in three paars (N. Tholayiram, Karai Keluthi and S. Tholayiram) was less than 1 oyster per square yard and the population in the northern paars (Devi, Cruxian, C. Thundu, Authurai arupagam and Vanthivu arupagam) was 'rare' while in the other 15 paars, no oyster was available during 1961-62 and 1962-63 (Sambandamurthy, 1966; Chacko and Sambandamurthy, 1969). The pearl banks off Rameswaram, Thondi and Kilakarai were not productive during 1965 (Rajendran and Chandrasekaran, 1969).

Survey of Pearl Oyster Beds during 1975-1986 in the Gulf of Mannar

Intensive survey of the pearl oyster beds of the Gulf of Mannar was taken up by the Central Marine Fisheries Research Institute from the season 1975-76 onwards. The facility of SCUBA diving was utilised for the survey. The central region, as referred by Hornell (1922) is divided into north and southern group of paars (Fig. 1). The northern group of paars are near-shore paars, lying within a depth of 7 fathoms. This group extends from Vaipar periya paar in the north to Pasi paar in the south. The southern group includes the Tholayiram paar in the north to the Karuwal paar in the south. The depth at which these pearl banks situated ranges from 8 to 10 fathoms.

The results of the survey of the northern group of paars is given in Table 1. From the table, it is seen that there are a lot of fluctuations in the pearl oyster settlement from year to year during the period 1975-1986. Only in one season (1981-82), the number of spat/oyster exceeded 35 per diving minute.

The pearl banks of the southern group of paars was not at all productive during the years 1975 to 1986 (Table 2). Only during the season 1979-80, more number of oysters (4.5 oyster) per diving minute were collected from this group of paars. During 1980-81, only one spat of the size 22.2 mm was collected out of 10 hours and 38 minutes of diving. During the season 1983-84, no oyster could be collected during 2 hours and 8 minutes of diving effort.

Rameswaram group of paars (Palk Bay) were surveyed during August 1974 and September 1978. The paars in this group included Narikuzhi, Kannika, Kondal, Nadu and Kothandaraman Koil piditha paar. The depth of the paars ranged from 2.5 to 6 fathoms. During August 1974, 245 oysters were collected. But

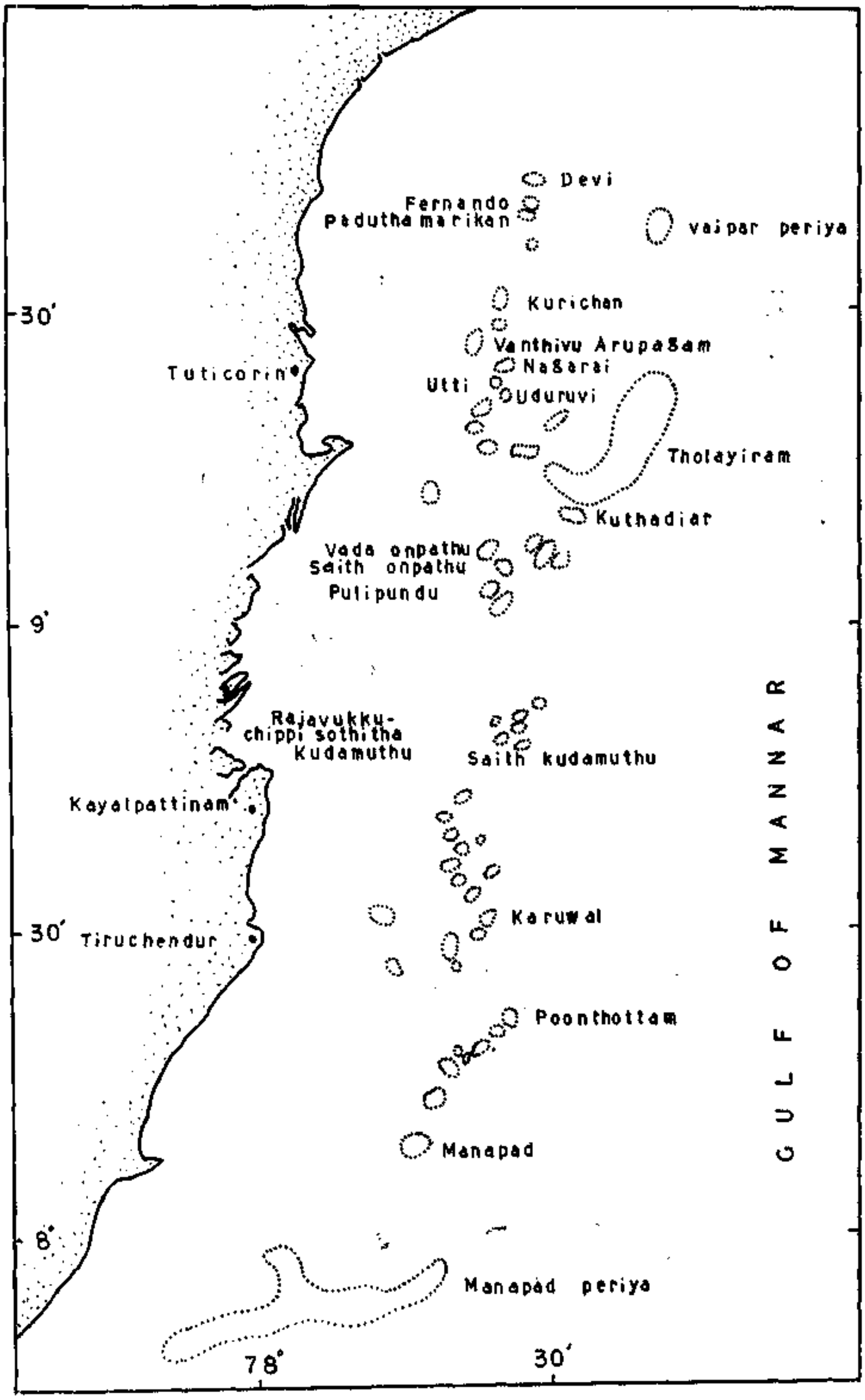

FIG. 1. Distribution of pearl oyster beds in the Gulf of Mannar.

TABLE 1. *Collection of pearl oysters from the northern group of paars from 1975 to 1986*

Year	Diving Hours hrs. min.	No. of oysters fished	Size range and (mean) (mm)	Paars surveyed
1975-76 ..	25.26	165	9.0 —43.8 (24.5)	Devi, Paduthamarikan, Fernando, Vanthivu Arupagam, Kurichan, Nagarai, Vaipar, periya, Karai, Utti and Uduruvi.
1976-77 ..	58.27	5748	11.0 —57.0 (33.9)	Devi, Paduthamarikan, Vanthivu Arupagam, Kurichan, Nagarai.
1977-78 ..	58.50	9720	6.2 —69.3 (24.7)	Devi, Kurichan.
1978-79 ..	98.16	33417	15.4 —69.6 (34.8)	Devi, Vaipar periya
1979-80 ..	29.44	9171	9.5 —58.0 (32.0)	Devi, Kurichan, Nagarai, Vaipar Periya
1980-81 ..	18.10	45	7.8 —31.1 (19.6)	Devi, Paduthamaraikan, Fernando, Vaipar Periya
1981-82 ..	46.25	99568	8.2 —50.5 (29.5)	Kurichan, Nagarai
1982-83 ..	44.36	36461	36.0 —62.0 (47.7)	Kurichan, Nagarai
1983-84 ..	13.43	260	7.5 —37.3 (22.1)	Devi, Fernando, Kurichan, Nagarai, Paduthamaraikan
1984-85 ..	39.40	10890	9.0 —47.5 (30.5)	Devi, Fernando, Kurichan, Nagarai, Vanthivu Arupagam
1985-86 ..	8.25	190	18.5 —42.6 (29.0)	Vanthivu Arupagam, Fernando, Kurichan

TABLE 2. *Collection of pearl osyters from the southern group of paars from 1975 to 1980*

Year	Diving Hrs.	Hours Min.	No. of oysters fished	Size range and and (mean) (mm)	Paars surveyed
1975-76 ..	60	50	820	5.5 —46.4 (24.1)	Tholayiram, Kudamuthu, Kuthadiar, Pulipundu, Poonthottam, Karuwal, Sayathu Kudamuthu, Karai Kudamuthu, Outer Kudamuthu, Sayathu onpathu, Vada onpathu.
1976-77 ..	29	15	2240	13.1 —58.0 (37.1)	Tholayiram, Kudamuthu, Kuthadiar, Pulipundu, Poonthottam, Karuwal, Sayathu Kudamuthu.
1977-78 ..	4	37	428	12.4 —67.0 (29.8)	Tholayiram, Kudamuthu.
1978-79 ..	22	12	233	15.2 —61.3 (37.4)	Tholayiram
1979-80 ..	8	58	2302	16.2 —57.5 (39.9)	Tholayiram, Kudamuthu, Pulipundu, Poonthottam, Karuwal.

in September 1978, only 12 pearl oysters with length ranging from 43-56.5 mm were collected in 4 diving hours.

Density of Population

To have a picture of the density of pearl oysters available at the different paars, the oysters collected were combined paar-wise for the entire period of observation. The diving hours here indicated the total time spent underwater in collecting the oysters. Table 3 and Fig. 2 give the picture of the paar-wise collection of pearl oysters during the years 1975-1986. In all, a total of 289 sea trips were made to the pearl oyster beds and 2,39,025 oysters collected. Nagarai paar was the most productive one yielding 52.73% of the total collection. Vaipar Periya paar and Kurichan paar accounted for 6.02% and 5.37% respectively. It can be seen from Table 3 that, of the 595 diving hours spent on surveying the pearl oyster beds of the northern and southern groups, 36.98% of the effort was spent on Devi paar. The number of oyster per diving hour on different paars is given in Table 3.

Table 4 gives the diving effort and the number of oysters collected season-wise for the period 1975 to 1986. It is evident from the table that the least number of oysters were collected during 1980-81 and the more successful season was 1981-82, the one following the unproductive season.

Species Composition

Another important observation on the resource is the incursion of multispecies *Pinctada* populations especially in the inshore waters, which was not known before. They comprised of *P. atropurpurea*, *P. anomioides*, *P. sugillata* and other *Pinctada* species. Species other than *P. fucata* and *P. margaritifera* are referred to here as 'flat' oysters as in all these species the bulge of the valves is not as prominent as in *P. fucata*. They were most abundant in the shoreward paars, such as Paduthamarikan, Karai, Devi and Fernando than in the offshore paars such as Tholayiram, Karuwal, Utti and Uduruvi paar in certain years (Fig. 2). The flat oysters on the pearl banks constituted 20.8% of the total collection in 1975, 68.25% in 1976, 17.63% in 1977, 6.32% in 1978 and 6.99% in 1979. In the year 1980, a sudden increase to 50% was noticed and thereafter the flat oysters were not present in 1981 and 1982. They reappeared with 14.4% in 1984 and 23.69% in 1985 (Table 4). These species of flat pearl oysters at present do not carry any significance in pearl culture. Their declining trend which was noticed in 1977 and 1981 to 1985 and that of the 100% *P. fucata* component obtained in the years 1981 and 1982 would indicate that the incursion of multispecies *Pinctada* population was a temporary phenomenon. The economics of a pearl fishery, in future, would be badly affected if the flat pearl oysters were to occur in any significant proposition.

Size Distribution

For the study of size frequency distribution, only *P. fucata* was taken into account. In Table 1, the size range of oysters collected from the northern group of paars for the entire period is given. It is seen from the table that the average size ranged from 19.6 to 47.7 mm. The minimum size of the spat available in the collection indicated the fresh settlement during the season itself. The maximum size observed was 69.6 mm. The percentage of the size group 50.0-69.9 mm, among the oysters collected, never exceeded 6 per cent (Table 5) during the period. The same trend was observed in the southern group of paars for the period 1975-1980 (Table 2). The average size of oyster ranged from 24.1 to 39.9 mm. The minimum and maximum size of the spat/oyster collected during 1975 to 1980 was 5.5 and 67.0 mm. In Fig. 3, *P. fucata* collected from different paars during the period 1975 to 1986 is combined to give size-wise distribution and percentage frequency.

To find out the recruitment and growth of oysters on the pearl oyster beds, the pearl oysters collected from Devi paar for the two successive seasons (1976-77 and 1977-78) were studied (Table 5). In the beginning of the season, 1977-78 (November), the size group 10-20 mm and 20-30 mm were the dominant ones. This had moved to size group 30-40 mm in the month of March (1978) few individual moving to the groups 40-50 mm. In the next season (1978-79), the size groups 20-30 mm and 30-40 mm were the dominant ones. But at the end of 4 months, viz., April, 1979, this had moved to next group (40-50 mm) with a few numbers moving further to the 50-60 mm group. In order to find out whether different pearl banks of the southern and northern group of paars get the spatfall simultaneously or at different times, Devi and Kurichan from the northern group and the Tholayiram from the southern group were selected and the oysters were studied for the period 1975 to 1981, season-wise (Table 6). The mean length and mean weight were taken as the parameters. It may be seen from the table that the spatfall was simultaneous on all the pearl banks for the period of observation.

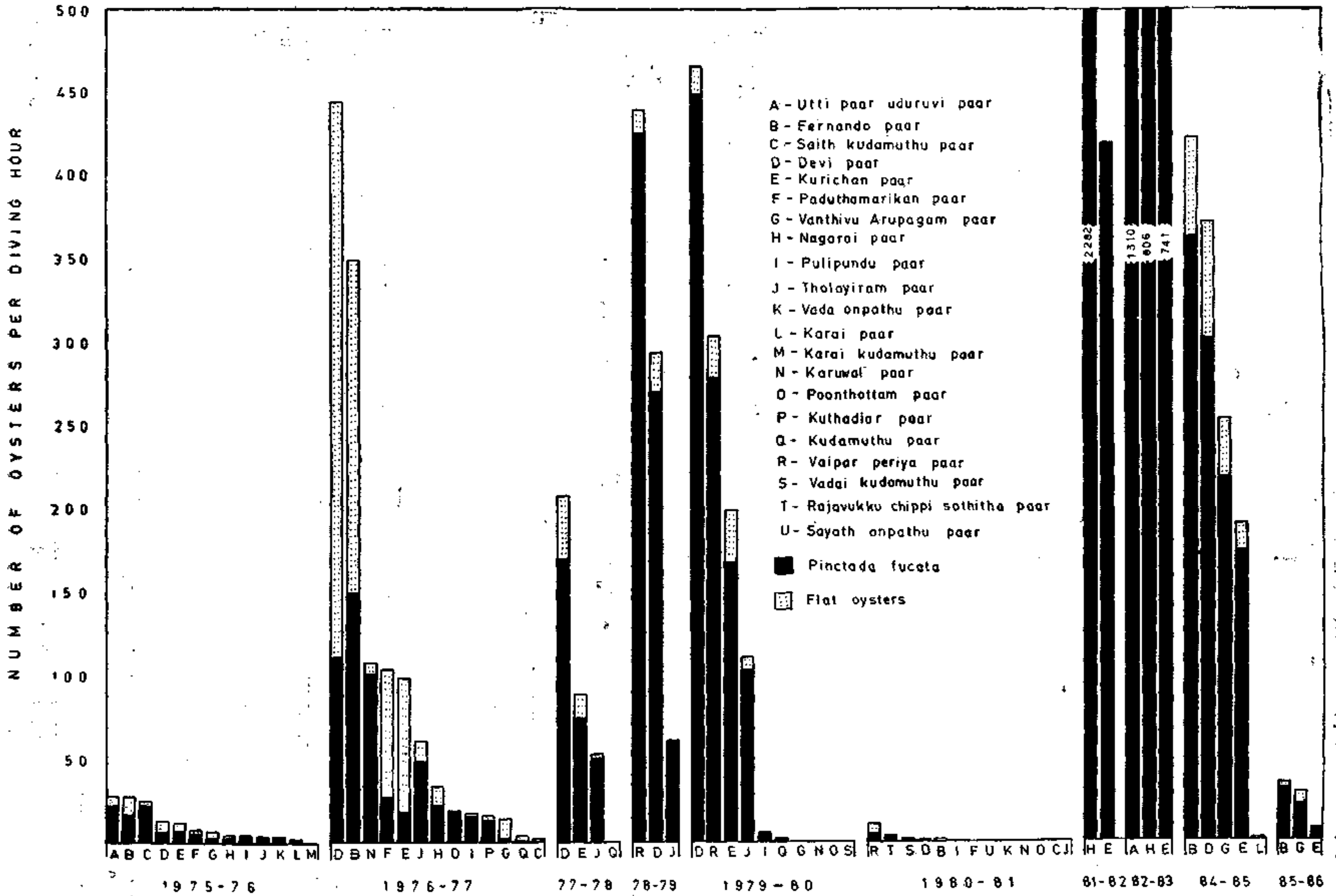

FIG. 2. Collection of pearl oysters from the pearl bnaks of Gulf of Mannar during 1975 to 1986.

TABLE 3. *Paar-wise collection of pearl oysters during the period 1975 to 1986 from the pearl banks of the Gulf of Mannar*

Name of the paar	No. of sea trips	Diving effort in Hours	Time spent %	Total No. of oysters collected	Percentage in total	*P. fucata* %	Flat oysters %
Northern paars :							
Devi paar ..	101	220.00	36.97	66181	27.69	67.18	32.82
Nagarai paar ..	39	80.13	13.47	126038	52.73	99.99	0.01
Vaipar periya paar ..	15	41.78	7.02	14394	6.02	96.00	3.90
Kurichan paar ..	20	40.30	6.77	12824	5.37	93.36	6.64
Fernando paar ..	13	27.00	4.54	8328	3.48	78.13	21.87
Van Thivu Arupagam paar ..	10	13.60	2.29	1328	0.56	88.63	11.37
Paduthamarikan paar ..	4	7.63	1.28	501	0.21	26.55	73.45
Karai paar ..	4	7.22	12.1	36	0.02	47.22	52.78
Utti paar and Uduruvi paar ..	2	4.00	0.67	2676	1.12	99.51	0.49
Southern paars :							
Tholayiram paar ..	40	73.35	12.33	4428	1.85	90.49	9.51
Saith Kudumuthu paar ..	12	38.63	6.49	876	0.37	86.99	13.01
Karuwal paar ..	7	15.72	2.64	1300	0.54	93.38	6.62
Poonthottam paar ..	4	5.42	0.91	25	0.01	96.00	4.00
Pulipundu paar ..	7	4.35	0.73	33	0.01	90.90	9.10
Kudamuthu paar ..	3	3.97	0.67	12	0.005	33.33	66.67
Vada onpathu paar ..	2	3.42	0.57	8	0.003	87.50	12.50
Sayath onpathu paar ..	1	2.33	0.39	—	—	—	—
Koothadiar paar ..	1	2.00	0.34	33	0.013	78.79	21.21
Vada Kudamuthu paar ..	2	1.97	0.33	3	0.001	100.00	—
Karai Kudamuthu paar ..	1	1.92	0.32	—	—	—	—
Rajavukku Chippi Sothitha paar ..	1	0.25	0.04	1	0.0004	100.00	—
	289	595.00	99.98	239025	100.00		

TABLE 4. *Season-wise collection of pearl oysters during the period 1975 to 1986 from the pearl banks of the Gulf of Mannar*

Season	No. of sea trips	Diving effort in Hrs.	Total oysters collected	%	*P. fucata*		*Flat oysters*		No. of oysters per diving hour
					Nos.	%	Nos.	%	
1975-76 ..	32	81.00	1244	0.52	985	79.18	259	20.82	15
1976-77 ..	50	120.03	27208	11.38	8638	31.75	18570	68.25	267
1977-78 ..	43	67.22	12322	5.16	10150	82.37	2169	17.63	183
1978-79 ..	38	110.23	35919	15.03	33650	93.68	2269	6.32	326
1979-80 ..	31	56.52	12335	5.16	11473	93.01	862	6.99	217
1980-81 ..	25	35.09	101	0.04	50	49.50	51	50.50	3
1981-82 ..	21	46.25	99569	41.66	99568	100.00	1	—	2164
1982-83 ..	23	44.36	36457	15.25	36457	100.00	—	—	829
1984-85 ..	18	42.45	13621	5.70	11657	85.58	1964	14.42	319
1985-86 ..	8	8.25	249	0.10	190	76.31	59	23.69	30
Total ..	289	595.00	239025	100.00	212828	89.04	26204	10.36	402

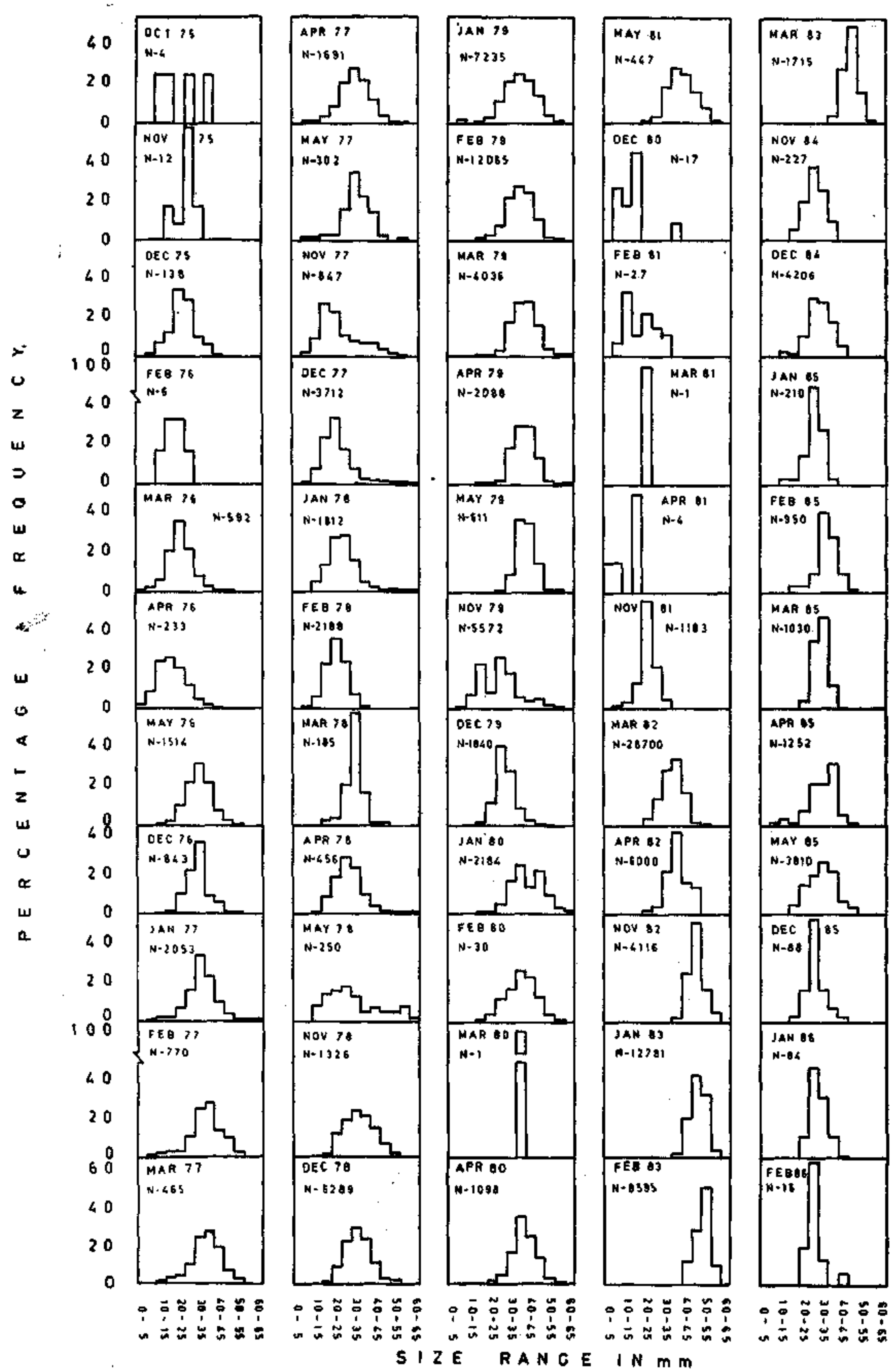

FIG. 3. Number and percentage frequencies of different size groups of *Pinctada fucata*, from the pearl oyster beds of the Gulf of Mannar.

TABLE 5. *Length/weight distribution of pearl oysters of Devi paar during two seasons, November 1977 to April 1978 and November 1979 to April 1979*

Period	% of oysters in size groups								% of oysters in weight groups							
	0-9.9 (mm)	10-19.9 (mm)	20-29.9 (mm)	30-39.9 (mm)	40-49.9 (mm)	50-59.9 (mm)	60-69.9 (mm)	Mean (mm)	0-5.9 (g)	6-11.9 (g)	12-17.9 (g)	18-23.9 (g)	24-29.9 (g)	30-35.9 (g)	36-41.9 (g)	Mean (g)
Nov '77 ..	1.6	36.0	33.3	15.6	10.8	2.6	—	25.48	67.47	19.48	7.14	2.85	1.43	1.18	0.25	5.66
Dec ..	1.4	32.9	52.0	10.2	2.6	0.7	0.2	23.14	91.58	4.80	2.15	0.90	0.38	0.07	0.12	3.10
Jan '78 ..	—	18.2	56.6	20.8	3.3	1.0	0.1	25.29	86.77	9.27	2.09	1.32	0.11	0.33	0.11	3.96
Feb ..	0.8	29.6	60.5	8.4	0.6	0.1	—	27.80	84.24	14.50	0.72	0.36	0.18	—	—	4.56
Mar ..	—	2.9	25.5	68.6	3.0	—	—	31.37	47.06	50.98	1.96	—	—	—	—	6.48
Apr ..	—	7.1	50.5	37.4	4.3	0.7	—	28.67	78.46	17.97	2.06	0.94	0.19	0.19	0.19	4.87
Nov '78 ..	—	1.2	30.6	44.4	22.2	1.6	—	33.95	50.07	32.38	13.80	3.00	0.45	0.30	—	7.50
Dec ..	—	1.4	31.3	52.9	13.6	0.8	—	33.30	53.75	36.02	8.35	1.44	0.29	0.13	0.06	6.92
Jan '79 ..	—	3.4	31.2	41.7	23.7	—	—	36.70	25.31	38.69	23.11	11.19	1.46	0.24	—	10.92
Feb ..	—	1.2	7.9	46.9	40.4	3.6	—	38.98	16.44	45.20	25.32	8.22	0.82	—	—	11.11
Mar ..	—	—	4.8	53.5	36.0	5.3	0.4	39.42	6.46	53.24	25.52	9.50	1.14	0.76	0.38	12.35
Apr ..	—	—	1.4	50.0	45.7	2.5	0.4	36.32	6.47	44.25	37.38	8.99	2.16	0.75	—	13.00

TABLE 6. *Length/weight distribution of pearl oyster at three different paars during the seasons 1975 to 1981*

Year	Devi paar			Tholayiram paar			Kurichan paar		
	No. of oysters	Mean length (mm)	Mean weight (g)	No. of oysters	Mean length (mm)	Mean weight (g)	No. of oysters	Mean length (mm)	Mean weight (g)
Oct 1975—Apr 1976 ..	53	23.58	2.57	51	23.38	3.15	14	24.64	3.14
Oct 1976—Apr 1977 ..	3174	32.89	10.50	482	37.14	8.80	6	37.65	11.75
Oct 1977—Apr 1978 ..	4871	25.59	4.07	214	29.86	8.10	—	—	—
Oct 1978—Apr 1979 ..	5108	35.36	8.23	97	37.42	9.01	—		—
Oct 1979—Apr 1980 ..	756	32.65	5.96	754	39.02	12.69	151	37.25	10.65
Oct 1980—Apr 1981 ..	3	21.00	2.00	1	22.20	5.30	—	—	—

Experimental Dredging

Collection of oysters by diving in the natural pearl oyster beds depends on clarity of water. On certain months, when collection of oysters from the natural beds became impossible, it was resorted to use a light dredge. Accordingly, an experimental light dredge was fabricated in the year 1978 and operated on a few paars in the Gulf of Mannar and Palk Bay. In all, a total of 14 oysters were collected with the dredge on 2 trials. In 1956, the first dredge was employed in Sri Lanka for harvesting oysters. The dredge had the capacity to scrap up as many as 45,00,000 oysters a day. The dredge inflicted massive disaster on the pearl oyster beds, brought up seed oysters as well as mature oysters and had a detrimental effect on future prospects of pearl fisheries (Sivalingam, 1958).

Coastal areas

At Vizhinjam Bay, an experimental pearl oyster farm was established in 1976 through the several thousand pearl oyster spat collected from the Bay. The spat were collected by suspending various types of spat collectors at the column water, 2 m below the surface. At the Tuticorin Harbour basin, the inner sides of the breakwater wall offer suitable site for the settlement and growth of pearl oysters. The breakwater has a greater slope and is filled with quarry rubbish leaving numerous crevices in which oysters are found settled. On the outer sides of the breakwaters there was very poor spat settlement as they are directly exposed to the breakers. A survey of breakwater was organised in November-December 1974 and a total of 2393 oysters were collected. In the first year of observation *P. fucata* formed about 15% of the samples. In the subsequent years 1975 and 1976 *P. fucata* component showed a decline to 8.7% and 3.3% respectively. In 1977 there was considerable reduction in the density of population as well as *P. fucata* component (0.5%). The reason attributed to the decline in oyster settlement may be due to the spreading of corals on the breakwaters (Alagarswami, 1977).

Andaman and Nicobar Islands

The survey of the Andaman and Nicobar Islands conducted by C.M.F.R.I. in 1978 provided some important information on the pearl oyster resource and pearl culture potential of the region (Alagarswami, 1983). The marine ecosystem of the Islands with numerous creeks and protected bays offer some of the best sites for pearl culture operations. The main species of pearl oyster which occurs at several regions is the black lip pearl oyster *Pinctada margaritifera.* The other there species available in the region are *P. fucata P. sugillata* and *P. anomioides. P. margaritifera* generally occurs in the intertidal reef flat to depths of 10 m. The reef flat is coralline interspersed with hard sandy bottom. The oysters are found attached to live on dead corals. Their population density is low on the intertidal reef flats. Moreover the survey report indicates the presence of suitable ecosystem for the culture of black lip oysters.

Lakshadweep

In Lakshadweep a sizable population of pearl oysters belonging to the species *P. fucata* and *P. margaritifera* were raised by suspending plain nylon rope and other spat collectors in the column waters of the lagoon (personal communication from C. G. Koya, Department of Fisheries, Lakshadweep). The lagoon is calm and water is clear during most part of the year. The bottom of the lagoon is mostly hard, rocky or coral stone or sand grit covered with marine plants. The lagoons of the Lakshadweep Island appear to be good for attempting pearl culture.

General Remarks

The information so far available indicate the fluctuating nature of the pearl oyster populations in the pearl banks of the Gulf of Mannar. Many reasons have been put forward as the causes of fluctuation. Herdman (1903) attributed the bottom currents caused by southwest monsoon to be responsible for the 'successive broods of young oysters to appear and as regularly to disappear'. Shifting of sand causes widespread mortality to oysters both young and old besides the natural enemies (Herdman, 1906). Predation by some fishes (Hornell, 1916), moray eels (Baschieri—Salvadori, 1960), settlement of *Modiolus* sp. covering the spat (Mahadevan and Nayar, 1973) and predation by gastropods (Chellam *et al.*, 1983) are some of the factors found responsible for the mortality of pearl oysters in the natural beds.

Replenishment of the beds of the Gulf of Mannar on the Indian and Sri Lankan coasts was considered possible by reciprocal supply of spat (Hornell, 1916). Hornell also discussed the possibility of rehabilitation of the deep water pearl banks from the scattered oysters of the shallow water around the reefs and islands at the head of the Gulf . But Devanesan and Chidambaram (1956) are of the opinion that the pearl banks get repopulated through self effort only. Alagarswami (1977) opined that the replenishment may be due to larval drift.

As a measure of conservation, transplantation of 'young strikes' or brood of oysters to paars which afford better condition (Hornell, 1916), maintaining a 'breeding reserve' in the Tholayiram paar (Devanesen and Chidambaram, 1956) and development of hollows in the pearl beds by filling with rocks to provide better anchorage (Baschieri-Salvadori, 1960) have been suggested.

The intensive survey made by the Central Marine Fisheries Research Institute on the pearl banks of the Gulf of Mannar from 1975 to 1986 indicates the continuation of the same trend as has been existing in the pearl banks since the post-fishery season (1961) to 1974. However, good settlement of spat was seen on some of the pearl banks of the northern group of paars during some seasons. But the same population did not continuously exist in the next year as evidenced from Table 5. Mahadevan and Nayar (1973) are of the opinion that the shoreward group of paars (Karuwal and Kudamuthu group) have been useful in sustaining oysters of fishable size. The observations made for a period of 11 years rule out the possibility of oysters of fishable size (50 mm and above) in the northern group of paars. This was indicated by Hornell (1916) and Mahadevan and Nayar (1973). No pearl fishery has been conducted in the northern group of paars so far. As far as the deep water southern group of paars were concerned, the settlement of spat was very poor during the period. The comparison of pearl oyster settlement on the northern and southern group of paars indicated that the spatfall was simultaneous. Alagarswami and Chellam (1977) based on the study of shell characters, felt that the population of the three paars, Tholayiram, Pulipundu and outer Kudamuthu had a tendency of heterogeneity among the populations.

The pearl oysters grown at Krusadai farm (Gulf of Mannar) attained the length of 45 mm, 55 mm, 60 mm and 70 mm at the end of first through fifth year (Devanesan and Chidambaram, 1956). Chacko (1970) also saw a similar age and growth situation on the oyster population in the pearl banks of Tuticorin based on his observations made during 1954-57. It was also seen that the spat of upto six months old attained a length upto 36 mm. The oysters produced in the hatchery and grown in the protected farm at the Tuticorin Harbour (Gulf of Mannar) had grown to 47 mm at the end of first year, 64.5 mm at the end of second year and 75.0 mm at the end of third year (Chellam, MS). The oysters of the Gulf of Kutch also had shown similar growth rate (Narayanan and Michael, 1968). Based on the above works, it can be confirmed that the pearl oysters upto two years old were available on the pearl banks of the Gulf of Mannar during the period 1975 to 1986. But the percentage of two year old oysters was very less. The bulk of the oysters belonged to '0' age group (Table 1 and 2). Baschieri-Salvadori (1960) has seen in the central sector (including Tholayiram paar) more oysters to reach the full maturity of third or fourth years and in the northern paars (Vaipar paar in the north and Tholayiram in the south) the pearl oysters rarely reach full maturity. Alagarswami and Qasim (1973), based on the collection of pearl oysters from November 1972 to June 1973 on Pulipundu, Outer Kudamuthu and Tholayiram paars felt that the populations on the Pulipundu and Outer

Kudamuthu were denser than the Tholayiram paar. Oysters of the size group 45-65 mm were dominant during this period.

On considering the resources of pearl oysters of the Gulf of Mannar for the period 1975 to 1986, it can be seen that there were spatfall but of fluctuating nature. Unless there is a series of good spatfall, the possibility of revival of pearl fisheries is remote at least for some years to come. The good spatfall in the northern group of paars during some seasons might be due to the farming of oysters in the inshore waters.

Added to the physical and biological factors affecting the survival of pearl oysters in the pearl banks, the recent industrialization along the coasts of Tuticorin, the operation of more number of trawlers and the increased movement of ships in the vicinity of the pearl banks may also affect the ecological conditions of the pearl banks.

REFERENCES

ALAGARSWAMI, K. 1977. Larval transport and settlement of pearl oysters (Genus *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm Water Zool.*, Spl. Pubin. UNESCO/NIO, 678-686.

ALAGARSWAMI, K. 1983. Black-lip pearl oyster resource and pearl culture potential. *C.M.F.R.I. Bull.*, 34 : 72-78.

ALAGARSWAMI, K. AND S. Z. QASIM. 1973. Pearl culture—its potential and implications in India. *Indian J. Fish.*, 20 (2) : 533-550.

ALAGARSWAMI, K. AND A. CHELLAM. 1977. Change of form and dimensional relationship in the pearl oyster *Pinctada fucata* from Gulf of Mannar. *Indian J. Fish.*, 24 (1 & 2) : 1-14.

BASCHIERI-SALVADORI, F. 1960. *Report to the Government of of India on the pearl and chank beds in the Gulf of Mannar.* FAO/EFTA Rep. 1119, 60 pp.

CHACKO, P. I. 1970. The pearl fisheries of the Madras State. *Proc. Symp. Mollusca*, Mar. Biol. Assn. India, Pt. III : 868-872.

CHACKO, P. I. AND P. S. SAMBANDAMURTHY. 1969. Condition of existence in twenty pearl beds in the Gulf of Mannar Off Tuticorin during 1962-63. *Madras J. Fish.*, 5 : 94-99.

CHELLAM, A (MS). Growth and biometric relationship of hatchery produced pearl oyster *Pinctada fucata* (Gould) in the farm at Tuticorin Harbour, Gulf of Mannar.

CHELLAM, A., T. S. VELAYUDHAN, S. DHARMARAJ, A. C. C. VICTOR AND A. D. GANDHI. 1983. A note on the predation of pearl oyster *Pinctada fucata* (Gould) by some gastropods. *Indian J. Fish.*, 30 (2) : 337-339.

DEVANESAN, D. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oyster farm, Krusadai Island, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar, Part I. *Contr. Mar. Fish. Biol. Station*, Krusadai Island, Gulf of Mannar, 4 : 1-89.

HERDMAN, W. A. 1903. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar*, Pt. I. Royal Society, London.

HERDMAN, W. A. 1906. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar.* Pt. V. Royal Society, London.

HORNELL, J. 1909. Report to the Government of Baroda on the prospects of establishing a pearl fishery and other marine industries on the coast of Okhamandal. *Report to the Government of Baroda on the Marine Zoology of Okhamandal in Kathiawar*, Pt. I. 34 pp. Williams and Norgate, London.

HORNELL, J. 1916. An explanation of the irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, 8 : 11 22.

HORNELL, J. 1922. The Indian pearl fisheries of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, 16 : 1-188.

MAHADEVAN, S. AND K. N. NAYAR. 1968. Underwater ecological observations in the Gulf of Mannar off Tuticorin. VII. General topography and ecology of the rocky bottom. *J. mar. biol. Ass. India.*, 9 (1) : 147-163 (1967).

MAHADEVAN, S. AND K. N. NAYAR. 1973. Pearl oyster resources of India. *Proc. Symp. Living Resources of the Seas Around India.* Spl. Publ., C.M.F.R.I., Cochin 659-671.

NARAYANAN, K. A. AND M. S. MICHAEL. 1968. On the relationship between age and linear measurements of the pearl oyster *Pinctada vulgaris* (Schumacher) of the Gulf of Kutch. *J. Bombay nat. Hist. Soc.*, 65 (2) : 441-452.

PANDYA, J. A. 1974. Pearl oyster resource and culture experiments in Gujarat. *Proc. Group Discussion on pearl culture*, C.M.F.R.I., Cochin: 25-27.

RAJENDRAN, A. D. I. AND F. CHANDRASEKHARAN. 1969. Report on the survey of pearl banks off Ramanathapuram coast, during 1965. *Madras J. Fish.*, 5 : 100-104.

SAMBANDAMURTHY, P. S. 1966. On a survey of the pearl banks of Tuticorin, Gulf of Mannar, in 1961-62. *Madras J. Fish* 2 : 71-77.

SIVALINGAM, S. 1958. Survey of the pearl banks, Gulf of Mannar 1955. *Indian J. Fish.*, 5 (2) : 308-325.

SIVALINGAM, S. 1961. The 1958 pearl fishery, Gulf of Mannar. *Bull. Fish. Res. Sta. Ceylon*, 11 : 1-28.

7

PEARL OYSTER SPAT COLLECTION

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INTRODUCTION

For running a pearl culture industry, a steady supply of pearl oyster seed is a pre-requisite. Collection of pearl oysters from the natural beds is not always dependable, owing to their irregular production. Inspection of pearl oyster beds during the last three decades has proved this. There are three ways to raise pearl oyster spat for pearl culture farms : (1) setting up of artificial spat collectors at subsurface during oyster spawning season (2) collection from the natural beds and (3) hatchery production of seed.

In setting up of artificial spat collectors, the best way is to provide the right type of spat collectors at the most propitious time, especially during the peak spawning season, in the farm area for the spat to attach in large numbers. This will prevent the spat collector from becoming fouled with barnacles and other organisms. There are several practices for spat collection of different species of pelecypod molluscs in different parts of the world. In France lime-coated, semicylindrical ceramic tiles are used to collect spat of *Crassostrea* sp. On the east coast of the United States and along the Gulf of Mexico, the most successful collectors have been strings of scallop shells for the spat of American oyster (Iverson, 1968). In Japan, the materials that are easily available in each region are used as collectors for the spat of edible oyster *e.g.*, bamboo, pine branches, twigs, tiles, shells of oysters and other molluscs, slate, stones, pebbles, earthern pipes, ropes etc. (Imai, 1970). While ropes intertwined with twigs are used in Italy, metal net baskets or triangular wooden frames with empty shells inside are used for edible oyster spat collection (Imai, 1970). In Japan long-line method is widely used in which leaves and twigs were tied to ropes as spat collectors for collecting scallop seed (Imai, 1970). In France, mussel seed are collected by suspending loosely woven ropes in the intertidal region near natural mussel beds (Bardach *et al.*, 1972). In Japan, shells of abalones, oysters and scallops and cedar sprigs are suspended from rafts from just below the surface to about 3 m in depth for collecting the spat of pearl oyster (Alagarswami, 1970). Achari (1980) has described the spat collectors and breeding hapas made of nylon frills used for collecting spat of pearl oysters at Vizhinjam. The present account deals with the results obtained while experimenting with various types of spat collectors, for collecting pearl oyster spat at Veppalodai and Tuticorin Harbour farms from November 1975 to March 1981. A large number of oysters, which were earlier collected from the natural pearl oyster beds are introduced in the farms served as the parent stock.

RESULTS OF SPAT COLLECTION

Pearl oyster shell collectors

Pearl oyster shells were pierced in the centre and strung to a 2 mm diameter polythene twine and the strings were tied to the iron frames in two rows, in

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each of the five sections of the sandwich type frame net measuring 60 × 40 cm. Three such frames were tied one below the other leaving a space of 1 m between the frames and suspended vertically into the water column so that each net is kept in place at surface, middle and bottom waters (Fig. 1, 1). Five sets of such shell collectors were under observation at the farm from November 1975 through October 1976. In April, 15 spat had settled on shells and in iron frames and, in June, 16 spat had settled on shells and frames.

Rope collectors

The rope collector consisted of a 9 m main rope made of synthetic material in which bunches of untwisted nylon filaments were inserted at intervals of 25 cm. One end of the main rope was firmly tied on the wooden pole of the raft and the other end was tied to a granite stone weighing around 5 kg. When the rope was suspended from the raft the filaments from the bunch spread in the entire water column from surface to bottom (Fig. 1, 2). The synthetic ropes and filamentous bunches were of three colours *viz.* blue, green and yellow. At the Tuticorin Harbour farm several such rope collectors were suspended from the raft and were examined at fortnightly intervals from January 1976 through April 1977. Periodically the collectors were removed from the raft and sundried for a day or two before being put into use. By this method the silt and the fouling organisms were removed. During the entire period of observation, only one spat was found settled on the blue coloured collector in July 1976.

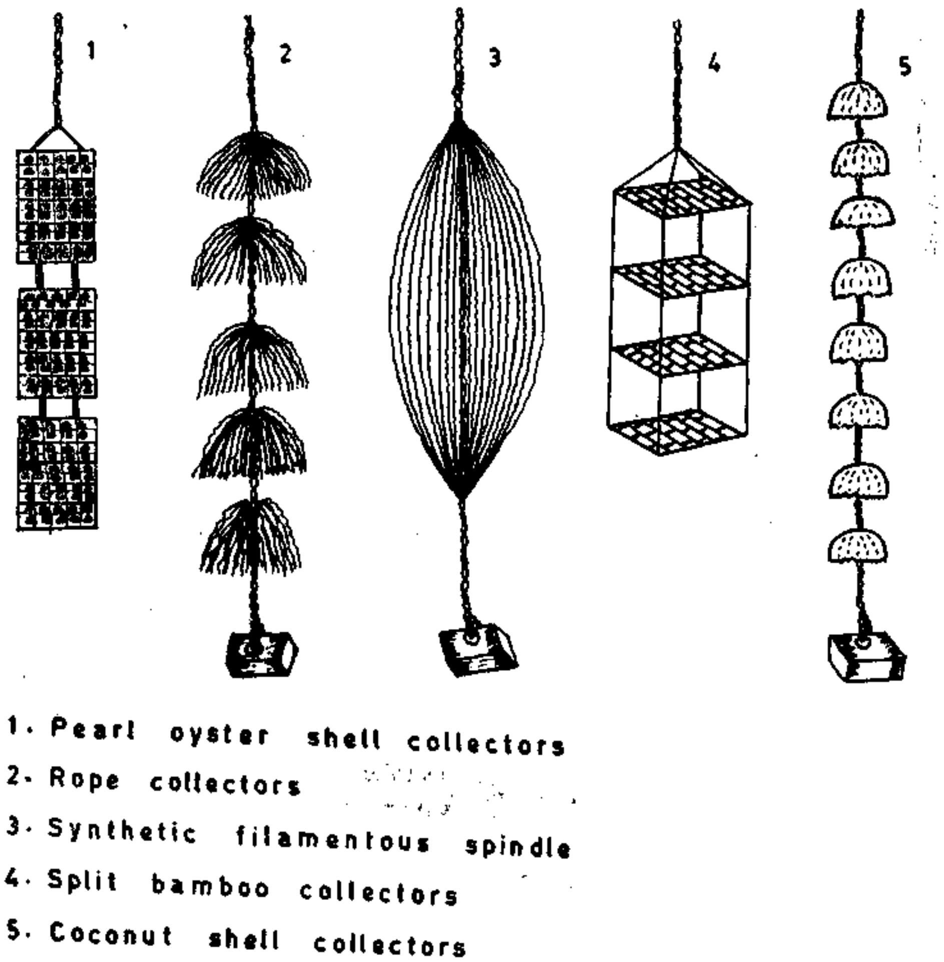

FIG. 1. Different types of experimental spat collectors used for pearl oysters.

Synthetic filamentous spindle

Bunches of synthetic monofilaments of 6 m length secured at both ends in the form of a spindle was suspended vertically into the water column. The spindle was supported by a main rope in the middle, one end was tied on the wooden pole of the raft and the other end on a 5 kg granite stone. A good spread of monofilament was noticed in the entire water column commencing from surface to bottom (Fig. 1, 3). In all a total of six such collectors were suspended from the raft in February 1976 and were examined regularly at fortnightly intervals till the end of April 1977. Nine spat had settled on the collector in July 1976. In June 1976, 10 spat had settled on the main rope and anchor.

Split bamboo collectors

Split bamboo reapers of 1.25 m length were arranged vertically with either ends tied to two horizontally placed wooden reapers leaving an interspace of 2 cm so as to form a platform of 1.25 X 1.25 m. Four such platforms were arranged at 2 m intervals and tied, securely on 4 casurina poles *i.e.* one pole at each corner and suspended from the raft. The bamboo platforms after suspension occupied the surface, middle and bottom water (Fig. 1, 4). There was no settlement of pearl oysters on this collector.

Coconut shell collectors

Holes were made in the centre of half coconut shells and the shells strung on a 5 mm diameter polythene rope of 8 m length at intervals of about 1.5-2.3 cm with plastic spacers between the shells (Fig. 1, 5). Six such shell strings were hung vertically in the water from the raft in June 1976 and were examined at monthly intervals till February 1977. No spat had settled on these collectors.

Apart from the above mentioned spat collectors, several experiments were conducted on selection of materials for effective collection of spat. Granite stones, old fishing nets, lime coated tiles, black polythene sheets and coir ropes were placed in book type frame nets and suspended in sea water at depths 2 m, 4 m and 6m. None proved successful.

Spat settlement along the slopes of the breakwater

As spat are found to settle on granite stones along the slopes of the breakwater of the wharf wall, 12 sets of spat collectors made of untwisted nylon ropes spread and tied with bamboo frames were kept on the slopes in December 1980. The spat collectors were examined at monthly intervals. The settlement of spat was totally absent on all the collectors. However, dense settlement of pearl oyster spat was noticed on the culturing units such as baskets, frame nets and live oysters.

Experiments on 'Hapa'

A breeding *hapa* of 1 m^3 was fabricated with velon screen of 1 mm mesh size and it was kept inside another frame which was encircled fully with coir ropes. Two ripe male and three ripe female oysters were kept inside the hapa and suspended from the raft at the surface water during June 1978. Various spat collection materials such as black polythene sheets, synthetic filaments and oyster shells were kept in the outer margin of the *hapa*. This was under observation at monthly intervals till March 1979. 33 spat settled on coir ropes in August, 11 in November and 1 in December 1978. However, no spat settlement was observed on the other spat collectors suspended adjacent to the *hapa*. The oysters inside the *hapa* had spawned and entered the post-spawning phase.

Spat settlement on culture units

Even though collection of spat on cultch materials did not prove successful, good settlement of pearl oyster spat had been observed on the frames and meshes of nets and on the cultivated oysters both at Harbour and Veppalodai during the years 1973-1979 (Table 1) Two peaks of spatfall were observed in the farm, one in May-July and the other in October-February. However, a small number of spat was observed in all the months.

TABLE 1. *Showing settlement of pearl oyster spat in the farms at Veppalodai and Tuticorin Harbour during 1973—79**

Year		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Veppalodai farm													
1973	..	..	..	..	..	173	128	163	..	7	1	4	12
1974	..	10	..	..	..	..	146	..	..	..	..	1	3
1975	..	163	..	..	17	53	276	17	1	..	6	25	12
1976	..	15	4	..	3	342	..	..	..	..	..	..	24
Tuticorin Harbour farm													
1975	..	..	..	..	..	..	..	..	..	4	15	..	565
1976	..	68	..	..	53	165	1444	47	..	..	..	..	4
1977	..	135	330	..	176	184	..	..	..	..	..	..	..
1978	..	..	..	..	..	..	..	..	..	..	141	15	1
1979	..	97	40	392	190	113	..	..	..	..	..	..	..

**Note :* Farming had been suspended in the harbour from June 1977 to August 1978.

DISCUSSION

In Japan spat collection is done by lowering different types of objects into the sea during spawning season. Shirai (1970) has reported that good settlement of pearl oyster spat took place on various types of cultch materials namely bunches of cedar branches, strings of common oyster and abalone shells and old fishnets when lowered to a depth of 1-3 m into the sea. Cahn (1949) has described an early experimental type of spat collector used in Japan. It consisted of a small cage 84 x 54 x 20 cm formed by covering a heavy wire frame with a 2 cm wire mesh. The spat per cage varied from 1,000 to 16,000 but the usual average was from 7,000 to 10,000. In Papua New Guinea, Lock (1982) reported about the success achieved in the collection of the spat of the black lip oyster using plain nylon rope. In French Polynesia, spat collectors made of polythene sheets protected against predators by plastic net bags gave best results for *P. margaritifera*. The collection period was from November to January and the average yield was 50 spat per collector (AQUACOP, 1982).

At Vizhinjam, roof tiles, strings of coconut shells split bamboo, frilled nylon ropes, iron *hapa* covered with nylon netting and fish cages were tried as spat collectors. Of these, the frilled nylon ropes, *hapa* or fish cages covered with nylon screen and nylon netting were useful as spat collectors. The profuse settlement of other fouling organisms affected pearl oyster settlement (Appukuttan, personal communication).

Mahadevan and Nayar (1976) reported that the settlement of pearl oyster spat on the paars was irregular and subject to quantitative fluctuations. Alagarswami (1977) observed good spat settling in the inshore areas and also resurgent population of species other than *P. fucata* in the natural beds off Tuticorin in the Gulf of Mannar, which he attributed to larval drift.

Recent studies indicate that the settlement of edible oyster spat *Crassostrea* sp. on cultch materials is influenced by various exogenous factors especially temperature, salinity, light, angle of surface, colour and texture of surface as well as cleanliness (Quayle, 1980). The depth at which the collectors are placed is very important with respect to both getting the maximum number of spat and avoiding the settlement of fouling organisms. The proper time for laying the spat collectors can be determined by examining the gonadal condition of the oyster or by sampling the farm area with plankton net to locate the drifting larvae.

Nayar *et al.* (1978) observed that stray settlement of pearl oyster spat on the heavily fouled surface of iron piles of pier, underside of steel drums used as floats for long time, channel buoys, keels and gunwales of permanently anchored launches. They have also experimented spat settlement on different spat collectors such as pearl oyster shell strings, oyster growing frame nets and cages, nylon twine, meshed iron ring, perforated and slotted plastic baskets, polypropylene and coir ropes and found that nylon twine meshes of circular and square cages appeared to be the best substratum for spat settlement. The present results reveal that the oyster growing baskets and cages appeared to be best spat collectors as compared with the other spat collectors.

REFERENCES

ACHARI, G. P. K. 1980. New designs of spat collectors, breeding hapas, cages and imrpoved technology for pearl farming. *Symp. Coast. Aquacult.*, Marine Biological Association of India, Cochin. Abstr. 182.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca, Mar. Biol. Ass. India*, Pt. III : 975-993.

ALAGARSWAMI, K. 1977. Larval transport and settlement of pearl oysters (genus *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm Water Zoopl., Spl. Publ.* UNESCO/NIO, 678-686.

AQUACOP. 1982. Country Reports : French Polynesia. In : *Bivalve Culture in Asia and the Pacific* (F. B. Davy and M. Graham, Eds.), International Development Research Centre, Ottawa, 31-33.

BARDACH, E. J., J. H. RYTHER AND O. MC LARNEY. 1972 *Aquaculture. The Farming and Husbandry of Freshwater and Marine Organisms.* Wiley-Interscience, New York, 674-789.

CAHN, A. R. 1949. Pearl culture in Japan. *Fish. Leafl., U.S. Fish Wildl.* Ser., 357 : 1-91.

IMAI, T. 1977. *Aquaculture in Shallow Seas : Progress in shallow* sea culture. Oxford & IBH Publishing Co., New Delhi, pp. 614.

IVERSON, E. S. 1968. *Farming the Edge of the Sea.* Fishing News (Books) Ltd., London, pp 301.

LOCK, J. M. 1982. Country Reports : Papua New Guinea. In : *Bivalve Culture in Asia and the Pacific* (F. B. Davy and M. Graham, Eds.), International Development Research Centre, Ottawa : 53-54.

MAHADEVAN, S. AND K. N. NAYAR. 1976. Underwater observations on the settlement of spat of pearl oyster on the paars off Tuticorin. *Indian J. Fish.*, 23 : 105-110.

NAYAR, K. N., S. MAHADEVAN, K. RAMADOSS, N. SUNDARAM AND C. T. RAJAN. 1978. Experimental study of the settlement and collection of pearl oyster spat from Tuticorin area. *Indian J. Fish.*, 25 : 246-252.

QUAYLE, D. B. 1980. *Tropical Oyster* : Culture and Methods. International Development Research Centre, Ottawa, Canada KIG, 3Hg , pp 80.

SHIRAI, S. 1970. *The Story of Pearls.* Japan Publications, Inc. Tokyo, pp. 132.

8

PEARL OYSTER CULTURE IN VIZHINJAM BAY

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INTRODUCTION

In India, Gulf of Kutch in Gujarat and Gulf of Mannar in Tamil Nadu are well known areas for pearl oyster resources. Hornell (1922) gave the history of pearl fishery of Gulf of Mannar in detail. Alagarswami (1970, 1975) and Alagarswami and Qasim (1973) have dealt with the distribution of pearl oysters in India, exploitation, farming methods and technology of culture of pearls. Mahadevan and Nayar (1973) reviewed Indian pearl fishery resources and identified *Pinctada fucata* as the common Indian pearl oyster from Gulf of Mannar and Gulf of Kutch. Rao and Rao (1974) have identified six important species of pearl oysters from Indian Coasts. Preliminary idea of pearl oyster resources from Gulf of Kutch is from Hornell's work (1909). Later Easwaran *et al.* (1968) described the present status of pearl fishery in Gulf of Kutch and Pandya (1974) gave pearl oyster fishery and culture experiments in Gujarat.

Recently occurrence of pearl oysters has also been reported from Kerala coast from Vizhinjam Bay. Periodical settlement of oyster spat takes place in the fishing harbour at Vizhinjam, which has been brought to light by Central Marine Fisheries Research Institute (Anon., 1977, 1978). Through a research project of Central Marine Fisheries Research Institute at Vizhinjam the spatfall of pearl oyster in the fishing harbour under construction has been taken advantage of in raising pearl oyster stock. The Fisheries Department of Government of Kerala had undertaken a Pilot Project on Pearl Culture at Vizhinjam in the year 1976. The species composition of pearl oysters from Vizhinjam was *P. fucata, P. sugillata, P. anomioides, P. chemnitzii*and *P. margaritifera* in the order of abundance. In the present account the details of pearl oyster culture work at Vizhinjam with special reference to environmental features of farm, spatfall in different years, spat collection methods, observations on the biology of *P. fucata* and details on fouling and predation in the farm from 1977 to 1980 are given.

ENVIRONMENTAL FEATURES OF VIZHINJAM BAY

Vizhinjam Bay situated in the southwest coast of India, about 16 km south of Trivandrum (Long. 76°59' E, Lat. 8°22'30" N) in a narrow bay enclosed by a breakwater jutting into the sea on the western side (Fig. 1). The depth of the bay varies from 10to15 metres and the bottom of bay is muddy. This area is protected from heavy wave action and violent wind and current during monsoon period.

Temperature, salinity and dissolved oxygen content of surface sea water of this bay was studied from 1977 to 1980 and the results are shown in Figs. 2 and 3. The surface water temperature varied from 20.75°C to 30.50°C, the lowest recorded in July 1978 (20.75°C) and the highest in January-February 1977 (30.50°C). Salinity ranged from a minimum of 31.44‰ in July, 1979 to maximum of 36.31‰ in October 1979. Dissolved oxygen varied from 4.05 ml/l to 5.85 ml/l during 1979-80. The minimum dissolved oxygen was found in March 1979 (0.05 ml/l) and the maximum in November 1979 (5.85 ml/L). Turbidity of water was high during monsoon, especially from May to October. Dharmaraj *et al.* (1980) have studied the seasonal variation in rainfall, salinity, temperature, light penetration, pH, dissolved oxygen content and availability of nutrients from Vizhinjam Bay for a period of one

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year during 1977-78. Their results agree with the present observations and they have found the nutrient value, high during northeast monsoon period.

Temperature and salinity showed increasing trend from October to March and were low during June to September when monsoon was active. During monsoon dissolved oxygen was high compared with rest of the months. There was no marked change in these features from year to year at Vizhinjam.

baskets and then to big box-type iron pearl oyster cage covered with plastic twine meshes.

In 1977, 60 spat collectors of various types were released and settlement in March-April period was found to be good. In the frilled nylon rope-spat collectors, 1-15 numbers of pearl oysters were found. A few numbers were collected from mussel ropes suspended from rafts and also from the nylon meshes of pearl oyster cages. During November-December period spat settlement was

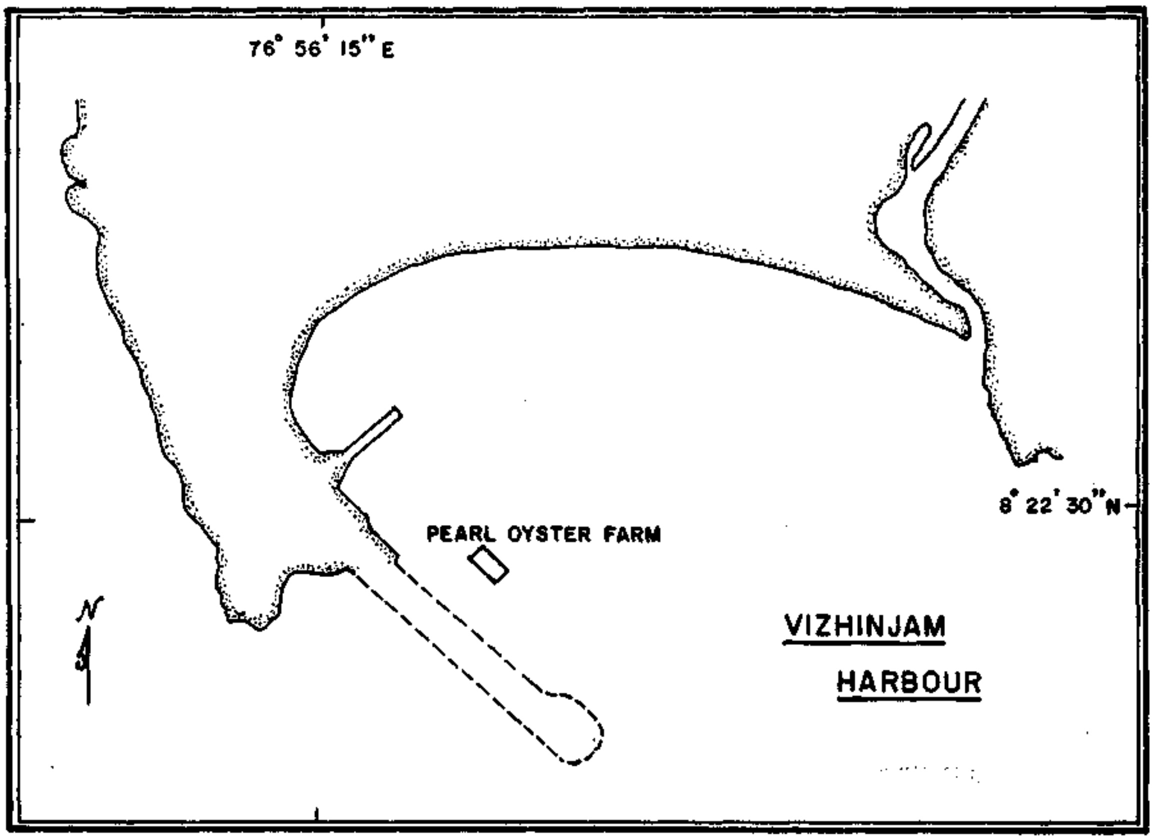

FIG. 1. Vizhinjam Harbour showing the site of rafts for pearl oyster farming.

OBSERVATIONS ON SPAT SETTLEMENT

Experiments were conducted from 1977 onwards to monitor the spatfall of pearl oysters in Vizhinjam Bay. Various types of spat collectors were used to identify a suitable spat collector for large scale collection of pearl oyster spat. The spat collectors used were roof tile, string of coconut shells, split bamboo poles, frilled nylon rope (Pl. I A), iron hapa covered with nylon netting and nylon net bags. These were released from rafts near the mother oyster stock. Spatfall pattern was noticed every year and the young ones were taken out from the spat collectors and stocked in plastic fruit

poor. A total of 550 spat were collected, mainly from frilled nylon rope. 80% of the spat collected were *Pinctada fucata* and rest flat oysters.

In 1978 February-March period 100 numbers of frilled nylon rope, 55 roof tiles, 15 *hapas* covered with nylon screen and 15 nylon netting bags were released. Inside the *hapas* and bags mother oysters were stocked to note the settlement of spat on the oysters. Frilled nylon ropes were taken to open sea mussel rafts, where also mother oysters were stocked in a few cages. It was found that good settlement of spat was observed in the spat collectors in the open sea rafts. Only 15 numbers of spat collectors could be retrieved from the open sea, when there was cyclonic weather and ultimate damage of rafts. From these, 500 spat in size 15-34 mm, were collected. Inside the bay a total of 750 spat were collected, mainly from frilled nylon rope (Pl. I B) iron *hapa*, mussel rope and pearl oyster cages in the order of abundance. The percentage of *P. fucata* was 60 to 70% and the rest flat oysters comprising *P. sugillata*, *P. anomioides* and *P. chemnitzii*. During November-December 225 spat were collected of which only 40% formed *P. fucata*.

During 1979 a total of 343 frilled nylon ropes were released. 125 numbers were released in the open sea, of which 45 only could be retrieved during May when sea was rough. From these spat collectors, 1350 spat were collected with an average of 30 spat per collectors. The size of spat ranged from 15 to 34 mm. 985 spat were collected from the spat settlers, pearl oyster cages and mussel ropes from March-June period from the bay. The percentage of *P. fucata* has come down to 30-40% with the rest flat oysters.

In 1980 February spat ranging from 24 to 35 mm were collected which is presumed to be of November-December spawning of the previous year. 3,895 numbers with 20-25% of *P. fucata* were collected from the spat settlers inside the bay. During March-June the spat settlement was very poor. 96 spat collectors released during July have also not shown good settlement, whereas it was interesting to note that profuse settlement of spat was noticed in the nylon netting covering the round fish cages suspended from rafts for fish culture, where the area of attachment is more, and the cage is a cylindrical one with 2-3 metre diameter and 3-4 metre depth. 5 such cages were there inside the bay. From all these cages a total of 6,000

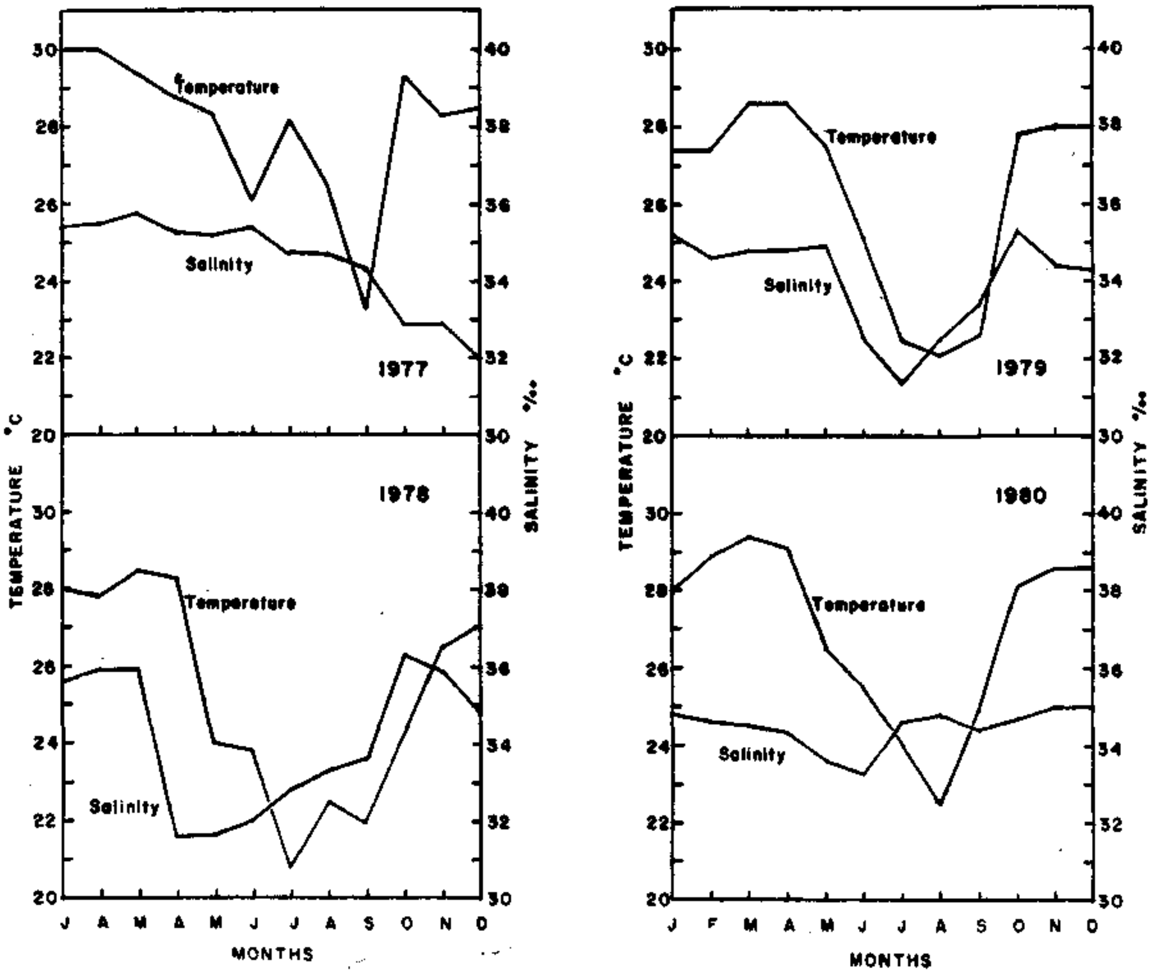

Fig. 2. Monthly average temperature and salinity in 1977, 1978, 1979 and 1980 in the farm site.

spat were collected from July to August. Another 250 numbers were collected from frilled nylon ropes and oyster cages. A total of 10,145 spat were collected of which only 20-30% were *P. fucata*. Mortality of young oysters was caused by crabs and 20-40% damage of the oysters was observed.

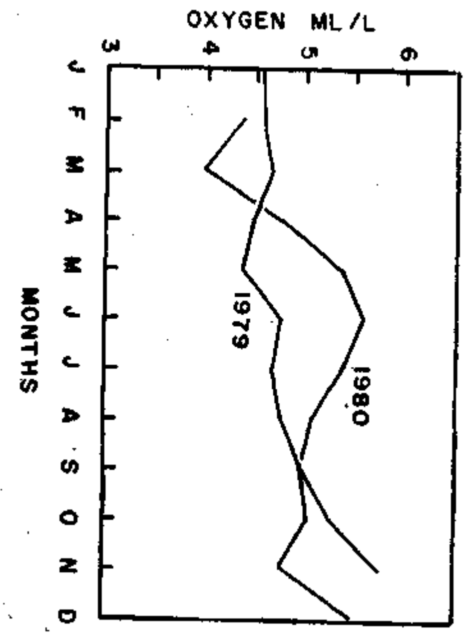

Fig. 3. Monthly averages of dissolved Oxygen in 1979 and 1980 in the farm site.

The observations showed that spat settlement from March to June was fairly good in first two years but in 1980 November-December settlement was good. Peak period of spat settlement coincided with the peak spawning period. It is also interesting to note that the percentage of occurrence of *P. fucata* gradually decreased in the bay. Though several types of spat collectors were tried, frilled nylon rope, nylon screen over *hapa* or fish cage seemed to be effective spat collectors for pearl oysters. It is felt that pearl oyster spat prefer smooth surface for attachment as evidenced by its preference towards the frilled nylon rope, nylon netting and nylon rope. The depth at which maximum number of spat occurred was upper 0.25 m. Very rarely young oysters were collected from depth beyond 2 m from the bay. The reason can be due to the clarity of water in the upper water column and the pearl oyster larvae are known to be phototrophic preferring surface water area for settlement. Another factor which interferes with the profuse settlement of oyster spat is the presence of *Modiolus* sp. and *Avicula vexillum* which appear simultaneously with pearl oyster spat settlement and reduce the space for attachment of pearl oysters.

Growth

Growth increment of farm grown pearl oysters *Pinctada fucata* was estimated by examining samples in the bay from 1978 onwards. During 1978-79 period peak modes of samples were traced for a period of 10 months. In October 1978 peak mode observed was 50-54 mm and through 10 months the peak mode has shifted to 65-69 mm. Thus an average growth of 15 mm for ten months with growth rate of 1.5 mm/month was estimated. Again observations from August 1979 to May 1980 were made by keeping 100 numbers of oysters ranging from 21-61 mm. In the first month the peak mode observed was 45-49 mm and in the tenth month the mode has shifted to 60-64 mm, thus showing 15 mm growth at an average of 1.5 mm/month. During these observations, average length of pearl oysters was calculated for every month and the results are plotted in Fig. 4. It could be seen that growth increments were 5.3 mm, 4.5 mm, 2.1 mm, 1.5 mm, 1.1 mm, 0.8 mm, 0.6 mm, 0.6 mm and 0.7 mm during the first

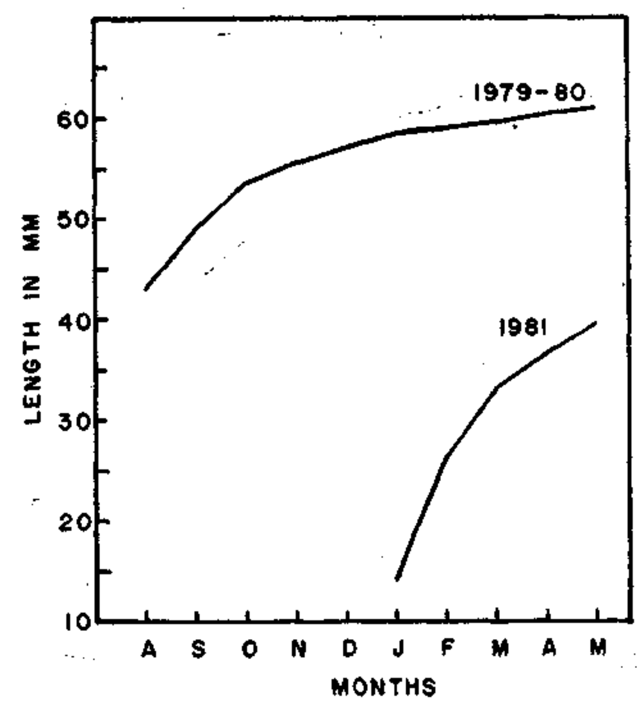

Fig. 4. Growth of pearl oyster based on monthly average size during 1989-80 and 1981.

nine months, respectively. This shows that pearl oysters in their young stage grow faster whereas growth rate is not fast in adults. Observations on spat collected from a single brood of same length range and kept in cages for 3 months have confirmed this information in

1981 beginning. In January pearl oyster spat showed a peak mode of 10-14 mm, in February it was 25-29 mm and in March 30-34 mm, thus a growth increment of 15 mm in the first month and 5 mm in the second month. It is thus quite evident that young oysters exhibit faster growth rate which slows down as the oysters grow.

Spawning condition

Regular samples of *P. fucata* were examined to note the gonadal condition of farm grown oysters in different months. The gonadal condition was grouped into 5 major stages *viz.*, stage I—inderterminate-sexes could not be identified; stage II—ova have not attained regular shape, sperm non-motile; stage III—granulation in the ovary appeared, sperm non-motile; stage IV—mature ova, motile sperm, reproductive body creamy coloured-spawning stage; and stage V—spent. The percentage of occurrence of each stage in different months from October 1978 to December 1980 is given in Table 1 which shows that from December 1978 to January 1979 mature stage was high. Again during March to June 1979 another peak of spawning condition was observed with cent percent spawners in April-May period. Thus two peak modes of spawning periods were observed in all the years, which was found agreeable with the spatfall periods observed. Incidentally the peak spawning periods coincide with the southwest and northeast monsoon also. Though these were the peak spawning periods, spawners were found in almost all the months of the year. There was slight variation in the peak spawning months from year to year.

TABLE 1. *Percentage of maturity stages of* Pinctada fucata from *October* 1978 *to December* 1980

Month		Maturity Stage				
		I	II	III	IV	V
1978 Oct	..	50.00	50.00	..	..	..
Nov	..	..	6.67	93.33	..	..
Dec	..	..	..	43.33	46.67	10.00
1979 Jan	..	..	46.67	13.33	40.00	..
Feb	..	..	..	100.00	..	..
Mar	..	..	..	33.33	66.67	..
Apr	..	..	..	..	100.00	..
May	..	..	..	..	100.00	..
Jun	..	..	..	..	46.67	53.33
Jul	..	..	..	6.67	30.00	63.33
Aug	..	100.00	..	..	..	..
Sept	..	86.67	13.33	..	..	..
Oct	..	..	90.00	10.00	..	..
Nov	..	..	..	43.33	56.67	..
Dec	..	..	..	40.00	60.00	..
1980 Jan	..	..	70.00	..	..	30.00
Feb	..	..	..	100.00	..	..
Mar	..	..	..	..	100.00	..
Apr	..	..	..	..	70.00	30.00
May	..	..	..	100.00	..	..
Jun	..	..	..	..	100.00	..
Jul	..	..	..	..	..	100.00
Aug	..	100.00	..	..	..	..
Sept	..	..	100.00	..	..	..
Oct	..	..	..	100.00	..	..
Nov	..	..	..	100.00	..	..
Dec	..	..	..	..	100.00	..

Feeding habits

Examination of the stomach contents of pearl oysters was made from October 1978 to September 1979. In October 1978, 93% of the oysters examined had bivalve eggs and larvae in the stomach. Specific identification of the eggs and larvae could not be done. In November 1978, 27% of oysters and in January 1979, 6% of oysters had eggs and larvae. In the rest of the period under observation the food item observed were only digested algae and detritus.

FOULING AND PREDATION

The important fouling organisms found in Vizhinjam Bay along with pearl oysters were rock oysters (Pl. I F), barnacles, tubicolous polychaetes, ascidians, bryozoans, alcyonarians, calcareous algae, hydrozoans and crinoids in the order of abundance. Apart from these animals, amphipods, crabs, flat worms, free living polychaetes and sea weeds were found in the pearl oyster cages and also in spat settlers. Seasonal profuse settlement of *Modiolus* spp. (Pl. I C) and *Avicula vexillum* were also observed. In 1977, 1978 and 1979 *Modiolus* and *Avicula vexillum* settlement over the cages and spat collectors were high during March-April. During November-December 1980 heavy settlement of both these bivalves was observed inside the bay. It could be seen that spat collectors, when released are subject to fouling and periodical cleaning of settlers is required to keep it clean for good pearl oyster settlement. Pearl oyster cages and fruit baskets used for stocking oysters were also subject to heavy fouling (Pl. I D,E) when it is kept for longer period in the bay. The main boring organisms observed in the oysters were the polychaete *Polydora* sp. and sponge *Cliona* sp. The bigger shells ranging 60-80 mm often had borers in the umbonal area. The effect of these borers on settlement and growth of oysters was also observed. The oyster and barnacle settlement over the shells hinder the growth of pearl oysters and become a competitor for food. Sponge encrustation even closes the shells of oysters leading to ultimate destruction of the animal. Heavy

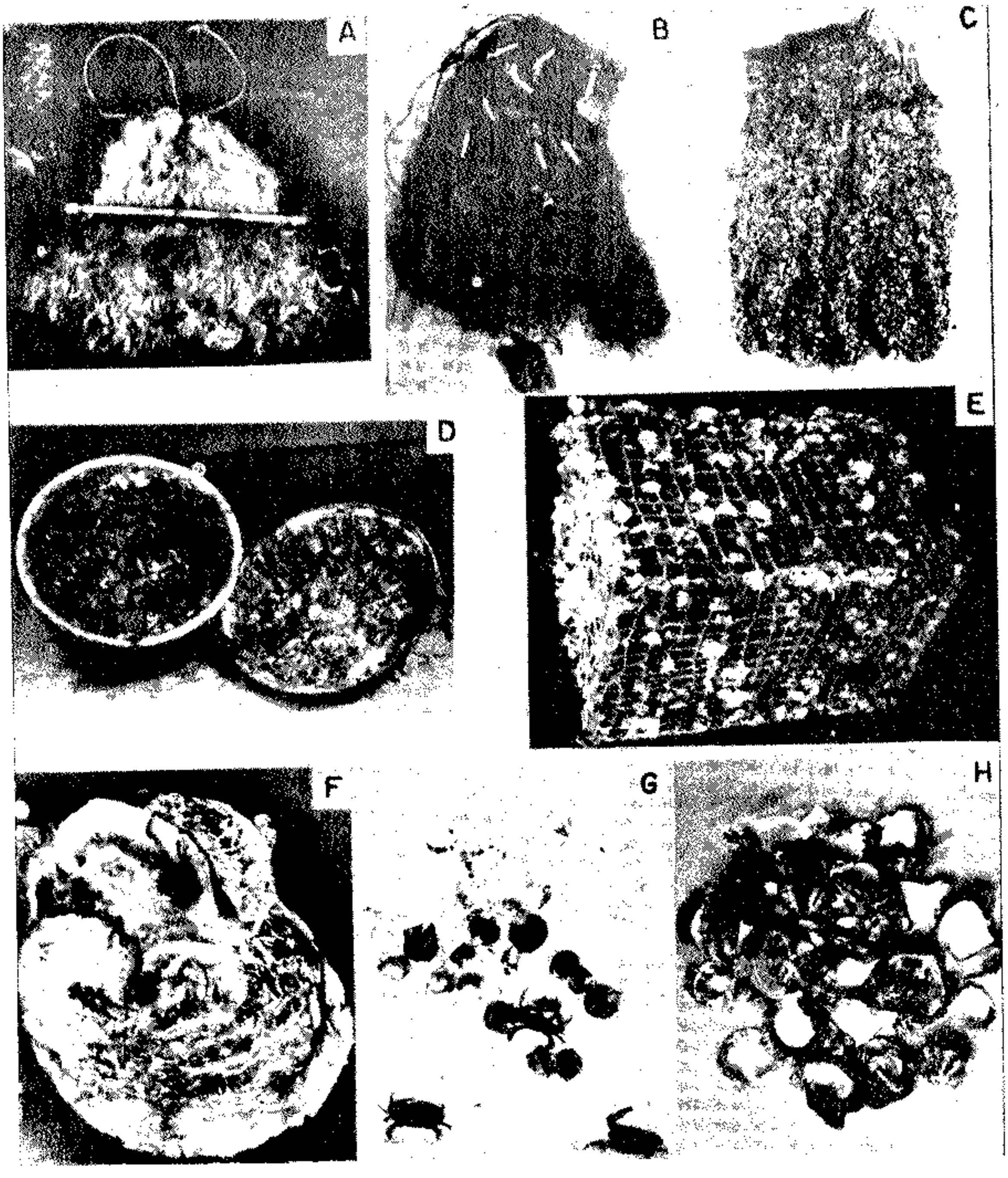

PLATE 1. A. Frilled nylon rope-spat collector. B. Spat collector with young pearl oysters - arrow indicating the position of attachment ; C. Spat collectors with *Modiolus* settlement ; D. Fruit basket with fouling organisms ; E. Pearl oyster cage with fouling organisms encrusted over the meshes ; F. Rock oyster settled over *P. fucata*. G. Predation of *P. fucata* by crabs in the laboratory. H. Broken shells of pearl oysters subject to predation, collected from cages.

fouling by oysters, barnacles, ascidians and sponges block the holes of fruit baskets and meshes of pearl oyster cages obstructing free flow of water through them. Cleaning of cages and spat collectors periodically was found to be effective to check the overcrowding of fouling organisms. The fouling problem was not so serious at Vizhinjam for pearl culture work except the periodical heavy settlement of *Modiolus* pp. and *Avicula vexillum*. Among the borers *Polydora* sp. causes blister formation inside the shell. About 5% of the shells examined had blisters due to polychaete boring. About 3-8% of farm grown oysters were also subject to *Cliona* boring. No serious destruction was caused by this borer to farm grown pearl oysters.

Predation by fishes *viz.*, *Diodon* sp. and *Arothron nigropunctatus* and *Ostraceon* spp. were observed in 1977, 1978 and 1979 in a minor scale. They usually feed on young pearl oysters settled over spat settlers. In 1980 mortality of spat was caused by the predation of crab *Charybdis* sp. which got inside baskets in very early stage and completely destroyed the oyster stock. In certain cases 100% oysters stocked were subject to predation. As a whole 20-40% of oysters stocked were subject to predation in 1980. The process of predation was closely observed in the laboratory keeping the pearl oysters and crabs in fibreglass tanks (Pl. I G). The crab first broke the antero-dorsal margin of the right valve with the chelipede and cut the adductor muscle, thus opening the shell valve. The crab ate away the flesh portion within 4-5 hours. All the oysters which were subject to crab predation had invariably a broken anterodorsal shell margin in the right valve (Pl. I, H). The peak period of predation observed was from October 1980 to January 1981. The size of pearl oysters subjected to predation ranged from 20-40 mm. The oysters of higher length range were not subject to crab predation. Appukuttan (1980) has observed mass-scale predation of mussel by *Rhabdosargus sarba* from Vizhinjam Bay, but it is interesting to note that these fishes were not causing any destruction to oyster stock.

Discussion

The occurrence of pearl oyster spat in Vizhinjam harbour has led to the initial investigation of this resource and attempts were made to raise a stock of pearl oysters for pearl culture work. Alagarswami (1977) has rightly pointed out that the success of shellfish culture depends to a great extent on the ability to collect and raise the spat of cultivable species. As observed by Alagarswami (1977) a multi-species composition with *Pinctada fucata* forming major species was observed at Vizhinjam. The protected bay is ideally suited for pearl oyster farming. Victor (1980) studied the seasonal changes in atmospheric temperature, surface water temperature, salinity, dissolved oxygen, pH, turbidity and silt deposition around the pearl culture farm at Veppalodai, Gulf of Mannar. He has reported double oscillation of temperature. High salinity during southwest monsoon and low salinity in northeast monsoon and high silt deposition in December are some of the features observed at Veppalodai. At Vizhinjam the spawning and high temperature were interrelated. Both peak spawning periods were observed during October-March coinciding with the period of high temperature and salinity. Compared with Gulf of mannar, the temperature and salinity ranges were low at Vizhinjam Bay.

Spatfall pattern at Vizhinjam was studied by using artificial spat collectors and as noticed at Tuticorin (Alagarswami, 1977). Incursion of species other than *P. fucata* was observed at Vizhinjam also. Experiments at Vizhinjam have shown that frilled nylon rope and *hapas* covered with nylon netting gave good results during peak spawning period. Mahadevan and Nayar (1976) also have suggested spat collection of pearl oysters from spat collectors as more reliable method than the collection from natural bed. Though there are two peak spatfall period at Vizhinjam, spawners and spat are observed in almost all the months of the year. Alagarswami and Chellam (1977) described dimensional relationship in *Pinctada fucata* and observed the heterogenous nature of the population at Tuticorin. At Vizhinjam also the heterogenous nature of *P. fucata* is seen as two peak spawning periods are observed and thus an overlapping of population. In 1977 and 1978 March spawning showed good settlement, whereas in 1979 and 1980 November-December spawning was good. Thus annual variation in spatfall was observed.

Malpas (1933) has used weight curve of pearl oyster from Ceylon as a reliable index of age since it was impossible to separate each generation of oysters from the natural bed, as there is considerable overlapping with successive spawning periods. Observations of Devanesen and Chidambaram (1956) show that the oysters grow to a height of about 36 mm in six months, 35-45 mm at the end of one year, 50-55 mm at the end of second year, 55-60 mm at the end of third year, 60-65 mm at the end of fourth year and 65-70 mm at the end of fifth year. Gokhale *et al.* (1954) and Narayanan and Michael (1968) have observed that pearl oysters from Gulf of Kutch grow fairly fast during the first three or four years and therefater show little growth. Observations at Vizhinjam also show that young oysters show faster growth and later growth rate is very slow. Compared with other areas the pearl oysters register a fast growth in first year itself at Vizhinjam. In Gulf of Mannar two spawning periods in an year are observed, one in the southwest monsoon period and the other in northeast monsoon period. Herdman (1906) found May-July and November-January as spawning period in Gulf of Mannar while Hornell (1916) gave April-May and September-October as intense spawning periods. Mahadevan and Nayar (1976) also noted biannual spawning in *P. fucata* after observing spatfall in the natural bed. In the present observations at Vizhinjam two peak spawning periods are observed.

Chellam (1980) observed bivalve eggs and larvae in the stomach inclusions of pearl oysters during certain periods of the year at Tuticorin. Phytoplankton and detritus formed the major items of food of pearl oysters at Tuticorin. The occurrence of bivalve eggs and larvae in the stomach of pearl oysters need further study to establish whether it is an isolated event or a regular phenomenon.

Rao and Rao (1974) have listed the major fouling organisms and predators found associated with Indian pearl oysters. Mahadevan and Nayar (1976) observed settlement of *Modiolus* spp. in the natural bed around Tuticorin and stated that increasing *Modiolus* settlement causes severe damage to the oyster bed from year to year. Alagarswami and Chellam (1976) studied the fouling and boring organisms found associated with pearl oysters at Veppalodai, Gulf of Mannar and the seasonal variation in abundance of various organisms and its effects on farming. At Vizhinjam though fouling organisms were not considered as a serious problem for pearl oyster stocking, predation of pearl oyster spat was alarming. Achari (1980) has indicated the impact of introduction of pearl oyster in the new environment and consequent concentration of their biological associates which are new to the locality and the subsequent development of a parallel community. The appearance of predators like crabs in the bay can be attributed to this principle.

REFERENCES

ACHARI, G. P. K. 1983. Artificial biocoenosis for ecological reconstruction to facilitate aquaculture. *Symposium on Coastal Aquaculture*, Mar. Biol. Ass. India. Abstr. 29 : 18.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca.*, Mar. Biol. Ass. India. Pt. III : 975-993.

ALAGARSWAMI, K. 1975. Preliminary study on the growth of cultured pearls. *Indian J. Fish.*, **22** (1 & 2) : 300-303.

ALAGARSWAMI, K. 1977. Larval transport and settlement of pearl oysters (genus *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm Water Zooplamkton. Spl. publication.* National Institute of Oceanography, Goa : 678-686.

ALAGARSWAMI, K. AND A. CHELLAM. 1976. On fouling and boring organisms and mortality of pearl oysters in the farm at Veppolodai, Gulf of Mannar. *Indian J. Fish.*, **23** (1 & 2) : 10-22.

ALAGARSWAMI, K. AND A. CHELLAM. 1977. Change of form and dimensional relationship in the pearl oysters *Pinctada fucata* from Gulf of Mannar. *Indian J. Fish.*, **24** (1 & 2) : 1-14.

ALAGARSWAMI, K. AND S. Z. QASIM. 1973. Pearlc ulture—its potential and implications in India. *Indian J. Fish.*, **20** (2) : 533-550.

ANON. 1977. Pearl culture training. Long term and short term courses. *CMFRI Special Publication*, No. 1 : 39 pp.

ANON. 1978. Mariculture Research and development activities. *CMFRI Special Publication*, No. 2. 48 pp.

APPUKUTTAN, K. K. 1980. Predation of mussels in culture by silver bream *Rhabdosargus sarba*. *CMFRI Bulletin*, **29** : 44-45.

CHELLAM, A. 1983. Study of the stomach contents of pearl oyster *Pinctada fucata* (Gould) with reference to the inclusion of bivalve eggs and larvae. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India. Pt. **2** : 604-607.

DEVANESAN, D. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oyster farm, Krusadai Island, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar. Part 1. *Cont. Mar. Biol. St., Krusadai*, **4** : 1-89.

DHARMARAJ, S. AND A. CHELLAM. 1983. Settlement and growth of barnacle and associated fouling organisms in pearl culture farm in the Gulf of Mannar. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India. Pt. **2** : 608-613.

DHARMARAJ, K., N. B. NAIR AND K. G. PADMANABHAN. 1980. Studies on the hydrographical features of Vizhinjam bay *Symposium on Coastal Aquaculture*, Mar. Biol. Ass. India. Abstr. 30 : 19.

EASWARAN, C. R., K. R. NARAYANAN AND M. S. MICHAEL. 1968. Pearl fisheries of the Gulf of Kutch. *J. Bombay Nat. Hist. Soc.*, **66** : 338-344.

GOKHALE, S. V., C. R. EASWARAN AND R. NARASIMHAN. 1954 Growth rate of pearl oyster, *Pinctada fucata* in the Gulf of Kutch with notes on pearl fishery 1953. *J. Bombay nat. Hist. Soc.*, **52** (1) : 124-136.

HERDMAN, W. A. 1906. Reproduction and life history of the pearl oyster. *Rep. Govt. Ceylon Pearl Oyster Fish. Gulf of Mannar*, **5** : 109-186.

HORNELL, J. 1909. Report to the Government of Baroda and the prospects of establishing a pearl fishery and other marine industries on the coast of Okhamandal. *Report to the Government of Baroda on the Marine Zoology of Okhamandal in Kattiawar*, Part I : 1-34.

HORNELL, J. 1916. An explanation of irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, **8** : 11-22.

HORNELL, J. 1922. The Indian pearl fishery of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, **16** : 1-188.

MAHADEVAN, S. AND K. NAGAPPAN NAYAR. 1973. Pearl oyster resources of India. *Proc. Symp. Living Resources of the Seas around India. Spl.* Publication, CMFRI, 659-671.

MAHADEVAN, S. AND K. NAGAPPAN NAYAR. 1976. Underwater observations on the settlement of spat of pearl oyster on the paars off Tuticorin. *Indian J. Fish.*, **23** (1 & 2) : 105-110.

MALPAS, A. H. 1933. Further observations on the age and growth rate of the Ceylon pearl oyster, *Margaritifera vulgaris* with special reference to oysters of Donnan's Muttuvarattu Paar. *Ceylon J. Sci.*, (Fish), **5** : 21-48.

NARAYANAN, K. R. AND M. S. MICHAEL. 1968. On the relation between age and linear measurements of the pearl oyster, *Pinctada vulgaris* (Schumacher) of the Gulf of Kutch. *J. Bombay nat. Hist. Soc.*, **65** (2) : 442-452.

PANDYA, J. A. 1974. Pearl oyster resources and culture experiments in Gujarat. *Proceedings of the Group Discussion on Pearl Culture* held at Tuticorin. January 1974, CMFRI.

RAO, K. V. AND K. S. RAO. 1974. Pearl oysters. In : *The Commercial Molluscs of India, Bull. Cent. Mar. Fish. Res. Inst.* **25** : 84-106.

VICTOR, A. C. C. 1980. Ecological conditions of the pearl culture farm off Veppalodai in the Gulf of Mannar. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India. Pt. **2** : 619-626.

9

HATCHERY TECHNOLOGY FOR PEARL OYSTER PRODUCTION

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INTRODUCTION

The successful development of hatchery technology for production of pearl oyster *Pinctada fucata* spat in 1981 at the Central Marine Fisheries Research Institute (Alagarswami *et al.*, 1983 a, b, c) is an important milestone in the progress of research and development of molluscan shellfish culture in India. This is evident from the fact that subsequently, similar developments have been achieved in the production of spat of the oyster *Crassostrea madrasensis* in 1982 (Nayar *et al.*, 1984), green mussel *Perna viridis* (Rangarajan, 1983) and brown mussel *P. indica* in 1983 (Appukuttan *et al.*, 1984). These developments have resulted in the establishment of a moderate shellfish hatchery at Tuticorin which has become capable of mass production of spat of any of these marine bivalves with a certain degree of predictabilitly. Although the larval rearing technology for the bivalves of temperate and sub-tropical regions had been known for over two decades prior to the above developments through the works of Loosanoff *et al.* (1963), Walne (1964), Imai (1977) and others, the achievements in India have established the validity and relevance of hatchery technology for the tropical species and situations. The present paper considers the subject in three parts: first, it outlines the hatchery system ; secondly, it deals with the experimental results obtained in pearl oyster spat production ; and last, it critically evaluates the technology with reference to its expected role in shellfish research and development.

HATCHERY SYSTEM

Site selection

Many factors are to be taken into account in the selection of a hatchery site. The primary requirement of an operational hatchery is the uninterrupted supply of good quality seawater free from pollutants. The seawater used in the hatchcery should be free from suspended particles and silt and hence the site of drawal of water should be rocky, coralline or sand mixed. It should be away from industrial and domestic sewages. It should not be close to river mouths, the flooding of which will dilute the seawater, resulting in problems during the times of monsoon. Places experiencing dust and hot summer winds are not ideal. Other aspects to be considered are proximity to the natural resource and farm sites and logistics of transplantation.

Hatchery building

The hatchery building should be designed and constructed in such a way as to get maximum light and air inside the hatchery. The roof should partly be provided with translucent fibreglass sheets. This will provide light for the algal culture inside. In order to minimise heat radiation, the height of roofing should be sufficiently high. Glass panelled, large windows with ventilation for free passage of light and air should be provided. Air vents and exhaust fans are required in sufficient numbers. Entry of insects, flies and birds should be avoided by fixing fine wire mesh panels to the air vents. Concrete flooring with sufficient gradient and gutters for easy drainage of water should be provided. Provisions must be given for fresh water supply and power supply inside the hatchery. In case of extremely high ambient temperature airconditioning would help in successful larval rearing.

Water management

Seawater drawn from beyond the low water mark is usually devoid of silt and suspended particles. This water is collected in a well, by placing PVC pipes of

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15 cm diameter, by gravitational force. The well acts as a sump-cum-sedimentation tank. The water is then pumped to a biological filter where the water passes through coarse river sand, pebbles and charcoal. The filtered water is stored in a sump with two compartments, facilitating easy cleaning and maintenance. The water stored in the sump is lifted to overhead tank. This water is then drawn to the hatchery through PVC pipelines. The water is allowed to pass through an ultraviolet sterilising chamber to destroy the bacteria and distributed to culture tanks.

The seawater requirement of a hatchery is about 10,000 litres a day when static or recirculation systems are under operation. In the flow-through system, the requirement will be very high. Metals which get rusted while in use should be avoided in the water circulation system. Parts made out of materials like PVC and stainless steel are preferable in the hatchery operation.

The seawater filter system should be maintained properly. Removal of sediment, replacement of river sand and charcoal and washing and drying of pebbles should be done periodically. The frequency for this maintenance operation can be decided by monitoring the bacterial load of the filtered water. Having an additional filter bed as a standby will help in uninterrupted supply of filtered seawater.

Aeration

Air compressors can be either of piston or rotary vane type. Rotary vane models give a high output at low pressure and are less prone to mechanical failure. Air is compressed into a storage tank. The automatic cut off allows the compressor to rest for a while, when the storage tank is full. The air is passed through a series of filters to remove oil and moisture and supplied to the hatchery through PVC pipes of diameter 2.5 cm. Air can be drawn at the required places from these pipes running the entire length of the hatchery at a height of 3 m through the nozzles. The air is supplied to the culture tanks through diffuser stones.

By using electrical air blower, oil free air is supplied to the tanks. The disadvantages of air blower are (i) the air blower should run non-stop since there is no storage tank ; (ii) there is no provision to regulate the air flow at the source and (iii) power failure will affect the air supply to the tanks.

Larval food production

Flagellates measuring less than 10 μm form the main food of pearl oyster larvae. The important phytoflagellate used as larval food is *Isochrysis galbana* (class : Haptophyceae). It measures 7 μm. Besides, species of *Pavlova*, *Chromulina* and *Dicrateria* have also been found to be satisfactory food for the larvae. Various culture media have been used depending on the organism, class and genera. Usually for culturing flagellates, Conway or Walne's medium is used in the laboratories for the maintenance of the stock culture as well as for mass culture. The composition of Walne's enrichment medium is as follows :

Solution—A

Ferric chloride ($FeCl_3.6H_20$) ..	2.60 g
Manganese chloride ($MnCl_2.4H_20$)	0.72 g
Orthoboric acid (H_3BO_3) ..	67.20 g
Sodium EDTA ..	90.00 g
Dibasic sodium acid phosphate ($NaH_2PO_4.2H_20$) ..	40.00 g
Potassium nitrate (KNO_3) ..	200.00 g
Distilled water ..	2 l

Solution—B

Zinc chloride ..	2.10 g
Cobalt chloride ..	2.00 g
Ammonium paramolybdate ..	0.90 g
Copper sulphate ($CuSO_4.5H_2O$) ..	2.00 g
Distilled water ..	1 l
Acidify with HCl to obtain a clear liquid.	

Solution—C

Vitamin B_{12} ..	10.00 mg
Thiamine ..	200.00 mg
Distilled water ..	2 l
(To be stored in a refrigerator)	

Culture medium

Solution—A ..	10 ml
Solution—B ..	1 ml
Solution—C ..	1 ml
Seawater ..	10 l

Isolation : For the isolation of the required species of phytoflagellates, the serial dilution culture technique is employed. In this method mainly 5 dilution steps (the inocula corresponding to 1, 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} ml) are employed. After filtering the seawater through 10 micron sieve, the filtrate has to be inoculated to 5 series of culture tubes in various concentrations. These are kept under sufficient light with uniform temperature (25°C) conditions. After 15-20 days, discolouration of the tubes can be observed. On examination, the growth of unialgal species can be observed. Purification of these organisms can be done by sub-culturing the same in 250 ml, 500 ml, 1 l and finally 3 or 4 l Haufkin culture flasks as stock culture.

Stock culture : Required quantities of nutrients are added to autoclaved or boiled and cooled seawater in Haufkin flasks. Walne's medium is found to be the ideal and suitable one to maintain the stock of all the Haptophycean flagellates. About 10 ml of the inoculum in the growing phase is transferred to the culture flask and placed under tube lights (800 lux). When the maximum exponential phase is reached, light intensity is reduced to 400 lux to enable further growth. Normally the flagellates will enter the stationary phase of growth after 15 days. In this phase the culture can be kept for a period of 2 months without aeration.

Mass culture of algae : Utilising the inoculum from the stock culture room, the flagellates are grown in large scale in 20-l glass carbuoys or in 100-l perspex tanks. Fully grown stock culture is used as inoculum for the mass culture in these containers. About 250 ml of the inoculum is used for the glass carbuoy and 2 l for the perspex tank. These containers will have the maximum concentration of cells in the growing phase within 5 to 6 days. After observing the thick brownish yellow colour and noting the cell concentration using a haemocytometer, the culture is drawn for use as food for the pearl oyster larvae. The composition of the medium used for mass culture as well as mixed algal culture is as follows :

Potassium nitrate	.. 0.4 g
Potassium dihydrogen orthophosphate	.. 0.2 g
Sodium silicate	.. 0.2 g
Sodium EDTA	.. 0.2 g
Filtered seawater	.. 30 l

Culture conditions : The right amount of illumination is an important factor for algal culture. Most of the flagellates require less light during the stationary phase. Too much of light causes early declining of culture. For the growth in mass culture 1,000-1,500 lux is optimum upto 5-6 days, and for maintaining the stock culture 400-500 lux is sufficient. A photoperiod of 12 hr light and 12 hr darkness is ideal for maintaining the stock as well as mass cultures. The algal cultures are maintained best at 23-25°C. It has been noticed that under aeration, the cultures remain in the growing phase 2-3 days more. Aeration helps the nutrients to be distributed uniformly in the medium.

Broodstock maintenance

In order to get spawners throughout the year, the brood oysters are kept in seawater, the temperature of which is maintained at 25-28°C. They are fed with mixed culture of algae at the ration of 4 l per oyster per day, the quantity being supplied twice a day at equal intervals. The algal food is supplemented by raw corn flour at 30 mg per oyster per day. Pearl oysters with maturing gonad fed with the above food for 45 days would spawn with 30% response. The mature oysters can be kept for prolonged period under 25-28°C and the spawning of these oysters can be induced with a slight elevation of temperature.

Larval rearing system

The eggs are fertilised as soon as they come in contact with sperms. The fertilised eggs settle at the bottom of the vessel along with unfertilised and undeveloped eggs, broken tissues and mucus. The column water contains the excess sperm. The developing embryos are sieved carefully through 30 μm mesh and are transferred to fresh seawater for further development. At 3-4 hrs after fertilisation the morula stage is reached. The embryos which are phototrophic rise from the bottom of the vessel and congregate near the surface leaving behind the unfertilised eggs, under developed embryos and other debris at the bottom. The morulae are collected by siphoning them out gently to another fresh vessel. Most of the embryos reach straight-hinge stage within 20 hrs. The size of larva is 57.5 μm. Congregation behaviour of the larva still persists. One more sieving with 40 μm mesh at this stage yields pure larval culture. Estimation of larval concentration and stocking the larvae is done at this stage. The larvae are fed from this stage onwards. Further growth depends mostly on the supply of right type of food. Otherwise the larvae would remain in this stage upto 30 to 40 days without any further development. The straight-hinge stage is considered to be a critical one.

In the larval rearing vessels, water is changed once in two days. The larvae are sieved through 40 μm mesh and introduced to clean vessels containing seawater. A differential growth rate is noted in larvae beyond straight-hinge stage and on any given day during larval rearing, a wide range of sizes is seen. To obtain better results the method of culling is resorted to at different stages of development and the slow growing ones are discarded.

Aeration seems to affect the growth of pearl oyster larvae and leads to greater mortality. The effect of aeration is more pronounced in smaller vessels than in larger ones. Agitation caused by aeration weakens the larvae. The larvae prefer diffused light or darkness. Fibreglass tanks are found to be ideal for larval and spat rearing. Mass production of spat is done in tanks of one tonne capacity. The larvae show better growth and settlement in tanks painted with dark colour.

In the water circulation system, the tanks should have provision for inlet and outlet of water. The outlet should be of an appropriate size fitted with a sieve of nylobolt which prevents the passage of larvae out.

Disease control of larvae

Natural mortality of larvae/spat may occur even under the best conditions. The weak and dying larvae are found infected heavily by bacteria and protozoans. In some cases the mortality is due to epizootic organism. Within a day or two after infection, heavy mortality is seen among the larvae/spat. Infection by fungus is perahps through untreated seawater. The mortality of larvae/spat can be minimised to a large extent by following certain precautionary measures such as (i) general cleanliness of all utensils used in larval rearing; (ii) sterilisation with germicidal ultraviolet irradiation of the culture water and (iii) use of appropriate antibiotics to control bacteria. Streptomycin, Kanamycin, Aureomycin and Combistrep in low concentration have been suggested for use in larval rearing systems. Use of antibiotics in higher doses beyond certain limits is likely to retard the growth or kill the larvae. The commercial preparation of Terramycin, Sulfathiazone and Sulfanilamide is considered to be somewhat toxic even in low concentrations.

Spat production

To enhance the survival rate of spat during the nursery rearing phase, the fully developed larvae are allowed to set on suitable collectors in the spat setting tanks (Pl. III A). The inexpensive, long lasting, light materials such as fibreglass plates, bunches of monofilament, old fish net, seasoned bamboo splits and coconut shells are selected as spat collectors. In general, these materials should not leach out any chemical on reacting with seawater which may affect settlement and growth of spat. The spat collection units should be compact and should facilitate easy *in situ* transplantation to the farm.

The spat on collectors are transplanted to the farm. These are kept in cages which are again covered by old fish net on the outer side. This provides protection to the spat from predators. The spat settled on the culture tanks (Pl. III B) are removed carefully by means of soft foam rubber and reared separately in spat rearing net-cages. When the spat on the spat collectors attain a size of 10-15 mm, they are removed from the spat collectors and reared in net-cages (Pl. III C, D, E). Periodical maintenance of the spat and cages and transferring spat to fresh cages will minimise mortality during the phase of juvenile rearing (Pl. III F).

Flow chart

The different functions involved in hatchery operation are shown in the form of a flow-chart in Fig. 1. The chart depicts the basic steps in each of the subsystems, namely seawater treatment, algal food production and pearl oyster breeding.

RESULTS OF EXPERIMENTAL PRODUCTION OF PEARL OYSTER SPAT

Spawning and fertilisation

In pearl oysters with mature gonads, a simple change of seawater often leads to spawning. The shock of shell cleaning is enough for some oysters to spawn when they are returned to seawater. During some months the pearl oysters from the natural beds spawn when they are brought to the surface and supplied with seawater drawn from the surface area. In all the above cases the males invariably initiate the act of spawning, followed by females.

In hatchery operation, occassional natural spawning in the laboratory alone cannot be depended upon. A series of experiments have been conducted on induced spawning of pearl oyster (Alagarswami *et al.*, 1983 a) and the results are as follows (Table 1):

TABLE 1. *Induced spawning in pearl oyster* Pinctada fucata (After Alagarswami *et al.*, 1983a)

Treatment	No. of oysters			Percentage of spawning
	Tested	Spawned		
		Male	Female	
Tris, pH 9.0	28	4	18	78.6
Tris, pH 9.5	28	8	2	39.3
Tris, pH 9.1 ∓ H_2O_2 (3.064 mM)	16	3	7	62.5
NaOH, pH 9.0	21	5	5	47.6
NaOH, pH 9.5	19	6	7	68.4

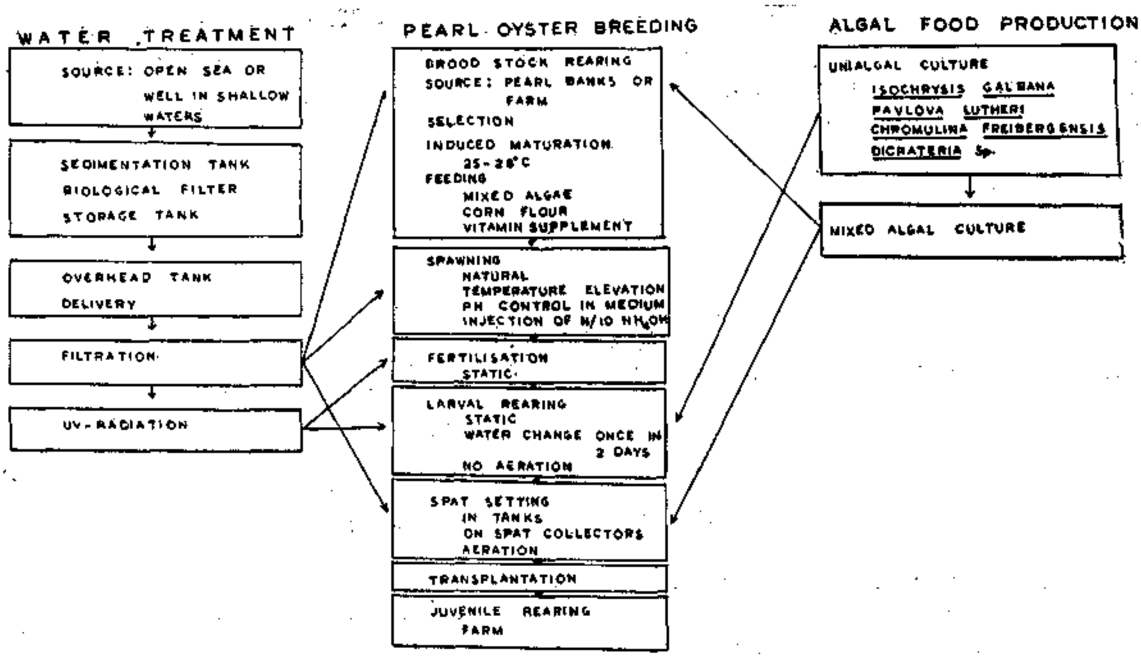

FIG. 1. Flowchart showing the hatchery operation.

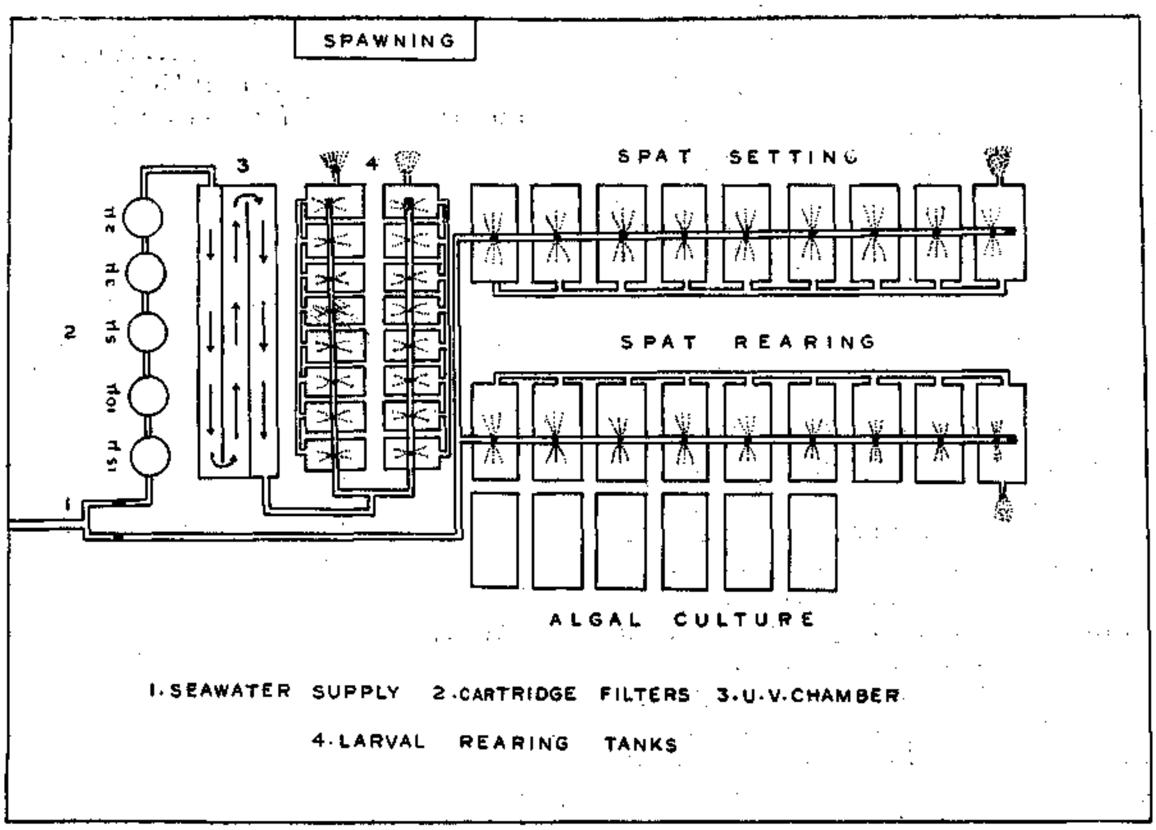

FIG. 2. Layout of hatchery.

Effect of hydrogen peroxide (H_2O_2) *:* Different concentrations of H_2O_2 at 1.532, 3.064 and 6.128 millimolars (m^M) were prepared by adding 6.25 ml, 12.5 ml and 25.0 ml of 6% H_2O_2 solution to 6 l of fresh seawater. The oysters were acclimatised for 12 h before experimenting. The oysters are kept in the experimental medium for 2 h at the end of which the solution was siphoned out and fresh identical seawater was added. Spawning (18.12%) occurred after the change to fresh seawater in the concentrations of 3.064 m^M and 6.128 m^M H_2O_2.

Effect of Tris buffer : The buffers with different pH such as 8.5, 9.0, 9.5 and 10.0 were prepared by slowly adding Tris buffer to fresh seawater. Normal seawater with a pH of 8.1-8.2 was used as control. The duration of the experiment was 3-4 h. A maximum of 78.6% of oysters spawned in the pH 9.0, 37.3% in the pH 9.5 and 20% in the pH 10.0. Spawning response started between 1-2 h in the Tris medium itself. There was no spawning in the control.

Effect of alkali (NaOH) *:* Solutions having a pH of 8.5, 9.0, 9.5 and 10.0 were prepared by dissolving pure pellets of sodium hydroxide in seawater. Normal seawater having a pH of 8.0 and 8.1 was kept as control. The duration of the experiment varied between 3-4 h. 68.4% of oysters spawned in pH 9.5 and 47.6% in pH 9.0. Spawning did not occur in other pH. In most cases, spawning occurred in NaOH medium itself.

Effect of H_2O_2 *in alkaline medium* (H_2O_2 + *Tris*) *:* The alkaline medium by Tris buffer acts to increase the porportion of animals that will spawn in response to H_2O_2. Oysters in Tris buffer solution at pH 9.1 formed the controls. The concentrations of H_2O_2 used here were the same as in the earlier experiment. 62.5% of oysters spawned in 3.064 m concentration of H_2O_2 buffer after the oysters were changed to fresh seawater at the end of 4 h of treatment.

Effect of H_2O_2 *in alkali medium* H_2O_2 + NaoH) *:* The pH was adjusted to 9.0 by adding NaOH pellets. The H_2O_2 concentrations were the same as above. The duration of the experiment ranged between 2-5 h. Two oysters spawned mildly out of 21 tested at 6.128 m^M concentration after changing to seawater. Spawning was observed in the control also.

Effect of injection of N/10 ammonium hydroxide : A dilute solution of N/10 NH_4OH was prepared from a stock solution. 0.1 ,0.2 and 0.3 ml of the solution was injected in the adductor muscle. 48% of oysters spawned at 0.2 ml injection but none at 0.1 and 0.3 ml. In one experiment when the injection was given at the base of the foot, all the oysters spawned profusely. Oysters without injection were kept as control and no spawning occurred in them.

Thermal stimulation : Experiments on thermal stimulation also resulted in spawning when the temperature was increased gradually from 28.5°C to 35.0°C.

Larval rearing

Spawning : Invariabily the males initiate spawning in the normal condition (P. I A). The presence of sperm in the water stimulates the females which follow act within 30 minutes. Majority of the eggs released first are pyriform, and measure 73.9 μm along the long axis and 45.2 μm in breadth on an average. A large clear germinal vesicle (nucleus) measuring 24.7 μm in diameter, is distinctly seen. The yolk cytoplasm is heavily granulated and is opaque (Pl. I B). The egg is enclosed in a vitelline membrane which remains upto trochophore stage.

Fertilisation : Soon after discharge, the eggs are fertilised. They assume a spherical shape and the germinal vesicle breaks down. The fertilised egg measures 47.5 μm in diameter (Pl. I C). During the process of fertilisation the first and second polar bodies are released. The polar bodies persist on the embryo even in the blastula stage.

Cleavage : The first cleavage begins 45 min after fertilisation resulting in a micromere and a macromere. Now the polar body lies at the cleavage furrow. During the second cleavage the micromere divides into two and the macromere divides unequally into a micromere and a macromere. The stage with three micromeres and a macromere is called Trefoil stage. (Pl. I D). Macromere does not take part in further divisions. Micromeres become smaller and smaller in size after passing through eight cell, sixteen cell and so on and reach morula stage (Pl. I E). Then each micromere develops a small cilium which makes rotation movement of the embryo.

Blastula : The stage is reached 5 h after fertilisation. Reorientation of cells result in the formation of blastopore and blastocoel.

Gastrula : Gastrulation takes place by epiboly. The cells convolute and differentiate into different layers. The archenteron formed at this stage communicates to the exterior through the blastopore. The embryo exhibits phototrophism. It takes 7 h to reach the stage.

Trochophore larva : The early trochophore larva develops preoral and postoral tufts of cilia thus marking antero-posterior region of the embryo (Pl. I F). A single apical flagellum is developed in the typical trochophore stage. The minute cilia noticed in the blastula stage disappear. A shell gland of the dorsal ectoderm secretes the prodissoconch I. The stage is attained in 10 h.

Veliger : The veliger stage is reached by the formation of straight hinge line, mantle, rearrangement of preoral cilia into a velum and disappearance of the apical flagellum, preoral and postoral ciliary bands. The straight hinge larva measures on an average 67.5 μm along the antero-posterior and 52.5 μm along the dorso-ventral axis (Pl. II A). The stage is reached in 20 h.

Umbo stage : The development of straight-hinge larva to umbo stage is gradual. Typical clam shaped umbo stage is reached between 10-12 days measuring 135 × 130 μm (Pl. II B). The shell valves are equal and develops mantle folds.

Eye spot stage : Eye spot is developed on 15th day when the larva measures 190 × 180 μm. The eye spot is situated at the base of the foot primordium. Eye spot is visible in a spat of 3.9 mm. The larva develops ctenidial ridges (Pl. II C).

Pediveliger stage : The foot is developed on 18th day at the size of 200 × 190 μm. The transitional stage from swimming to crawling phase has both velum and foot (Pl. II D). Later the foot becomes functional with the disappearance of velum. 2-4 gill filaments are seen at this stage.

Plantigrade : The stage is seen on 20th day and it measures 220 × 200 μm. Labial palps and additional gill filaments develop. The shell growth is by the formation of a very thin, transparent, uniform conchiolin film around the globular shell margin except in the vertex of the umbo region. This is the beginning of the formation of the adult shell or the dissoconch (P l.II E).

Spat : The plantigrade transforms to a young spat. The hinge line, anterior and posterior auricles and the byssal notch assume specific shape. The left valve is slightly more concave than the right one (Pl IIF). The spat attaches itself to the substratum with byssal threads. The typical spat is recognised at this size 300 μm on 24th day.

The sizes and days given for the different larval and post-larval stages vary from experiment to experiment according to the environmental conditions prevailing at that time.

Larval growth under different conditions

Larval density : Under identical conditions the larvae showed differential growth rate at different larval densities and was low in higher densities. In the experiment 1 of the Table 2 it can be seen that the growth increment from the day of stocking to first settlement was 137.9 μm, 134.7 μm, 131.2 μm, 132.8μm, 118.9 μm and 115.8 μm in the densities of 1, 2, 3, 4, 5 and 10 larvae/ml. The highest percentage (99.9 %) of settlement occurred in 2 larvae/ml concentration and the lowest (18.9 %) in 10 larvae/ml. A similar trend of settlement was also seen in the experiment 2 (Table 2)

TABLE 2. *Larval density, growth and settlement of larvae of* P. fucata

Expt. No.	Larval density (larva/ml)	Volume of water (1)	Average size of larvae (in μm)				Number of spat settled	Percentage of spatfall
			2nd day	8th day	15th day	28th day		
1	1	4	64.0	85.4	141.5	201.9	3,588	91.5
	2	4	64.0	93.4	142.6	198.7	7,991	99.9
	3	4	64.0	91.8	144.8	195.2	11,054	92.1
	4	4	64.0	95.6	142.8	196.8	15,540	97.1
	5	4	64.0	95.8	138.8	182.9	15,892	79.5
	10	4	64.0	95.2	133.7	179.8	7,562	18.9
2	2	500	67.5	88.0	174.8	302.2	3,16,334	31.6
	3	500	67.5	67.1	125.9	214.8	2,86,833	19.1
	4	500	67.5	83.8	164.8	281.5	2,81,666	14.0
	5	500	67.5	77.5	144.1	323.1	3,39,333	13.6

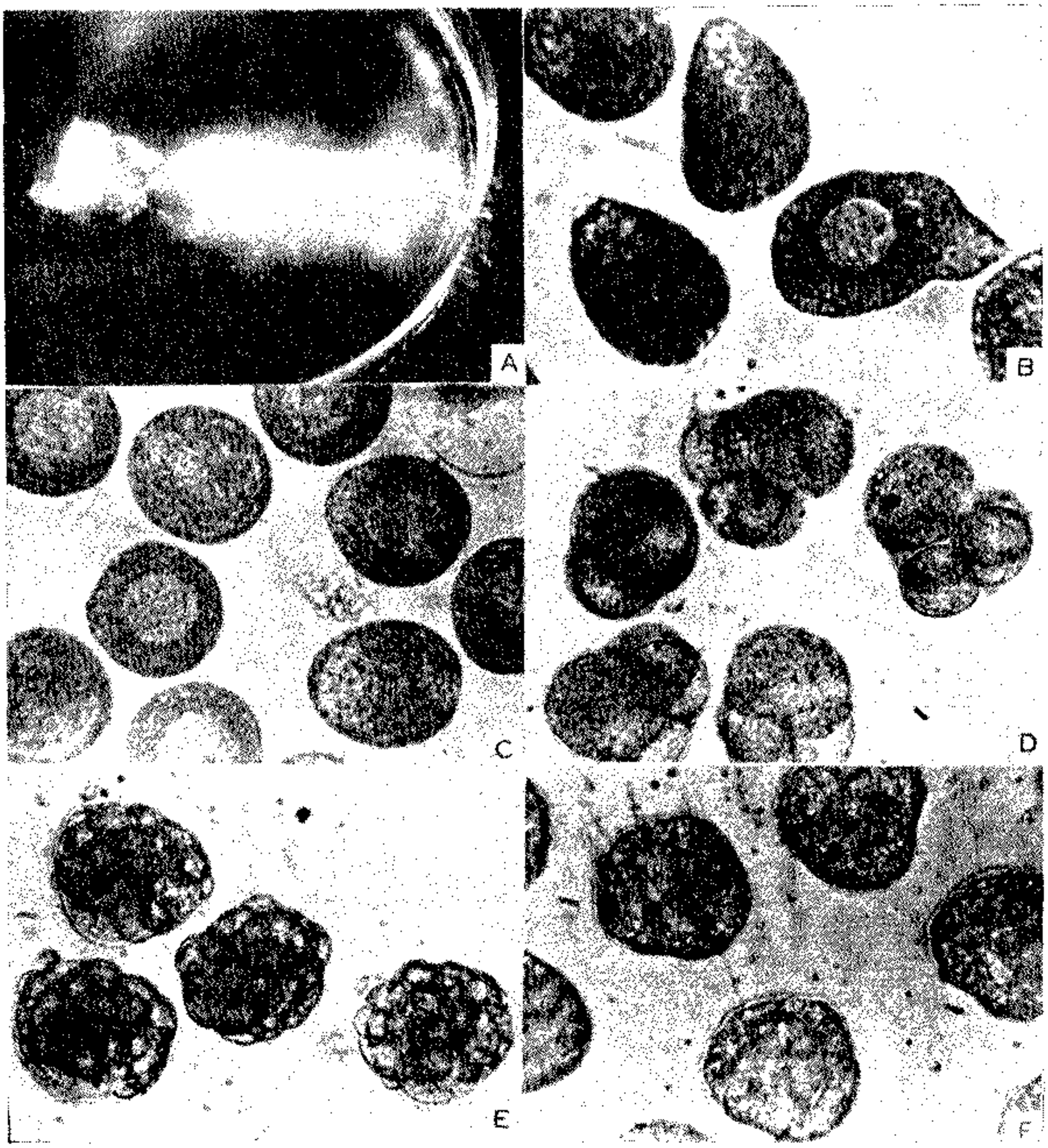

PLATE I. A. A spawning male ; B. Released eggs ; C. Fertilised eggs assuming spherical shape ; D. Cleavage, 2-celled and 4-celled stages ; E. Advance stages of cleavage ; F. Trochophore larvae.

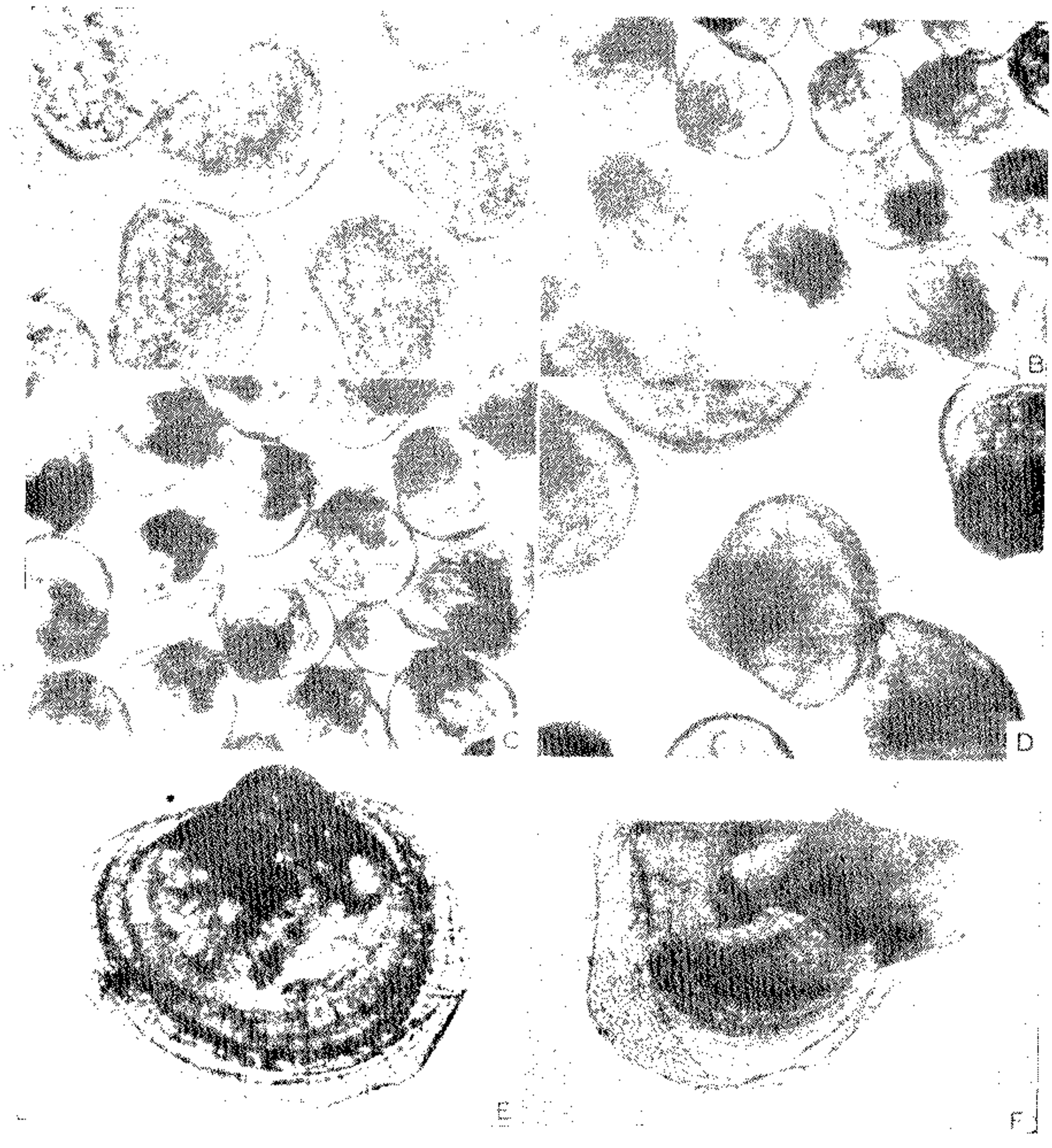

PLATE II. A. Straight-hinge stage; B. Umbo stage; C. Eyed stage; D. Pediveliger stage; E. Plantigrade stage; F. Young spat.

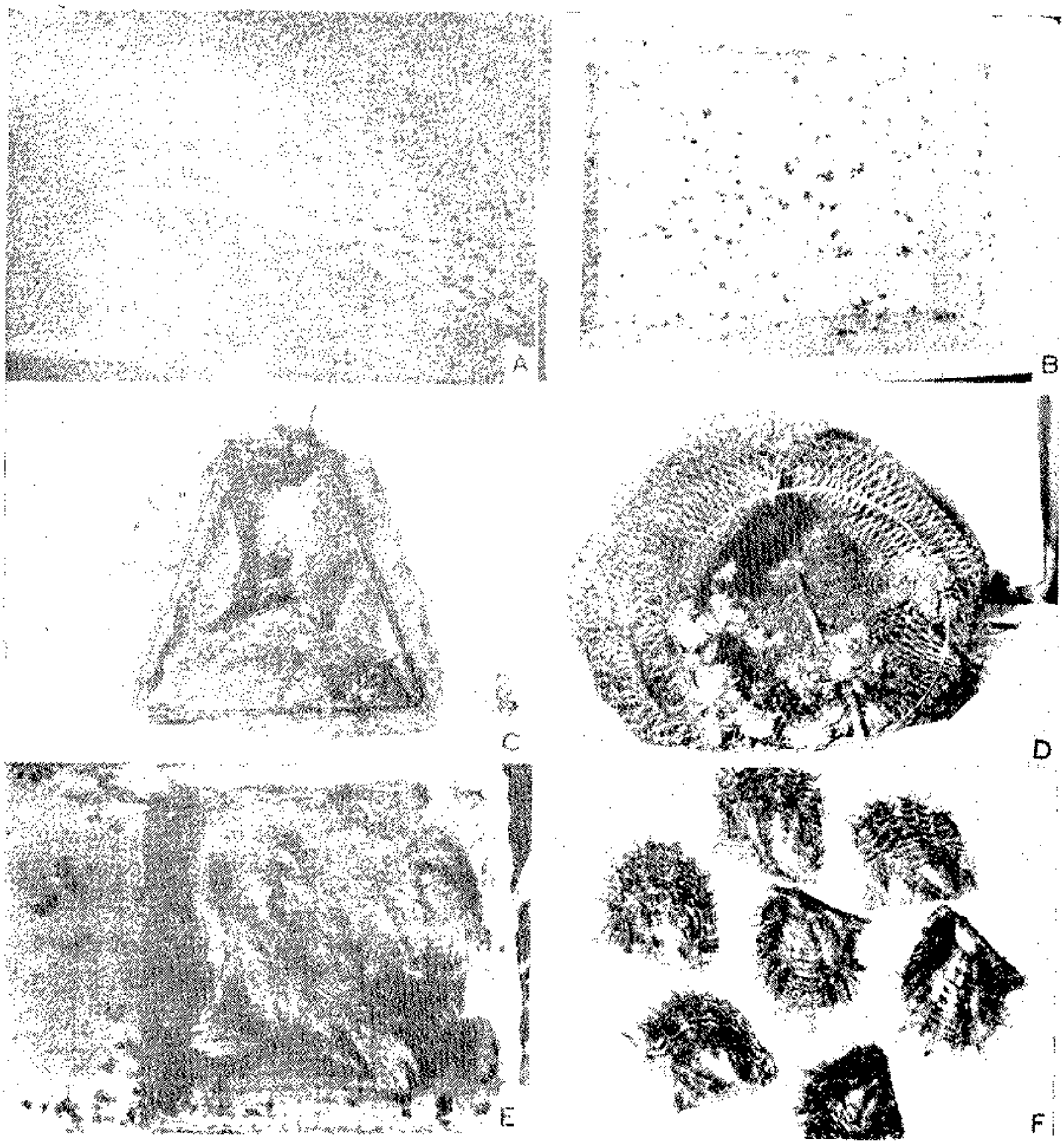

PLATE III. A. Spat settlement on a glass plate (spat collector) ; B. Spatfall in the FRP tank ; C. Spat rearing in the farm (velon screen net-cage) ; D. Large spat reared in a fish net-cage ; E. Spat on a bunch of monofilament in box-cage ; F. Hatchery produced young oysters.

where the percentage of spatfall was 31.6, 19.1, 14.0 and 13.6 in the densities of 2, 3, 4 and 5 larvae/ml. In this particular experiment where the volume of culture water was 500 l, the increase in growth was 252.7 μm, 147.3 μm, 214.0 μm and 255.6 μm for the larval densities 2, 3, 4 and 5 larvae/ml. From the experiment it was seen that 2 larvae/ml was found to be the optimum both for larval growth and spatfall.

Colour of larval rearing vessels : Apart from the larval densities and feeding levels, the colour of the larval rearing vessels was also found to influence the spatfall. Vessels of black colour received more settlement followed by white and light blue ones (Table 3). In the three experiments conducted 1.4, 2.4 and 7.3 per cent larvae settled respectively. It was also seen that the total spatfall in the black colour vessels was 64.5% in the first experiment, 73.7% in the second and 47.7% tn the third. Among the white and blue colour vessels the spatfall was almost similar.

TABLE 3. *Effect of colour of larval rearing tanks (FRP) on spatfall*

Expt. No.	Colour of tanks	Total No. of larvae stocked (million)	Volume of water (l)	No. of spat settled (%)	Percentage in total settlement
1	Black	.. 4.0	60	70,262 (1.8)	64.5
	White	.. 4.0	60	38,762 (0.97)	35.5
2	Black	.. 3.0	60	71,679 (2.4)	73.7
	White	.. 3.0	60	25,560 (0.85)	26.3
3	Black	.. 11.85	500	86,555 (7.3)	47.7
	White	.. 11.85	500	53,000 (4.5)	29.2
	Blue	.. 11.85	500	42,055 (3.6)	23.2

Culling : The effect of culling was not felt much in the growth of larvae (Table 4). The survival rate of spat obtained from the experiment was worked out. Under identical treatment for 44 days in the hatchery the survival was 91.3% in the non-culled case, 71.2% in one culling, 62.4% in two cullings and 68.2% in three cullings. On transplantation of the spat to the farm condition, the spat of non-culled experiment suffered mortality but the spat got through culling withstood the farm condition well and more than 50% of survival was obtained here than in the non-culled spat.

Aeration : Agitation of the culture water through aeration was found to have direct impact on the growth and settlement of larvae. The result of the three exerpiments conducted on this aspect is given in the Table 5. The effect of agitation was more pronounced in smaller vessels of 5 l capacity than in larger vessels. The growth as well as the settlement of the larvae was affected by aeration. The percentage of spat settlement in aerated condition was 0.6%, 9.0% and 8.7% in the three sets of experiments whereas it was 15.9%, 40.6% and 14.3% for the non-aerated experiments.

Spat production and rearing

Larval rearing was conducted almost throughout the year in the hatchery laboratory of Central Marine Fisheries Research Institute at Tuticorin and spatfall was achieved in all the cases (Table 6). However, during the months May-August, the spatfall was at the minimum level. This was because of the high salinity of the rearing water. This was particularly true in the year 1983 (Table 6). In addition to the rise in salinity, heavy dust fall and warmer landward wind were experienced during May-August at Tuticorin. Occasional spurt in the growth of ciliates resulted in heavy mortality in larvae. This was more common only during May-August. It may be seen from Table 6 that higher rates of mortality in the larval rearing were observed in the initial period. Later, steps were taken to overcome some of the problems of larval rearing which resulted in higher survival rates.

TABLE 4. *Effect of culling on the growth and settlement of larvae and survival rate of spat*

Treatment	Av. growth of larvae (in μm) 2nd day	6th day	12th day	19th day	22nd day	No. fo spat settled (%)	Percentage of survival in lab (44 days)
No Culling ..	67.5	68.9	90.9	183.6	293.2	24,776 (24.8)	91.3
One Culling (at umbo) ..	—	—	99.7	192.8	291.9	26,597 (66.5)	71.2
Two Cullings (at umbo & eyed) ..	—	—	107.0	192.4	315.2	15,130 (33.6)	62.4
Three cullings (at umbo, eyed & Pediveliger) ..	—	—	105.6	187.7	288.7	16,296 (47.9)	68.2

TABLE 5. *Effect of aeration on the grwoth and settlement of larvae*

Expt. No.	Vessel	Treatment	Larval density (ml	Vol. of water (1)	Average growth of larvae in µm				No. of spat settled & %	Percentage in total spatfall
					3rd day	10th day	17th day	24th day		
1	Glass beaker	Non-aerated	.. 2	5	60.7	95.4	152.5	242.4	1591 (15.9)	96.36
	Glass beaker	Aerated	.. 2	5	60.7	97.6	103.0	286.7	58 (0.6)	3.64
2	FRP tank (Blue)	Non-aerated	.. 2	50	62.1	100.8	173.2	351.0	40,567 (40.6)	81.87
	FRP tank (Blue)	Aerated	.. 2	50	62.1	80.5	99.3	314.8	8,980 (9.0)	18.13
3	FRP tank (Black)	Non-aerated	.. 2.5	500	—	—	—	—	1,69,943 (14.3)	62.31
	FRP tank (Black)	Aerated	.. 2.5	500	—	—	—	—	1,02,777 (8.7)	37.69

Transplantation

After spat setting in the hatchery they are further grown in nursery tanks. Feeding with mixed algae, especially with *Chaetoceros* enhances the juvenile growth. Spat of 3 mm and above withstand transplantation to the new farm environment. High mortality is noted in transporting spat of size smaller than 3 mm. Silt deposition and settlement of other organisms on the spat and culture containers greatly affect the minute spat. The spat collectors with the spat *in situ* are transported in wet condition and reared. The spat settled on the tank are removed with sponge and transported in water and reared further in net-cage.

TABLE 6. *Pearl oyster spat production in the experimental hatchery at Tuticorin during* 1981—86

Expt. No.	Date of spawning	No. of spat set
1	20-8-81	70,496
2	16-9-81	14,450
3	2-11-81	1,374
4	4-12-81	42,151
5	17-8-82	—
6	1-12-82	5,17,521
7	23-2-83	1,05,856
8	23-4-84	1,818
9	1-6-83	71
10	10-8-83	3,314
11	16-9-83	6,627
12	23-11-83	1,30,292
13	7-1-84	99,308
14	22-3-84	20,559
15	2-5-84	5,36,015
16	16-8-84	22,260
17	1-1-85	6,00,000
18	17-2-85	6,700
19	19-3-85	10,32,000
20	24-4-85	7,60,000
21	23-6-85	10,500
22	28-8-85	9,93,000
23	26-11-85	70,000
24	10-12-85	6,18,000
25	15-2-86	5,60,534
26	19-5-86	2,14,131
27	26-6-86	13,06,965

CRITICAL EVALUATION OF HATCHERY TECHNOLOGY

The development of hatchery technology for production of pearl oyster seed has been timely (Alagarswami *et al.*, 1983) both in respect of this specific resource and for marine bivalves in general. Seed availability has been felt a major constraint in the development of shellfish culture in India. The pearl oyster resource in the natural beds of Gulf of Mannar and Gulf of Kutch have fluctuated unpredictably in the past and no one would venture into pearl culture with total dependence on supply of oysters from the natural source. Also, experimental spat collection in the open-sea has not been successful and that in the coastal waters has yielded mixed species populations at Tuticorin and Vizhinjam, with a very low and uneconomical component of *Pinctada fucata.* Under these circumstances, the hatchery technology has proved very useful and given a positive direction to the effort on pearl culture in solving the resource problem.

High level of production achieved in certain batches of rearing, upto a maximum of 1.3 million spat, under minimal conditions would show the viability of the technology. Such mass production has enabled development in another direction to attempt to repopulate the natural beds themselves by sea-ranching. This has a great potential to control or minimise the vagaries of natural production and re-open pearl fisheries for natural pearls if successful. Pearl culture also can benefit considerably if full grown oysters can be taken from the beds after a period for nucleus implantation and subsequent culture.

The technology developed and practised is simple for adoption and is of low cost in terms of equipment and operational expenditure. The technology has been tested under severe conditions of fluctuations of environmental parameters and, under more ideal situations, the results can even be excelled.

Besides establishing a source of supply of pearl oysters to pearl culture operations, the hatchery technology has opened up new possibilities of improving the quality of pearl oyster and thereby the pearls through genetic selection and breeding. The Japanese pearl culture industry is paying utmost attention to the genetic improvement of the stocks, without which the production and value of cultured pearls is likely to suffer. The areas for genetic studies are to increase the shell growth, shell cavity size, and strains with potentiality for secreting nacre of desirable quality to improve lustre and colour. The breeding programme takes considerable time to establish strains of desirable characteristics, but this approach has become possible only through the hatchery technology.

The spin-off from this development has been the possibility of research in the microalgae which form the food of the larvae. The techniques of isolation of local species of microalgae and their mass culture in the hatchery facility have enabled several lines of investigations on these organisms.

Hatchery technology is multidisciplinary in nature and there are several aspects which need further directed research. These relate to broodstock management for continuous supply of quality mature oysters for the breeding programme ; genetic improvement as already stated ; water quality management ; nutritional needs of larvae at different stages ; larval physiology ; identification of diseases and control measures ; improvement in larval survival ; synchronisation of growth and metamorphosis ; spat setting requirements ; spat nutrition and juvenile rearing.

Economics of hatchcery production of seed have to be duly considered in terms of fixed assets and working capital requirements. Given the fixed assets, the break-even point of production can be minimised and profitability enlarged only through achieving scheduled production rates, high survival, fast growth, early spat setting and high amount of success in juvenile rearing. These aspects need careful consideration and would decide the future of shellfish hatchery programme in India.

REFERENCES

ALAGARSWAMI, K. 1980. Review on controlled breeding of bivalves of aquaculture importance. *Proc. of First Symp. Invert. Reproduction* : 194-202.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM AND A. C. C. VICTOR. 1983a. On controlled spawning of Indian pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Pt. 2 : 590-597.

ALAGARSWAMI, K, S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM AND A. C. C. VICTOR. 1983b. Embryonic and early development of pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India Pt. 2 : 598-603.

ALAGARSWAMI, K, S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983c. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301.

APPUKUTTAN, K. K., T. PRABHAKARAN NAIR AND K. T. THOMAS. 1984. Larval rearing and spat settlement of brown mussel *Perna indica* in the laboratory. *Mar. Fish. Infor. Serv. T & E Ser.*, No. 55 : 12-13.

IMAI, T. 1977. *Aquaculture in Shallow Seas : Progress in Shallow Sea Culture*. Oxford & IBH publishing Co., New Delhi, pp. 614.

LOOSANOFF, V. L. AND H. C. DAVIS. 1963. Rearing of bivalve molluscs. *Adv. mar. Biol.*, 1 : 1-136.

NAYAR, K. N., M. E. RAJAPANDIAN, A. D. GANDHI AND C. P. GOPINATHAN. 1984. Larval rearing and production of spat of the oyster *Crassostrea madrasensis* (Preston) in an experimental hatchery. *Indian J. Fish.*, 31 (2) : 233-243.

RANGARAJAN, K. 1983. Proven technology. Technology of open sea mussel culture. *Mar. Fish. Infor. Serv. T & E Ser.*, No. 49 : 23-24.

WALNE, P. R. 1964. The culture of marine bivalve larvae. In : *Physiology of Mollusca*. Vol. I (K. M. Wilbur and C. M. Yonge, Eds), Academic Press, New York ; 197-210.

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PEARL OYSTER FARMING

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INTRODUCTION

The pearl oysters are reared for production of cultured pearls. They grow and reproduce in the farm. The nucleus implanted oysters grow in the farm and secrete the mother of pearl around the nucleus. The selection of a farm site is of paramount importance. The selection should be based on an appraisal of the life history and habits of the pearl oysters and the ambience of the environmental parameters. It should provide congenial conditions in the form of protection, sufficient tide/current flows, clarity, optimum salinity, temperature and adequate amounts of phytoplankton. The farm area should be free from any form of pollution.

SOURCE OF OYSTERS

The source of oysters for pearl culture is either the natural populations in the pearl oyster beds and/ or from the hatchery. Spat collection in the sea is done to augment the supply. Several pearl banks are distributed off Tuticorin, Gulf of Mannar at a distance of 12-15 km at depths of 12-25 m. Pearl oysters are collected by skin diving or using SCUBA from the oyster beds. Wide fluctuations in the production of pearl oysters in different pearl banks have been noted during the last few centuries, as also during the recent years. If and when the production in the natural beds is good, the oysters can be collected and used in pearl culture. In the Gulf of Kutch, the pearl oyster population is sparse. They are found on the 'khaddas' in the intertidal flats. Collection is effected by hand picking.

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The recent achievement in the controlled production of pearl oyster seed by hatchery method (Alagarswami *et al.*, 1983) has opened up a new chapter in pearl oyster production in India. Millions of pearl oyster seed are produced in the hatchery and reared in the farm to adult size and are used in the production of pearls. Dependence on the natural populations for culture has largely been dispensed with. Production of pearl oyster in hatchery is more dependable and the required quantities can be produced and supplied for pearl culture.

Spat collection in Japan is done by sinking cedar sprigs in bundles near the water surface in peak spawning season. Hyzex films and old fish nets are also immersed to get spat settlement. The spat settled on the materials are allowed to grow to a size of 2 cm and separated and reared in cages. Almost the entire requirement of pearl oyster supply to the culture industry is met from this type of spat collection in Japan. The attempts in spat collection in India has not been successful. This may be due to the occurrence of pearl oyster beds in the open sea. In the inshore region, particularly the recently constructed harbour basins of Tuticorin and Vizhinjam, some spatfall occurs but the species composition of pearl oyster includes predominantly those which are not useful in production of pearls.

METHOD OF REARING

Raft culture

This method is found to be the most suitable and appropriate one to farm the oysters in the sheltered bays. Wooden poles lashed with coir ropes and floated with the help of 4 buoys and moored by 2 anchors served well as a raft. Wooden barrels, empty oil drums coated with fibreglass, mild steel barrels and FRP/form floation buoys are some of the materials used in achieving buoyancy of the rafts. The dimensions of the raft can be altered according to the sea conditions and convenience of handling. A raft of the size 6 m × 5 m is found to be a suitable one. Rafts are also fabricated with sized timber. The holding capacity of a standard raft of 6 m × 5 m is 100 cages, Due to rough sea conditions, independent mooring of rafts is preferred to the serial type where several rafts which are interconnected as commonly practised in Japan.

Collapsible raft

A collapsible raft with 16 empty oil barrels, arranged in 4 rows and connected with one another by chain was assembled. Four anchors were used at four corners so as to stretch the structure in all directions. From the interconnections, the pearl oyster cages were suspended. During rough weather, the pearl oyster cages came together due to wave action, rubbing against one another and also on the bottom. Hence, some damage to the boxes and oysters was noticed in this system of culture.

On-bottom culture

In the Tuticorin Harbour basin where the breakwater was constructed with granite stones, the slope of the breakwater has been made use of to culture the pearl oyster by keeping them along it below the low water mark. In an area of 100 × 3 m, about 300 oyster cages are kept. Due to constant splashing of water along the slopes, settlement of fouling organisms, especially barnacles, is virtually nil. However, the growth of oysters themselves is less compared to the oysters grown from the raft.

CULTURE CONTAINERS

Juvenile rearing

Juveniles are reared in net-cages. It is a frame, made of 6 mm steel rod with 35 cm sides, in the form of a prism. All sides are encased with retrievable synthetic fabric of velon screen. The mesh size of the velon screen depends on the size of the spat reared. The velon screen bag can be opened or closed as and when required by tying the open sides with nylon twine. This velon screen bag with the steel frame inside, is again inserted into an old nylon fishnet bag having meshes around 10 mm knot to knot. This can also be easily removed when required. The idea of providing this additional protection is to ensure that the velon screen covering is not damaged by predatory crabs and fishes. The flow of water is not affected by this arrangement. The fouling intensity is also restricted by the fine nylon meshes. The clogging of the mesh by silt and fouling organisms can be cleared by periodical replacement of the velon screen bag. Suspension of these net-cages from the raft is effected with synthetic ropes. Spat of the size upto 20 mm are reared in these net-cages.

Ordinary box-cages of the size 40 cm × 40 cm × 10 cm, which are used for oyster rearing, are also used for spat rearing, by providing an additional velon screen cover inside the cage.

Plastic baskets with numerous small perforations which are available in the market, are used for rearing spat of 10-20 mm. The bottom of the basket is perforated to prevent accumulation of silt inside the basket.

Oyster rearing

Box-cages of the size 40 cm × 40 cm × 10 cm with a lid and meshed with 2 mm synthetic twine are used to rear adult oysters. The size of mesh varies with the size of oysters to be reared. These are good for general culture of mother oysters.

Frame nets are useful to follow up the history and performance of individual oysters. Generally these nets are used for keeping the oysters under experimentation. Two frames, 60 cm × 40 cm with 5 compartments, meshed, and hinged at one end, open as a book. The arranged oysters are held in the compartments when closed. The space in between the two frames is about 10 mm and is sufficient for the oyster to open the shells while feeding.

SITE OF CULTURE

A sheltered bay with protection from the wind and wave action offers an ideal site for farming the pearl oysters. It gives protection not only to rafts but also to oysters from rubbing with one another resulting in damage to the growth. The pearl oysters open their valves for feeding only when water is calm and undisturbed. The farm site should be selected along the coastline where such conditions prevail in most part of the year. The bottom should be rocky or hard substratum. The depth of water should be more than 5 m. River mouth should be avoided because of the prolonged less saline conditions during floods. Places where frequent blooms of noxious plankters occur should be avoided. A mild current, which brings in food and removes faeces and detritus from the farm site, enhances the growing conditions in a farm site.

Stock size

The density of the pearl oysters in the culture grounds should be kept at optimum level. Overcrowded culture conditions can have such adverse effects as retardation of growth, poor quality of pearls, slow formation of the pearl layer and spread of diseases or parasites causing heavy damage to the pearl oysters. A stock size of 70-100 oysters has been recommended for one square metre in 5-10 m depth in the Japanese waters (Matsui, 1958). In the Gulf of Mannar a raft of the size 6 m X 5 m takes a load of about 100 standard cages. The number of oysters to be reared in each cage is decided by the size of oysters. 125 oysters in the size group 35-45 mm, 100 oysters in the size group 45-55 mm and 75 oysters in the size group 55-60 mm can safely be reared without much deleterious effect on them. The oyster load per unit surface area is dependent on the depth of the farm and various other factors such as physical conditions and primary production of the area and needs to be worked out for each site.

Survival rate

By adopting appropriate management techniques, the survival rate of pearl oysters in the farm can be enhanced.

The stock size of oysters and the mortality in the inshore farm at Veppalodai and the protected farm at the Tuticorin Harbour is given in Table 1.

TABLE 1. *Pearl oyster stock and percentages of mortality in the farm at Veppalodai and Tuticorin Harbour during the year* 1976-77 *to* 1982-83.

Year	Veppalodai farm		Tuticorin Harbour farm	
	Stock size	%Mortality	Stock size	%mortality
1976-77 ..	4,910	2.0	—	—
1977-78 ..	7,085	5.2	3,448	4.4
1978-79 ..	10,276	26.8	21,869	10.4
1979-80 ..	4,618	13.8	18,187	9.7
1980-81 ..	3,230	ND	ND	ND
1981-82 ..	—	—	54,558	31.6
1982-83 ..	—	—	55,891	58.8

ND : No data.

NOTE : The above stock was built from the collection from natural pearl oyster beds and the spat produced in the hatchery was not included.

The highest mortality in the Tuticorin Harbour farm during 1982-83 was due to the predation caused by the gastropod, *Cymatium cingulatum*. This predator got introduced in the farm accidentally along with the young oysters collected from natural beds (Chellam *et al.*, 1983). Periodical maintenance of the oysters and culture containers and removal of fouling and predatory organisms from the pearl oyster cages and oyster help in minimising the mortality. Mortality upto 26.8% was noticed in the farm at Veppalodai, due to deteriorating sea conditions in the site caused by the introduction of shrimp trawling activities. This led to the closure of the experimental farming in that area subsequently.

Farm maintenance

On testing rafts of different types and dimensions, the unit raft system with 4 floats with the dimensions of 6 m X 5m was found to be the most suitable one for this area. Mild steel barrels made of 14 gauge thick sheet, 3 feet long and 2 feet diameter with two pairs of clamps welded to it, was found to be long lasting with maintenance. Lashing the wooden poles with coir ropes was found to be convenient in raft making. Lacaloid black, high build black and coal tar were used for anticorrosive coatings. Periodical painting of the wooden structure, scrapping and painting the floats and replacement of the coir ropes, will enhance the life of the rafts. The FRP/foam floatation buoys, though expensive, perform very well with much longer life than any other tested so far.

A lot of undesirable organisms settle on the pearl oyster during farming. Since these have a direct bearing on the formation of low quality pearls, retarded growth and mortality in oysters, they are removed periodically depending on their intensity and seasons of settlement. They are removed manually. Care is taken not to damage the shell margins. The culture containers are brushed well to remove silt and other outgrowths.

Monitoring of growth and reproduction

Close observations on the growth of oysters of the farm gives an indication of the suitability of the site for pearl farming and pearl production. Culturing density in the rafts and culture grounds are kept at a suitable level. Overcrowding affects the growth as well as the quality of pearls. The season of spawning is monitored to make use the spent oysters for nucleus implantation and to spread spat collectors around the area.

Control of boring and fouling organisms

Under farming conditions majority of the boring organisms of the pearl oysters were polychaetes and sponges. Immersion in freshwater for 6-10 hours

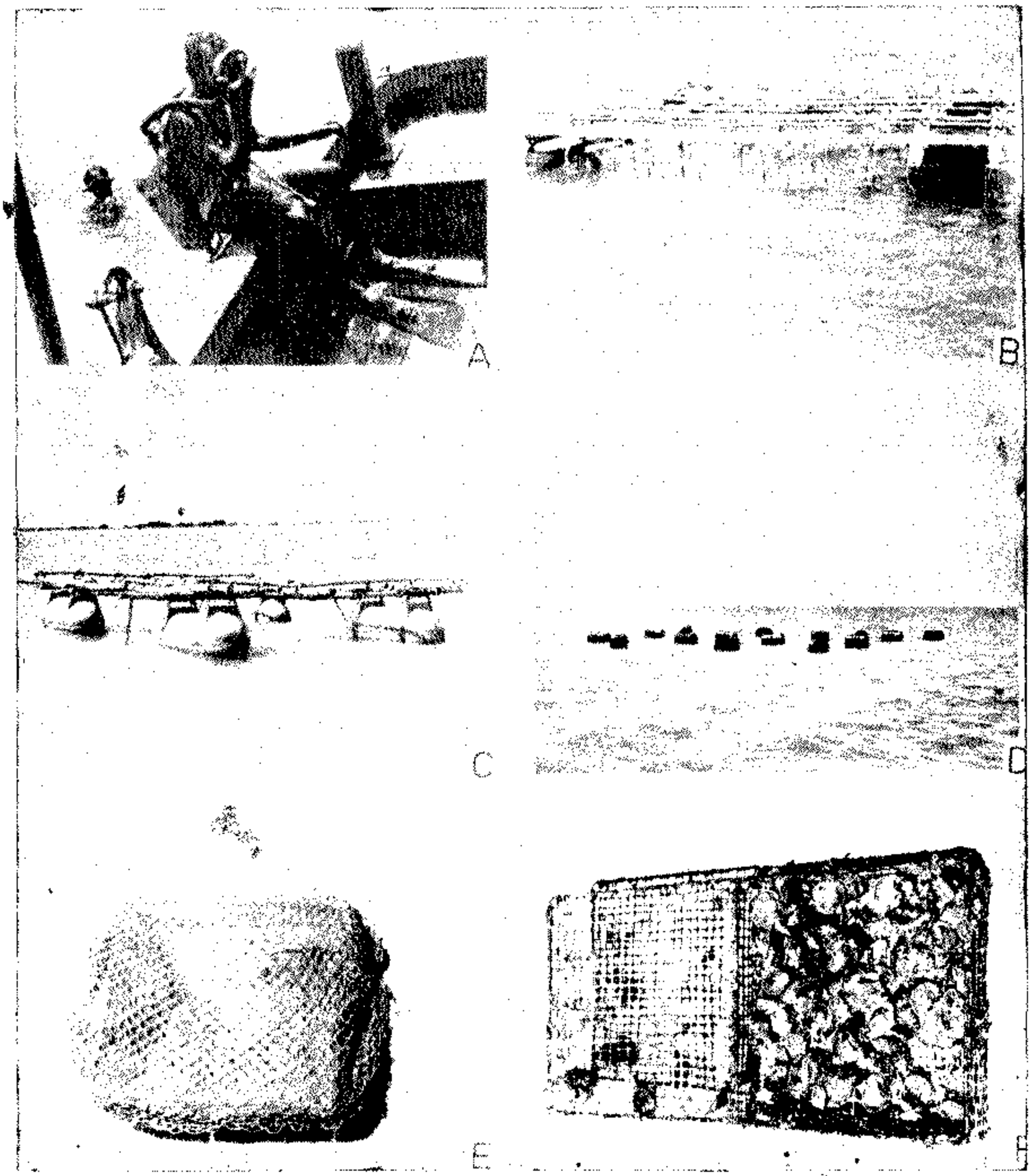

PLATE 1. A. Diving for pearl oysters using SCUBA ; B. Mother oyster culture raft, MS barrels as floats ; C. FRP/Foam floatation buoys ; D. Collapsible raft ; E. Net cage for juvenile rearing ; F. Box cage for oyster rearing.

eradicated the boring polychaetes. About 80% of the boring sponges were killed by immersing the infected oysters in 0.1% formalin for 60 seconds (Velayudhan 1983). The barnacle, *Balanus amphitrite* variety has been the main fouling organism in the farm throughout the year. Apart from the main fouling organisms, seasonal and temporary fouling organisms can also cause mortality to farm oysters. As high as 37.2% mortality was noted in the farm oysters at Veppalodai in June, 1974 when the oysters were not looked after for a continuous period of 120-150 days (Alagarswami and Chellam, 1976). The amphipods and polychaetes were controlled by immersing in freshwater for 3-4 hours. Subsequent immersion in 0.1% formalin had killed 50% of the barnacles and eradicated all the other fouling organisms (Velayudhan, 1983). Exposure of the oysters and culture containers to the air for 2-3 hours had killed the fresh settled larvae and juveniles of the fouling organisms. Suspension of the culture containers at 5 m depth and modification of the culture routine were some of the measures recommended to avoid to some extent, the potential damage by fouling organisms. Some snails in the family Cypraeidae and Lamellariidae and some crabs are found feeding on the compound ascidian in Japanese waters (Arakawa, 1980). The puffer fish (*Tetradon* sp.) is found to crush the barnacle growth and *Siganus* sp. to nibble on the algal growth on the culture cages in the Tuticorin Harbour farm.

The pesticides, DDT (1%) and BHC are found effective in controlling fouling organisms particularly barnacles (Arakawa, 1980). Compounds of chlorine, copper sulphate, ferric chloride, pentachlorophenyl—NaCl, mercury, arsenate, blueing agents, naphthalene, alkaloids and other poisonous chemicals used as antifouling agents in oyster culture could pose health problems (Arakawa, 1980).

Environmental Parameters

Primary productivity

The growth of pearl oyster and the size and colour of the pearl is strongly affected by the water temperature, physiological state of the pearl oyster and the condition of culture grounds. The latter seems to depend principally on the difference in chemical constituents of the seawater as well as on the kind and amount of plankton in the seawater. The chief source of conchiolin is probably found to be the nitrogen substance of the plankton (Matsui, 1958). Suzuki (1957) while working on the relationship occurring between the growth of pearl oyster and its environmental factors has found a seasonal relationship between the contents of carbohydrate, crude fat and crude protein in meat and those of plankton. The aminoacid composition in the pearl oyster and in the plankton by paper chromatography revealed the presence of 13 aminoacids in the meat and 12 in the plankton suggesting that the plankton is the main source of aminoacids and proteins of the pearl oysters. But the blooms of *Trichodesmium thiebautii* had caused mortality to the oysters when the bloom-rich seawater was used in experimenta tanks at Veppalodai(Chellam and Alagarswami, 1978).

Temperature

Temperature plays an important role in the biological activities of pearl oysters in the temperate waters. The optimum temperature for the growth of oyster in Japan is found to be 20-25°C. Above 28°C, the pearl oysters show signs of exhaustion. Spawning is effected by heating the water temperature from 25-30°C (Mizumoto, 1979). The thickness of the layers of the pearl is affected by the minute changes of the water temperature during the day and varies considerably according to the seasons of the year. The deposition of calcium is stopped at water temperature of 13°C or lower and the oyster perishes at 6°C (Matsui, 1958). In the Gulf of Kutch, *Pinctada vulgaris* (Schumacher) grew vigorously in winter months when the temperature varied from 23°C to 27°C (Gokhale *et al.*, 1954). In the Gulf of Mannar, a slight decrease in temperature triggered spawning in the farm oysters and during higher temperature, gonad development was observed. Growth-temperature relationship is presumably valid only upto a maximum temperature for optimum growth.

Salinity

Pearl oysters seem to prefer high salinities but oysters raised in such water produced pearls with a golden tint (Alagarswami, 1970). However, the effect of salinity on the growth of pearl oyster is not clear. An unusual dilution of seawater to 15.69‰ at the Veppalodai farm in November, 1977 did not affect the oyster (Alagarswami and Victor, 1976). The pearl oysters tolerated a wide range of salinity from 24-50‰ for short duration of 2-3 days. The salinities 14‰ and 55‰ brought in 100% mortality in oysters.

Depth

For farming pearl oysters, the depth preferred is usually 15-20 m as the growth of oyster is good at such depths. The minimum depth required is more than 5 m which is favourable for formation of high quality pearls of pinkish colour though the rate of deposition of nacre is slow (Alagarswami, 1970).

Bottom

Gravelly bottom is suitable and sandy and muddy bottom are avoided (Alagarwsami, 1970). Matsui (1958) has found the growth of pearl oysters to be affected by the water temperature and nutritional condition of the ground. The conspicuous variation was on the width of the shell. The degree of convexity of the shells has practical advantages because more convex shells harbour larger pearls.

Repeated culture on the same ground often leads to deterioration of the quality of pearls produced. A very small amount of chemical substance dissolved in the seawater which affects the quality of the pearl is apparently related to the conditions of the bottom. The organic substance discharged from the pearl oysters and the fouling organisms are deposited on the sea bottom and affect its chemical and physical state. Removal of such deposited organic substances from the bottom of the grounds often increases the production (Matsui, 1958).

Oysters are equipped with food consumption cells which directly remove organic matter and calcium dissolved in water. This calcium passes through the mantle to be deposited on the surface of the shell or pearl in the process of formation. Presence of trace metals in small quantities influence the colour of the nacre (Shirai, 1970). When lime stone was placed in a culture cage, growth of the oyster was accelerated; 42 per cent of the pearls produced were of good quality whereas only 16% of those from the basket containing no lime stone were of such kind (Matsui, 1958).

Current

The farming area must be naturally sheltered against violent winds and waves. Tides and currents must be sufficient to change the water completely and frequently with oxygen and fresh plankton and carry away the excretory waste. Current velocities of 5 cm/sec and over hinder the edible oyster (*Crassostrea* sp.) in its filter feeding and therefore oysters can starve in the richest water when too strong currents prevail for too many hours a day (Korringa, 1970). If the water current is strong, the formation of pearl layer is fast but the quality of the pearl produced will be lower (Kafuku and Ikenoue, 1983).

Proximity to river flow

Rich nutrients are discharged by the rivers into the sea which help in high primary productivity of the waters. The organic matter and calcium dissolved in the water is directly removed by food consumption cells (Shirai, 1970). Hence, growth of oysters and a quick secretion of nacre is possible at these places. A prolonged dilution of the seawater due to heavy floods during monsoon may affect the growth of oyster if river mouths are selected as farm site.

Silt load

The silt load of the culture water affects the filtration efficiency of pearl oyster. A decline in the condition of oysters noted at the Veppalodai farm, was probably due to this cause besides other factors such as load of boring and fouling organisms, pests, diseases, food availability etc. (Alagarswami and Chellam, 1976).

REFERENCES

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Symp. Mollusca* Pt. III, Mar. Biol. Ass. India, 975-998.

ALAGARSWAMI, K. AND A. CHELLAM. 1976. On fouling and boring organisms and mortality of pearl oysters in the farm at Veppalodai, Gulf of Mannar. *Indian J. Fish.*, 24 (1 & 2): 1-14.

ALAGARSWAMI, K. AND A. C. C. VICTOR. 1976. Salinity tolerance and rate of filtration of the pearl oyster *Pinctada fucata* (Gould). *J. mar. biol. Ass. India*, 18 (1): 149-158.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34: 287-301.

ARAKAWA, K. Y. 1980. Prevention and removal of fouling on cultured oyster. A handbook for growers. Marine Sea Grant Technical Report 56: 38 pp.

CHELLAM, A. AND K. ALAGARSWAMI. 1978. Blooms of *Trichodesmium thiebautii* and their effect on experimental pearl culture at Veppalodai. *Indian J. Fish.*, 25 (1 & 2): 237-239.

CHELLAM, A., T. S. VELAYUDHAN, S. DHARMARAJ, A. C. C. VICTOR AND A. D. GANDHI. 1983. A note on the predation of pearl oyster, *Pinctada fucata* (Gould) by some gastropods. *Indian J. Fish.*, 30 (2): 337-339.

GOKHALE, S. V., C. R. EASWARAN AND R. NARASIMHAN. 1954. Growth rate of the pearl oyster (*Pinctada pinctada*) in the Gulf of Kutch with a note of the pearl fishery of 1953. *J. Bombay nat. Hist. Soc.*, 52 (1): 124-136.

KAFUKU, T. AND H. IKENOUE (Eds.) 1983. Modern methods of Aquaculture in Japan. Pearl Culture: 161-171. Kodamsha Ltd. Tokyo and Elsevier Scientific Publishing Company, Amsterdam—Oxford—New York.

KORRINGA, p. 1970. The basic principles of shellfish farming on the continental coast of Europe. *Symp. Mollusca*, Pt. III: 818-823. Mar. Biol. Ass. India.

MATSUI, Y. 1958. Aspects of the environment of pearl culture grounds and the problems of hybridization in the Genus *Pinctada*. In: *Prospects of Marine Biology*. Buzzati—Traverso (Eds.): 519-531. Univ. of Cali. Press, Berkeley and Los Angeles.

MIZUMOTO, S. 1979. Pearl farming in Japan. In: *Advances in Aquaculture*. TVR. Pillai and Wm. A. Dill (Eds): 431-435. Fishing News Books Ltd., Farnham, Surrey.

SHIRAI, S. 1970. *The story of pearls*. Japan Publication Inc. Tokyo, 127 pp.

SUZUKI, K. 1957. Biochemical studies on the pearl oyster (*Pinctada martensii*) and its growing environments. 1. Seasonal changes in the chemical components of the pearl oyster-plankton and marine mud (with English summary). *Bull. Natl. Pearl Res. Lab.*, **2**: 57-62.

VELAYUDHAN, T. S. 1983. On the occurrence of shell boring polychaetes and sponges on the pearl oyster *Pinctada fucata* and control of boring organisms. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Pt. **2**: 614-618.

11

ECOLOGY OF PEARL CULTURE GROUNDS

A. C. C. VICTOR[1] AND T. S. VELAYUDHAN[1]

INTRODUCTION

The growth of pearl oysters either in the natural beds or in the culture farms is strongly influenced by the oceanographical conditions of the ground, the chemical substances present in the sea water, particularly some of the salt and trace elements, the quality of the plankton taken by the oysters, hydrogen-ion concentration etc. The kind and quantity of the minute amount of the chemical substances and metal ions might affect the quality of the cultured pearls (Matsui, 1958). He also pointed out that the difference in the water temperature and nutritional conditions of the grounds strongly affect the growth of the oysters, especially a conspicuous variation occurs in the thickness of the shell which in turn influence the lustre, colour, shape, degree of scratches and size and weight. Besides growth, the propagation of the oysters depend greatly on the quality of the water and the currents prevailing from time to time. Alagarswami (1970) has drawn attention to the necessity of hanging pearl oyster nets and cages at such depths where optimum temperature conditions prevail and also the importance of altering the depths of nets and cages when the hydrological conditions change according to the seasons of the year. A good current is also found to be necessary not only as a source of oxygen but also to bring in planktonic organisms on which the pearl oysters feed.

PHYSIOGRAPHY OF INDIAN COAST

The configuration of Indian coasts is of a straight stretch of exposed sandy beaches without any sheltered bays and rocky coves except the shore line from Bombay upto Karwar and that of Andaman and Nicobar Islands where the coast line is irregular and crenulate (Easterson and Mahadevan, 1980). The major interruptions are the numerous rivers and rivulets which open into the Arabian sea and the Bay of Bengal. These rivers discharge into the sea every year immense volumes of water which bring along large quantities of organic and inorganic substances. The shore line between Mandapam and Kanyakumari is mainly sandy but here and there the coast is indented and rocky with some cliffs.

In Japan pearl culture farms are located in enclosed bays which have connections with open sea. Areas with minimal tidal effect are preferred for establishing pearl culture farms. In places where bays are absent, farming is done in open sea, such as the Seto Inland Sea. Areas bordered by chains of Islands are desired (Alagarswami, 1970).

TOPOGRAPHY

The pearl oyster *Pinctada fucata* lives attached to rocks or any other hard substratum with the byssus threads on the bottom of the sea. In the Gulf of Mannar it inhabits depths from 10—20 m. The same species occupies the intertidal habitat in the Gulf of Kutch. Thus the species can adapt itself to varying depth conditions within the above range. *P. margaritifera* occurs in the intertidal flats of the Andaman and Nicobar Islands. In the Gulf of Mannar farming of pearl oyster is being done at Veppalodai and at Tuticorin Harbour basin. At Veppalodai the farm was in the open sea located 1.5 km away from the shore where the depth of the water is 4.5 m. It is bounded on the east by two small Islands and on the west by the mainland coast. These two islands give some protection

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to the farm from winds and waves. In spite of the presence of the two islands, the farm is exposed to prevailing winds and some swells and therefore the area is subjected to vigorous wave action. The farm at Tuticorin Harbour is located within the two arms of the breakwater and hence is protected from winds and swells. The depth ranges between 5.75 and 6.5 m. It is well known that the benthic ecology of the pearl oyster grounds play a vital role in the rate of production as well as the quality of pearls. Rocky and gravelly bottom is more suitable. Matsui (1958) is of opinion that culturing pearl oysters in the same ground often causes serious decline in the rate of production as well as in the quality of pearls. The fouling organisms which settle on the oysters and culture materials discharge enormous quantity of organic matter which get deposited on the sea bottom. The sea bottom of Veppalodai farm is hard and devoid of mud but with a thin layer of shells and coral fragments. In the Tuticorin Harbour the sea bottom is predominantly muddy and devoid of weeds and sandy patches. The accumulation of mud on the bottom of Harbour enclosure is mainly due to the blasting of rocks at the Harbour entrance.

WIND

Climatically, Tuticorin has four distinct periods in the year. November to February is the characteristic north-east monsoon season, with the mean monthly surface wind velocity of 22.45 km per hour. There is heavy rainfall especially in November. The annual rainfall in the Tuticorin Harbour basin varies from 345 mm to 863 mm and the maximum precipitation occurs during November (221 mm) and December (108 mm). With the onset of winter, local heat and moisture give rise to tropical cyclones, most of which originate near Andaman Islands and move in westerly or north westerly direction towards the east coast of India. The rains lash along with wind the Circar and Coromandal coasts and the southern districts during October to December (Easterson and Mahadevan, 1980). March to May is the period of premonsoon or summer and the prevalent wind is south east, south south west and west with its mean velocity ranging between 19.96 and 25.91 km per hour. Next comes the south west monsoon period from June to the beginning of September. The west coast of India receives heavy rainfall. But, for the Gulf of Mannar coast the period June-August is the period of least or no rainfall. The direction of the prevalent wind is towards west and its mean velocity is increased to 29.52 km per hour. September and October constitute a transitional period with a fairly dry weather with occasional rains in October. In October the wind velocity is decreased to 20.61 km per hour. A maximum speed of 104 km per hour was recorded during June 1975 and a minimum of 10 km per hour during March and October 1979.

WAVES

In the Veppalodai and Harbour basin, the predominant wave generating wind is north east monsoon, in directions of north north east, north east, east north east and east. The size of the wave is due to the velocity and the distance travelled (fetch) by the wave generating wind. The north east monsoon is powerful on the coast of Tuticorin and the water becomes clear from mid October to mid April. During this period survey of pearl oyster beds is possible by direct under water observations by SCUBA. At the entrance of the Harbour basin a maximum of 1.78 m wave height was recorded during the years 1974-1980 and the monthly mean wave height ranges from 0.10 to 1.10 m. Inside the Harbour basin, where the pearl culture rafts are moored, the wave height ranges upto 0.90 m. At the entrance of the Harbour basin, the duration between the successive waves is 2.90-5.41 seconds whereas inside the Harbour basin and at the farm site it is between 9 and 11 seconds.

CURRENTS

A good current is necessary not only as a source of oxygen but also to bring in the planktonic organisms on which the pearl oysters feed. The current also helps in removing the deposited silt on the oysters as it flows through the farm. The water current to a larger extent influences the propagation and dispersal of pearl oyster.

The current system in this area is generated by the south-west and north-east monsoons and is of low velocity. At the entrance of Tuticorin Harbour basin the current velocity ranged from 0.047 knots (March 1980) to 1.15 knots (December 1979). The current velocity is high during the period of north-east monsoon, the velocity being 0.65, 0.69, 0.48 and 0.50 knots during November, December, January and February respectively.

TIDES

Next to waves and currents, tides are the most striking movements of sea water. The vertical movements of sea water can be transformed into tidal currents of high speed in narrow inlets, river mouths, small bays or entrances to inland seas. The tides are semidiurnal in east coast of India. The strength of the tide both at Veppalodai and Tuticorin Harbour is extremely weak. The tidal amplitude is 0.16 m at neap tide and 0.70 m at spring tide.

Turbidity

In order to measure the rate of siltation, plankton bottles of 270 ml volume with a mouth diameter of 2.54 cm are attached to nylon twins and suspended from the raft to a depth of 2 metres for a period of six days. In the laboratory the sediment was allowed to settle in a measuring cylinder and the volume measured. The rate of silt deposition at Veppalodai varies between 0.87 ml day and (March 1976) to 3.13 ml day and (December 1975). Visual observations were made to measure the transparency of water using a sechhi disc. At Veppalodai the transparency of water was very poor during most part of the year. At a depth of 2.00-2.75 m in the farm, the light penetration was confined to 1.5 m. At Tuticorin Harbour farm the light penetration was confined to 1.00-4.5 m at a depth of 5.75-6.50 m. The south-West and north-east monsoons are active in the south-east coast of India resulting in large quantities of suspended matter in the water. This accounted for high turbidity at both the farms.

Temperature

Temperature plays a vital role in the reproductive activities of marine benthic molluscs of inshore waters. The oceanographical data collected during the period 1980 to 1985 show that the monthly mean atmospheric temperature exhibits, a clear double oscillation with a single peak in July (31.5°C for 1980) and a depression in December-January (25.9°C for 1982-83). April and May are the months of high atmospheric temperature, the highest individual value being in May 1983 (33.5°C). The monsoon months are colder, the lowest individual value being in January 1982 (23.8°C). At Veppalodai the annual temperature fluctuation in the surface sea water is from 25.5°C in winter (December 1974) to 32.1;C in summer (May 1978). At the Harbour basin farm the monthly mean surface temperature fluctuates between 25.2°C (December 1984) and 31.6°C (May 1982). Similarly the bottom temperature ranges between 25.2°C (December 1984) and 31.6°C (April 1985) (Fig. 1). The lowest individual surface temperature recorded during the present study was 24.3°C for January 1978 and the highest was 32.5°C in May 1978. The surface and bottom water temperatures have three distinct periods in the year. The first, extending from January to April is the period of temperature rise in which the surface temperature is invariably low in January, increases steadily and reaches the maximum in April-May. The gradual increase in the surface temperature is due to the reversal in the direction of currents (Ganapathy and Murthy, 1955) which brings highly saline water from the equitorial region. The second, extending from June to October is the period of temperature fluctuations in which the temperature begins to fall in June until the minimum is reached in July-August which coincides with the period of south-west monsoon. The third extending from November to December is the period of temperature decrease in which the temperature begins to fall in November until the minimum is reached in December. The steep fall in the surface temperature was primarily due to the onset of the rain bearing north-east monsoon and the influx of freshets into the sea from the numerous rivers and rivulets. In all these years, the coincidence between atmospheric temperature and surface temperature is not continuous, although the air temperature was higher than the surface temperature. The air and sea temperature appear to be correlated with rainfall. The air temperature is as low as that of surface temperature during peak rainfall period. During non-rainy or least rainy periods in June-August the air temperature is higher than that of the sea temperature.

Salinity

The pearl oysters are stenohaline and prefer high salinities and when reared in such waters produce pearls with golden tint. The monthly mean salinity in the Harbour farm varies from 30.5‰ (December, 1983) to 35.75‰ (September 1983). The highest individual salinity value of 36.68‰ was recorded in September 1983 and the lowest value of 26.27‰ was recorded in December, 1983. The salinity shows a single peak in July-August preceded by a gradual rise from January and followed by a gradual decline to December. High saline conditions prevail over a period of six months from May to October and low saline from November to April. The period of high values and low values coincide with south-west and north-east monsoons respectively. The salinity is lowest during January-February which is the result of rainfall in October-November (Fig. 1).

Dissolved oxygen

The surface waters of Tuticorin coast are rich in dissolved oxygen throughout the year. Jayaraman (1954) opined that high oxygen values for surface

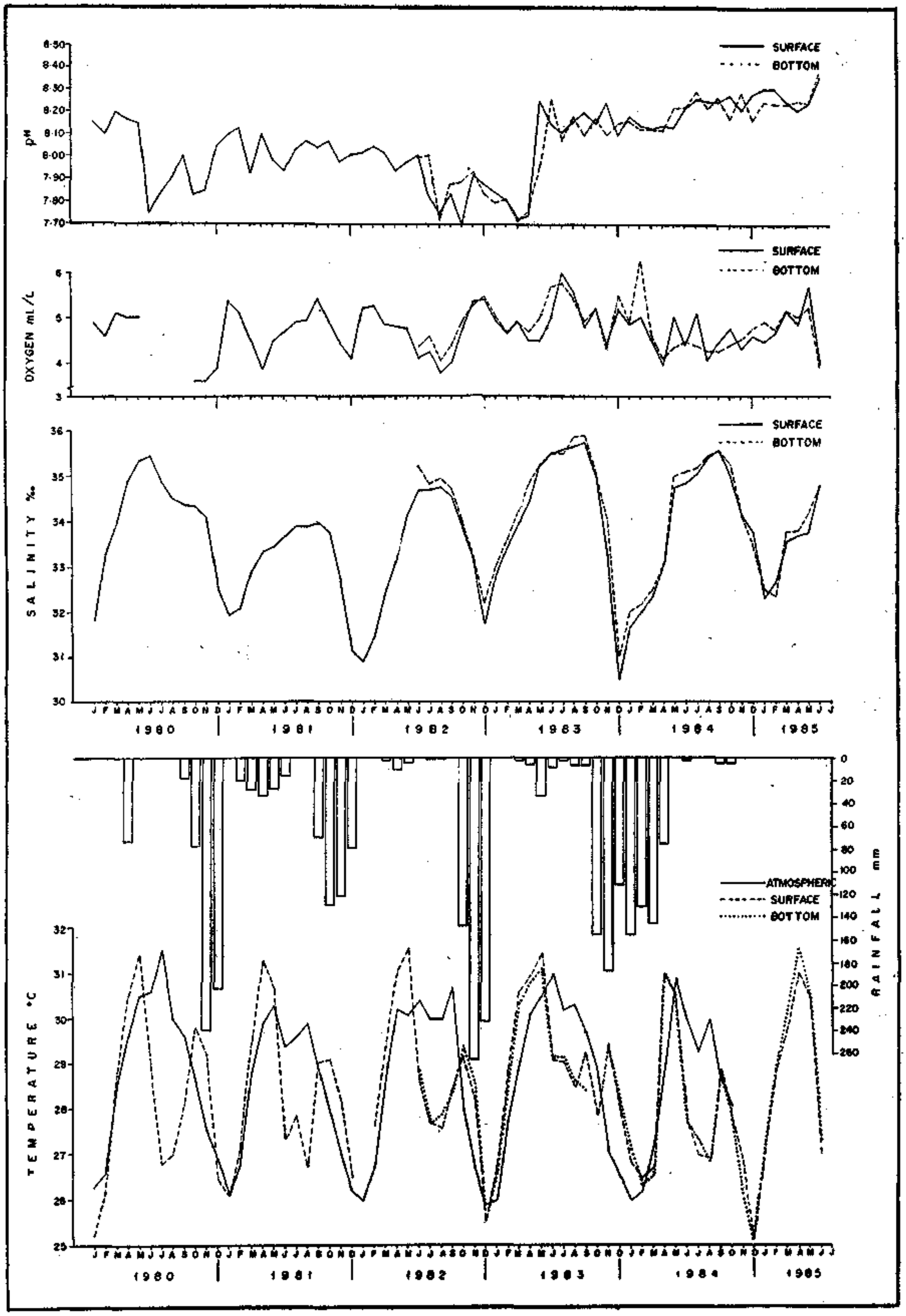

Fig. 1. Monthly variations in the mean values of temperature, rainfall, salinity, dissolved oxygen, pH at Tuticorin Harbour basin from January 1980 to July 1985.

waters could indicate increased photo-synthetic activity. The monthly mean dissolved oxygen at Veppalodai ranges from 4.4 ml/l (November 1978) to 6.4 ml/l (August 1978). The monthly mean dissolved oxygen in the surface waters of Tuticorin Harbour farm varies from 3.2 ml/l (November 1980) to a maximum of 6.0 ml/l in July 1983, while the bottom water dissolved oxygen content fluctuates between 4.0 ml/l (August 1982) and 6.5 ml/l (February 1984). There is no perceptible seasonal variation in the dissolved oxygen (Fig. 1).

pH

The monthly mean pH values at the Veppalodai farm varies from 7.96 (February 1974) to 8.42 (November 1974). In the Harbour farm the monthly mean surface water pH and bottom water pH ranges were 7.7 (October 1982) to 8.30 (January 1985) and 7.73 (August 1983) to 8.30 (July 1984) respectively (Fig. 1).

Phosphate

The inorganic phosphate of Tuticorin waters does not show any perceptible seasonal variation. The monthly mean surface water inorganic phosphate fluctuates between 0.16μg at P/l (October 1980) and 1.66 μg at P/l (August 1984) while in the bottom waters it varies from 0.11 μg at P/l (May, 1983) to 2.06μg at P/l (December 1983) (Fig. 2).

Silicate

The silicate content in the Tuticorin waters exhibit wide fluctuations. The monthly mean silicate values from surface waters ranges from 0.001 μg at Si/l (January 1983) to 9.872 μg at Si/l (June 1984). Similarly in the bottom water the silicate values fluctuates between 0.001 μg at Si/l (January 1983) and 10.975 μg at Si/l (April 1982) (Table 1).

Calcium

The monthly mean calcium content varies between 0.316 g/l to 0.454 g/l. The individual lowest value is 0.311 g/l in January 1982 and the highest 0.466 g/l in January 1985. The monthly average in the bottom

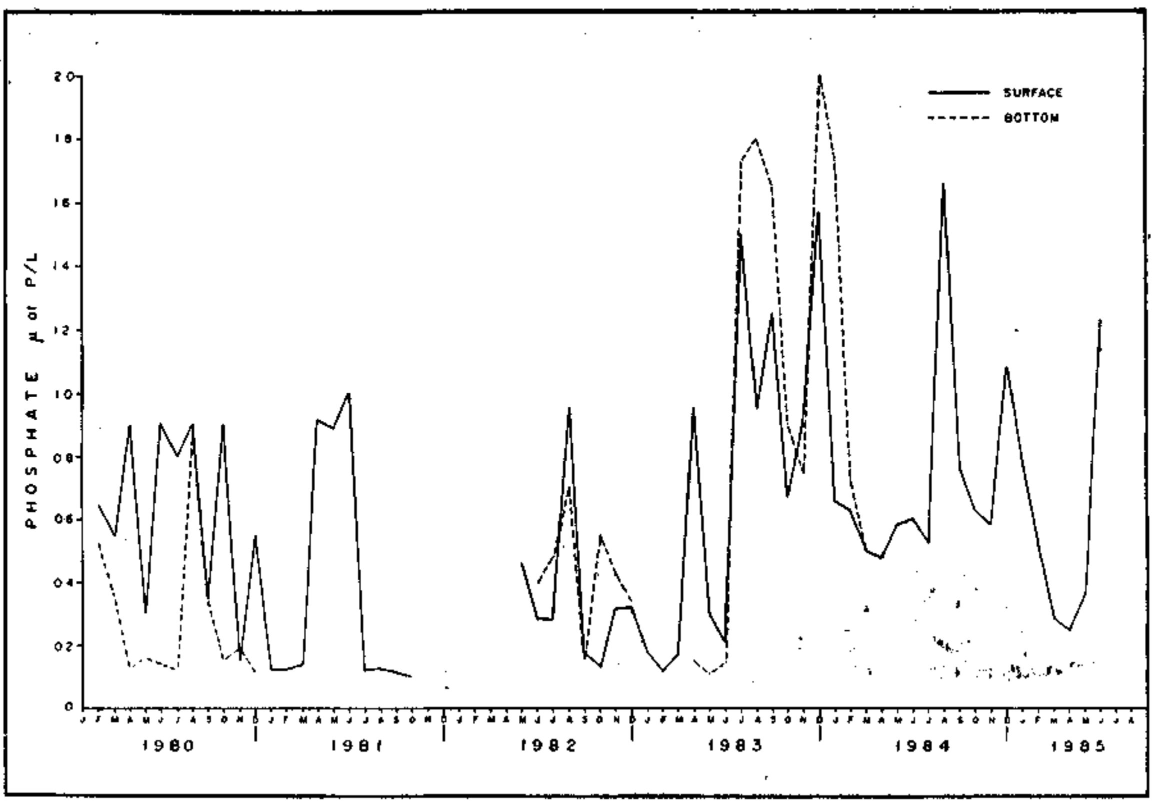

Fig. 2. Monthy variations in the mean values of phosphate at Tuticorin Harbour basin from January 1980 to July 1985.

water indicate a maximum of 0.447 g/l in August 1982 and a minimum of 0.350 g/l in June 1984 (Fig. 3).

Magnesium

The monthly mean magnesium values for the surface water of Tuticorin Harbour varies from 1.229 g/l (December 1982) to 1.406 g/l (June 1980), while the bottom water varies between 1.229 g/l (September 1983) and 1.445 g/l (June 1980) (Fig. 3).

in the surface waters. In the case of bottom waters he values vary from 0.067 g/m^3 (March 1984) to 6.592t g/m^3 (June 1983) (Table 1).

Primary Production

The mean monthly values of gross production at Veppalodai farm vary between 196 mgC/m^3/12 hours day (March 1978) and 377 mgC/m^3/12 hours day (September 1978). There are two peaks of production,

TABLE 1. *Monthly mean values of gross productivity, chlorophyll and silicate at Tuticorin Harbour farm for the period January* 1983 *to September* 1985

Month		Gross productivity mg/Cm^3/day		Chlorophyll (a) g/m^3		Silicate µg at-Si/l	
		Surface	Bottom	Surface	Bottom	Surface	Bottom
Jan 1983	..					0.001	0.001
Feb	..					0.001	0.001
Mar	..					0.001	0.001
Apr	..			1.068		0.073	0.165
May	..			0.935	1.341	0.189	0.295
Jun	..			5.140	6.592	7.200	0.098
Jul	..			0.935	0.948	0.102	0.034
Aug	..			1.600	0.534	0.038	0.032
Sep	..			1.202	1.335	0.029	0.030
Oct	..			1.869	0.668	1.000	1.008
Nov	..			6.140	2.003	5.833	5.649
Dec	..			1.469	2.136	5.583	9.895
Jan 1984	..	1029	772	6.942	2.759	7.508	9.895
Feb	..	2240	2153	1.739	0.267	3.276	3.740
Mar	..	257	103	1.335	0.067	6.143	6.552
Apr	..	—	—	0.801	0.623	1.151	1.638
May	..	876	—	0.701	0.173	1.549	1.646
Jun	..	382	283	0.801	0.468	9.872	8.875
Jul	..	1167	176	2.136	1.335	3.057	6.170
Aug	..	652	1869	3.115	0.801	5.460	4.313
Sep	..	1244	517	0.623	0.712	2.948	1.420
Oct	..	558	—	2.670	0.801	2.851	7.340
Nov	..	132	127	0.670	—	3.822	9.719
Dec	..	415	313	0.890	0.178	5.667	1.751
Jan 1985	..	200	243	0.267	1.060	0.601	0.601
Feb	..	47	329	0.359	0.801	2.949	2.211
Mar	..	315	176	1.268	0.312	6.552	6.279
Apr	..	165	457	0.935	0.267	6.552	10.975
May	..	256	325	1.424	1.938	3.929	6.279
Jun	..	282	9	3.393	1.157	2.184	3.822
Jul	..	188	795			3.325	2.719
Aug	..	141	24			2.858	3.112
Sep	..	12				2.498	1.532

Chlorophyll

The chlorophyll values indicate a high seasonal variability in Gulf of Mannar. Values ranging from a minimum of 0.267 g/m^3 (January 1985) to a maximum of 6.942 g/m^3 (January 1984) have been observed

one in May (345 mgC/m^3/12 hours day) and another in September (377 mgC/m^3/12 hours day). Two depressions noticed are in March (196 mgC/m^3/12 hours day) and in October (212 mgC/m^3/12 hours day).

Table 1 illustrates the mean monthly values of gross

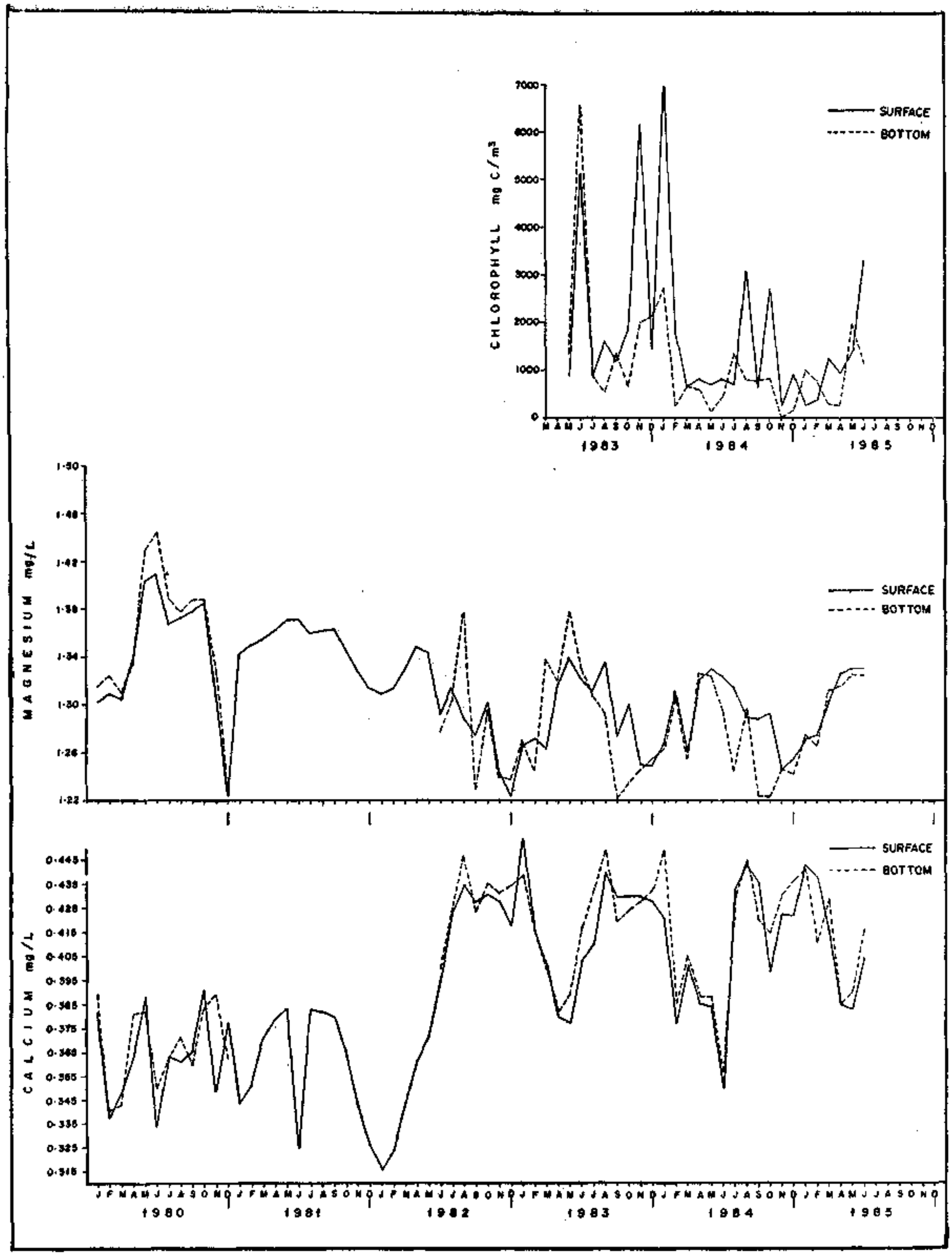

Fig. 3. Monthly variations in the mean values of calcium, magnesium and chlorophyll at Tuticorin Harbour basin from January 1980 to July 1985.

productivity at Tuticorin Harbour farm. The results indicate that there is considerable variation in unit volume production $mgC/m^3/day$. In the surface waters, the production rate ranges from 12 $mgC/m^3/day$ (Spe. tember 1985) to 2240 $mgC/m^3/day$ (February 1984). In the bottom waters the production rate varies from 9 $mgC/m^3/day$ (June 1985) to 2153 $mgC/m^3/day$ (February 1984).

Growth of Pearl Oysters

The pearl oyster *Pinctada fucata* under conditions of raft culture at Veppalodai and Tuticorin Harbour exhibits differential growth rate. The progress of growth is better in younger size groups than in the older groups. Growth is relatively faster during September-January (Chellam, 1978). Comparative growth studies reveal that the Harbour farm oysters grow faster and could attain a size as large as 70 mm DVM whereas the Veppalodai farm oysters grow to a maximum of 60 mm DVM. The large difference in the growth rate and attainment of maximum size is attributable to differences in the habitat namely greater depth, low silting, lesser fouling and calm sea conditions prevailing in the Harbour farm. Strong coastal current is also responsible for erosion of growth shoots along the margin of the shells and thereby causing retardation of growth of Veppalodai oysters.

Studies on the maturity and spawning of *P. fucata* indicate that it spawns intensly during July-September. The average condition index of oysters is 50.5 at Veppalodai farm, 52.3 at Harbour farm and 61.5 in the natural beds. The flesh weight constitute 21.4% of total weight at Veppalodai, 22.9% at Harbour and 30.4% in the natural beds. These data would broadly indicate that the ecological conditions at the three different locations play a key role in the well-being of the oysters.

Larval Life

Like many benthic invertebrates with a sedentary adult life and a dispersive larval stage, *P. fucata* larvae settle and establish in new areas by larval drift. The planktonic larval life span under laboratory condition lasts about 18-20 days at the end of which it attaches to the substratum by means of byssus. During larval life, the free swimming larvae are being carried away from the parental site by currents. Therefore, the larvae which settle on a particular paar need not necessarily be from the same area whereby mass spawning in one area could result in dense settlement in another area. This could be the reason for the wider annual fluctuation in the density of colonisation of *P. fucata* in different paars.

Pearl Production

Despite the various ecological factors that affect the growth of Veppalodai oysters, pearl-sac formation proceeds normally and production of cultured pearls has been equally good at Veppalodai farm and Harbour basin. The average success in production of cultured pearls through single implantation was 60%. In some batches, even 100% success could be achieved. In multiple implantation, pearl production with reference to the number of nuclei was 68.3% and with reference to the number of oysters was 180.6%. The quality of pearls produced ranged from dull prismatic to bright nacreous pearls. Pearls of different colours have also been produced. The more common colours are silver white, cream and golden yellow; less so is pink and rarely steel grey.

Discussion

The present study has concentrated on some of the ecological parameters of the pearl culture farms at Veppalodai and Tuticorin Harbour. Compared to the environmental conditions of pearl culture farms in Japan (Matsui, 1958; Alagarswami, 1970) and Australia, (Hancock, 1973) those at Veppalodai and Harbour farms are far different in regard to many factors. The pearl oyster *P. fucata* whose natural habitat in the Gulf of Mannar is in the deep water of 15-20 m can be successfully farmed in the shallow waters of 4-8 m. At Veppalodai rough sea conditions prevail during most part of the year while Tuticorin Harbour is almost calm throughout the year. Silt load and fouling is relatively heavier in the Veppalodai area than in the Harbour basin and these factors adversely affect the growth of the oysters. At the Harbour basin the oysters grow faster and attain a greater size than it does at Veppalodai. Despite the fact that good quality pearls were produced at the Veppalodai farm, Harbour basin has been found to give better results on the well being of the oysters and production of cultured pearls.

In Japan, pearl oyster inhabits calm and serene bays which have connections with the open sea. The salinity in the bays is not appreciably decreased by the river water flowing in. As these bays are under the influence of warm currents the temperature does not fall below 10°C. These bays have either rock or gravel bottom (Matsui, 1958). Pearl oysters are cultured in shallow waters of about 5 to 10 m deep where a large number of organisms attach to culture rafts, cages and on pearl oysters themselves (Matsui, 1958). Pearl culture is also being practised in open seas such as the Seto Inland sea and in areas bordered by chains of small islands (Alagarswami, 1970).

A comparison of ecological conditions prevailing in the pearl culture farms at Tuticorin and Japan show more dissimilarity than similarity, especially in regard to some factors—protection from winds and waves, depth and turbidity and temperature. According to Victor (1983), in the absence of suitable bays in the Indian mainland the shallow open coastal areas could be considered for establishing pearl culture farms.

The Andaman and Nicobar group of islands have many protected bays with clear water more similar to that of Japan (Mahadevan and Easterson, 1983). In Andaman group of islands pearl culture could be very succesfully carried out in Port Cornwalis area, in the bays of Ritchie's Archipelago, around Shoal Bay, and in the enclosed waters of Port Blair. The sheltered waters of Expedition Bay and Nancowry harbour in the Nicobars are also highly deserving for locating pearl culture farms. In Lakshadweep the pearl oysters are collected by hand picking from the lagoons. The Lakshadweep Fisheries Department has started a pearl culture unit at Bangaram in the year 1982. On the north-east side of the island the farm is located at 5-10 m deep. The bottom is sandy and the water is fairly clear with very little wave action. This area may be considered ideal for establishing pearl culture farm.

REFERENCES

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca.* Mar. Biol. Ass. India, Pt. III : 975-993.

CHELLAM, A. 1978. Growth of pearl oyster *Pinctada fucata* in the pearl culture farm at Veppalodai. *Indian J. Fish.*, 25 : 77-83.

EASTERSON, D. C. V. AND S. MAHADEVAN. 1980. Review of open sea environmental conditions along Indian coast. In : Mussel farming—Progress and prospects, *Cent. Mar. Fish. Res. Inst. Bull.* 29 : 17-21.

GANAPATHI, P. N. AND V. S. R. MURTHY. 1955. Preliminary observations on the hydrography and inshore plankton in the Bay of Bengal off Vishakhapatnam Coast. *Indian J. Fish.*, 2 : 84-95.

HANCOCK, D. A. 1973. Kuri Bay pearls some of the finest in the world. *Austr. Fish.*, 32 (4) : 11-12.

JAYARAMAN, R. 1954. Seasonal variations in salinity, dissolved oxygen and nutrient salts in the inshore waters of the Gulf of Mannar and Palk Bay near Mandapam. (S. India). *Indian J. Fish.*, 1 : 345-364.

MAHADEVAN, S. AND D. C. V. EASTERSON. 1983. Topographical features of areas surveyed. In : *C.M.F.R.I. Bulletin.* Mariculture potential of Andaman and Nicobar islands—An indicative survey, 34 : 10-25.

MATSUI, Y. 1958. Aspects of the environment of pearl culture grounds and the problems of hybridization in the genus *Pinctada*. In : *Perspectives in marine biology.* A. A. Buzzati-Traverse (Ed), University of California Press, Berkeley and Los Angeles, 519-531.

VICTOR, A. C. C. 1983. Ecological conditions of the pearl culture farm at Veppalodai in the Gulf of Mannar. *Proc. Symp. Coastal Aquaculture,* Mar. Biol. Ass. India, Pt. 2 : 619-626.

12

PROSPECTS FOR SELECTIVE BREEDING OF PEARL OYSTERS IN INDIA

T. S. VELAYUDHAN[1]

INTRODUCTION

Recently a variety of approaches has been introduced in the field of genetics of molluscs, including Mendelian genetics, cytogenetics, quantitative genetics, biochemical genetics and hybridization. Wada (1975 a, b, 1985) has estimated the response to selection for several attributes of *Pinctada fucata* for shell variance of full siblings. He analysed the genetic variability and gene frequencies at three loci in two strains selected for four to five generations. The change of frequencies of colour of nacre in the selected lines of pearl oyster to yellow prismatic layer for five generations has been studied (Wada, 1985). Wada (1976, 1985) and Wada and Komaru (1985) have studied the chromosome morphology of different species of bivalves.

VARIATIONS IN INDIAN PEARL OYSTER POPULATION

In India, Alagarswami *et al.* (1983) artificially produced pearl oysters from wild brood. Alagarswami and Chellam (1977) have reported the change of form and dimensional relationship in the pearl oyster *P. fucata* from Tholayiram, Pulipundu and Kudamuthu paars and compared the regressions of different shell characters in young and adult oysters from the three paars which indicated the heterogenous nature of the population. Hornell (1922) stressed the need for a knowledge of the special growth peculiarities of pearl oysters from the different beds since some paars by reason of abundant food supply hasten the growth of oysters to surprising degree, while others where less favourable conditions prevail have oysters of an unhealthy appearance and stunted size. Herdman (1905) reported that the pearl oysters from Cheval paar (Sri Lanka) were fairly evenly distributed and in quality they proved to be best of all those examined or fished. They were all well grown, healthy and richer in good pearls than any other. For pearl culture an accurate knowledge of the various traits of the oysters from different paars is necessary in order to pick up the necessary traits to be developed in the brood stock.

The pearl oysters *P. fucata* and *P. sugillata* were successfully crossed at the Central Marine Fisheries Research Institute and viable spat were produced. *P. fucata* without black lamellar growth on the outer shell were produced by inbreeding. Attempts have also been made to produce cent percent *P. fucata* with black lamellar growth on the outer shell by inbreeding.

SELECTIVE BREEDING AND HERITABILITY OF PEARL OYSTER

According to Wada (1975 a, b, 1985) the estimated heritability of the shell size of *P. fucata* was greater at one year of age than at two years but not much difference was observed in the shell shape. Wada (1985) has mentioned the heritability of the shell trait to be about 0.22-0.25 and that selective breeding of the trait would be effective for other shell traits such as shell height and shell width also. Wada has reported the change of frequencies of colour of nacre in the selected lines of pearl oyster to yellow prismatic layer for 5 generations. No significant difference was observed in the mortality of pearl oysters and the rate of low grade pearls between two groups such as white and yellow prismatic layer secreting forms. Wada (1985) specifically mentioned the frequency distribution of shell weight of three year old pearl oyster of back crossed (TNT, NTT and the selected TL) lines in the

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third year. Wada (1975 a, b) conducted crossing experiments between DD and DD as well as with heterozygotes DF and DF. In the former only DD bands appeared and in the latter three band types DD, DF and FF segregated. And he explained the Namako Lagoon of Kamikashijma Island may be geographically separated from other habitats of pearl oyster, but it should not be assumed that the samples consisted of two or more populations with different gene frequencies as in the case of excess homozygotes and he doubted whether negative heterosis operated. He illustrated the zymogram of maleate dehydrogenase (MDH) of crude extract from digestive diverticulum showing mobility of each MDH band population.

Wada (1976) studied the morphology of chromosomes of the oyster *P. fucata* (Gould) collected from the two regions of Japan. Wada and Komaru (1985) explained the karyotypes in 5 species of Pteridae. Haley (1977), as reported by Newkirk (1980) has been following the frequency of changes in the 5 fullsib families of *Crossostrea virginica*. Matsui (1958), in *Pinctada martensii* the right shell is slightly convex, whereas the left shell is more strongly so. The degree of convexity of shells is very important from the practical point, because oysters with more strongly convex shells harbour larger pearls. Haley (1978), as reported by Newkirk (1983) explained that the sex determination of these oysters was a three locus (two alleles each) model with certain genotypes as fixed males and others as fixed females and the remaining with potential sex change.

From the studies on chromosomes of different species of pearl oysters, it is clear that there are possibilities for cross breeding of those bivalves which are having same number of chromosomes. Singh and Green (1984) have reported that the relative mortality of the heterozygotes (faster growers) of *Macoma balthica* during the larval period is expected to vary from year to year depending on the environmental conditions, particularly the relative abundance of the phytoplankton blooms and faster growing heterozygotes with higher food requirements have relatively higher mortality. This may account for the poor spat years where relatively few larvae grow into spat and in such years there are also slow growers which take longer time to reach market size (Galtsoff, 1964).

From the experimental results obtained in his observation and other studies Wada (1975) stated that the pearl oyster of Namako Lagoon may be a form of *P. fucata* (Gould) more or less generally differentiated from the species of other habitats in Japan.

An Approach to Pearl Oyster Genetic Studies in India

In animals with external fertilization meiosis takes place in the egg and artificial process can be applied to either gamete before fertilization or later to alter genetic characters to fertilized egg or at any period during the formation of zygote. Suppressing metaphase prevents replicated chromosome sets from separating into daughter cells and it can be achieved either by physical means such as pressure or temperature shock or by use of chemicals such as colchicine or its analogue colcimid. The more phenotypic variation in a trait the more intense the selection from the natural populations. The selected oysters are then mated according to a prearranged plan. Unless there are sufficient numbers of spawners, at least 50, significant inbreeding may occur and a number of stocks can be taken and performance evaluation could be done during the first generation.

With very little or no information as guidance in choosing stocks there are several approaches that can be used. First, a simple stock based on available information can be chosen. This can be risky if the information on which the decision relies is incomplete. Taking all our eggs from one source is really 'putting all our eggs in one basket.'

Second, one can take a number of stocks and do performance evaluation during the first generation. This will require maintaining stock identity and performance records.

The third approach is to cross males and females from different populations to form mixed base population. This can be done if parents from a number of stocks spawned together. We have produced pearl oysters without black lamellar growth on the shell in the laboratory. *P. fucata* and *P. sugillata* were crossed and spat were produced. Maintenance of broodstock is useful to keep the identity of the progeny groups. If we keep each generation (50 males and 50 females) of each stock or line, the inbreeding rate will be 0.5% per generation and total accumulation of inbreeding after 5, 10 and 20 generations of 1, 3 and 5% respectively (Newkirk, 1983). More control can be exercised and consequently less inbreeding will occur if separate lines are maintained. If the founding stock has been derived from a small number of parents (10-20) it is strongly recommended that separate families should be maintained at least in the first generation. Thereafter a number of pooled lines can be formed by careful crossing of the original families. At present the crossing of *P. fucata* and *P. sugillata* is not continued due to the fear of the problem of interbreeding and adverse effect on the local strains. The wild stock is used as brood for increasing the farm stock. And now we are using the hatchery stock also as one of the lines for stock improvement. In the larval period as well as adult stage we face many problems such as slow growth, mortality etc. To increase the quality of pearls and growth and survival of oysters we have to adopt some genetic approaches to raise the quality of stock. From the natural stocks, these qualities have to be identified and the broodstock with necessary traits could be used for producing pearl oysters of desired traits. The genetic diversity of different populations of pearl oysters of India has to be identified to improve the quality of the product for aquaculture.

The pearl oysters collected from different paars have to be examined for the rate of pearl production, quality, mortality, growth variance, shell size, shell weight, meat weight and colour of nacre. Along with this, hatchery development of stocks from the required paars has to be carried out. The heritability of pearl oyster has to be studied. The genetic variability of the pearl oyster *P. fucata* (Gould) collected from Gujarat, Lakshadweep, Andaman Islands, Vizhinjam and Tuticorin has to be determined by studies on the number and gross morphology of chromosomes in pearl oysters collected from the above regions. Experiments should also be carried out on the electrophoretic markers for different traits of pearl oyster species in India. Crossing experiments using different strains from Gujarat, Vizhinjam, Lakshadweep, Andamans and Tuticorin to produce hybrids, production of hundred percent yellow and white nacre producing oysters on a large scale by inbreeding and the raising of faster growing and quality pearl producing oysters for commercial operations are some of the areas which require attention.

REFERENCES

ALAGARSWAMI, K. AND A. CHELLAM. 1977. Change of form and dimensional relationship in the pearl oyster *Pinctada fucata* (Gould) from Gulf of Mannar. *Indian J. Fish.*, **24** (1 & 2) : 1-14

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould.) *Aquaculture*, **34** : 287-301.

HERDMAN, W. A. 1905. Discovery of brood oysters on the Periya paar. In : *Report to Ceylon Pearl Oyster Fisheries of Gulf of Mannar*. W. A. Herdman *et al.* (Eds). Royal Society, London, **3** : 1-48.

HORNELL, J. 1922. The Indian pearl fisheries of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, **16** : 1—188.

GALTSOFF, P. S. 1964. The American Oyster *Crassostrea virginica* Gmelin. *U.S. Fish and Wildlife Serv. Fish. Bull.* **64** : 1-480.

MATSUI, Y. 1958. Aspects of the environment of pearl culture grounds and the problems of hybridization in the genus *Pinctada*. In : *Perspectives in Marine Biology*. (A. A. Buzzati—Traverso Ed.), Univ. of California Press, Berkely : 519-531.

NEWKIRK, G. F. 1980. Review of the genetics and the potential for selective breeding of commercially important bivalves. *Aquaculture*, **19** : 209-228.

NEWKIRK, G. F. 1983. Applied breeding of commercially important molluscs. A summary of discussion. *Aquaculture*, **33** : 415-422.

SINGH, S. M. AND R. H. GREEN 1984. Excess of allozyme homozygosity in marine molluscs and its possible biological significance. *Malacologia*, **25** (2) : 569-581.

WADA, K. T. 1975a. Electrophoretic variance of leucin aminopeptidase of the Japanese pearl oyster *Pinctada fucata* (Gould). *Bull. Natl. Pearl Res. Lab.*, **19** : 2152-2156.

WADA, K. T. 1975b. Genetic differentiation of the pearl oyster *Pinctada fucata* (Gould) collected from Namako Lagoon of Kamikoshijima Island, Kagoshima Prefecture. With English summary, 2183-2184. *Bull. Natl. Pearl Res. Lab.*, **19** : 2169-2185.

WADA, K. T. 1976. Number and gross morphology of chromosomes in pearl oyster, *Pinctada fucata* collected from two regions of Japan. *Japan. J. Malacol.*, (*Venus*), **35** (1) : 9-14.

WADA, K. T. 1985. The pearl produced from the groups of pearl oysters selected for nacre in shell for two generations. *Bull. Natl. Res. Inst. Aquaculture*, **7** : 1-7.

WADA, K. T. AND A. KOMARU. 1985. Karyotypes in five species of Pteridae (Bivalvia : Pteriomorpha). *Japan J. Malacol.*, (*Venus*), **44** (3) : 183-192.

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EXPERIMENTAL SEA-RANCHING OF PEARL OYSTER IN THE GULF OF MANNAR

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INTRODUCTION

Sea-ranching of laboratory/captive reared organisms/animals is a technique which aims at rebuilding the wild population from its destruction/catastrophe by man-made and natural causes. One important difference between land-ranches and sea-ranches is that the land-rancher retains ownership of his animals whereas the sea-ranched animals become part of the common property resource which can be harvested by anybody. Artificial supplementation of commercial catches is thus the theme of sea-ranching and forms part of fishery management technique.

In species enlisted as endangered, attempts were made to sea-ranch them with a little success. Taking advantage of their high potentialities in reproduction and simultaneously slashing their early natural mortality through captive rearing of hatchlings, offers a powerful tool to help rebuild and conserve these endangered species like turtles (Henry, 1979). To achieve this in turtles, he has recommended two courses of action, to reduce man's incidental and intentional catch of wild turtles and restock the wild population with captive-reared animals from commercial operation. Sea-ranching is advantageous for 'homing' species where the sea-ranching country stands to benefit.

Abalones are produced in the hatcheries and transplanted in the sea as a practice to increase production (Imai, 1977). In the case of pearl oysters which are sedentary, no attempt was made in the past to sea-ranch them for augmenting the natural population. The recent development in the mass production of spat of pearl oysters (Alagarswami *et al.*, 1983) has opened up this possibility and an experimental sea-ranching programme was started in the Gulf of Mannar.

FLUCTUATIONS OF PEARL OYSTER RESOURCE IN NATURAL BEDS

The widespread mortality of pearl oysters, both young and old, in the beds of Gulf of Mannar may be due to physical causes such as shifting of sand due to strong currents, or to destruction by natural enemies. Factors like overfishing, overcrowding and diseases may also be responsible for the depletion of stock from the beds (Herdman, 1903). Predation by fishes like *Balistes* sp., *Lethrinus* sp., *Serranus* sp., *Tetrodon*, sharks and rays, mainly *Rhinoptera* and *Ginglymostoma* (Hornell, 1916), moray eels and octopi (Salvadori, 1960), covering the spat by *Modiolus* ('suran') mat (Mahadevan and Nayar, 1973, 1976) and predation by gastropods (Chellam *et al.*, 1983) have been found to be some of the causes responsible for the destruction of oysters. In the recent years, several industries have sprung up along the coast which discharge their effiluents into the sea. Ship traffic has been on the increase with the construction of a commercial harbour at Tuticorin with resultant oil spillage. Operation of fishing trawlers in the paars and their vicinity is disturbing the bottom ecology of pearl oyster beds.

Revival of natural beds may be possible only with a series of favourable seasons. The mutual dependence between the pearl banks of Sri Lanka and India in replenishing the beds by larval drift was suggested by Hornell (1916). But Devanesan and Chidambaram (1956) were of the opinion that the beds revive by self-effort only. Alagarswami (1977) observed good spat setting in the inshore areas and also resurgent populations of species of pearl oyster other than *Pinctada fucata* in the natural beds which he attributed to coastal larval drift.

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Conservation of pearl oyster in the natural beds

Herdman (1906) suggested transplantation of young 'strikes' or brood of oysters from useless or unreliable paars to other paars which afford better growing and survival conditions. Hornell (1916) endorsed the above strategy and suggested rehabilitating the outer series of pearl banks by transplanting the scattered oysters found in the shallow areas (5-7 f) around the reefs and islands at the head of the Gulf. Maintaining a 'breeding reserve' of *P. vulgaris* (= *fucata*) in the Tholayiram paar (Devanesan and Chidambaram, 1956) and development of hollows in the pearl oyster beds by filling with rocks to provide better anchorage for oyster (Salvadori, 1960) are some of the measures suggested to conserve and promote the survival of the pearl oyster population.

Sea-ranching experiment at Tuticorin*

For the sea-ranching of pearl oyster in the Gulf of Mannar one of the shorewards paars, the Vanthivu arupagam paar was selected initially for its accessibility and easy monitoring. The depth of the paar is 12 m. Between December, 1985 and July, 1986 a total of 7,20,000 spat of *P. fucata* (Gould) were sea-ranched on 6 occasions. The size of the spat ranged from 1.7 mm to 4.8 mm with an average length of 3.1 mm. The spat collected from the hatchery tanks were allowed to settle on synthetic materials like old fish nets, velon screen fabric and tufts of monofilaments. These materials with the spat were placed in large rectangular cages (90 × 60 × 15 cm) covered with synthetic webbing. The cages were further enclosed with old fish nets. The spat could crawl out through the meshes for dispersal on the paar. The spat-filled cages were lowered and kept inside hollows or secured to coralline projections with synthetic ropes to prevent drifting. Efforts are underway to monitor the sea-ranched stock of pearl oysters.

REFERENCSS

Alagarswami, K. 1977. Larval transport and settlement of pearl oysters (Genus *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm Water Zoopl.*, Spl. Publn. UNESCO/NIO, 678-686.

Alagarswami, K., S. Dharmaraj, T. S. Velayudhan, A. Chellam, A. C. C. Victor and A. D. Gandhi. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301

Baschieri-Salvadori, F. 1960. Report to the Government of India on the pearl and chank beds in the Gulf of Mannar. FAO/EPTA Rep. 1119, 60 pp.

Chellam, A., T. S. Velayudhan, S. Dharmaraj and A. C. C. Victor. 1983. A note on the predation of pearl oyster *Pinctada fucata* (Gould) by some gastropods. *Indian J. Fish.*, 30 (2) : 337-339.

Devanesan, D. W. and K. Chidambaram. 1956. Results obtained at the pearl oyster farm, Krusadai Island, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar—Part I. *Contr. Mar. Fish. Biol. St. Krusadai*, 4 : 1-89.

Henry, A. Reichart, 1979. Farming and ranching as a strategy for sea turtle conservation. In : *Biology and conservation of sea turtles.* (Karen A Bjorndal, Ed.), *Proc. Sea Tur. Con.*, Washington DC, 26-30 Nov. 1979 : 465-471.

Herdman, W. A. 1903. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar.* Pt. I. Royal Society, London.

Herdman, W. A. 1906. *Report to the Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar.* Pt. V. Royal Society, London.

Hornell, J. 1916. An explanation of irregularly cyclic character of the pearl fisheries of Gulf of the Mannar. *Madras Fish. Bull.*, 8 : 11-22.

Imai, T. (Ed.). 1977. *Aquaculture in Shallow Seas*, Oxford & IBH Publishing Co., New Delhi.

Mahadevan, S. and K. N. Nayar. 1973. Pearl oyster resources of India. *Proc. Symp. Living Resources of the Seas Around India*, CMFRI, Cochin : 659-671.

Mahadevan, S. and K. N. Nayar. 1976. Underwater observations on the settlement of spat of pearl oyster on the paars off Tuticorin. *Indian J. Fish.*, 23 (1 & 2) : 105-110.

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BIOFOULING, BORING AND PREDATION OF PEARL OYSTER

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INTRODUCTION

During the course of the experiments in pearl culture since 1972 in the Gulf of Mannar, several problems were encountered in the farm due to biofouling, boring and predation of oyster stocks. An account of fouling and boring organisms in the farm at Veppalodai was given by Alagarswami and Chellam (1976). Nishii (1961) and Nishii *et al.* (1961) indicated some relationship between the frequency of cleaning and growth of pearls in the Japanese waters. Wada (1973) reported that animals and seaweeds setting on the oysters and baskets inhibited the growth not only of the oysters but also of the pearls. The occurrence of polychaete and sponge borers on the pearl oyster *Pinctada fucata* and their control measures were given by Velayudhan (1983). Instances of predation by some gastropods on *P. fucata* in the pearl banks was reported by Chellam *et al.* (1983). Variation in the settlement and growth of barnacles on live oysters, shells and wooden test panels was studied by Dharmaraj and Chellam (1983). The problems and the effects of fouling, boring and predation in the pearl oyster farms at Tuticorin are discussed here.

MATERIAL AND METHODS

The pearl oysters of the farm themselves formed the material for the study on fouling and boring organisms. The oysters were grown in the rafts which were moored at a distance of 1.5 km from the sandy shore of Veppalodai and at a depth of 4.5 m. The sea bottom in the farm site was fairly hard with a mixture of sand, mud and broken pieces of shells and corals. The frame nets holding oysters were suspended at a depth of 3.5 m. The farm area was turbid almost throughout the year with moderate to heavy wave action. Data on fouling and boring organisms on live oysters were collected. The size and number of barnacles and volume of fouling load were recorded from the oysters collected randomly from the frame nets.

The extent of damage caused to the shells by the different boring organisms was recorded. The polychaetes were collected after narcotising them along with the pearl oysters. Other organisms were collected by digging them out of their perforations.

Settlement and growth of barnacle was studied in the farm at Veppalodai using the following material as the substratum: (i) wooden test panels (ii) live oysters and (iii) shells of pearl oysters. A panel set consisted of three square planks (each 20 × 20 × 2.5 cm). Such panels were suspended in a manner that the top-most plank was at 0.5 m, the middle one at 1.5 m and the bottom one at 2.0 m from the surface. Each panel set was terminated after one month and the barnacles were counted and other organisms recorded.

Live pearl oysters and shells arranged in separate frame nets were suspended in the farm. They were examined on completion of one month. The number and size of barnacles on the live oysters and shells were recorded.

In the experiments on the control of boring organisms, the affected oysters were arranged in a frame net and were brushed with 1% formalin. After exposing these oysters to air for 15 min to 2 hours they were washed in freshwater and transferred to seawater. In another experiment oysters with borers were treated in salinity

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ranging from 42.3% to 78% for a period from 4 to 21 hours. Freshwater treatment was also experimented upon.

Fouling Organisms

Seasonal variation of the dominant groups of the fouling complex and their measurable effect on the oyster stock in the farm was studied. Barnacles, bryozoans and molluscs were the most numerous and larger organisms in the fouling complex. Tunicates, decapod crustaceans, hydroids and anthozoans were the less significant ones.

Barnacles

The cirriped *Balanus amphitrite variegatus* was the most important fouling organism in the farm. *B. a. communis* and *B. a. venustus* were a few in numbers. Though the barnacles were present throughout the year, larger-sized ones dominated during July-September. Two peaks of heavy settlement were recorded; one was from the middle of June to August and the other from September to November. The settlement of barnacles at different depths was found to differ from month to month. The panel study in the farm at Veppalodai showed that a minimum of 2,500 barnacles (July) to a maximum of 3,460 barnacles (June) was noted during the first peak and it was from 1,290 (September) to 2,710 (November) in the second peak. When the total number of barnacles settled was taken into account for the whole year, the bottom panels showed higher settlement (39.3%) and the surface panels had less (23.8%). In the first half of the year the maximum size of barnacle recorded was 6.0 mm (dominant size 0.1-1.5 mm) and it was 9.0 mm (dominant size 1.6-6.0 mm) in the second half. Small barnacles were seen throughout the year.

The settlement of barnacles per unit area (10 sq. cm) per oyster ranged from 3.4 in number in May to 62.2 in November. The maximum size of barnacles on oysters was found to be 8.9 mm in August. The maximum fouling load recorded per oyster was 33.18 in November. The settlement of barnacles per unit area per shell was 2.6 in number in May and 113.9 in November. The maximum size of barnacles recorded on the shells was 15.7 mm in August. The maximum fouling load recorded per shell was 55.9 g in November. The different aspects of settlement of barnacles are shown in Pl. I A-F.

The barnacles caused physical interruption to opening and closing of the valves. At the time of dense growth, the margins of the valves were overgrown by barnacles thereby cementing them together. When the barnacles grew on the hingeline, they disabled the oysters from opening of the shells. In both situations the oysters died eventually. In addition to this, during the removal of barnacles, growth processes of the oyster shell were damaged resulting in the recession of shell growth.

Bryozoans

In the farm at Veppalodai the bryozoans formed the next dominant group. The species of *Membranipora, Thalamoporella* and *Lagenipora* represented the group occurring almost throughout the year. They were numerous during November and December. Other species like *Watersipora* and *Bugula* were more during February and June.

Molluscs

Among the fouling molluscs *Avicula vexillum* and spat of *Crassostrea* sp. were numerous in the farms during April to June. The heavy settlement and faster growth of *A. vexillum* resulted in carpet-like formation over the entire surface of cages, thereby affecting the waterflow. *A. vexillum* was so numerous that the spat of pearl oyster could not be separated. Added to this they competed for food and space causing much mortality of the spat. Occurrence of this species was erratic and was only a few in numbers during the particular season in certain years. Settlement of spat of *Crassostrea* sp. was seen on the pearl oysters and nettings during May-June. *Modiolus metcalfei* was seen in large numbers in July at Veppalodai. Its occurrence was negligible in the harbour farm. Spatfall of the pearl oyster species *P. fucata, P. sugillata* and *P. chemnitzii* was recorded at Veppalodai during May-July and at harbour farm during November-January. Though they formed part of fouling complex, the settlement of spat was significant for mother oyster culture for the production of cultured pearls (Alagarswami, 1974).

Ascidians

Simple ascidians *Ascidia depressiuscula* and *Dicarpa* sp. and compound ascidians *Diplosoma* sp. and species of *Botrilloides* were recorded almost throughout the year. The ascidians were found in large numbers during October-December in both the farms.

Fouling sponges

The profuse growth of the sponges *Callyspongia fibrosa* and *Haliclona exigua* resulted in complete covering of an oyster or a cluster of oysters. Frequency of occurrence of these sponges was less in the farms and the damage caused to the oysters was negligible.

Other orgynisms

Besides the above significant groups, the fouling complex was composed of a large number of gammarids and other amphipods. Hydroids and algae were common in the farm at Veppalodai throughout the year and were numerous during October-December. The hydroids comprised *Campanularia obelia, Sertularia fissa, Abeitineria, Lytocarpus hornelli, Diphasia mutalata* and *Thuiaria palans*. Commonly occurring algae were *Gracilaria edulis, Codium tormentosus, Boergesenia forbesii, Ceramium* sp. and *Cladophora* sp. The presence of algae was less in the habour farm. Other organisms such as anthozoans (*Paranemonia* sp. and *Bunadactis* sp.) ; juveniles of *Panulirus* sp., crabs (*Porcellana* sp. and *Pinnotheres* sp.) ; pycnogonids (*Nymphon* sp.) tubicolous polychaetes (*Serpula* sp. ; *Spirorbis* sp., and *Hydroides norvegicus*) ; polyclad worms ; crinoids, alcyonarians (*Sarcophytum* sp. and *Clavularia margaritiferae*) ; opisthobranchs, blennid fishes (*Blennius steindachneri*) and *Pinna* shells were found to occur on the oysters and cages in certain months.

BORING ORGANISMS

Boring organisms, comprising polychaetes, sponges, molluscs and isopods caused considerable damage to the shells of the pearl oysters. Polychaetes belonging to the families Syllinidae, Nereidae, Spionidae, Terebellidae and Cirratulidae were found to bore pearl oyster shell. Among them the spionid *Polydora ciliata P. flava* and the cirratulid *Cirratulus cirratus* were the common borers. *Polydora* sp. caused simple and compound blisters on the inner side of the shells (Pl. II-B). In a few cases, the blisters erupted as tumour like protrusion mostly near the adductor impression. The intensity of boring by the polychaetes *P. ciliata* and *P. flava* was found to differ from place to place. These species were more in the sheltered bay farm at Tuticorin Harbour than in the open sea farm at Veppalodai. Boring of oysters from the natural beds was insignificant. Blisters caused by the boring polychaetes were practically negligible in the oysters of 40 mm in DVM and less. Of the shells examined, 78.4% were with blisters. Among the infested shells, 28.3% carried single blisters and the rest more than one.

The cirratulid worm inhabited the pearl oyster shell in between the layers of periostracum. As a result the furrow became deeper by the accumulation of mud. This caused the peeling of periostracal layer making the shell weak. The intensity of this species was more on the oysters reared in the farm for prolonged period. Each furrow had more than one worm.

The boring sponges comprised *Cliona celata, C. vastifica* and *C. margaritiferae*. In the farm at Veppalodai, of the shells examined, 20.7% was infected by sponge borers. The attack of these borers was initially near the umbo and later spread to all sides. The oysters have to secrete more nacre to seal off the perforations. At the extreme condition of infestation the shell was very fragile and susceptible to further infections. The maximum infestation by *C. vastifica* was recorded on the oysters at Veppalodai farm and the intensity was less in the habour farm and negligible in pearl banks (Pl. II A).

The pholadid mollusc *Martesia* sp. and mytilid *Lithophaga* sp. and the isopod *Sphaeroma* sp. were occasionally met with in the farm. *Martesia* sp. was found to make a number of holes on the shell. Similar damage has also been caused by *Lithophaga* sp. *Sphaeroma* sp. was found to make shallow groove on the surface of the shells.

CONTROL MEASURES FOR BORING ORGANISMS

Treatment with 1.0% formalin

The oysters infested with boring polychaetes, sponges and *Martesia* ap. were arranged in a frame net. After brushing both the valves with 1.0% formalin, the oysters were exposed to air for 15 minutes to 2 hours. They were returned to normal seawater after washing in freshwater. The treatment was found effective for killing the sponges and *Martesia* sp. completely and *Polydora* sp. about 87.7%.

Treatment with brine solution

The oysters affected by boring polychaetes were immersed in brine solutions having the salinity range between 42.3% and 78%. The duration of the treatment varied from 7 hours to 21 hours. In the concentration of 78% all the polychaetes were killed within 7 hours 40 min.

Treatment with freshwater

The oysters with borers were treated in freshwater. The time duration ranged from 1 hour 15 min. to 10 hours. On return to normal seawater, they were under observation for a week in the laboratory. Cent percent mortality of *Polydora* and *Cirratulus* was observed in treatments lasting between 6 and 10 hours.

Application of control measures on farm oysters

Two batches of oysters were selected for the purpose of treating them with freshwater and 1.0% formalin respectively during August. Mortality rates of 0.1%,

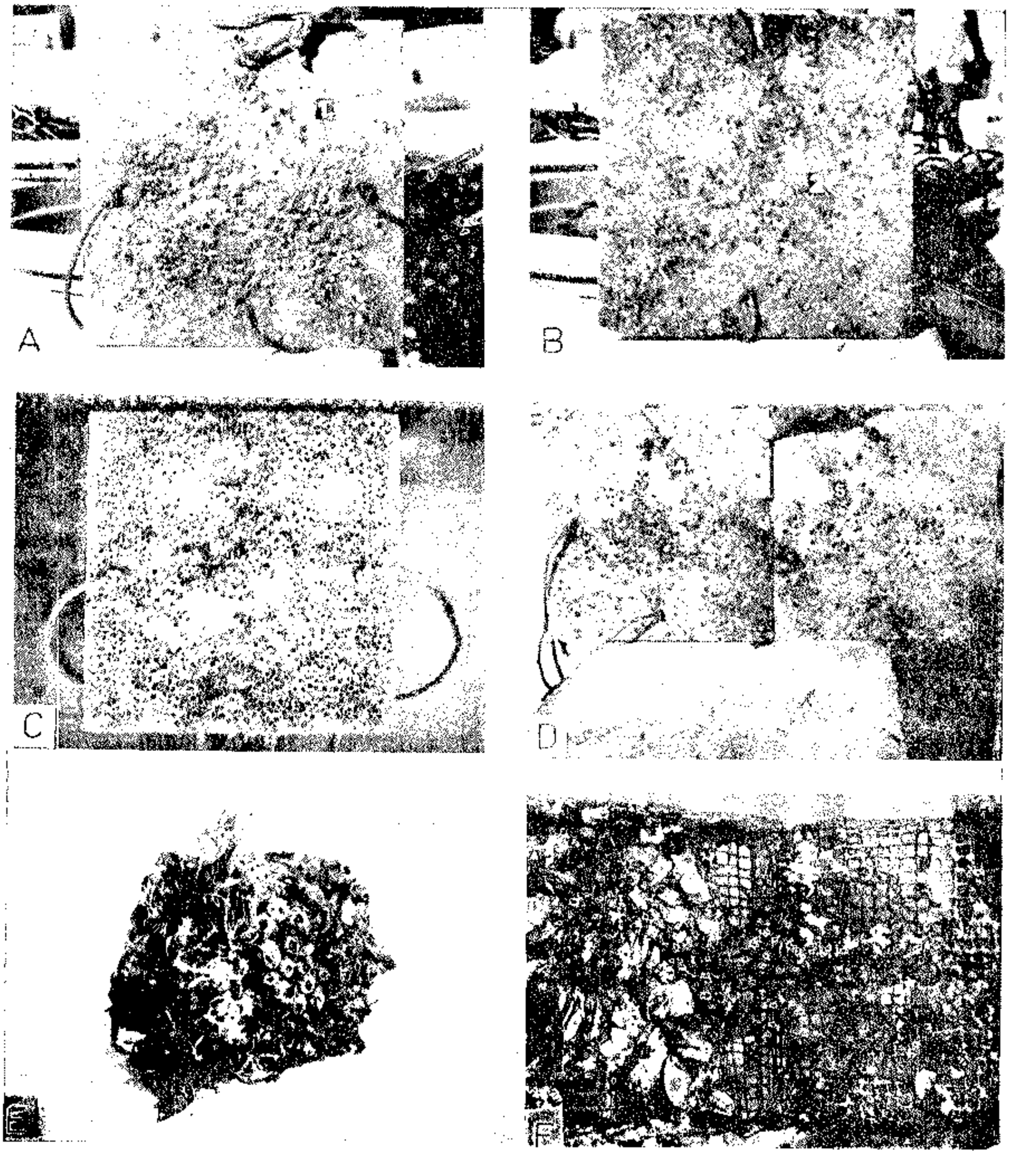

PLATE I. A. Settlement of barnacles at 1 m depth ; B. Settlement of barnacles at 2 m depth ; C. Settlement of barnacles at 3 m. depth ; D. Settlement of barnacles at 4 and 5 m depth ; E. Settlement of barnacles and hydrozoans on live pearl oyster *Pinctada fucata* ; F. Oyster cage attached with foulers.

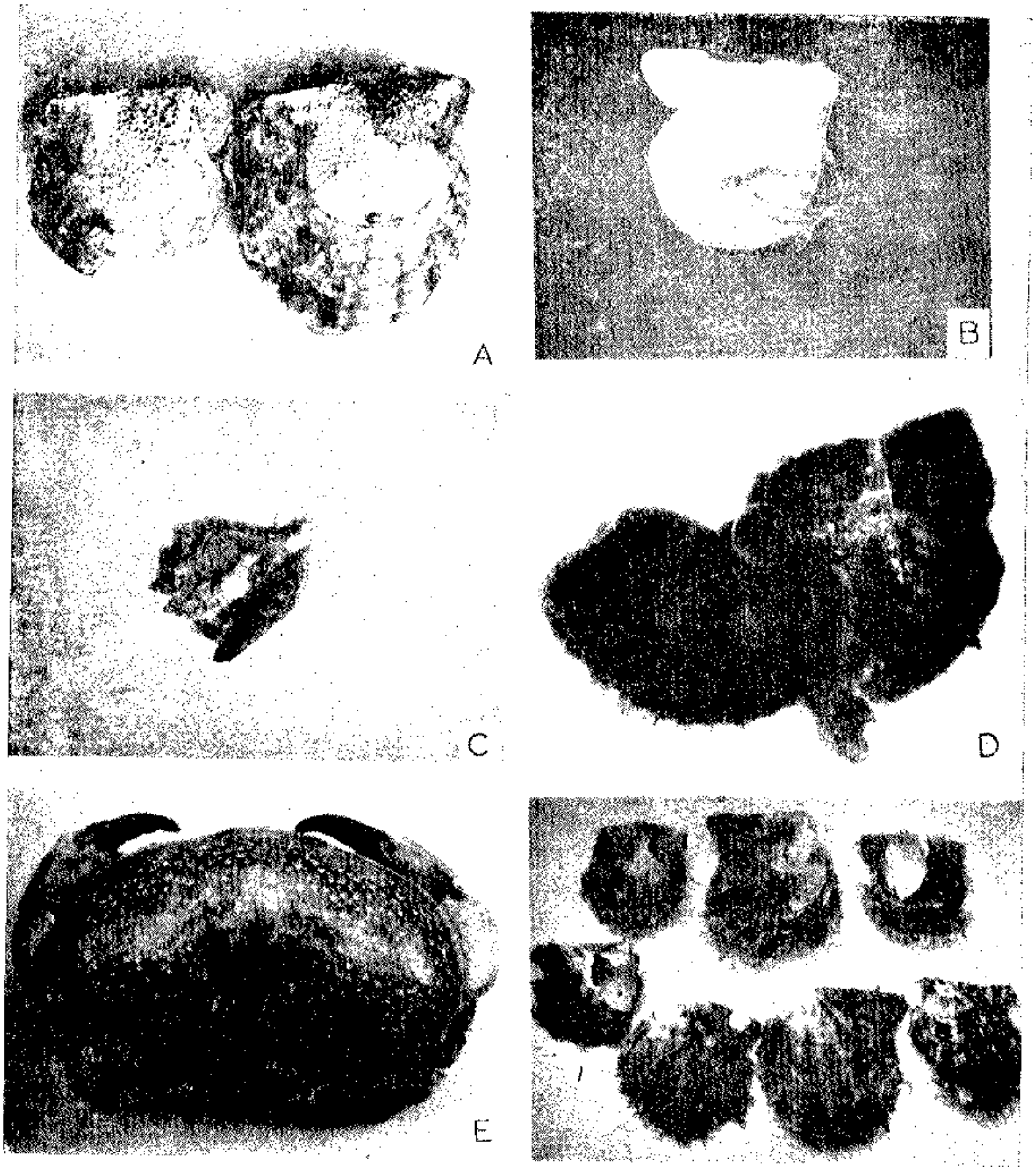

PLATE II A. Pearl oyster shell showing boring by sponge ; B. Shell with polychaete blisters ; C. Predator *Murex virgineus* feeding on oyster ; D. Predator *Cymatium cingulatum* attacking oyster ; E. Predatory crab *Atergatis integerrisimus* ; F. Pearl oyster shells damaged by crabs.

2.3% and 0.8% were recorded in the formalin treated oysters during the months of September, October and November respectively. The incidence of boring by sponges was again seen in the freshwater treated oysters which ranged from 1.4 to 4.3% whereas no fresh sponge boring was noticed in the formalin treated oysters (Velayudhan, 1983).

PREDATION

Besides fouling and boring, predation was also encountered in the pearl culture farms and in the natural pearl banks off Tuticorin coast. Earlier report revealed the aspect of predation by rock fishes, rays, octopus and starfishes on pearl oysters in the natural beds (Hornell, 1916).

The rock fishes comprising of *Balistes mitis*, *B. stellaris*, *B. maculatus*, *Lethrinus* spp., *Serranus* spp. and *Tetrodon* spp. have been reported to eat young oysters below one year old and the rays *Rhinoptera javanica* and *Ginglymostoma* spp., octopus and starfish on adult oysters. Herdman (1903, 1905) considered the possibility of predation by gastropods and the boring molluscs, chiefly *Sistrum spectrum*, *Pinaxia coronata*, *Nassa*, *Purpurea* and *Turbinella*. The elephant chank *Murex ramosus* was also considered as an enemy of oysters by Hornell (1922).

In recent years a few other predatory gastropods have also been found to feed on pearl oysters in the natural beds. *Cymatium cingulatum* and *Murex virgineus* were the most serious predators as reported by Chellam *et al.* (1983). Predation by *C. cingulatum* was recorded for the first time (Pl. II D). The rate of feeding of these species has been found in the laboratory as 20 oysters in 37 days by two *Cymatium* of the size 26.0 mm in length, 20 oysters in 20 days by two (40.5 mm) and 20 oysters in 19 days by two (61.8 mm). The rate of feeding of *M. virgineus* was 20 oysters in 49 days by two specimens (54.0 mm) (Pl. II C). These gastropods were found to survive 57 to 125 days of starvation. Other species of gastropods such as *C. pileare*, *M. ramosus*, *Bursa rubeta*, *Thais margariticola* and *Gyrineus natator* were also recorded in the pearl banks. Though predation by these gastropods was not observed in the laboratory, being carnivores, they might cause havoc to pearl oyster in natural conditions. Accidental entry of the predator *C. cingulatum* into pearl oyster farm at Tuticorin caused serious mortality of young oysters on several occasions. *M. virgineus* did not occur in the farm.

Equally important predators were the crabs which during their larval phase entered into cages with fine mesh. *Charybdis lucifera*, *Atergatis integerrisimus*, *Leptodius exaratus*, *Neptunus* spp. and *Thalamita* spp. were the common crabs feeding on pearl oysters in the farm (Pl. II E). The damage caused to the oysters in the infested cages was severe (Pl. II F).

Shipley and Hornell (1906) identified several stages of cestode larvae in the liver and gills of the pearl oyster *Margaritifera vulgaris* (= *P. fucata*). They have also identified the larvae of trematode *Muttua margaritiferae* in the muscles, mantle and foot of pearl oyster. Except a few such reports not much work has been done on this aspect in the Indian pearl oysters.

Large-scale mortalities of pearl oyster have been reported from the Japanese waters due to red tides and other causes. In the pearl culture farm at Veppalodai widespread blooms of the blue green alga, *Trichodesmium thiebautii* appeared during March-April and September, 1973 but it did not affect the oysters in the farm (Chellam and Alagarswami, 1978).

GENERAL REMARKS

Fouling is a major problem in culture practices throughout the world. The constituents of fouling complex and the dominant organisms are found to vary from place to place, season to season and also year to year. In the Ago Bay, the most important area of pearl culture in Japan, the dominant fouling organisms are the tubicolous polychaetes, bryozoans, barnacles, ascidians, edible oysters and other bivalves (Yamamura *et al.*, 1969). Takemura and Okutani (1955) found tunicates and barnacles to be the dominant organisms on the pearl oyster *P. maxima* in Arafura sea. In the shallow coastal farm at Veppalodai the dominant fouling organisms were the barnacles (*Balanus amphitrite*), bryozoans and bivalves (Alagarswami and Chellam, 1976). The tubicolous polychaetes (*Hydroides* sp.) have not been found to be significant. In the sheltered bay farm at Tuticorin Harbour the barnacles, ascidians, crabs, bivalves and tubicolous polychaetes were the major fouling organisms. Presence of tubicolous polychaetes is the characteristic feature for the bay area. Occurrence of small barnacles throughout the year indicated their continuous breeding. It resulted in successive settlement which caused heavy loading on pearl oysters. Herdman (1906) found crabs, barnacles and sponges on the pearl oyster shells on the Sri Lanka pearl banks. There may be some relation between the frequency of cleaning and the growth of pearls and that dense growth of sessile organisms like edible oysters and barnacles might adversely affect the growth of the pearl oysters and the pearls (Nishii, 1961, Nishii *et al.*, 1961 and Wada, 1973).

Though the bryozoans were abundant in the shallow farm at Veppalodai throughout the year, occurrence was less in the sheltered bay at Tuticorin Harbour.

The boring polychaete *Polydora* has been widely held responsible for great damages in the pearl culture farms in Japan. Mizumoto (1964) found *P. ciliata*, *Terebella ehrenbergi* and *Syllis armillaris* causing extensive blisters on the pearl oyster shells. The spionids *P. ciliata* and *P. flava* were found to be the important borers in the Gulf of Mannar. The intensity of these borers as well as of cirratulid *Cirratulus cirratus* was more at the sheltered bay at Tuticorin Harbour, less in the coastal farm at Veppalodai and negligible in pearl banks (Dharmaraj and Chellam, 1983). Probably depth and the sea conditions may be responsible for the variations noticed in the incidence of these polychaetes.

Herdman (1905a) found that about 78% of pearl oysters examined was infested with *Cliona margaritiferae* in the south west Cheval paar in Sri Lanka pearl banks. He also found *C. margaritiferae*, *Polydora hornelli* and *Lithodomus* sp. which were responsible for the increasing mortality of oysters in Modragam paars (Herdman, 1905b). The occurrence of *C. celata*, *C. vastifica* and *C. margaritiferae* was reported in the farms at Tuticorin by Velayudhan (1983). Infection by *C. celata* and *C. vastifica* was high at Veppalodai farm, less at Harbour farm and negligible in the pearl banks (Dharmaraj and Chellam, 1983). Hundred per cent control of sponge boring was effected by brushing the affected oysters with 1.0% formalin and exposing to air for 15 minutes (Velayudhan, 1983).

Earlier report on predation of pearl oysters in the natural beds in the Gulf of Mannar showed the involvement of different species of *Balistes*, rock fishes, rays, octopus and starfishes (Hornell, 1916). Herdman (1903) had identified some predatory gastropods which caused mortality to pearl oysters. A few others, particularly *C. cingulatum* and *M. virgineus*, have been found to cause oyster mortality in the pearl banks as well as farm during recent years (Chellam *et al.*, 1983).

REFERENCES

ALAGARSWAMI, K. 1974. Development of pearl culture technology in India and scope for a pearl culture industry. In : *Proc. Group Discussion on Pearl Culture*, (R. V. Nair, Ed.), Centr. Mar. Fish. Res. Inst., Cochin : 4-19.

ALAGARSWAMI, K. AND A. CHELLAM. 1976. On fouling and boring organisms and mortality of pearl oysters in the farm at Veppalodai, Gulf of Mannar. *Indian J. Fish.*, **23** (1 & 2) : 10-22.

CHELLAM, A. AND K. ALAGARSWAMI. 1978. Blooms of *Trichodesmium thiebautii* and effect on experimental pearl culture at Veppalodai. *Indian J. Fish.*, **25** (1 & 2) : 237-239.

CHELLAM, A., T. S. VELAYUDHAN, S. DHARMARAJ, A. C. C. VICTOR AND A. D. GANDHI. 1983. A note on the predation of pearl oyster *Pinctada fucata* (Gould) by some gastropods. *Indian J. Fish.*, **30** (2) : 337-339.

DHARMARAJ, S. AND A. CHELLAM. 1983. Settlement and growth of barnacle and associated fouling organisms in pearl culture farm in the Gulf of Mannar. *Proc. Symp. Coastal Aquaculture*, Mar. biol. Ass. India, Pt. **2** : 608-613.

HERDMAN, W. A. 1903. *Report to the Government of Ceylon on the Pearl oyster Fisheries of the Gulf of Mannar*. Royal Society, London. **1** : 1-307.

HERDMAN, W. A. 1905a. The pearl fishery of 1904. In : *Report to Government of Ceylon on the Pearl Oyster Fisheries, of the Gulf of Mannar* (W. A. Herdman *et al.*, Eds.), Pt. III : 1-36, Royal Society, London.

HERDMAN, W. A. 1905b. The present condition of the pearl banks. In : *Report to Government of Ceylon on the Pearl oyster Fisheries of the Gulf of Mannar* (W. A. Herdman *et al.*, Eds)., Pt. III, : 37-48. Royal Society, London.

HERDMAN, W. A. 1906. Pearl oyster report : General summary and recommendations. In : *Report to Government of Ceylon on the Pearl oyster Fisheries of the Gulf of Mannar* W. A. Herdman *et al.*, Eds.), Pt. V : 109-153, Royal Society, London.

HORNELL, J. 1916. An explanation of irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, **8** : 11-22.

HORNELL, J. 1922. The Indian pearl fishery of the Gulf of Mannar and Palk Bay. *Madras Fish. Bull.*, **16** : 1-188.

MIZUMOTO, S. 1964. Studies on disease of the shells of the pearl oyster (*Pinctada martensii*). I. On the species of parasitic polychaetes in shells, the condition of the damages and the extirpation technique. *Bull. Natl. Pearl Res. Lab.*, **9** : 1143-1155.

NISHII, T. 1961. The influence of sessile organisms on the growth of pearl oyster and the quality of cultured pearls. *Bull. Natl. Pearl Res. Lab.*, **6** : 684-687.

NISHII, T., S. SHIMIZU AND M. TANIGUCHI. 1961. Experiments on the cleaning of pearl shells and culture cages in relation to both the growth of pearl oyster and the quality of cultured pearls. *Bull. Natl. Pearl Res. Lab.*, **6** : 670-675.

SHIPLEY, A. E. AND J. HORNELL. 1906. Report on the cestode and nematode parasites from the marine fishes of Ceylon. In :

Report to Government of Ceylon on the Pearl Oyster Fisheries of the Gulf of Mannar. (W. A. Herdman *et al.* Eds.), Pt. V, pp. 43-96. Royal Society, London.

TAKEMURA, Y. AND T. OKUTANI. 1955. Notes on animals attached to the shells of the silver-lip pearl oyster *Pinctada maxima* (Jameson), collected from the ' Best ' fishing ground of Arafura Sea. *Bull. Japanese Soc. Sci. Fish.*, 21 (2) : 92-101.

VELAYUDHAN, T. S. 1983. On the occurrence of shell boring polychaetes and sponges on pearl oyster *Pinctada fucata* and control of boring organisms. *Proc. Symp. Coastal Aquaculture*, Mar. biol. Ass. India, Pt. 2 : 614-618.

WADA, K. 1973. Modern and traditional methods of culture. *Underw. J.*, 5 (1) : 28-33.

YAMAMURA, Y., Y. KUWATANI AND T. NISHII. 1969. Ecological studies of marine fouling communities in pearl culture ground-I. Seasonal changes in the constitution of marine fouling communities at a pearl cultivating depth in Ago Bay. *Bull. Natl. Pearl Res. Lab.*, 14 : 1836-1861.

15

TECHNOLOGY OF CULTURED PEARL PRODUCTION

K. ALAGARSWAMI[1]

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).

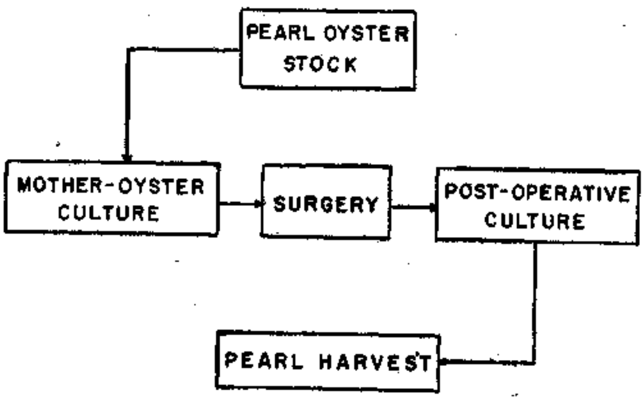

FIG. 1. The five major subsystems of pearl culture system.

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

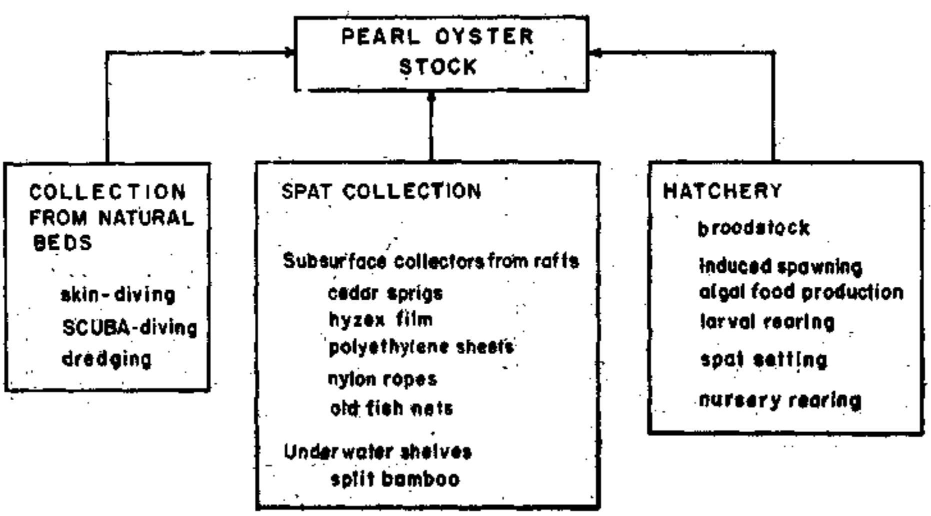

FIG. 2. Steps/methods for raising pearl oyster stock.

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).

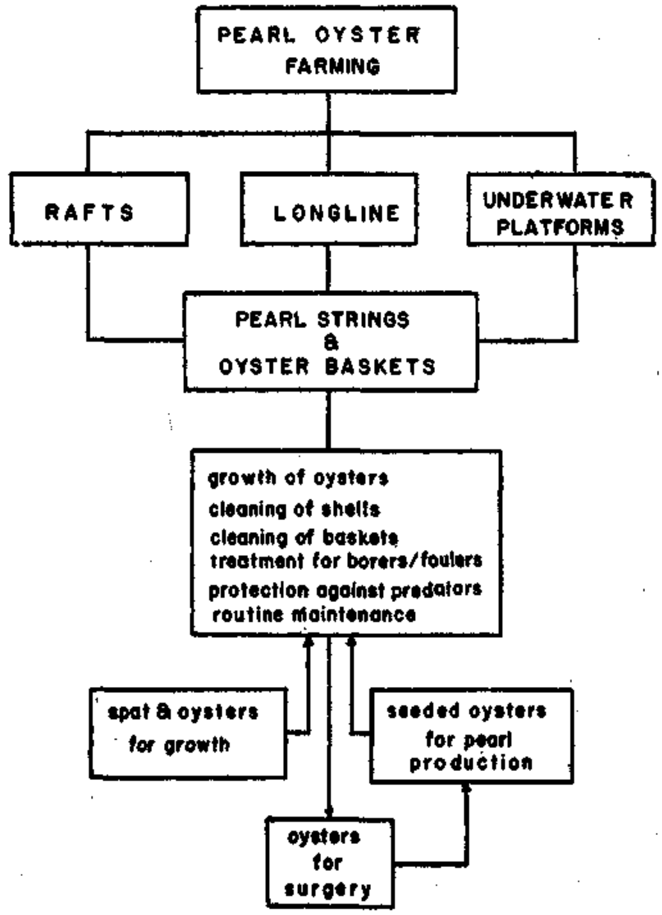

FIG. 3. Steps involved in pearl oyster farming (mother-oyster culture and post-operative culture).

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 μm), the surface of the pearl would be good. If it is more than 20 μm 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

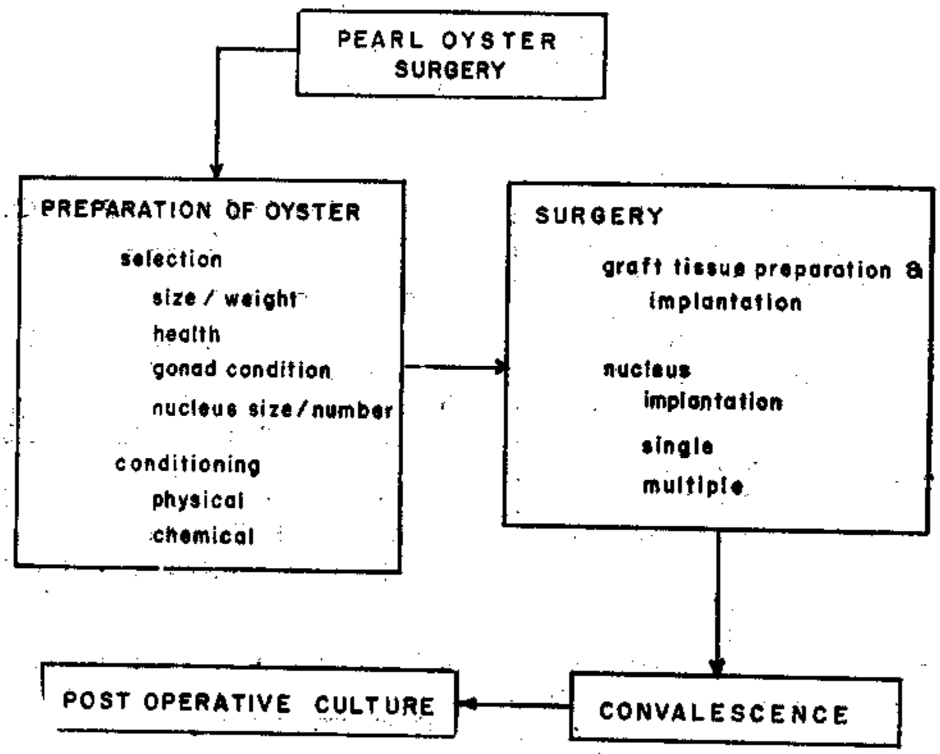

FIG. 4. Steps involved in pearl oyster surgery.

(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).

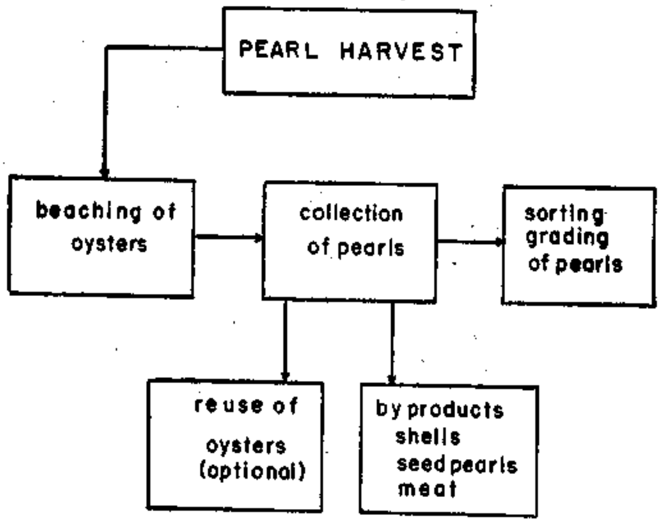

FIG. 5. Steps involved in pearl harvest.

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.

REFERENCES

ABBOTT, R. T. 1972. *Kingdom of the sea-shell.* Hamlyn Publ. Goup Ltd, London, 256 pp.

AHMED, M. 1982. Bangladesh-Country Report. In: *Bivalve culture in Asia and the Pacific* (F. B. DAVY AND M. GRAHAM, Eds.), Proceedings of a workshop held in Singapore, 16-19 February 1982, Ottawa, Ont., IDRC, p. 20.

ALAGARSWAMI, K. 1965. On pearl formation in the venerid bivalve *Gafrarium tumidum* Roding. *J. mar. biol. Ass. India*, 7 : 345-347.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca*, 3 : 975-993. Mar. Biol. Ass. India.

ALARARSWAMI, K. 1974 *a*. Development of cultured pearls in India. *Curr. Sci.*, 43 (7) : 205-207.

ALAGARSWAMI, K. 1974 *b*. Results of multiple implantation of nuclei in production of cultured pearls. *Indian J. Fish.*, 21 (1) : 601-604.

ALAGARSWAMI, K. 1980. Review on controlled breeding of bivalves of aquaculture importance. In : *Progress in invertebrate reproduction and aquaculture* (T. SUBRAMONIAM AND S. VARADARAJAN, Eds.), Univ. Madras, pp. 194-202.

ALAGARSWAMI, K. 1983. The black-lip pearl oyster resources and pearl culture potential. In : Mariculture potential of Andaman and Nicobar Islands (K. ALAGARSWAMI, Ed.), *Bull. Centr. Mar. Fish. Res. Inst.*, 34 : 72-78.

ALAGARSWAMI, K. AND S. Z. QASIM. 1973. Pearl culture-its potential and implications in India. *Indian J. Fish.*, 20 (2) : 533-550.

ALAGARSWAMI, K., S. DHARAMRAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301.

AQUACOP. 1982. French Polynesia-Country Report. In : *Bivalve culture in Asia and the Pacific.* (F. B. DAVY AND M.

GRAHAM, Eds.), Proceedings of a Workshop held in Singapore, 16-19 February 1982, Ottawa, Ont., IDRC : 31-33.

CAHN, A. R. 1949. Pearl culture in Japan. *Fish. Leaflet, U. S. Fish and Wildl. Serv.*, 357, 91 pp.

FAO. 1962. Report to the Government of Sudan on the Sudanese shell industry and Red Sea fisheries. *FAO/EPTA Rep.* (1489), based on the work of William Reed, 47 pp.

HANCOCK, D. A. 1973. Kuri Bay pearls-some of the finest in the world. *Austr. Fish.*, **32** (4) : 11-12.

HERDMAN, W. A. 1903-1906. *Report to the Government of Ceylon on the pearl oyster fisheries of the Gulf of Mannar.* Royal Society, London, Parts I to V.

KAFUKU, T. AND H. IKENOUE (Eds). 1983. *Modern methods of aquaculture in Japan.* Kodansha Ltd, Japan and Elsevier Scientific Publishing Co., Amsterdam, 216 pp.

LOCK, J. M. 1982. Papua New Guinea-Country Report. In : *Bivalve culture in Asia and the Pacific* (F. B. DAVY AND M. GRAHAM, Eds.), Proceedings of a workshop held in Singapore, 16-19 February 1982, Ottawa Ont., IDRC : 53-54.

MACHII, A. 1974. Organ culture of mantle tissue of the pearl oyster *Pinctada fucata* (Gould). *Bull. Natl. Pearl Res. Lab.*, **18** : 2111-2117.

MACHII, A., K. T. WADA, S. J. TOWNSLEY, K. SASAKI AND M. AWAJI. 1985. Application of invertebrate cells *in vitro*. A. Satellite Symposium of the Third International Cell Culture Congress, 14 September 1985. Sendai, Japan. Abstract p. 14.

MATSUI, Y. 1958. Aspects of the environment of pearl-culture grounds and the problems of hybridization in the genus *Pinctada*. In: *Perspectives in Marine Biology* (Ed. A. A. Buzzati-Traverso), Univ. California Press, Berkeley and Los Angeles : 519-531.

MIZUMOTO, S. 1979. Pearl farming in Japan. In : *Advances in aquaculture* (T. V. R. PILLAY AND WM. A. DILL (Eds.), Fishing News Books Ltd, England : 381-385.

MORSE, D. E., H. DUNCAN, N. HOOKER AND A. MORSE. 1976. An inexpensive chemical method for the control and synchronous induction of spawning and reproduction in molluscan species important as protein-rich food sources. *FAO Fish. Rep.* No. 200, FIR/R 200 (E/ES) : 291-300.

SHIRAI, S. 1970. *The story of pearls.* Japan Publications Inc., Japan, 132 pp.

SRIRAMACHANDRAMURTY, V. 1978. Note on the natural pearl of *Placenta placenta* (Linnaeus). *Indian J. Fish.*, **23** (1 & 2) : 243-246.

VELU, M., K. ALAGARSWAMI AND S. Z. QASIM. 1973. Technique of producing spherical shell beads as nuclei for cultured pearls. *Indian J. Fish.*, **20** (2) : 672-676.

WADA, K. 1972. Nucleation and growth of aragonite crystals in the nacre of some bivalve molluscs. In : *Biomineralization Research Reports* (H. K. ERBEN, Ed.), F. K. Schattauer Verlag, Stuttgart : 141-159.

WADA, K. 1973. Modern and traditional methods of pearl culture. *Underwater Journal*, **5** (1) : 28-33.

WADA, K. 1983. Spectral characteristics of pearls. *Gem News*, **10** (4) : 95-103.

WADA, K. T. 1975. Electrophoretic variants of leucin aminopeptidase of the Japanese pearl oyster *Pinctada fucata* (Gould). *Bull. Natl. Pearl Res. Lab.*, **19** : 2152-2156.

WADA, K. T. 1984. Breeding study of the pearl oyster, *Pinctada fucata*. *Bull. Natl. Res. Inst. Aquaculture*, **6** : 79-157.

WADA, K. T. 1986. Color and weight of shells in the selected populations of the Japanese pearl oyster *Pinctada fucata martensii*. *Bull. Natl. Res. Inst. Aquaculture*, **9** : 1-6.

WARD, F. 1985. The pearl. *National Geographic*, **168** (2) : 193-222.

16

CULTURED PEARLS-PRODUCTION AND QUALITY

K. ALAGARSWAMI[1]

INTRODUCTION

Pearls have a premium on quality. The quality differences are so subtle and discrete that even professionals in the pearl trade can make wrong judgements. The value of pearls, on the one hand, is decided on bulk by weight and, on the other, by the quality of individual pearls. Being a biological product, not coming from the assembly line of a factory, individual variations are infinitely large. The secretion of the mantle or the pearl-sac which leads to the formation of the pearl may be organic or inorganic or their combination with unpredictable variations in structure and composition and the product may range from the finest to the trash, ever under the highest possible human control. Therefore, it is opt in this paper to consider the factors that contribute to successful production and to the quality of cultured pearls.

PRODUCTION

The average pearl production rate in the Indian pearl oyster *Pinctada fucata* is about the same as in the Japanese pearl oyster *P. fucata martensi* because the techniques employed are almost identical. However, from batch to batch some differences are common. These are due to various factors such as the health and physiological condition of the oyster, gonad condition, treatment and care at surgery and the seasonal changes in the environmental conditions. Differences in production rates are illustrated in Table 1 which gives the data from the Veppalodai laboratory. These difference can be narrowed down through careful selection of oysters for seeding with nuclei and by controlling the human factors at the surgery.

TABLE 1. *Some examples of gross pearl production rates to show differences as observed at Veppalodai during* 1974-1977

Examined on	No. of oysters	Gross production of pearls (No.)
22.1.'74	17	10
23.2.'74	9	9
23.7.'74	6	1
23.5.'75	38	25
10.12.'75	16	11
3.5.'76	22	17
24.9.'76	22	10
22.9.'77	12	10
Total	142	93 (65.5%)

The factors which are required to be controlled for achieving enhanced production rates are as follows:

Selection of oysters : Size and weight ; fouling load, boring by sponges and polychaetes and blisters ; gonad condition ; and general health as can be judged from the colour of visceral mass and gills.

Conditioning process : amount of menthol used for volume of water and number of oysters ; and duration of narcotisation.

Graft tissue preparation : One of the critical factors controlling the rate of production ; size and quality of donor oyster ; condition of mantle ; region from which mantle is drawn ; process of stretching, cleaning trimming and piece-cutting ; care of orientation ; water quality and chemical agents used in maintaining the tissue pieces and duration of stay on the blocks ; orientation of epithelial sides and standard for nucleus-graft tissue size relationship.

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Implantation : The most important factor in cultured pearl production ; selection of site ; deft handling of needles to reach site ; positioning and orientation of graft tissue in contact with nucleus ; general skill in surgery and patience ; extra care on multiple implantation.

Convalescence : removal of effect of narcotisation by periodic change of water or gentle flowthrough of water ; time for healing of incision ; and subdued metabolism.

Maintenance of tools : sharpness of tools ; sterilisation or good cleaning and sun-drying ; prevention of rusting.

Alagarswami (1974 *a*) reported 55.8% pearl production in the initial six batches of seeded oysters. He (1974 b) obtained 62.8% success in single implantation and 68.3% in multiple implantation with reference to the number of nuclei used and 62.8% and 180.6% respectively with reference to number of oysters used. It is possible to improve these rates further by careful control of the factors mentioned above. Shirai (1970) suggested 70% gross yield rate with 6-mm nuclei and 40% yield with 7-mm nuclei and stated that in the Japanese pearl oyster large nuclei involve a greater financial risk.

Gross production of pearls obtained during harvest is comprised of from the finest pearl to trash. Some of the pearls may be of outstanding colour and perfectly round shape ; many are inferior ; some are totally valueless as gems or jewels ; in some cases the oyster would have only the nucleus in round or eroded form ; and in others even the nuclei would not be present (Shirai, 1970). Such composition is common to pearl culture anywhere in the world. The economic succes of pearl culture depends on the percentage composition of the various categories. The examples of results obtained at Veppalodai are given in Table 2. The categorisation has been simplified to denote only the following three grades of pearls to include those of the best quality or with one minor flaw in grade A, those with minor flaws which can be corrected through processing in grade B and those which cannot be considered to have any economic value except for retrieval of nuclei in grade C.

It may be useful to note the finer categorisation of cultured pearls of the Japanese beaching as given by Shirai (1970) as it is generally common for the pearls harvested from the Indian pearl oyster. Shirai's (1970) categorisation can be represented as follows :

TABLE 2. *Examples of composition of grades of pearls obtained in experimental work at Veppalodai in some batches during* 1974-1976.

Examined on	Gross production (No.)	Grades (No.) A	B	C
22. 1.'74	10	7	2	1
24. 1.'74	8	3	5	..
23. 2.'74	9	6	2	1
6. 9.'74	13	5	3	5
23. 5.'75	25	10	8	7
10.12.'75	11	2	6	3
3. 5.'76	17	2	9	6
Total	93	35 (37.6%)	35 (37.6%)	23 (24.8%)

Class A : flawless, one flaw, small flaws, small stain, pink, silver or light cream. Further categorised into : (A-1) top pearls-perfectly round, pink, flawless and lustrous ; but may include those with small blemishes about the size of a pin-point. (A-2) first class pearls with slightly larger pits and protuberances ; once treated, will become indistinguishable from top pearls.

Class B : fairly large flaws, stains, cream colour, irregularities of shape.

Class C : trash pearls ; wild shaped, badly coated, heavily pock-marked, clayey lumps, half good and half bad.

According to Shirai (1970), Class A and B pearls together usually account for about 60% of a beaching and class B pearls the rest 40%.

STRUCTURE AND COMPOSITION OF PEARL

According to Dubois (1909), as cited by Bolman (1941), the *Pteria* (= *Pinctada*) pearl has the following chemical composition :

Water	..	3.97%
Organic matter	..	3.83%
Calcite and aragonite	..	91.59%
Loss	..	0.61%
		100.00%

It is evident from the above that the pearl is essentially composed of calcium carbonate, which occurs in the two forms of calcite and aragonite, in a sparse organic matrix.

Wada (1970) describes the process of mineralisation of *Pinctada martensii* pearl as follows : A part of the organic substances in the specific solution secreted by the pearl sac epithelium is denatured to form conchiolin. The latter forming the organic matrix over the surface of an inserted nucleus provides the active surface for the initiation of crystal nucleation of calcium carbonate. For the first one or two weeks small crystals of calcium carbonate precipitate here and there on the matrix. These crystals grow larger and larger, join each other and develop into the first mineral lamella. Intercrystalline matrix is sandwiched between them. The second, third and subsequent lamellae are formed and crystals precipitate alternatively with conchiolin layer which is termed the interlamellar matrix. Consequently, the nacre of *Pinctada* pearl consists of the typical laminar structure just like a brick wall.

Wada (1970) further states that the particle size, shape and aggregation of crystals are influenced by the secreting activity of the pearl sac which in turn varies according to the physiological condition of the oyster and environmental factors. Regular laminar structure of nacre gives pearls the iridescence and good lustre, while pearls with an irregular laminar structure are poor in transparency and lustre.

Given the structure and composition of cultured pearl as above, it can be classified into three kinds, namely the nacreous layer pearl, prismatic layer pearl and organic layer pearl. In the nacreous pearl, which alone is valued as jewel, the mineral component is calcium carbonate in aragonite form and the organic matrix is composed of a protein having large amounts of aspartic acid, serine, glycine and alanine residues. The aragonite in the nacre is in a tabular form. The thickness of the lamella is in the range of 0.29 μm to 0.6 μm (Wada, 1970).

Bolman (1941), in his classification of pearls, refers to the following six categories : (1) conchiolin pearls entirely composed of organic matter or mixed with a certain percentage of calcium carbonate ; (2) nacre pearls or aragonite pearls whose outermost layers consist of mother-of-pearl having the same relief drawing as on the internal surface of the shell of the pearl-producing mollusc exhibiting the terrace-shaped structure of the elemental lamellae of mother-of-pearl ; (3) calcite-prism pearls consisting of some prism layers of calcite with or without a covering of nacre layers ; (4) aragonite-prism pearls in which the prism layers are composed of aragonite (typical of freshwater mussel pearls) ; (5) pearls of translucent layers with columnar aragonite crystals situated perpendicular to the terrace-shaped mother-of-pearl laminae ; and (6) pearls of composite structure in which the above different substances appear in variable quantities.

It is evident from the structure and composition of the pearl that several formations are possible during the development of cultured pearls. Only those pearls formed by aragonite crystals in tabular (not prismatic) form, presenting a regular laminar brickwall like structure with microlayers of elemental mineral lamellae alternating with homogenously deposited organic matrix in concentric layers around the inserted nucleus would qualify as gems. The rest of the formations would not and, therefore, will have less or no commercial value. It is important to realise that the present level of technology is not adequate to ensure bulk production of such quality and, hence the scientific pursuit is on towards achieving such a goal in future.

LUSTRE AND COLOUR OF PEARL

The lustre and colour of pearls are mainly due to the reflection and interference of light, and to some extent the colour of the component substance. There is a close correlation between colour and lustre and these are derived from the concentric and external structure of nacreous layers. The colours produced by the Indian pearl oyster are predominantly golden yellow and ivory white and some are grey (Alagarswami and Qasim, 1973). Other pearl colours are pinkish white, silver, cream, yellow, yellowish pink, gold, green, green pink, blue, steel black and black (Matsui, 1960).

Basically the colour of pearl follows the colour of nacre of the shell of the mollusc which produces the pearl which is genetically determined. Thus the pearls produced by *Pinctada maxima* are silver white, *P. margaritifera* black or steel grey, abalone green, freshwater mussels pink. The site at which the nucleus has been implanted also determines the colour. In *P. fucata* while the pearls produced in the ventral region of the gonad are white or golden, those produced in the dorsal region of the gonad in proximity to the hepatopancreas are grey or white. The physiological condition of the oyster again determines the colour of pearl. The environmental factors of the culture grounds play a role in colour formation. The important factors are depth and light penetration. The quality of phytoplankton forming the food of pearl oyster is another factor which is considered important.

Uchida and Ueda (1947) (*vide* Matsui, 1960) found that the golden and cream coloured pearls contain more copper and silver, skin coloured and pink pearls contain more sodium and zinc and that the gold pearl contains more metal elements than the green ones ; the colour varies according to the amount of porphyrins and metalloporphyrins present in the pearls. Sawada (1961) (*vide* Wada, 1970) observed that the iron-bound peptide in the nacre favours the formation of yellow pearls. The organic substances deposited at the beginning of pearl formation also would decide the colour. The good quality blue pearls are of this origin. Above all the granular and laminar structure of nacre produces the iridescence of pearls.

Factors Determining Quality of Pearls

Although several species of pearl oysters occur in the sea, only a few have been found to produce pearls of gem quality. As already mentioned *P. maxima, P. fucata* and *P. margaritifera* stand out distinct from other species in this respect. Efforts to produce pearls in *P. sugillata, P. anomioides* and *P. atropurpurea* at Veppalodai with graft tissue either from the same species or from *P. fucata* did not yield satisfactory results. The pearls were translucent and dull in lustre and the rate of rejection of nuceli was higher. It shows that quality pearls can be produced only by certain species which are genetically capable of producing nacre of high quality.

The culture grounds play a significant role in determining the quality. According to Matsui (1960), some culture grounds yield pearls of good quality, whereas others do not. Some yield pink or white pearls while others produce only yellow and gold pearls. He opined that repeated culture on the same ground often affect the quality of pearl. The Japanese pearl culturists shift their rafts to different locations to take advantage of their potential for yielding good quality pearls. ' Make-up ' culture during the final phase of farming has been a common practice (Alagarswami, 1970). There have been real difficulties in maintaining the quality of pearls in Japan since the late 1960s partly because of pollution problems affecting the quality of seawater (Simkiss and Wada, 1980).

Short-culture practice has been another reason for deterioration in the quality of pearls. Pearls should be allowed to reach maturity in proper time. As quoted by Ward (1985), the Japanese farmers kept the oysters in the water for two and a half years before 1960, but subsequently dropped the duration to one and a half years by 1979 and presently to six to eight months. This short-culture practice results in reduced thickness of nacre on the nucleus and affects the quality of the pearl. Pearls with 0.5 mm nacre in 18 months is acceptable, but those with 0.2 mm nacre achieved in about 6 months are rushed into the market (Ward, 1985).

The rate of growth of nacre is dependent on the size of nucleus. Alagarswami (1975) observed growth of nacre in *P. fucata* pearls at Veppalodai as follows :

Nucleus diameter mm	Thickness of nacre mm	Duration of culture
3.00	0.32	191 days
4.00	0.31	161 days
5.81	0.26	159 days

The above data would show that in the Indian waters the rate of deposition of nacre is much faster than in the Japanese waters and hence pearls of acceptable nacre thickness can be produced at much shorter time.

The time of beaching of oysters for pearl harvest is considered important in getting the best quality. Winter has been found the ideal time in Japan. When the temperature falls down to about 10°C the oyster's metabolism is at the minimum and the nacreous layers deposited are thinner than at higher temperatures. The thinner mineral lamellae on top of the pearl enhances the lustre of the pearl. Also the pH of the body of the oyster is in the range of 7.3-7.5 in winter and the pearl at this time has a good iridescence (Alagarswami, 1970). Thus the time of harvest has to be decided in accordance with the rate of deposition of nacre and the thickness of the mineral lamellae laid down in different seasons, keeping the above factors in view.

Besides the factors of management of pearl culture for improving the quality of pearls as stated above, the current thrust is on application of modern tools such as genetic improvement and tissue culture. These technologies are in early stages of development. The future for improving the quality of cultured pearls appears to be in the advancement in these two areas, besides improving the practices of pearl culture.

The technology of processing of cultured pearls through bleaching and dyeing is a highly specialised area for value addition which is managed by the pearl processing technicians according to the market needs of various trading centres (Shirai, 1970). It is believed that most of the cultured pearls in the market go through some kind of processing for removal of minor defects and improvement of colour.

REFERENCES

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca*, 3 : 975-993. Mar. Biol. Ass. India.

ALAGARSWAMI, K. 1974 *a*. Development of cultured pearls in India. *Curr. Sci.*, **43** (7) : 205-207.

ALAGARSWAMI, K. 1974 *b*. Results of multiple implantation of nuclei in production of cultured pearls. *Indian J. Fish.*, **21** (1) : 601-604.

ALAGARSWAMI, K. 1975. Preliminary study on the growth of cultured pearls. *Indian J. Fish.*, **22** (1 & 2) : 300-303.

ALAGARSWAMI, K. AND S. Z. QASIM. 1973. Pearl culture—its potential and implications in India. *Indian J. Fish.*, **20** (2) : 533-550.

BOLMAN, J. 1941. *The mystery of the pearl*. Internat. Archiv Ethnographie, E. J. Brill, Leiden, 170 pp.

MATSUI, Y. 1958. Aspects of the environment of pearl culture grounds and the problems of hybridization in the genus *Pinctada*. In : *Perspectives in marine biology* (A. A. BUZZATI-TRAVERSO, ed.). Univ. Calif. Press, Berkeley : 519-531.

SHIRAI, S. 1970. *The story of pearls*. Japan Publications Inc., Japan, 132 pp.

SIMKISS, K. AND K. WADA. 1980. Cultured pearls—commercialised biomineralisation. *Endeavour*, **4** (1) : 32-37.

WADA, K. 1970. Cultured pearl and its structure. *Proc. Symp. Mollusca*, 3 : 972-974. Mar. Biol. Ass. India.

WARD, F. 1985. The pearl. *National Geographic*, **168** (2) : 193-222.

17

TRAINING PROGRAMMES IN PEARL CULTURE

K. Alagarswami[1]

Introduction

At the Group Discussion on Pearl culture held at Tuticorin in January 1974, an important decision was taken that the Central Marine Fisheries Research Institute, which had developed the indigenous technology for pearl culture should also organise training courses in this specialised area for the benefit of the development programmes in the country (Swaminathan, 1974 ; Alagarswami, 1974a). India is one of the few countries in the world known for production of natural pearls from time immemorial and had developed a sizable export trade to countries such as Greece and Rome about 2,000 years ago. Realising that the pearl oyster resource of the Gulf of Mannar was of a highly fluctuating nature with several ' barren ' years between sporadic fisheries, Hornell (1916) had concluded that cultivation of pearl oysters and inducing them to produce pearls would be a sound way of making the Indian and Ceylon (now Sri Lanka) pearl fisheries consistently remunerative. This was the period when Japan had just developed the technology of pearl culture and was attempting to put the product in the markets in Europe. Since 1933 conscientious efforts were made by the Department of Fisheries, Government of Tamil Nadu (then Madras), over a period of more than three decades, to develop the technology of pearl culture at Krusadai (Alagarswami and Qasim, 1973). However, success was achieved only in 1973 when the Central Marine Fisheries Research Institute took up an experimental project on pearl culture at Veppalodai near-Tuticorin (Alagarswami, 1974b).

At that point of time, the pearl oyster beds in the Gulf of Mannar were in the midst of a most unproductive phase, having been heavily exploited from 1955 to 1961. Even though the technology for pearl oyster farming and production of cultured pearl became available indigenously, the natural beds of pearl oysters were ' barren ' and there were apprehensions in several quarters that the technology could not be put to use as there were no oysters (Tamilnadu Fisheries Dept., 1974). The situation of pearl oyster resource in the Gulf of Kutch was no better (Pandya, 1974).

Not losing hope, the Central Marine Fisheries Research Institute developed another research project for the hatchery production of pearl oyster which resulted in a breakthrough in 1981 (Alagarswami *et al.*, 1983). Production through breeding, larval culture and spat rearing became a reality and, subsequently, the technology was scaled up to produce over a million spat in one rearing. This gave the answer to the critical situation of paucity of resource.

Thus the Central Marine Fisehries Research Institute became the nucleus of pearl culture R & D in India. In consonance with the policy of transfer of technology of the Indian Council of Agricultural Research, the Institute developed training courses in the areas of (1) technology of pearl culture and (2) technology of hatchcery production of pearl oyster and implemented such training programmes, beginning from 1976.

Training Programmes in Pearl Culture

Ever since Japan developed the technology of pearl culture and captured the world market for cultured pearls, the industry was operating on certain principles to guard the technology, with provisions for joint ventures abroad (Alagarswami, 1970 ; Ward, 1985). The pearl culture industry of Australia, Burma, Indonesia, Malaysia, Philippines and Thailand was developed under this provision but the technology was

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never made available to the host countries. After the World War II, Cahn (1949) published information on Japanese pearl culture which was perhaps the first document in English which gave the details to the rest of the world. Two decades later, Alagarswami (1970) updated the information. With indigenous developments in technology (Algaraswami, 1974b ; Alagarswami *et al.*, 1983), the CMFRI adopted an open policy of training. Possibly this is the only centre which offers such training in pearl culture not only for Indian nationals but also to foreign technicians who are sponsored through the Governments.

Long-term course

CMFRI (1977) gives the details of the two types of training courses offered in pearl culture technology. The 'Manual on Pearl Culture Techniques' is a helpful guide for the trainees in practical exercises (Alagarswami and Dharmaraj, 1984). The first training course was a long-term course of six months duration which was held from 24 September 1976 to 23 March 1977. This was a comprehensive course for managerial and supervisory personnel dealing with pearl oyster resources, biology, ecology, farming, surgery, production and management. The long-term course was not repeated due to practical problem of taking time off for six months from the trainers' and trainees' jobs in their respective organisations. The detailed curriculum of the long-term course was as follows :

Introduction

Theory : Origin of pearls, molluscs producing pearls ; pearl oysters of the world ; pearl fishing in the world : development of cultured pearls ; pearl culture in Japan and other countries ; ecology of pearl culture ; modern trends in pearl culture ; developments in India.

Pearl oyster-its biology

Theory : Morphology ; dimensional relationship ; anatomy ; systems and functions ; histology of mantle : pearl-sac formation ; development and growth ; age ; feeding ; maturation and spawning.

Practical : Examination of specimens for morphological features ; dissection and display of systems ; observation of maturity conditions ; location of potential sites for pearl production.

Pearl oyster resources

Theory : Habitats of pearl oysters ; history of pearl fisheries of the Gulf of Mannar and Gulf of Kutch ; production of oysters in recent years ; fishing techniques ; SCUBA-diving ; spat settlement in new areas and its development.

Practical : Sea trips to pearl banks to observe and collect pearl oysters ; collection trips to other areas ; observations on spatfall ; collection of spat and rearing.

Mother-oyster culture

Theory : Site selection ; raft culture of pearl oysters ; collapsible and rigid rafts ; designs and construction of rafts ; buoying and mooring ; holding nets ; baskets ; boxes ; depth of suspension ; farm maintenance.

Growth of oysters in the farm ; fouling and boring organisms ; shell-cleaning operations ; effect of fouling on the well-being of oysters ; mortality of oysters.

Spat collectors ; collection and rearing of spat.

Practical : Construction of rafts ; floating and mooring ; farm work including cleaning of oysters, measurement of oysters, rearing of oysters to suitable size and maintenance of rafts.

Pearl-oyster surgery

Practical : Selection of oysters for operation : acclimatisation ; conditioning of oysters.

Selection of donor oysters ; use of special instruments ; graft-tissue preparation.

Selection of nucleus according to size and physiological condition of oysters and nature of seeding.

Operation on oysters ; fixing sites of implantation ; single and multiple implantation ; use of special instruments ; insertion of graft tissue ; implantation of nuclei.

Convalescence of operated oysters ; rate of rejection of nuclei ; rate of mortality ; returning the oysters to farm for post-operative culture.

Post-operative culture

Practical : Post-operative culture ; observations on pearl-sac formation and nacre deposition ; limiting duration to the requirement of maturity of cultured pearls. Rearing of oysters according to size of nucleus and nucleus load.

Pearl collection

Practical: Beaching of oysters for harvest of pearls ; opening oysters without injury to the pearls ; collection and cleaning of pearls ; decision-making on re-use of oysters and proper care of oysters selected for re-use. Estimation of yield of pearls in relation to the culture techniques. Retrieving unsuccessful nuclei for further use.

Sorting of pearls, shape, size, colour and lustre ; standards of grading ; storage of pearls.

By-products of pearl culture ; seed pearls, edible meat and shells.

Management

Theory : Scale of operation in other countries : family scale—cooperative—big business ; preparation of projects ; farm management; personnel management ; relationship between inputs and outputs ; adjusting inputs ; evaluation ; marketability ; profitability ; constraints and possible methods of overcoming them ; pearl trade in India ; imports and exports ; consumer preference in India and abroad ; scope of pearl culture in India.

Short-term course

The course content for the short-term programme was developed with a view to impart training at the technician's level. This is of 4-6 weeks duration. The course is more popular among the interested organisations. Four short-term courses have been held so far : (1) 22 August 1977 to 24 September 1977 ; (2) 9 July 1979 to 18 August 1979 ; (3) 8 October 1984 to 2 November 1984 ; (4) 8 September 1986 to 4 October 1986. The curriculum of short-term course is as follows :

Introduction

Theory : Morphology and anatomy of pearl oyster ; functions of mantle ; pearl-sac formation ; mechanism of production of cultured pearls.

Mother-oyster culture

Practical : Raft culture of oysters ; construction of rafts and holding baskets ; pearl-oyster collection and farming ; farm maintenance ; care of oysters.

Pearl-oyster surgery

Practical : Handling of surgical instruments ; selection and conditioning of oysters ; graft-tissue preparation ; nucleus implantation ; post-operative care of oysters.

Pearl collection

Practical : Beaching ; collection of pearls ; cleaning of pearls ; sorting of pearls.

Training Programme in Pearl Oyster Hatchery

The course which is of four weeks duration is not only useful to those concerned with pearl culture but can benefit any molluscan aquaculturist wishing to raise marine bivalve stocks in hatchery. The first training programme in hatchery technology was organised from 27 October 1986 to 22 November 1986. The course curriculum includes shellfish hatchery, breeding of pearl oyster, induced maturation and spawning, larval rearing, water quality management, microalgal production and larval feeding, disease control, spat settlement and collection, and juvenile rearing.

Impact of Training

The main objective of the training courses on pearl culture and pearl oyster hatchery has been to help the development effort of the country in establishing cultured pearl production projects and also to aid research effort in certain centres on location-and species-specific problems. Naturally the participants were drawn from the fisheries organisations of the maritime States and Union Territories. Tamil Nadu and Gujarat are the two States in India which have pearl oyster beds exploited for several centuries. They had the maximum participation in the training courses. Tamil Nadu has a commercial project in pearl culture as a joint venture. Gujarat has an R & D programme in pearl culture at the Department of Fisheries.

Lakshadweep has responded to the programme very favourably, after realising the potential for pearl culture in the islands. The Union Territory has an R & D project in Bangaram based on the local resource of pearl oysters. Andaman & Nicobar Islands has even a greater potential for pearl culture (Alagarswami, 1983). The Central Agricultural Research Institute of Indian Council of Agricultural Research is implementing a research project on the black-lip pearl oyster. Kerala had a pilot project in pearl culture based on the pearl oyster spat settlement in the Vizhinjam Bay which was identified and developed by this Institute (Achari, 1982). Besides, training was given to officials of Department of Fisheries, Karnataka, a scientist of the Konkan Krishi Vidyapeeth and a candidate sponsored by the Department of Fisheries, West Bengal. A Fisheries Technician from South-East Asian Fisheries Development Centre, Iloilo, Philippines attended one of the short-term training courses.

The training programme organised have had positive impact in the country and it is hoped that it will generate and sustain further interest both in terms of research and development.

REFERENCES

ACHARI, G. P. K. 1982. New designs of spat collectors, breeding hapas, cages and improved techonology for pearl farming. *Symp. Coastal Aquaculture*, Abstract No. 182, 12-18 January 1980, Cochin, Mar. Biol. Ass. India.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca*, Part III : 975-993. Mar. Biol. Ass. India.

ALAGARSWAMI, K. 1974a. Development of pearl culture in India and scope for a pearl culture industry. *Proc. Group Discussion on Pearl Culture* (R. V. Nair, Ed.), 24 January 1974. Cent. Mar. Fish. Res. Inst.: 4-19.

ALAGARSWAMI, K. 1974*b*. Development of cultured pearls in India. *Curr. Sci.*, 43 (7) : 205-207.

ALAGARSWAMI, K. 1983. The black-lip pearl oyster resources and pearl culture potential. In : Mariculture potential of Andaman and Nicobar Islands (K. ALAGARSWAMI, Ed.), *Bull. Centr. Mar. Fish. Res. Inst.*, 34 : 72-78.

ALAGARSWAMI, K. AND S. DHARMARAJ. 1984. *Manual on pearl culture techniques.* CMFRI Special Publication, 20, 42 pp.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301.

ALAGARSWAMI, K. AND S. Z. QASIM. 1973. Pearl culture—its potential and implications in India. *Indian J. Fish.*, 20 (2) : 533-550.

CAHN, A. R. 1949. Pearl culture in Japan. *Fish. Leaflet, U. S. Fish and Wildl. Serv.*, 357, 91 pp.

CMFRI. 1977. *Pearl culture training*. CMFRI Special Publication, 1, 39 pp.

DEPT. OF FISHERIES, TAMIL NADU. 1974. The present status of pearl oyster resources along the Tamil Nadu Coast. *Proc. Group Discussion on Pearl culture* (R. V. Nair, Ed.), 24 January 1974, Cent. Mar. Fish. Res. Inst.: 20-24.

HORNELL, J. 1916. An explanation of irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, 8 : 11-22.

PANDYA, J. A. 1974. Pearl oyster resource and culture experiments in Gujarat. *Proc. Group Discussion on Pearl Culture* (R. V. Nair, Ed.), 24 January 1974, Cent. Mar. Fish. Res. Inst.: 25-27.

SWAMINATHAN, M. S. 1974. Speech by Dr. M. S. Swaminathan. *Proc. Group Discussion on Pearl Culture* (R. V. Nair, Ed.), 24 January 1974. Cent. Mar. Fish. Res. Inst.: 28-32.

WARD, F. 1985. The pearl. *National Geographic*, 168 (2) : 193-222.

18

PROGRESS OF RESEARCH UNDER SCHEME ON PEARL CULTURE, 1974-78

DEPARTMENT OF FISHERIES*, GOVERNMENT OF TAMILNADU

The lucrative pearl fishery in the Gulf of Mannar could not be conducted after 1961 due to the paucity of oysters in the natural beds. So the only way to have continuous supply of pearls is the production of cultured pearls utilising the available oyster resources. This needs preliminary investigations. Only when the cultured pearl production technology, farming and other allied techniques are perfected, a venture can be made in the direction of commercial production.

To perfect the technique of cultured pearl production and farming, the Pearl Culture Scheme of Department of Fisheries, Tamil Nadu Government was started in collaboration with Central Marine Fisheries Research Institute, Tuticorin. The programme commenced functioning from 8-2-1974. During the period under report, significant progress in all aspects of pearl culture were achieved.

Establishment of farm

Modern method of raft culture was employed for farming pearl oysters. Unit raft system was adapted to suit the turbulent conditions prevailing in the sea. The rafts used were of size 5 × 5 m, constructed with 'Venteak' and 'Kongu' timber. To the four corners were attached four wooden barrels which acted as buoys. The wooden frames of the rafts were bolted with iron bolts. The fabrication of the raft was completed on shore, pushed into the sea, towed to a place of desired depth and moored with the help of anchors.

Oysters collected from the natural beds by skin-diving and SCUBA diving were segregated size-wise, measured and put in different types of cages which included sandwich type, box type and pigeon-hole cages. The frames of the cages were made of iron rods, which were painted with anticorrosive paints and then woven with nylon twine of 1-2 mm size into meshes of size 2 × 2 cm. Then specified number of oysters were put in the cages according to the size and they were suspended from the raft at a depth of about 6 m.

Rearing of oysters at Tuticorin

A raft was fabricated and floated in the Tuticorin Major Harbour basin on 12-3-1975 for the first time. An initial stock of 1,146 pearl oysters collected from the natural beds were put in box type and sandwich cages and reared. In the subsequent year, the stock of live oysters was raised to 3,328 numbers. The second raft was constructed and kept afloat in the same area on 15-7-1976. In March, 1977 a stock of 840 *Pinctada fucata* and 5,500 flat oysters were there in the farm. From April 1977 onwards the rafts were maintained outside the harbour basin near the wharf wall of the north breakwater. After the damage caused to the rafts in December 1977 due to the cyclonic weather, the rafts were shifted and moored near the jetty of the Hare Island in calm waters. Thereafter the rafts were kept afloat near the wharf wall in the north breakwater from May to September and during the rest of the year near the jetty of the Hare Island. On 30-6-1977, 2,009

Note : The 'Scheme on Pearl Culture' was an *ad-hoc* project of the Indian Council of Agricultural Research implemented by the Central Marine Fisheries Research Institute in collaboration with the Department of Fisheries, Government of Tamil Nadu during the period 1973-1978. This progress report received from the Department of Fisheries and edited for inclusion in this Bulletin gives the results achieved by the Department under the Scheme during 1974-1978.

* Y. Jeyabhaskaran was the Assistant Director of Fisheries (Pearl culture), Tuticorin in charge of the programme. Others who were associated with the Scheme for various durations were N. Radhakrishnan, Assistant Director (additional charge) and Research Assistants S. M. Dowlath, R. Shaick Jalaludeen, Daniel Sudhandra Dev, S. Subramanian, P. Muthiah, I. Nalluchinnappan and M. Ayyannan (taken from the Report).

flat oysters which could not be utilized for culture work were released in Vantivu Arupagam paar. At the end of 1978, 622 *Pinctada fucata* and 592 flat oysters were there in the rafts.

Farming at Krusadai island

The first raft at Krusadai Island was fabricated and kept afloat near the jetty of the island on 26-2-1977 and 2,025 *P. fucata* transferred from Turicorin farm were reared in it. The second raft was moored on 21-3-1978 with 2,800 *P. fucata* also transported from the collections at Tuticorin.

Utility of oysters

From the experiments conducted it was found that *Pinctada fucata* is the best suited pearl oyster for the culture pearl experiments. Besides the above species, flat pearl oysters like *Pinctada sugillata, P. chemnitzii, P. margaritifera, P. anomioides* and other *Pinctada* species were also available in the Gulf of Mannar. Since these flat oysters could not be effectively utilized in culture work, they were released in Vanthivu Arupagam Paar in batches in January and June 1977 and further collection of flat oysters was stopped.

Planktonology and hydrology of the farm area

From March 1975 after the establishment of farm to the end of the period under report regular plankton and water samples were collected and analysed. Since the results obtained in the different farm areas in these inshore waters did not exhibit any marked difference, the data have been pooled and furnished.

In the plankton samples, the diatoms recorded were *Rhizosolenia* spp., *Navicula* spp., *Nitzschia* spp., *Coscinodiscus* spp., *Biddulphia* spp., *Thallassiosira* spp., *Thalassiothrix* sp., *Ditylium* spp., *Planktoniella* sp., *Trichodesmium* spp. *Oscillatoria* spp. *Gyrosigma* spp.. *Pleurosigma* spp. *Hemidiscus* sp., *Isthima* sp. *Bacillaria* sp., and *Triceratium* sp. Among the Dinophycean members *Peridinium* spp., and *Ceratium* spp., were observed.

The protozoans identified include *Noctiluca* sp., *Globigerina* sp., *Acanthopteran* sp. and *Tintinopsis* sp. The common copepods noticed were *Eucalynus* spp., *Acrocalanus* spp., *Corycaeus* sp., *Rhincalanus* sp., *Oithona* spp., *Metis* sp. and *Macrostella* sp. The cladocerans seen were *Evadne* spp. and *Penilia* sp.

The copepod abundance was seen tn August and November-February. Lucifers and cladocerans were abundant in December and February. *Pleurobrachia* sp. and coelenterate medusae were found in considerable numbers in September and March. *Trichodesmium* bloom was noticed in March.

Among crustacean larvae penaeid nauplius, zoea and mysis were very common. Chaetognath *Sagitta* sp. was abundant during April-Septmber. Trochophore and polychaete post larval stages of annelids were recorded throughout the year. Bivalve larvae were abundant in August and Septmber. The pteropod *Creseis* sp. was noticed in March, May and December. Tunicate *Doliolum* sp. and *Oikopleura* sp. were also recorded.

The hydrographical investigations of the pearl oyster farm were carried out intensively during 1975-78 and the annual range of average values are furnished in Table 1.

Growth studies

From December 1975 till the end of the period under report different growth experiments were conducted. Rate of growth of pearl oysters was observed in groups and in individual oysters.

TABLE 1. *Average analytical data of water samples collected from the pearl oyster farm area*

Year	Temperature °C	pH	Dissolved Oxygen ml/l	Free CO_2 ppm	Carbonates ppm	Bicarbonates ppm	Salinity ‰	Phosphate ppm	Silicate ppm	Calcium ppm
1974	24.4-25.5	7.8-8.0	5.04	Nil	18-22	80-85	33.05	Tr-0.02	Tr-4.0	—
1975	26.1-32.3	7.8-8.4	3.9-7.3	Nil	10-28	87-112	32.17-37.00	Tr-0.18	Tr-16.0	9.98-12.99
1976	25.2-30.6	8.0-8.4	3.6-7.4	Nil	9-12	94-118	30.16-36.00	Tr-0.04	Tr-6.0	8.01-10.01
1977	24.8-32.0	8.2-8.4	1.98-6.9	Nil	12-32	70-130	24.2-33.97	Tr-0.08	Tr-14.0	8.74-11.02
1978	29.5-31.0	8.3--8.4	4.4-5.3	Nil	12-22	102-118	34.03-35.63	0.04-0.2	1.0-3.6	10.16-10.81

Two sets of 50 *Pinctada fucata* each belonging to two different size groups were studied for one year. These oysters were collected from Tholyiram paar and reared in box-cage (40 × 40 × 10 cm) in the farm from March 1977 to March 1978. The average values of dorsoventral measurement, hinge length and width of the first batch of young oysters were initially 20.2 × 26.4 × 7.0 mm and at the end of the experiments they reached an average of 48.2 × 41.2 × 18.4 mm. The batch of bigger oysters measuring 47.6 × 40.9 × 16.5 mm initially, attained 57.9 × 47.9 21.7 mm only in March, 1978.

Another experiment to study the individual growth of oysters for one year commenced in January 1978. A special cage called 'Pigeon-hole cage' with 20 cubicles or compartments was designed. The size of the cage was 60 × 45 × 9 cm and that of each cubicle was 12 × 11.2 × 9 cm.

From the experiments conducted it was observed that the growth of oysters was continuous. Young oysters exhibited faster rate of growth and older size group showed comparatively poor and retarded growth. Appreciable and continuous growth measurements were recorded during November to February. In January and February finger-like growth processes were noticed which is evidence of luxurient growth, especially in young oysters. It was recorded that the growth rate was influenced by temperature, salinity and settlemnt of foulers on oysters. Faster growth was generally noted when the temperature and salinity of the inshore waters were relatively low and when the settlemen of foulers was less.

Isolation and rearing of bivalve larvae

Attempts were made to rear bivalve larvae in laboratory condition by segregating larvae from plankton samples. Rearing of bivalve larvae required many secondary investigations such as phytoplankton culture as food and control of bacterial and ciliary infections etc. This experiment was started in October 1975.

Observations revealed that at 202 μm size foot began to develop and at 280 μm the functional foot and velum were present. At 300 μm velum disappeared and a well-developed foot formed.

Bivalve larvae were isolated from the plankton samples, brought to the laboratory, measured and reared. They were reared in sterilized seawater and fed with cultured phytoplankton. The size of the larvae measured between 48 μm and 448 μm in the experiments conducted. Phytoplankton culture was carried out in Loosanoff's medium and enrichment medium. Using Agar agar as medium in petriplate technique, monoculture was carried out. The larvae were successfully kept alive for a period of 27 days. Bacterial and ciliary infections caused mortality and antibiotics were tried to overcome this.

Studies on fouling and boring communities

Usually oysters collected from the natural beds exhibited very little fouling. But heavy biofouling on oysters, cages and other material of the rafts pose problems in the farm. The study of fouling organisms commenced along with the establishment of pearl oyster farm in March 1975. The foulers were collected and studied while cleaning oysters, cages and during replacement of wooden barrels. Experiments were conducted to study the intensity of settlement and seasonal abundance of foulers. Settlement was heavy towards the surface. From March onwards an increase in settlement of foulers was noted. However the peak months were May-August. Comparatively high rate of mortality of oysters was observed when there was heavy load of foulers. A decline in settlement was seen from November to January. The best method to minimise the effect of foulers and control them was periodical and regular cleaning.

The predominant fouling organisms throughout the year were barnacles. During the winter months the oysters were vulnerable to the attack of borers like the sponge *Cliona* sp. and polychaete *Polydora* sp.

Seaweeds recorded from the cages include *Enteromorpha* sp., *Dictyota* sp. and *Gelidium* sp. in December, January and March. *Ceratium* sp. was found throughout the year. Hydrozoans, sea anemones and turbellarians were observed in cages and on oysters in March, September and January. Polyzoans *Membranipora* sp., *Thalamoporella* sp. were noted in March, April, May, August and September. Among the annelids *Polynoe* sp., *Perinereis* sp. and *Eunice* sp. were seen in April and May. The arthropod *Balanus* spp. was found throughout the year. *Lytamata* sp. was abundant in August-December and March-May. *Gonodactylus* sp. was recorded in April. Isopods *Cilicaea* sp. and amphipods were seen throughout the year. Decapods *Charybdis* spp. and *Pinnotheres* sp. were found throughout the year. *Panulirus* sp. and pycnogonids were noted in May and August respectively. Among the molluscs *Cypraea* spp., *Murex* sp., *Drupa* sp., *Pyrene* sp., *Cymbium* sp., *Pleurobranchus* sp., *Doris* sp., *Onchidium* sp., *Pinna* sp. and *Crassostrea* spp. were observed. *Avicula* sp. spat occurred in October. *Modiolus* sp. appeared in April, May and December and green mussel spat was seen in November and July. Echinoderm *Antedon* sp. was found in June-August. Tunicates *Ascidia* sp., *Diandrocarpa* sp., *Stylea* sp., *Leptoclinum* sp., *Didemnum* sp. and *Botrylloides* spp. were noted in March-May and September. *Rhadocynthia* sp. was found in March-August. Fishes like *Pteroscrites* sp., *Blennius* sp., *Gobius* sp., *Siganus* sp., and *Acanthurus* sp. were also found throughout the year inhabiting the pearl oyster cages and dead shells.

Spat collection employing spat collectors

Variously designed spat collectors were laid in the farm to attract settlement of pearl oyster spats so that continuous availability of oysters could be ensured for pearl culture experiments in future.

The experiments conducted in this regard during the period 1974-78 yielded very poor results. So far no effective spat collector was found out. Spat collectors such as cement coated iron frames, tar coated iron frames, tiles, tiles white-washed, nylon frills, tar coated wooden planks, cement coated iron cages, fibre-netted frames etc. were used. However the settlement noticed was only stray and very poor. Such stray settlements were noticed on oyster cages, ropes and wooden barrels of the rafts also.

Implantation of nucleus in culture pearl production at Tuticorin and Krusadai

The surgery and implantation of nuclei for the production of cultured pearls was started at Tuticorin laboratory on 3-6-1976. Since there was no needed facility available at Krusadai Island, the implantation work of oysters of the Krusadai farm were conducted at Mandapam in the Krusadai Marine Biological Station from 7-7-1977. The first pearl at Tuticorin was produced on 12-11-1976 and for the first time pearls were produced in the Kursadai farm on 7-12-1977. Fully formed pearls were collected after three months from the date of implantation.

During the period 1976-78 the success achieved in pearl production was estimated to be upto 38%. The pearls produced were of different shades. The colours were silver white, cream, golden yellow and steel grey. The rate of mortality was successfully brought down during the post-operative period. Use of menthol to narcotise the oysters was minimised, but in an effective way. Multiple implantation was also tried to increase pearl production.

Indigenous production of nuclei

From the inception of this Scheme efforts were made to make chank bead nuclei from the shells of sacred chank *Xancus pyrum*. The outcome with chank beads locally made were not upto the expectations and yielded only poor results.

Use of Japanese nuclei

From 1977 onwards Japanese nuclei were used for implantation work at Tuticorin and Krusadai. Experiments with these nuclei proved that the imported nuclei were the best suited for cultured pearl production.

Instruments for implantation work

Sets consisting of various precision instruments were manufactured and supplied by the Indian Drugs and Pharmaceuticals Limited, Madras. These tools were being effectively employed in the minute surgery during nucleus implantation work to produce cultured pearls.

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PROBLEMS AND PROSPECTS OF PEARL CULTURE IN INDIA

P. S. B. R. JAMES[1]

INTRODUCTION

When Kokichi Mikimoto took the small step forward in 1893 by producing a few blister pearls in the Japanese pearl oyster *Pinctada martensii* (= *P. fucata*) at the coastal village of Jinmiyonmura on Ago Bay, a new industry of pearl culture was born. As he was building up a small-scale industry, a few marine scientists and technicians got themselves interested in it and, in 1907, Tokichi Nishikawa produced the first spherical cultured pearl in the oyster. Subsequently, the credibility of cultured pearl as jewel was established in the 1920s and was followed by a boom of pearl culture industry with a master touch of Mikimoto and several other industrialists who joined the bandwagon. After World War II, pearl culture industry was established in Australia, Philippines, Burma, Thailand, Malaysia and Indonesia, all with Japanese collaboration.

In India, since late James Hornell sowed the idea of pearl culture in 1916, there has been interest and some experimental work done in Tamil Nadu since 1938 and in Gujarat since 1958. However, success in developing the technology was achieved only in 1973 when the first batch of free, spherical cultured pearls was produced at the Central Marine Fisheries Research Institute (Alagarswami, 1974). While research on pearl culture continued since then, it took a decade for the establishment of an industry for the production of cultured pearls in 1983. This paper briefly identifies the problems of pearl culture in India and indicates the prospects for future.

RESOURCE OF PEARL OYSTERS

The pearl fisheries of India in the Gulf of Mannar and Gulf of Kutch have been well known for the production of the finest of natural pearls. Both are based on the species *Pinctada fucata*. The major problem with these resources has been that production in natural beds has fluctuated very wildly and the years when they have yielded to fishery have been a few and far between (Mahadevan and Nayar, 1973). Resource of such character cannot be depended upon in pearl culture for which the supply of oysters has to be on time and in required numbers. A second species of pearl oyster *P. margaritifera* has recently been suggested as a potential candidate species for pearl culture in India based on the indicative survey on mariculture potential of Andaman and Nicobar Islands carried out by the CMFRI (Alagarswami, 1983). The species does not occur along the mainland coast in any appreciable numbers. A species which is believed to occur in the Andaman and Nicobars, based on the analogy of its occurrence and culture in the Mergui Archipelago of Burma, is *P. maxima*. Several other species such as *P. sugillata* and *P. anomioides* occur in the Indian waters but these have not been found useful in production of cultured pearls. It is obvious that *P. fucata* will form the mainstay in any pearl culture effort in India with *P. margaritifera* as supporting species when technology is worked out. The problem has been in the area of assured steady supplies of pearl oyster.

The efforts on enhancing the resource through spat collection have not been very successful as can be seen from the data presented in some of the chapters of this Bulletin. Spat collection on the natural beds of Gulf of Mannar is logistically difficult in terms of distance, depth, accessibility and security and no meaningful effort could be made so far. Spat settlement in inshore areas has been moderate but it is composed of multispecies *Pinctada* populations with a progressively declining *fucata* component as seen at Vizhinjam (Achari, 1982) and at Tuticorin (Alagarswami, 1977). The general conclusion that arises from the experimental work conducted so far is that inshore spat collection would not be of much use in pearl culture.

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In this despairing situation, the silver lining was the development of hatchery technology for production of pearl oyster at the CMFRI (Alagarswami *et al.*, 1983). It has been shown that over a million spat of *P. fucata* can be produced in one larval rearing in the hatchery. The technology is adoptable for any species of marine bivalve. Experimental success has recently already been obtained with *P. margaritifera.* It is a question of rearing the spat upto the stage they can be used in pearl production programme which is one of farm management problems.

Maintaining a 'breeding reserve' of pearl oysters in the Gulf of Mannar has been a popular suggestion put forward by earlier workers (Devanesen and Chidambaram, 1956). The present author has been interested in sea-ranching of pearl oyster from hatchery to the natural beds to see the possibility of reviving the pearl oyster population. The programme, commenced by end of 1985, is under monitoring.

Technology of Pearl Culture

For over half a century the technology of pear culture has not undergone much change from the basics of cultured pearl production (Cahn, 1949; Alagarswami, 1970; Wada, 1973; Mizumoto, 1979; Kafuku and Ikenoue, 1983; Ward, 1985). Till late 1960s when the pearl crash occurred after 1966, even the need for change was not recognised at the farmer's level. Subsequently there has been overwhelming interest in experimental work in two directions, namely genetic improvement of stocks and tissue culture of mantle. Practical application of mantle tissue culture in production of cultured pearl has already commenced (*Technocrat*, 18 (4), 1985).

The techniques of farming and pearl production developed in 1973, continue to remain in the region of basics. The rate of pearl production and composition of grades remain around the average. There is need for change and improvement in technology along modern lines if pearl culture in India is to be competitive.

Infrastructure and Manpower

Pearl oyster farming is the major component of the activities of pearl culture. This is a continuous operation with rafts, longlines or bottom platforms in position in the sea round the year, with the pearl oysters coming in and going out of the farm. The marine conditions are dynamic with seasonal changes and annual variations. Areas subject to monsoon, typhoon and cyclone have to pay a very high premium in maintaining structures in the open-sea. Certain countries have ideal locations along their coast in their bays and lagoons to carry out pearl oyster farming without any major problem such as Japan, Australia and Philippines. The Indian pearl culture at present has a special problem in this respect with almost straight coastlines of the mainland. The only area whch has some protection and affords tolerable sea conditions is the Gulf of Mannar where pearl culture is being carried out. By no means these are ideal conditions as compared to the Japanese bays. The Andaman-Nicobar and Lakshadweep islands offer better scope and conditions for pearl culture but lack other necessary infrastructure facilities. The future for pearl culture would appear to lie in these islands. Pearl culture on the mainland coast would need greater logistic support and investment in farming than in the islands,

A programme of manpower development for pear culture was initiated at the CMFRI as early as 1976 with the establishment of training courses (CMFRI, 1977). Transfer of technology has been done at various levels and in different manner through training, technical expertise and consultancy. There is no problem in this respect and certain foreign institutions have been interested in the Indian expertise in pearl culture.

R & D Requirements on Pearl Culture

Some of the major thrust areas for further development of pearl culture are identified here. Directed efforts are needed to improve gross production and quality of cultured pearls in *Pinctada fucata.* Specific technology for *P. margaritifera* has to be developed for production of high value black pearls. Spat collection of the latter species in the Andaman-Nicobar Islands will have to be attempted adopting standard methods already available in other areas such as Sudan and French Polynesia (AQUACOP, 1982).

An important aspect of pearl culture which remains to be looked into is production of shell bead nuclei indigenously. The early experimental work by Velu *et al.* (1973) has not been followed up. This engineering problem will have to be solved with some urgency if the dependence on imports of nuclei from Japan has to be dispensed with.

Identification of sites and development of appropriate farming technology would need priority attention. Modern systems and materials should replace the structures used in farms. Prevention and control of fouling and boring organisms appear to be a major area where simple and cost-effective measures have to be developed.

It will pay more dividends if the Central Agricultural Research Institute of ICAR at Port Blair could strengthen their pearl culture programme in the Andaman and Nicobar Islands with a proper resources and site survey and experimental work on *P. margaritifera*. The inference on possible occurrence of *P. maxima* has to be followed up. Likewise, |the small effort in Bangaram island of Lakshadweep will have to be strengthened by the Administration with continued support from CMFRI.

The CMFRI which forms the nucleus for pearl culture research in the country may get involved in finer and critical aspects of pearl production adopting modern techniques of breeding and tissue culture. Oysters in the farm suffer high mortality due to unknown factors and investigations on pathology and disease control would be essential. Hatchery production has to be further examined for achieving higher survival rate and faster growth of larvae. Multidisciplinary research involving genetics, reproductive physiology, nutrition, pathology and water quality management will require greater purposeful orientation for achieving the intended results.

REFERENCES

ACHARI, G. P. K. 1982. New designs of spat collectors, breeding hapas, cages and improved technology for pearl farming *Symp. Coastal Aquaculture*, Abstract No. 182, 12-18 January, 1980, Cochin, Mar. Biol. Ass. India.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca*, Part III : 975-993. Mar. Biol. Ass. India.

ALAGARSWAMI, K. 1974. Development of cultured pearls in India. *Curr. Sci.*, 43 (7) : 205-207.

ALAGARSWAMI, K. 1977. Larval transport and settlement of pearl oysters (genus *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm Water Zoopl. Spl. Publ.* UNESCO/NIO, pp. 678-686.

ALAGARSWAMI, K. 1983. The black-lip pearl oyster resources and pearl culture potential. In : Mariculture potential of Andaman and Nicobar Islands (K. ALAGARSWAMI, Ed.), *Bull. Centr. Mar. Fish. Res. Inst.*, 34 : 72-78.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, 34 : 287-301.

AQUACOP. 1982. French Polynesia—Country Report. In : *Bivalve culture in Asia and the Pacific* (F. B. DAVY and M. GRAHAM, Eds.), Proceedings of a Workshop held in Singapore, 16-19 February 1982, Ottawa, Ont., IDRC, pp. 31-33.

CAHN, A. R. 1949. Pearl culture in Japan. *Fish. Leaflet, U.S. Fish and Wildl. Serv.*, 357, 91 pp.

CMFRI 1977. *Pearl culture training*. CMFRI Special Publication, 1 : 39 pp.

DEVANESAN, S. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oyster farm, Krusadai Islands, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar, Part I. *Contr. Mar. Biol. St. Krusadai Is., Gulf of Mannar*, 4 : 1-89.

KAFUKU, T. AND K. IKENOUE (Eds.). 1983. *Modern methods of Aquaculture in Japan*. Kodansha Ltd., Japan and Elsevier Scientific Publishing Co., Amsterdam, 216 pp.

MAHADEVAN, S. AND K. N. NAYAR. 1973. Pearl oyster resources of India, pp. 659-671. *Proc. Symp. Living Res. Seas India* CMFRI, 1973.

MIZUMOTO, S. 1979. Pearl farming in Japan. In : *Advances in aquaculture* (T. V. R. PILLAY and W. M. A. DILL, Eds), Fishing News Books Ltd., England, pp. 381-385.

VELU, M., K. ALAGARSWAMI, AND S. Z. QASIM. 1973. Techique of producing spherical shell beads as nuclei for cultured pearls. *Indian J. Fish.*, 20 (2) : 672-676.

WADA, K. 1973. Modern and traditional methods of pearl culture. *Underwater Journal*, 5 (1) : 28-33.

WARD, F. 1985. The pearl. *National Geographic*, 168 (2) : 193-222.

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ANNOTATED BIBLIOGRAPHY ON PEARL OYSTERS OF INDIAN COAST

S. MAHADEVAN[1]

The object of the present annotated bibliography on Pearl Oysters from Indian Coast is to make available a synopsis of information gathered by pearl fishery experts and Indian scientists on various aspects connected with pearl fishery management, pearl oyster distribution, ecology of the pearl beds, biology and reproduction and culture of pearls. Such information will be of considerable value at a time when our scientists, having achieved a breakthrough in pearl culture technology, are helping the process of establishing a viable pearl culture industry in our country. The present research thrust is on hatchery production of seed, manufacture of indigenous materials for serving as nuclei for implantation, improvements in farming techniques and system and training of skilled technicians. The references and information collected up-to-date from all sources and media of publications in India will, it is hoped, stimulate further work in strengthening our efforts. The idea of annotating the publications was given by Dr. E. G. Silas and fulfilling this assignment was in no small measure due to his encouragement as it was due to the active help rendered by all my colleagues of the Molluscan Fisheries Division. I am really indebted to them.

Scanning through some of the very old records of the Madras Government Revenue Board proceedings I found very interesting observations by those reporting on pearl bank inspections done in yesteryears, before a separate directorate for fisheries came into existence. To allow this material to languish unread by posterity will be doing great injustice to those pioneers who had evinced abiding interest in the subject. Hence I have given a resume of such observations as are of relevance to present day interest.

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A total number of 165 references has been scanned in this work. The publications are listed in the alphabetical order. Each reference is divided into four parts, namely (1) author and year of publication; (2) title; (3) periodical, volume and pages; and (4) subject dealt with in the reference.

Great care has been taken to update the bibliography. If by any chance a few scientific publications do not find a place in this it is only due to oversight.

ACHARY, G. P. KUMARASWAMY. 1980. Artificial biocoenosis for ecological reconstruction to facilitate aquaculture. *Proc. Symp. Coastal Aquaculture*, India; Abstract 29 : 18.

The oyster farm at Vizhinjam provides a good area for the healthy growth of oysters with a variety of fouling organisms settling and growing on the cages. By introducing biological associates, it has been stated that it is possible to attract desirable cultivable animals to settle down and grow.

ACHARY, G. P. KUMARASWAMY. 1980. New designs of spat collectors, breeding hapas, cages and improved technologies for pearl farming. *Proc. Symp. Coastal Aquaculture*, India; Abstract 182 : 107-108.

The designs and details of nylon frills, breeding hapas of 1.5 × 1.5 × 1 m size and cages of 50 × 45 × 45 cm with nylon netting to accommodate 800 oysters used in the experiments at Vizhinjam has been given. A new method of nucleus implantation to produce quality pearl has been attempted.

ALAGARAJA, K. 1962. Observations on the length-weight relationship of pearl oysters. *J. mar. biol. Ass. India*, 4 (2): 192-205.

The data on linear relationship between the length and weight of oysters of Gulf of Mannar arrived at earlier by

Devanesan (1956) was statistically tested and found to be significantly different for each year age group. The importance of finding out effective methods to determine the time of pearl fishing has been pointed out.

ALAGARSWAMI, K. 1970. Pearl culture in Japan and its lessons for India. *Proc. Symp. Mollusca*, Pt. III : 975-993.

The paper mentions the names of various molluscs employed in pearl culture work in Japan and also the 25 prefectures engaged in pearl culture farming in an area of 30,000 acres. Spat collection techniques, farm establishment, specification of floating raft, pearl oyster net and the tools used for nucleus implantation have all been described. The technology of pearl culture and the post operational care have been highlighted. The status of oyster fisheries in India and the efforts on culturing pearls have been discussed to show the need for developing an indigenous technology for culturing pearls and for the establishment of a cultured pearl industry.

ALAGARSWAWI, K. 1974. Development of cultured pearls in India. *Curr. Sci.*, April 5, 43 (7) : 205,07.

Six batches of operated oysters, of which 77 were examined, produced 43 pearls. Deposition of nacreous layer was observed 30 days after operation and pearly lustre appeared in 43 days. Those produced between 69-191 days had bright lustre. Cent percent success was achieved in pearl production, in one batch of experiments.

ALAGARSWAMI, K. 1974. Pearls cultured in India. *Gems and Jewellery*, 8 (6) : 13-16.

The paper describes the technology of pearl culture developed in India.

ALAGARSWAMI, K. 1974. Development of pearl culture technology in India and scope for a pearl culture industry. *Proceedings of group discussion on pearl culture*, C.M.F.R.I. publication, Tuticorin : 4-19.

The genesis of pearl culture work in India culminating in the successful production of spherical pearls by CMFRI has been given in the paper. One problem that has to be solved is the large-scale availability of pearl oyster to meet the needs of pearl farmer. Research efforts are needed for evolving satisfactory techniques for oyster seed production. Establishment of culture pearl industry will help to uplift the economy of the people of the coastal rural sector.

ALAGARSWAMI, K. 1974. Results of multiple implantation of nuclei in production of cultured pearls. *Indian J. Fish.*, 21 (2) : 601-604.

2-5 pearls were produced in individual oysters by this method, with comparable retention rate of nuclei as in single implantation. The average production achieved worked out to 180.6%.

ALAGARSWAMI, K. 1975. Preliminary study of the growth of cultured pearls. *Indian J. Fish.*, 22 (1 & 2) : 300-303.

Quick growth of cultured pearls has been reported. In the case of 3.0-3.05 mm nuclei the growth seen in 24 months in Japan was achieved in a little over 6 months in Tuticorin. In the case of 3.95-4.00 mm the ratio of nacreous layer to radius of nucleus was 0.155 in 161 days in India while it was 0.183 in 11, 12 days (2½ years) in Japan.

ALAGARSWAMI, K. 1975. Pearl Culture. *Indian Farming*, Sep. 1975 (I.C.A.R., New Delhi).

Prospects and progress of pearl culture described.

ALAGARSWAMI, K. 1976. Pearl culture and its potential for development of coastal villages. *Indian Sci. Congress* 63rd Session, Waltair, Jan. 3-7 (Zoology section). Ent. & Fish., Inland and Coastal Aquaculture Symposium Abst. No. 2.

The pearl oyster farming can afford employment opportunities for several skilled labourers and workmen and will improve the economic prosperity of coastal villages.

ALAGARSWAMI, K. 1977. Larval transport and settlement of pearl oysters (Genus : *Pinctada*) in the Gulf of Mannar. *Proc. Symp. Warm water zoopl.*, spl. publication UNESCO/NIO : 678-686.

'Larval rift theory' across the Gulf of Mannar propounded by earlier pearl fishery scientists appears to be a plausible one as judged by the settlement and growth of *P. fucata*, *P. sugillata* and *P. anomioides* in the newly constructed harbour basin, at Tuticorin. *P. chemnitzi* was also seen in the fishing harbour basin, another sheltered coastal area.

ALAGARSWAMI, K. 1977. Towards the commercial production of cultured pearls. *Gems and Jewellery*, 11 (8 & 9) : 25-28.

Describes the feasibility of commercial pearl culture in India.

ALAGARSWAMI, K. 1977. Pathology of pearls and pearl production. *31st Tamil Nadu State Medical Conference Souvenir*, Tuticorin, I.M.A.

The process of pearl sac formation and subsequent coating of nacreous layer on the irritant as implanted nuclei has been explained.

ALAGARSWAMI, K. 1980. Fishery and biology of pearl oysters. *Proc. of the Summer Institute in the culture of edible molluscs*. C.M.F.R.I. Publication : 72-77.

The trend in the Indian pearl fisheries for the past several years and an account of the rate of growth of oysters in natural beds, reproductive cycle, and pearl formation processes had been enumerated.

ALAGARSWAMI, K. 1980. Technology of pearl culture. *Proc. of the Summer Institute in the culture of edible molluscs*. C.M.F.R.I. Publication : 93-98.

An exhaustive account of the various aspects of culture has been given.

ALAGARSWAMI, K. 1980. Seed production and hatchery development. *Proc. of the Summer Institute in the culture of edible molluscs*. C.M.R.I. Publication : 111-121.

The important role played by hatchery development of edible and culturable molluscan seed to meet large-scale demand of the industry has been stressed by drawing to the attention to the development in this area of work in advanced countries in Mariculture.

ALAGARSWAMI, K. 1983. A critical review of the progress and problems in pearl culture in India. *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Part 2 : 574-583.

A major breakthrough was achieved when techniques for the production of cultured pearls were successfully developed in 1973 by CMFRI in India. Training programmes have been conducted to extend the know-how to maritime states. The paper identifies areas needing major thrust to strengthen the technological base.

ALAGARSWAMI, K. 1983. The black-lip pearl oyster resource and pearl culture potential. In: Mariculture potential of Andaman and Nicobar Islands—An indicative survey (K. Alagarswami, Ed.). *Bull. Cen. Mar. Fish. Res. Inst.*, **34**: 72-78.

The survey of Andaman and Nicobar Islands has brought out *Pinctada margaritifera* as a resource of some importance. *Pteria penguin*, the black-winged pearl oyster was also collected from Mayabunder, Camorta and Havelock Is. The distribution of the former suggests possibilities of raising population of these in column waters. The ecosystem appears suitable for developing pearl culture in Andamans. It is also suggested to try the transplantation experiments on *Pinctada maxima*.

ALAGARSWAMI, K. AND A. CHELLAM. 1976. On fouling and boring organisms and mortality of pearl oysters in the farm at Veppalodai, Gulf of Mannar. *Indian J. Fish.*, **23** (1 & 2): 10-22.

Heavy fouling noticed in the Veppalodai farm necessitated periodical cleaning operations to remove heavy barnacle settlement, bryozoans and bivalve spat, *Avivula* sp. and *Crassostrea* sp. which showed a seasonal pattern in the occurrence. *Polydora* and *Cliona* were the chief borers. The rate of mortality of oysters due to the foulers and borers ranged from 0.9% to 27.5%. Exposure of oysters to sun, immersion in freshwater for limited duration, treatment with Pentachlorophenol at 1 ppm, formalin treatment and Dichlorophine at 10 ppm as practised elsewhere have been suggested for experimentation in tackling fouling nuisance.

ALAGARSWAMI, K. AND A. CHELLAM. 1977. Change of form and dimensional relationships in the pearl oyster, *Pinctada fucata* from Gulf of Mannar. *Indian J. Fish.*, **24** (1 & 2): 1-14.

A change of form occurs from subquadrate in the young to oblong in the adult oysters. The hinge length of both valves becomes equal at a size of 35 mm. Consequent on the change of shell shape the young and adult oysters have significantly different regression coefficients, except in some instances.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM AND A. C. C. VICTOR. 1983. On controlled spawning in the pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Part 2: 590-597.

Thermal stimulation, salinity variation, chemical control using NaOH, NH_4OH, Tris-buffer and hydrogen peroxide were tried during the experiments to induce the ripe oyster to spawn with reasonable amount of success.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM. AND A. C. C. VICTOR. 1983. Embryonic and larval development of the pearl oyster *Pinctada fucata* (Gould). *Proc. Symp. Coastal Aquaculture*, Mar. Biol. Ass. India, Part 2: 598-603.

In a series of experiments on rearing of *Pinctada fucata*, success was achieved in rearing the hatched out larvae only upto 'D' shaped veliger stage (straight-hinge stage) which was reached in 24 hours from fertilization. Metamorphosis did not take place even after 16 days when the larvae died. Feeding the larvae with *Tetraselmis* and *Synechocystis* did not help. Right type of food is necessary to tide over this problem.

ALAGARSWAMI, K., S. DHARMARAJ, T. S. VELAYUDHAN, A. CHELLAM, A. C. C. VICTOR AND A. D. GANDHI. 1983. Larval rearing and production of spat of pearl oyster *Pinctada fucata* (Gould). *Aquaculture*, **34**: 287-301.

The larvae of *P. fucata* were reared successfully in the laboratory. The pediveliger metamorphosed to plantigrade and settled as spat. *Isochrysis galbana* was used as a standard food at a cell concentration of 8 0-350/L. Spatfall occurred on days 24-32. Fibreglass tank bottom showed the highest density (4.71/cm^2) of spat settlement.

ALAGARSWAMI, K. AND S. Z. QASIM. 1974. What are pearls and how are these produced? *Seafood Export J.*, **6** (1): 1-10.

The article gives details of pearl producing areas in India, level of exploitation, process of natural pearl formation, experiments on culturing pearls in India and future prospects.

ALAGARSWAMY, K. AND S. Z. QASIM. 1974. Pearl culture—its potential and implications in India. *Indian J. Fish.*, **20** (2): 533-550.

By adopting the raft culture technique pearl oyster culture experiments proved successful giving 78% survival. The growth of oysters was faster. At Veppalodai, a coastal village near Tuticorin the technique of producing cultured pearls was developed and for the first time spherical cultured pearls were produced. The results indicate good scope for reviving pearl oyster resources by aquaculture and the establishment of an industry of cultured pearls entirely by indigenous efforts.

ALAGARSWAMI, K. AND G. S. SIVARAMAN. 1975. Surgical equipment for pearl culture. *Indian J. Fish.*, **22** (1 & 2): 231-235.

The surgical instruments needed for preparation of tissue grafts from mantle lobes and in the insertion of nuclei in culture pearl operations in India had been manufactured indigenously and described.

ALAGARSWAMI, K. AND A. C. C. VICTOR. 1976. Salinity tolerance and rate of filtration of the pearl oyster, *Pinctada fucata*. *J. mar. biol. Ass. India*, **18** (1): 149-158.

During 1975-77 oysters were experimented in salinities from 14-58‰ range which showed that they can tolerate 24-50‰ range for 72 hrs. Rate of mortality in salinity dilutions of 16, 15 and 14‰ were 10, 50, and 100%. In higher concentrations of 52, 55 and 58‰ it was 67, 100 and 100% respectively. Rate of filtration was low in dilutions and total below 25% in salinities 14 and 20‰. In higher concentration the filtration rate was 49,53.7 and 41.8% in 44, 50 and 57‰. salinities.

ANANTHANARAYANAN, R. 1967. The fouling organisms of the pearl oyster farm Krusadi Island, Gulf of Mannar. *Madras Jour. Fisheries*, **31**: 145-146.

Marine settlers and wanderers in the farm at Krusadi cause nuisance value if not periodically removed from the cages. A list of such organism has been presented.

ANONYMOUS. 1835. Records on pearl bank inspection 1834-1835. *Proceedings of the Revenue Board of the Madras Government*, 1835.

A report on the results of pearl bank inspection conducted in February-March, 1834 by Jadhi Thalaivan shows the discovery of 34 beds between Kootapuli and Kooduthalai villages (Cape Comorin Zone). A pearl fishery was predicted in 1835; but subsequent poaching by fishermen led to the total disappearance of fishable oysters.

ANONYMOUS. 1836. Records on pearl bank inspection 1835-1836. *Proceedings of the Revenue Board of the Madras Government*, 1836.

The Collector of Tirunelveli reported 192 oysters having been fished from Thollayiram paar during the inspection of that bed. On the recommendation of Sir Frederick Adam in 1834, the Governor of Madras appointed Lt. Col. Monteith, Superintending Engineer for future pearl bank inspection. This was done in November, 1835 wherein the occurrence of 2½-3½ year old oysters was reported; but clandestine fishing by fishermen again spoiled the possibility of fishery being declared.

ANONYMOUS. 1837. Records on pearl bank inspection 1836-1837. *Proceedings of the Revenue Board of the Madras Government*, 1837.

The dismal record of pearl bank inspections made the Government to requisition the services of Captain Quinton, Supervisor of Ceylon pearl banks to inspect the Tirunelveli Coast and authorised a boat to guard against the depredation of clandestine fishers as well. Quinton stressed the need for charting the pearl banks. He also advocated the policy of avoiding the use of dredges adopted by Monteith and precaution to be taken to prevent 'Dhoney' or boat anchoring on or near oyster beds.

ANONYMOUS. 1839. Records on pearl bank inspection 1838-1839. *Proceedings of the Revenue Board of the Madras Government*, 1839.

Mr. Franklin appointed for pearl bank inspection till 1939 divided the banks into: (1) 12 banks from Vaipar to Mookur, (2) 21 banks off Tuticorin, (3) 24 banks off Pinnakayal and (4) 14 banks off Tiruchendur making in all 71 banks. The locations and names of these were listed. The report mentioned about the existence of 2½ year old oysters in 13 beds but population estimation was apparently not done due to overgrowth of 'Suram' on oyster beds.

21 banks off Tuticorin which contained oysters were considered good for fishing. Dredging in deeper areas where divers cannot reach was also recommended.

ANONYMOUS. 1841. Records on pearl bank inspection 1840-1841. *Proceedings of the Revenue Board of the Madras Government*, 1841.

Mr. Franklin's report to Government was discouraging, stating that the oysters had disappeared from the beds, probably due to natural causes.

ANONYMOUS. 1848. Records on pearl bank inspection 1847-1848. *Proceedings of the Revenue Board of the Madras Government*, 1848.

Mr. Thomas, Collector of Tirunelveli suggested the leasing out of pearl banks and the right of fishery to wealthy merchant on 50-50 basis to effectively check the poaching on beds by divers. Government rejected the suggestion. The banks continued to be plundered as revealed by the results of inspection.

ANONYMOUS. 1849. Records on pearl bank inspection 1848-1849. *Proceedings of the Revenue Board of the Madras Government*, 1849.

The results of inspection confirmed the fears of Mr. Thomas. The entire oysters had disappeared. But the Master Attendant who conducted the inspection attributed this to the action of increased current occasioned by the enlargement of the Pamban Pass and also due to the frequent passage of vessels in consequence of increased trade.

ANONYMOUS. 1850. Records of pearl bank inspection 1849-1850. *Proceedings of the Revenue Board of the Madras Government*, 1850.

During the pearl bank survey only 17 young oysters were reported from the beds.

(Till 1855 no record is available to show that inspection was conducted—S.M.)

ANONYMOUS. 1856. Records on pearl bank inspection 1855-1856. *Proceedings of the Revenue Board of the Madras Government*, 1856.

Only 6 banks were inspected by a cargo schooner boat. 'Suram' was abundant on the beds. No oysters were found.

ANONYMOUS. 1858. Records on pearl bank inspection 1857-1858. *Proceedings of the Revenue Board of the Madras Government*, 1858.

Results of inspection indicated the possibility of a fishery in 1860 provided the oysters did not migrate from 23 beds off Tuticorin and 6 eastward of it. This theory of Master Attendant did not find favour with the Government who doubted the power of locomotion of a mollusc which habitually lies attached to rocks. They attributed the reasons for a possible failure to imperfect inspectoin and plundering of oysters by fisherfolk.

ANONYMOUS. 1859. Records on pearl bank inspection 1858-1859. *Proceedings of the Revenue Board of the Madras Government*, 1859.

A pearl fishery was held in 1860 in the eastern beds off Tuticorin for 23 days yielding a gross revenue of Rs. 250,276-0-0.

ANONYMOUS. 1861. Records on pearl bank inspection 1860-1861. *Proceedings of the Revenue Board of the Madras Government*, 1861.

Captain Phipps examined 2 banks with poor results. In his report to Mr. J. Silver, Collector of Tirunelveli, he described the reasons to fierce current washing away oysters. He was optimistic about a fishery in 1867 based on his finding of oysters in the northern beds.

ANONYOMUS. 1862. Records on pearl bank inspection 1861-1862. *Proceedings of the Revenue Board of the Madras Government*, 1862.

Captain Phipps inspected Tiruchendur beds where he found 5 year old oysters a plenty and recommended a fishery in 1860-1864 season. A submarine diver Mr. Farmer was employed to dive with local divers in all the beds.

(A letter written by Mr. Silver dated 2-4-1862, however, shows that there was a fishery in 1862 for 21 days fishing 2,980,900 oysters fetching a revenue of Rs. 128,769-4-0 -S.M.)

Later in 1862 Phipps examined southern beds at the end of which he was disappointed at the intelligence of the failure of Tiruchendur banks.

ANONYMOUS. 1863. Records on pearl bank inspection 1862-1863. *Proceedings of the Revenue Board of the Madras Government*, 1863.

73 banks were inspected and the results were disappointing. Only 4 banks had a few oysters free of *Modiolus* (Suram). The inspection lasted from 20-10-1862 to 3-3-1863. In November, 17 banks south of Tuticorin Tholayiram Parr were inspected again but no oyster settlement was seen.

ANONYMOUS. 1865. Records on pearl bank inspection 1864-1865. *Proceedings of the Revenue Board of the Madras Government*, 1865.

Captain Phipps reinspected seaward banks north of Turicorin and found them barren.

ANONYMOUS. 1866. Records on pearl bank inspection 1865-1866. *Proceedings of the Revenue Board of the Madras Government*, 1866.

Vembar, Kilakarai and Pamban group of paars were inspected by Captain Phipps in addition to the banks off Tuticorin, Manapad and Tiruchendur. There were no oysters.

ANONYMOUS. 1867. Records on pearl bank inspection 1866-1867. *Proceedings of the Revenue Board of the Madras Government*, 1867.

66 paars were inspected during January-March. Young oyster settlement was seen in 15 of them. Pearling prospects were bleak.

ANONYMOUS. 1869. Records on pearl bank inspection 1868-1869. *Proceedings of the Revenue Board of the Madras Government*, 1869.

67 paras were reinspected by Captain Phipps in March 1869 and found to be mostly barren except those of Pinnakayal which had 1 year old stock. Captain Phipps was of the view that it was a waste of time examining Manapad banks in future.

ANONYMOUS. 1870. Records of pearl bank inspection 1869-1870. *Proceedings of the Revenue Board of the Madras Government*, No. 1530 dated 4-5-1870.

In December 1869 Captain Richardson conducted examination of Vaipar banks only to find *Modiolus* settled over the banks extensively to 2 feet thickness. But the shoreward paars of Tuticorin had dense population of 2½ year old oysters capable of yielding fishery in 1893. The extent was calculated to cover 4 miles length and half mile width. Similarly those banks off Pinnakayal also had dense stock. Manapad banks condemned by Captain Phlpps, had a good population of 2½ year old oysters.

ANONYMOUS. 1870. Records of pearl bank inspection 1869-1870. *Proceedings of the Revenue Board of the Madras Government*, No. 4648 dated 2-7-1870.

In February 1870 inspection, it was found that Pamban paars were dense with oysters. On March 5th, Captain Richardson found evidences of large scale poaching judged by the remains of what must have been an extensive calendestine pearl oyster fishing in Nallathanni Theevu. Many millions of pearl oyster shells were heaped up. The people of Kilakarai and Valinokam must have plundered the oyster banks. His findings sparked off a big controversy.

ANONYMOUS. 1871. Records on pearl bank inspection 1870-1871. *Proceedings of the Revenue Board of the Madras Government*, No. 1332 dates 27-2-1871.

Captain Richardson inspected Vaipar banks from 27-12-1870. Results were not encouraging in Vaipar, Pinnakayal and Manapad banks.

ANONYMOUS. 1871. Records on pearl bank inspection 1870-1871. *Proceedings of the Revenue Board of the Madras Government*, No. 2737 dated 5-7-1871.

Captain Phipps conducted further detailed survey of all banks from Pamban to Tiruchendur and stated oysters did not exist except in small quantities. No possibility of a fishery.

ANONYMOUS. 1872. Records on pearl bank inspection, 1871-1872. *Proceedings of the Revenue Board of the Madras Government*, 1872.

Mr. Eastland, an European diver was engaged to dive in 73 pearl banks from which he could collect 30 oysters only. 43 banks were barren of oysters.

Mr. Puckle stated that 'there is but little difference of opinion among authorities on the subject; all seem to agree that under-current and formation of sand on some banks, the deposit of mud and the ravage of the skate and parrot-fish and the moonings of fishing canoes destroy the oysters here and there while no one can give an opinion as to how the oysters may best be matured'.

ANONYMOUS. 1873. Records on pearl bank inspection 1872-1873. *Proceedings of the Revenue Board of the Madras Government*, No. 1137 dates 30-6-1873.

Paars were inspected by Captain Phipps who found that prospects were still not encouraging. He found Tuticorin banks with very large quantities of young oysters attached to the rocks and weeds. He suggested prohibition of fishing activities in this area.

(No records are available upto 1876—S.M.)

ANONYMOUS. 1876. Records on pearl bank inspection 1875-1876. *Proceedings of the Revenue Board of the Madras Government*, No. 1387 dated 26-5-1876.

Out of 18 banks inspected 5 paars gave hopes of a fishery in 1878 or 1880.

ANONYMOUS. 1878. Records on pearl bank inspection 1877-1878. *Proceedings of the Revenue Board of the Madras Government*, No. 1775 dated 27-6-1878.

Capt. Phipps examined 35 paars from Vaipar to Manapad and came across only crunched oysters brought out by divers by which he concluded that extensive depredation by sharks and skates had precluded the possibility of a fishery. Mr. Pennington, Collector, commenting on those observed in his report dated 25-5-1878 that there had been no fishery since 1861-1862 but the proceeds of that and the previous years' fishery alone were enough to cover all the cost establishment since the beginning of the century.

ANONYMOUS. 1881. Records on pearl bank inspection 1880-1881. *Proceedings of the Revenue Board of the Madras Government*, No. 1786 dated 13-7-1882.

Examination of 25 banks by Captain G. A. Phipps showed spat settlement along with *Modiolus*. Pinnakayal banks were singled out for a fishery in 1885.

ANONYMOUS. 1883. Records on pearl bank inspection 1882-1883. *Proceedings of the Revenue Board of the Madras Government*, No. 2899 dated 35-8-1883.

Captain G. A. Phipps conducted inspection in 31 pearl banks in four months of 1882. No oyster population of value was found. Pinnakayal beds disappointed this time.

ANONYMOUS. 1885. Records on pearl bank inspection 1884-1885. *Proceedings of the Revenue Board of the Madras Government*, No. 1246 dated 21-4-1885.

G. W. Wicks completed inspection of 46 banks and found only Tuticorin banks with oysters, perhaps fit for conducting pearl fisheries.

(Details of inspection of banks from 1885-1905 are furnished by Hornell (1905) in his report to the Government of Madras. See pages 93 to 107. Repeated inspections yielded a fishery in 1889, 1890 and 1900 when 12,600,531 oysters and 1,806,762 oysters were fished respectively from Thollayiram paar and in 1900, when 2,801,036 were fished off Tiruchendur. Again in 1908, 1.1 million oysters were fished in 20 days from Thollayiram paar. Inspection report from 1906-1916 are not readily traceable—S.M.).

ANONYMOUS. 1918. Administration report of Madras Fisheries Department for 1917-1918. *Government of Madras Publication* : 173-175.

Inspection of banks off Tuticorin revealed paucity of oysters. Pamban to Vaipar beds were also inspected but with negative results. A few scattered oyster spat settlement was reported on the seaward eastern edge of Rameswaram, settled on pier. The scheme to start pearl culture experiments at Krusadi island was kept in abeyance.

ANONYMOUS. 1920. Administration report of Madras Fisheries Department for 1918-1919. *Government of Madras Publication* : 1-42.

No inspection was possible due to the non-availability of launch facilities.

ANONYMOUS. 1922. Administration report of Madras Fisheriess Department for 1920-21. *Government of Madras Publication* : 18.

Hornell's inspection of oyster bed revealed total absence of oyster settlement.

ANONYMOUS. 1923. Administration report of Madras Fisheries Department for 1921-1922. Report 1 of 1923. Madras Fisheries Bulletin, 7 : 13-14.

Based on the results of pearl bank survey made with M.T. 'Lady Nicholson' a, fishery was forecast for 1927-1928.

ANONYMOUS. 1924. Administration report of Madras Fisheries Department for 1922-1923. *Government of Madras Publication* : 17-18.

28 banks inspected showed the spat settlement (1 year old) and a fishery was forecast for 1926-1927. Hornell observed that 1926 fishery will be a farewell gift legacy as he was relinquishing office.

ANONYMOUS. 1925. Administratin report of Madras Fisheries Department for the year 1923-1924. *Government of Madras Publication* : 13 & 30.

Possibil8ty of a fishery in 26 banks has been indicated.

ANONYMOUS. 1926. Administration report of Madras Fisheries Department for the year 1924-1925. *Government of Madras Publication* : 13.

24 crores of oysters were estimated to be ready for fishing in 1926 from all pearl banks covering an area of 770 sq. miles. Declaration of rules under 6 of Indian Fisheries Act of 1897 was made this year for preventing theft of oysters.

ANONYMOUS. 1927. Administration report of Madras Fisheries Department for year 1925-1926. *Government of Madras Publication* : 10-21.

There had been a pearl fishery in February-March 1926 in Tholayiram paar. 33 days of fishing yielded 14,096,839 oysters and another fishing in November-December for 23 days yielding 16,08,931 oysters fished from Tholayiram paar. The gross revenue for Rs. 2,56,884-0-0. Cholera outbreak forced the fishing to be closed after 40 days of commencement in March.

ANONYMOUS. 1928. Administration report of Madras Fisheries Department for the year 1926-1927. *Government of Madras Publication* : 14-24.

The conduct and progress of 1926 autumn fishery and 1927 spring fishery have been given. In the former, 29 days of fishing was possible and the latter was in progress from 11-2-27 to 30-4-27, during which time 10,337,059 oysters were fished out. A special feature of this fishery was the participation of 38 Arab divers. (There is no incongruity in the record about the number of days of actual fishing in 1926—S.M.).

ANONYMOUS. 1929. Administration report of Madras Fisheries Department for the year 1927-1928. *Government of Madras Publication* · 26-30.

Prosperous spring pearl fishery was held for a period of 97 days from 9-11-1927 to 14-1-1928 and the second from 1-3-1928 to 31-3-1928. The fishery was closed due to outbreak of cholera. A total of 6,251,940 and 3,477,593 oysters were fished bringing a revenue of Rs. 3,38,930-10-11 and Rs. 1,93,483-0-0 respectively to Government. It was considered that there might be beds of pearl oysters in deeper waters beyond 11 fathoms. It was recommended that a trawler for conducting dredging in these areas be purchased. A set of dredges was also prepared according to the design of Capt. Cribb. Operations commenced on 27-3-1928 at 9 F and oysters were dredged upto 11 F limit. The area dredged extended from Pamban to Colachal. Results not shown.

ANONYMOUS. 1930. Administration report to Madras Fisheries Department for the year 1928-1929. *Report No.* 1 *of Madras Fisheries Bulletin*, **24** : 43-45.

Inspection of pearl banks yielded very poor results. Three banks off Manapad were also inspected for the first time in 25 years, apart from 39 paars from Tuticorin to Manapad.

ANONYMOUS. 1931. Administration report of Madras Fisheries Department for the year 1929-1930. *Government of Madras Publication* : 41-43.

Pamban group was inspected according to a system of triennial inspection principle of Dr. B. Sundararaj who considered that it was enough to inspect one group once in 3 years since oyster settlement, if noticed will not be ready for fishing before the third year was over. 15 bankar from Vembar to Pamban, 13 from Vaipar to Tuticorin 11 banks off Tuticorin were inspected but no oysters were found. A Japanese diving equipment was tested at Sethubavachatiram sea coast when it was possible for one person, to remain under water at 4 feet depth for 12 minutes.

ANONYMOUS. 1932. Administration report of Madras Fisheries Department for the year 1930-31. *Government of Madras Publication* : 47.

In Palk Bay area 14 shoreward paars off Rameswaram and 2 beds off Tuticorin were also searched. All were barren of oysters.

ANONYMOUS. 1933. Administration report of Madras Fisheries Department for the year 1931-32. *Government of Madras Publication* : 40.

Efforts to get diving apparatus continued. 45 banks from Tuticorin to Cape Comorin were studied from 11th March to 9th April. Only stray specimens of oysters were obtained.

ANONYMOUS. 1934. Administration report of Madras Fisheries Department for the year 1932-33. *Government of Madras Publication* : 49-50.

Diving experiments at 5 feet to 2½ fathoms were carried at Sethubavachatram when a person remained under water for 18 minutes. 28 pearl banks from Tuticorin to Pamban were surveyed and found to be barren. It was suggested that poor rainfall had affected spat settlement.

ANONYMOUS. 1935. Administration report of Madras Fisheries Department for the year 1933-34. Government of Madras Publication : 57.

10 pearl banks were inspected and found to be bare of oysters.

ANONYMOUS. 1936. Administration report of Madras Fisheries Department for the year 1934-35. *Government of Madras Publication* : 13.

Apart from the continued maintenance of oysters in farm at Krusadai nothing of interest about the natural oyster population has been mentioned. 47 banks of South division upto Manapad were inspected from 26-2-35 to 14-4-35. No encouraging result was got.

ANONYMOUS. 1937. Administration report of Madras Fisheries Department for the year 1935-36. *Government of Madras Publication* : 15.

An account of how Kundugal Point area near Krusadai was selected for pearl oyster farm establishment had been given. 28 banks of Central division were inspected during March 1936. All beds were barren of oysters.

ANONYMOUS. 1938. Administration report of Madras Fisheries Department for the year 1936-37. *Government of Madras Publication* : 44.

During March-April 1937, 3 Palk Bay beds and Tholayiram paar were inspected which were found to be barren of oysters.

ANONYMOUS. 1940. Administration report of Madras Fisheries Department for the year 1938-39. *Government of Madras Publication* : 51.

Spatfall was reported in the Vedalai area. At Mallipatnam (near Tanjore) 74,519 oysters were collected from the nets of gill net fishermen. These were taken to Krusadai farm in addition to 364 oysters collected at the time of pearl bank inspection during April 1939.

ANONYMOUS. 1941. Administration report of Madras Fisheries Department for the year 1939-40. *Government of Madras Publication* : 14-15.

An account of attempts to grow oysters at Krusadai farm has been given. 6,782 oysters were farmed and attempt at pearl culture initiated. Inspection of Palk Bay area and Tholayiram paars did not reveal any oyster population.

ANONYMOUS. 1952. Administration report of Madras Fisheries Department for the year ending March 1951. *Government of Madras Publication* : 13.

During 7 days of inspection of 9 Tuticorin paars 1,250 pearl oysters were collected. A possibility of fishery was hinted.

ANONYMOUS. 1954. Administration report of Madras Fisheries Department for the year 1952-53. *Government of Madras Publication* : 3.

Inspection of banks started in November 1952 and concluded on 17th covering central and southern sector paars. In 13 paars a total of 6,390,000 oysters were estimated due to the good spatfall of 1952. Pearl fishery in 1955 appeared to be a distinct possibility.

ANONYMOUS. 1956. Administration report of Madras Fisheries Department for the year 1954-55. *Government of Madras Publication* : 39-40.

27 banks were inspected in April 1954 with 16 banks having fishable oysters. A preliminary account of the organisation of 1955 pearl fishery at Tuticorin has been given. The fishery continued upto 14th May helping to fish 3,508,967 oysters from Tholayiram paar fetching a revenue of Rs. 1,46,000. Labour trouble thwarted a more successful fishery.

ANONYMOUS. 1957. Administration report of Madras Fisheries Department for the year 1955-56. *Government of Madras Publication* : 19.

The details of a survey of Tholayiram paar is given. An estimated 850,000 of oysters was reported fishable, being the leftover population, unfished during 1955 fishery. A pearl fishery was commenced on 29-2-1956 which continued for 18 days after which it was closed on 18th March 1956. 2,129,058 oysters were fished. Detailed inspection late in 1956 revealed prospects of a fishery in 1957 from Pinnakayal beds. 12.7 million oysters were estimated good for next year's fishery.

ANONYMOUS. 1958. Administration rceport of Madras Fisheries Department for the year 1956-57. *Government of Madras Publication* : 64-65.

Inspections in December 1956 and January 1957 revealed bright prospects of a pearl fishery. Labour trouble postponed the start of the fishery to 14th March 1957. The fishery was closed on 20th May 1957 during which period a total of 1,175,214 oysters were fished bringing a revenue of Rs. 168,807.37. Aqualung diving was done on paars by two departmental divers remaining under water for 10 minutes at a stretcth. Routine inspection of Tiruchendur beds from 16th December 1957 to 11th January 1958 revealed that the Karuval group of paars had good stock of fishable oysters. A population of 3½ year old oysters totalling 21.7 million was estimated available for fishery in 1958.

ANONYMOUS. 1958. Pearl fisheries of Tuticorin. *Curr. Aff. Bull. Indo-Pacif. Fish. Council*, 21 : 13-14.

A popular article.

ANONYMOUS. 1959. Pearl bank and chank bed survey. *Indian Fish. Bull.*, 6 : 11-12.

Pearl bank survey work done at Tuticorin by the Scientists of C.M.F.R.I. has been briefly mentioned.

ANONYMOUS. 1959. Administration report of Madras Fisheries Department for the year 1957-58. (*MS obtained from Directorate of Fisheries, Madras*).

Pearl fishery of 1957 continued upto 20th May for a period of 51 days. Kudamuthu paar group was exploited, 11.175 million oysters were fished during the period, realising a gross amount of Rs. 168,807.31. Elaborate details of the various formalities undergone pearl fishery declaration find a place for future guidance. Based on encouraging result of the inspection in December 1957 to January 1958 another pearl fishery was organised from 3rd March 1958 exploiting 6 southern sector paars off Pinnakayal and Tiruchendur. Till March 1958 end it was in progress for 21 days, fishing 8,315,870 oysters. After some labour trouble during which there was a strike, fishing commenced from 14th May 1958 lasting for another 11 days closing on 26th May 1958. On the whole 55 fishing days brought 21,476,817 oysters, bulk of which came from Karuval paar (7,638,997). A total income of Rs. 265,097.77 was realised. During October 1958 to January 1969, 28 banks off Tuticorin were examined. Tiruchendur-Punthottam paar was found ripe for a fishery as also for Karuval and Kodamuthu. During the fishery Dr. Dumas, a French man conducted aqualung diving in many paars to demonstrate the utility of diving with self contained breathing apparatus.

ANONYMOUS. 1960. Administration report of Madras Fisheries Department for the year 1958-59. *Government of Madras Publication* : 55-58.

5th year in the series of pearl fisheries. 5 paars in Karuval and Kudamuthu groups of paars were fished. A rapid inspection of paars in the same group of paars done in November-December 1958 enabled declaration of another fishery in February 1959 which started on 12the February 1959. Pearling operations continued for 36 days (upto March end) and the total catches upto this date were 10,738,520. (The fishery continued upto 16th May for a total of 62 days). Altogether 16,496,246 (16,428,298?) oysters were fished mainly due to Punthottam paar stock. Total income was Rs. 800,568.22 (Rs. 874,001.26 ?). Inspection of pearl banks Tholayiram paar, Kudamuthu group and Tiruchendur group made again during Spring of 1959 gave hopes of a fishery in 1960. 22 million oysters were estimated fishable.

ANONYMOUS. 1961. Administration report of Madras Fisheries Department for the year 1959-60. *Government of Madras Publication* : 45-47.

Another fishery was conducted from 17th March 1960 to 7th May 1960 for 52 days. A total of 16,175,839 oysters were fished bringing a revenue of Rs. 215,266.88. This time the bulk of oysters fished were from Thollayiram paar (14,459,698) and the rest from the nearby Kuthadiar paar.

ANONYMOUS. 1963. Administration report of Madras Fisheries Department for the year 1960-61. *Government of Madras Publication* : 37-39.

13 banks were inspected of which Tholayiram paar alone was estimated to contain 20 million oysters and Kuthadiar another 1.3 million. P.B. Salvadori, FAO expert in SCUBA diving and his counterparts helped in the inspection. A total of 16,176 million of oysters were fished out on 30 days. During November-December 1960 again Tholayiram paar area was inspected and a fishery was declared from 22-3-1961 to 15-5-1961. This fishery for 37 days yielded 15,360,928 oysters (vide histogram in Annexure I, III of report in page 131).

ANONYMOUS 1966. Dictionary of Indian raw materials and industrial products. *The Wealth of India*, VII : N-Pe. 204-207. Publication of C.S.I.R. New Delhi.

Five distinct species of *Pinctada* have been listed as occurring in Indian waters namely *Pinctada vulgaris*, *P. margaritifera*, *P. chemnitzii*, *P. anomioides*, and *P. atropurpurea*. *P. vulgaris* occurs in the Gulf of Mannar and in the Gulf of Kutch. *P. margaritifera* occurs sparsely. *P. chemnitzii* is found in the Gulf of Mannar, Andaman and near Bombay. Ten grades of pearls are recognised viz., Ani, Vadivu, Anathari, Masagoe, Kallipu, Korrower, Peesal, Mandangoe, Kural and Thul. The market price of pearl increases as the square of its weight or size. An account of the physical structure of cultured pearls and imitation pearl has been given.

ARUNACHALAM, S. 1952. The history of the pearl fishery of the Tamil Coast. *Annamalai Univ. Historical Series*, **8** : 197 pp.

The book is divided into 14 chapters giving information about pearl fishing which existed in ancient times as evident from the writings and avilable records during the days of imperial Cholas, later Pandyas, Portuguese, Dutch and 19th Century Governments. Apart from its historic treatment of the subject, little of scientific interest is aimed.

AWATI, P. R. 1928. An account of the pearl fisheries of Tuticorin, March and April, 1927. *J. Bombay nat. Hist. soc.*, **32**(3) : 524-531.

The paper presents an account of the salient features of the oyster biology, the habitat of oyster off Tuticorin, theory of pearl formation and the general organisation of pearl fishery, diving methods and the day to day fishing details.

BAUGHMAN, J. L. 1947. Annotated bibliography on oysters. *Texas A & M Research Foundation*, Texas : 794 pp.

Although mostly devoted to edible oysters this contains a few references on pearl oysters as well.

CHACKO, P. I. 1954. Prospects for a pearl fishery off Tuticorin, Gulf of Mannar in 1955. *Ind. Com. J. Madras*, 9 (3) : 368-369.

The possibility of a pearl fishery in 1955 based on the inspection results indicating fishable oyster population in Thollayiram paar during 1953-54 has been forecast.

CHACKO, P. I. 1956. The first pearl fishery of independent India. *Ind. Com. J. Madras*, **11** : 280-283.

An account of 1955 pearl fishery held at Tuticorin is given.

CHACKO, P. I. 1956. An overland transhipment of the pear oyster. *Ind. Com. J. Madras*, : 145-146.

It has been mentioned that oysters can be transhipped from natural beds to areas of farming keeping down mortality rate while in transit by adequate precautionary steps.

CHACKO, P. I. 1957. The pearl fishery conducted off Tuticorin in 1956, *Ind. Com. J. Madras*, **126** : 326-331.

An account of a minor fishery held in 1956 has been given with details of area fished.

CHACKO, P. I. 1959. Food and feeding habits of the fishes of the pearl banks, Thollayiram paar, in the Gulf of Mannar. *Fisheries Station Reports and Year Book* 1955-56 (Madras Fisheries Dept.) : 80-83.

The bottom feeding fishes, *Abalistis stellaris* and *Scolopsis bimaculatus*, the carnivorous *Cephalopholis miniatus* and *Epinephelus undulosus* constituted the main threat to pearl oyster spat.

CHACKO, P. I. 1970. The pearl fisheries of Madras State. *Proc. Symp. Mollusca*, Mar. Biol. Ass. India, Pt. III : 868-872.

A brief review of the past and recent pearl fisheries held in the Gulf of Mannar and Palk Bay upto 1961.

CHACKO, P. I. AND C. MALUPILLAY. 1959. Marine turtles as possible distributors of pearl oysters. *Fisheries Station Reports and Year Book for* 1955-56 (Madras Fisheries Dept.) : 101-102.

The settlement and growth of oyster spat (5-40 mm size) noticed on the carapace of *Chelone mydas* has made the authors suggest that the turtles may act as dispersing agents, during their sojourns to different areas of ocean.

CHACKO, P. I. AND P. S. SAMBANDAMURTHY. 1969. Conditions of existence in twenty pearl banks in the Gulf of Mannar off Tuticorin during 1962-63. *Madras J. Fish.*, **5** : 94-99.

An account of the oyster stock.

CHARI, S. T. 1966. Chemical composition and food value of chank and pearl oysters. *Madras J. Fish.*, 2 : 84-85.

Chemical analysis shows that chank and oyster meat are fit for human consumption due to the high protein value. The flesh contains 14.42% protein in the case of oyster and high in minerals and glycogen. The oyster flesh is palatable.

CHELLAM, A. 1978. Growth of pearl oyster *Pinctada fucata* in the pearl culture farm at Veppalodai. *Indian J. Fish.*, 25 (1 & 2) : 77-83.

Dorso-ventral dimension and hinge line showed positive growth upto a certain period followed by growth recession. Thickness increased uniformly throughout the period in size range 30-45 mm stagnating in older size groups 45-60 mm during certain periods of the year. Weight increase was steady in the early size groups. Growth appeared to be faster during September-January and less in other months.

CHELLAM, A. 1983. Study of the stomach contents of the pearl oyster, *Pinctada fucata* (Gould) with reference to the inclusion of bivalve eggs and larvae. *Proc. Symp. Coastal Aquaculture*, Pt. 3 : 604-607. Mar. Biol. Ass. India.

Bivalve eggs and larvae along with appendages of copepods, gastropod and crustacean larvae and spicules of sponges have been observed regularly while analysing the stomach contents of *Pinctada fucata*. Very often, oyster eggs and larvae fed to the starving pearl oysters were expelled along with faecal discharge as such.

CHELLAM, A. AND K. ALAGARSWAMI. 1983. Blooms of *Trichodesmium thiebeauti* and their effect on experimental pearl culture at Veppalodai. *Indian J. Fish.*, **25** (1 & 2) : 237-239.

Blooms of *Trichodesmium* were observed at the pearl oyster farm site during March, April and September 1973 but the high concentration did not cause any unusual mortality of oysters. But in the laboratory, oysters died when they were kept in bloom laden water perhaps due to the decaying algal filaments.

CHELLAM, A., T. S. VELAYUDHAN, S. DHARMARAJ AND A. C. C. VICTOR. 1983. A note on the predation of pearl oyster

Pinctada fucata (Gould) by some gastropods. *Indian J. Fish.*, 30 (2) : 337-339.

Cymatium cingulatum and *Murex virgineus* cause considerable mortality of young oyster on the beds and farm. *Cymatium* eats the flesh in 7-10 hrs after narcotising the oyster by inserting its proboscis. *Murex* breaks the shell margin first and through this gap the proboscis is inserted and flesh eaten in 24 hrs.

CHIDAMBARAM, K., A. D. ISAAC RAJENDRAN AND A. P. VALSAN. 1951. Certain observations on the hydrography and biology of the pearl bank, Thollayiram paar off Tuticorin in the Gulf of Mannar. *Jour. Madras Univ.*, 21 : 48-74.

During pearl bank inspection conducted in 1949, 8 days of intense search of Thollayiram paar produced 38 oysters all under one year of age. A list of 49 animals belonging to 8 phyla collected, has been furnished together with details of inspection done during 1924 to 1949. A general account of the physico-chemical characteristics of the water of the area studied has been included.

CHOODAMANI, N. V. AND S. MAHADEVAN. 1962. Report on the inspection for pearl oyster beds off Tondi (Ramanathapuram District) and Mallipatanam (Thanjavur District) in Palk Bay during September 1958. *Fisheries Station Reports and Year Book for* 1957-58 (Madras Fisheries Department): 99-103.

Only *Pinctada chemnitzii* (22 nos.) were collected from Tondi sandy beds. Mallipatnam inspection failed to show any rocky beds.

CMFRI. 1977. Pearl Culture Training. *CMFRI Special Publication* No. 1 : 39 pp.

Manpower training to develop a cadre of competens technical personnel in pearl culture is aimed at by thit cause. This course includes training in all aspects of pearl culture covered in six months duration and limited programme on specific aspects in a short duration.

CMFRI. 1978. Culture of pearl oyster and production of cultured pearl. (Mariculture Research and Development Activities). *CMFRI Special Publication* No. 2 : 14-15.

The achievements in research and development of the Institute's scheme on pearl culture since 1973 have been highlighted as one of special breakthroughs in mariculture research in India.

CMFRI. 1982. Proven technology, 2. Technology of cultured pearl product on. Proven technology, 3. Technology for hatchery production of pearl oyster. *Mar. Fish. infor. Serv. T & E Ser.*, 45 : 22-24.

The techniques of pearl oyster farming and cultured pearl production are described. Artificial breeding, larval rearing, spat collection, nursery rearing, microalgal food production and water management have been successfully done at Tuticorin to produce pearl oyster seed. It is estimated that 500,000 spat per spawning can be produced using 50 larval tanks.

DEVANESAN, D. W. AND P. I. CHACKO. 1958. Report on culture pearl experiments at the Marine Fisheries Biological Station, Krusadai Island, Gulf of Mannar. *Contribution from the Marine Fisheries Biological Station, Krusadai Island, Gulf of Mannar*, No. 5 : 1-26.

James Hornell initiated culture pearl experiments in India and claimed to have obtained 'six tiny, smooth surfaced perfectly spherical free pearls', but the technique followed by him was not made known. The publication mentions of techniques followed in Japan for culturing pearls and also a technique evolved as how to implant the mother of pearl nucleus in the virtual chamber formed by the adductor muscle, pallial muscle insertions and the hinge line. This method would, it was hoped, yield quality pearl.

DEVANESAN, D. W. AND K. CHIDAMBARAM. 1956. Results obtained at the pearl oyster farm Krusadai Island, Gulf of Mannar and their application to problems relating to pearl fisheries in the Gulf of Mannar, Part I. *Contr. from the Marine Fisheries Biological Station, Krusadai Island, Gulf of Mannar*, No. 4 : 86 pp.

Krusadai Island oyster farm work started as early as in 1933 and standardisation of methods and materials used for rearing oysters finally enabled the scientists working on the project to device wooden cubicles with 49 compartments in each of which oyster of known length and weight can be put and covered by a close meshed iron framed cage and hung in water column in the 'park'. Another cage type used for oyster growing was the 'wine net cage' with provision for meshed trays to be so positioned as to give six compartments where oysters can be put. A total of 2,500 oyster spat stocked at different periods from 1933-40 provided the material for data collection. Sixteen pages of the report are devoted (pages 9-25) to various general aspects of pearl oyster shell measurements, problems of pearl fisheries, breeding stimuli, sex ratio, current pattern in the Gulf of Mannar, comparison of pearl fisheries of Persian Gulf with that of Gulf of Mannar and periodicity of pearl fisheries, mostly observations made and inferences drawn by earlier pearl fishery scientists. Analysis of the data collected by the authors shows that the shell length and body length and weight are more reliable than other factors for growth studies. Shell length is said to be addition till the end of third year when it reaches maximum. According to the authors fourteen generations are affected in every pearl fishery. The maximum growth (60.65 mm) belongs to three year old and more. 36 pages are devoted fo furnishing the data collected during the study period.

DHARMARAJ, S. 1983. Oxygen consumption in pearl oysters, *Pinctada fucata* (Gould) and *P. sugillata* (Reeve). *Proc. Symp. Coastal Aquaculture*, Pt. 2 : 627-632. Mar. Biol. Ass. India.

Oysters from natural beds showed low rate of oxygen consumption compared to those collected from near inshore waters, 0.5-1.5 m depth. Younger oysters (20 mm and below) were found to consume more oxygen/hour. The measure of gap between margin of shell valves was found to vary inversely with the amount of oxygen present in sea water.

DHARMARAJ, S. AND A. CHELLAM. 1980. Settlement and growth of barnacle and associated fouling organisms in pearl culture farm in the Gulf of Mannar. *Proc. Symp. Coastal Aquaculture, Mar.* biol. Ass. India, 2 : 608-613.

Balanus amphitrite, *Membranipora* and *Dicarpa* sp. formed the major fouling organisms while *Polydora ciliata* and *Cliona vastifica* were the main borers. Barnacle settlement was heavy and seasonal particularly on shells than on live oysters. The seasonal fluctuations in the occurrence of fouling organisms in Veppalodai farm area, Tuticorin harbour basin and in the natural beds showed many contrasting features.

ESWARAN, C. R., K. R. NARAYANAN AND M.S. MICHAEL. 1969. Pearl Fisheries of the Gulf of Kutch. *J. Bombay Nat. Hist. Soc.*, 66 : 338-344.

42 khadas occupying 60,000 acres lying from Jodiya to Ajad are exploited for pearl oysters by fishermen. From statistics of pearl fisheries ever since 1913 to 1967 it can be seen that oysters numbering from 522 (1938-39) to 76,658 (1916-17) were fished during the years of fishery. Unproductiveness and thinness of population of oysters have been the main problems of Gujarat Coast.

FAO REPORT. 1960. Pearl and chank beds in the Gulf of Mannar. *FAO report ETAP./No.* 1119 *to the Govt. of India* : 1-60.

For the first time a scientific method of charting and studying the pearl banks and their fauna and flora in India, using Aqua-lung for direct observations had been followed and reported. 3 selected paars were surveyed in detail by a F.A.O. diving scientist and 4 of his Indian counterpart scientists, trained by him. The studies helped in population estimation of oysters.

FAO REPORT. 1962. Pearl and chank beds in the Gulf of Mannar. *FAO Report EDTA No.* 1323. *Second report to the Govt. of India* : 1-7.

The report indicates the progress of work done by Indian scientists using SCUBA in the study of pearl banks. Exploration at intervals of 600 m covering an area of 100 sq. miles of sea bed had been taken up in addition to studies on environmental parameters.

FAO REPORT. 1962. Pearl and chank beds in the Gulf of Mannar. *FAO Report EPTA No.* 1498. *Third report to the Govt. of India.*

The last report gives further details of the progress made in the underwater studies of pearl banks off Tuticorin by SCUBA diving and outlines the future lines of technical programme to be implemented.

FREDA CHANDRASEKARAN, A. D. ISAAC RAJENDRAN AND C. MALUPILLAY. Salinity and temperature variations over pearl and chank beds of Tuticorin. *Madras Jour. Fish.*, 4 : 21-27.

Atmospheric temperature recorded was lowest in January rising upto May, falling again in June and July. A secondary maximum was seen in September-October. The range of variation in surface temperature of water 4.1°C-6.4°C in different years. Salinity increase was noticed upto June from February. The lowest was in November and December.

FREDA CHANDRASEKARAN AND K. SUDHAKAR. 1967. Observations on the hydrography and planktology of pearl banks of Gulf of Mannar. *Madras Jour. Fish.*, 4 : 28-33.

Zooplanktonic abundance followed a peak phytoplankton production. During April-May the plankton biomass was low, although phytoplankton abundance appeared to coincide. Low salinity period in January was marked by zooplanktonic abundance.

FREDA CHANDRASEKARAN AND S. VICTOR CHANDRA BOSE. 1971. Free amino acids in Indian pearl oyster flesh. *Madras Jour. Fish.*, 6 : 80-88.

Chromatograms showed bands corresponding to B Alanine, Glutamic acid, Glycine, Taurine and Aspartic acid were also seen in the extracts.

GOKHALE, S. V. 1963. Shell fisheries of Saurashtra region, Gujarat State. *Publication of the Department of Fisheries, Gujarat Government* : pp. 6.

Records of Jamdarkhana show that during the days of Jam Vibha pearls were not fished but the vaghers could collect and give them to Jam Sahebs of Jamnagar. It is surmised that Persian Gulf oysters would have helped originally to populate the Gujarat Coast also. A pearl park was created in 1952 for carrying out investigations. The average output of Gulf of Kutch has been given as 30,000-40,000 oysters per year due to the sparse populations.

GOKHALE, S. V. AND C. R. EASWARAN. 1954. Growth rate of the pearl Oyster, *Pinctada pinctada* in the Gulf of Kutch with a note on the pearl fishery of 1953. *J. Bombay. Nat. Hist. Soc.* 52 (1) : 124-136.

The oyster shows two distinct periods-one of active growth and the other of rest in a year. They grow fast till they attain their fourth year after which a fall was discernible. Sexual maturity was seen at the age of three or four and the life span calculated to reach up to seven years normally. No overfishing of beds has been reported. On an average 15-20% pearl yield has been obtained from oysters of 4, 5 and 6 year old. Pearl formation might start at the age of 2-3 years.

HORNELL, J. 1905. Report to the Government of Madras on the Indian pearl fisheries in the Gulf of Mannar. *Madras Govt. Publication.*

Depredation by pearl bank fishes wipe out large quantity of oysters in the early stage itself. Of these, filefishes and breams devour enormous number of oyster spat. Oyster-eating rays *Rhinoptera* sp. rank next in importance as oyster enemy causing wide spread devastation of beds. The extent of damage done has to be seen at the sea bottom to be believed as did the author during his descent to the oyster bed so ravaged.

HORNELL, J. 1909. Report to the Government of Baroda on the Marine Zoology of Okhamandal in Kathiawar. *William Norgate, London* : 8-18.

Rich pearl oyster reefs are reported lying scattered along the coast line of Nawanagar. The salient features of the pearl fishery of that state are given. The fisherfolk received 1/8th of the value of pearls in cash, 1/4 th in cloth and 1/20th in food, in addition to prices for the best pearls.

HORNELL, J. 1913. A preliminary note on the preponderant factor governing the cyclic characters of the pearl fisheries of Ceylon and India. *Communication to 9th Congr. Inter. Zool. Monaco.* Ser. 2 : 35-36.

HORNELL, J. 1915. The recent pearl fishery in Palk Bay, with biological notes upon pearl oysters. *J. Asiat. Soc. Bengal, Calcutta*, 11 : 15-3154.

A detailed account of the results are given.

HORNELL, J. 1916. An explanation of the irregularly cyclic character of the pearl fisheries of the Gulf of Mannar. *Madras Fish. Bull.*, 8 : 11-22.

The history of Gulf of Mannar pearl banks witnessed periodic recurrence of alternating conditions. A cycle of years when oysters were abundant yielding valuable fisheries resulted in increasing predator competition for preying on oyster flesh in the next years thus turning the balance in favour of fishes, sharks, rays and skates which devour oyster spat, crunching the shells and destroying the population.

HORNELL, J. 1916. Professor Huxley and the Ceylon pearl fishery with a note on the forced or culture production of free spherical pearls. *Madras Fish. Bull.*, 8 : 93-104.

Transplantation of pearl oysters from deeper area to oyster 'parks' had been advocated to ensure a good and dependable source of revenue from pearls produced by oysters grown in such areas.

HORNELL, J. 1916. Report on the pearl fishery held at Tondi, 1914. *Madras Fish. Bull.*, 8 : 43-92.

The fishery was the first ever held in Palk Bay. The fishing commenced on 27th August 1914 and closed on 19th September 1914. The beds off Karangadu and Pasipatnam at 5½ fathom depth were exploited, fishing in all 315,998 oysters off Pasipatnam and 39,613 oysters from Karangadu beds. Never before were pearl oysters noticed to thrive on muddy ground as in the present case. The revenue realised was poor and the scale of cholera epidemic kept away many from participating. Added to this, unfavourable weather from 14th September brought about premature closure of fishery. Hornell suggested that dredging for the oysters in such areas might be more economical. He mooted out the idea that Palk Bay area should be observed as a 'breeding reserve' for populating the Gulf of Mannar paars, the dispersal of larvae taking place with the help of south flowing current and drift.

HORNELL, J. 1922. The common molluscs of South India. *Madras Fish. Bull.*, 14 : 161-165.

Description of *Margaritifera vulgaris* has been furnished. Oyster spat, it is stated, are capable of locomotion in the initial stages for finding out a suitable substratum for attachment before they finally settle down. The spat settling stage is achieved in a weeks time from the time the eggs are fertilized. Gulf of Mannar, Gulf of Kutch and Palk Bay are three areas where oysters settle down and grow in Indian waters.

HORNELL, J. 1923. Reports on the inspection of pearl banks in the Gulf of Mannar and Palk Bay in March 1923. *Madras Fish. Bull.*, 17 : 199-214.

Inspection of beds from Vaipar to Manapad indicated very dense pearl oyster spat settlement in majority of the banks (28 out of 54). The prospects for a bumper fishery in next few years appeared bright. Legal restrictions to protect the banks appeared to be unnecessary. Beds of Tondi were barren of live oysters, as also the Rameswaram area.

HORNELL, J. 1949. The Study of Indian Molluscs. Part II and Part III. *J. Bombay. Nat. Hist. Soc.* 48 (3) : 543-569 and 48 (4) : 750-774.

Mention of oyster resources in India has been made.

KURIYAN, G. K. 1950. The fouling organisms of pearl oyster eggs. *J. Bombay. Nat. Hist. Sec.* 49 (1) : 90-92.

A list of marine foulers and epifauna of oysters grown in Krusadai farm has been given based on observations made at the time of routine cleaning operations of the cages. The importance of the barnacle as the most prolific fouler has been shown. The foulers during southwest and northeast monsoon periods were most abundant, and the various species collected have been listed under two groups.

MAHADEVAN, S. 1971. Fishing for pearls in India. *Sea Food Exp. Jour.*, 3 (3) : 11-23.

This article describes the preparations made by skin divers before diving for oysters in India, the role of tenders and the routines of divers when a pearl fishery is in progress.

MAHADEVAN, S. 1971. Whither pearl fishing. *Souvenir., Fish. Exporters Chamber* : 181-184.

Popular article which emphasises the need for culture pearl operations to be started in India.

MAHADEVAN, S. AND K. NAGAPPAN NAYAR. 1967. Underwater ecological observations in the Gulf of Mannar off Tuticorin. VII. General topography and ecology of the rocky bottom. *J. mar. biol. Ass. India*, 9 (1) : 147-168.

For the first time results of scientific survey of oyster beds carried out using 'SCUBA' in the Central and Northern sectors off Tuticorin have been presented. The area covered, at intervals of 600 m, was 769 sq. km. and the pearl beds charted out have been mapped showing the extent and position of each. The characteristic fauna and flora have been identified and the interaction among the animal communities explained. The effects of starfish population, *Modiolus* spp. settlement, Octopus population and the bottom dwelling fishes on oyster life have been described. Chank beds have also been surveyed and marked showing the density of population. Under water photographs of important denizens of pearl banks have been given.

MAHADEVAN S. AND K. NAGAPPAN NAYAR. 1972. Free diving in Indian waters. *Sea Food Exp. Jour.* (4) 2 : 25-27.

An account of 'SCUBA' diving and its progress in scientific investigations of pearl and chank beds in the Gulf of Mannar is given.

MAHADEVAN, S. AND K. NAGAPPAN NAYAR. 1973. Pearl Oyster resources of India. *Proceedings Symp. Living Resorces of the Seas around India C.M.F.R.I., Cochin, Special Publication* : 659-671.

An overall review of the pearl oyster resources of world has been given. The areas where oyster occur, an account of pearl fisheries in India and the methods of fishing by skin diving and picking oysters as in Gulf of Kutch have been described. A review of traditional inspection methods used in oyster population estimation and the progress achieved by modern method of Aqualung diving are given showing their comparative efficiency in exploitation. The paper outlines the role played by *Modiolus* spp. and Octopus in destroy.ing pearl oyster population over natural beds.

MAHADEVAN, S. AND K. NAGAPPAN NAYAR. 1974. Ecology of pearl oyster and chank beds. *Bull. Cent. Mar. Fish-Res. Inst.* 25 : 106-121.

The flat rock nature of Gulf of Mannar beds covered by coarse band affords ideal substratum for oyster settlement and the sandy bottom of Palk Bay is less ideally so. Predominant pearl bank fishes in the Gulf of Mannar are the characteristic bottom dwelling *Balistes* spp. *Gaterin* spp. and *Serranus* spp. The Palk Bay area fauna is monotonous and shows contrasting composition.

MAHADEVAN, S. AND K. NAGAPDAN NAYAR. 1976. Underwater observations on the settlement of pearl oyster spat in the paars off Tuticorin. *Indian J. Fish.*, 23 (1 & 2) : 105-110.

Periodic ' SCUBA ' diving observations on the pearl bank during 1970 to 1972 showed that it was not advisable to depend entirely on wild oyster stock for getting requirements of seed for pearl oyster farming work. The spatfall has been irregular and vitiated by the settlement of competitor *Modiolus* in all beds. The intensity of such settlement is so enormous in almost all years that healthy oyster survival becomes a matter of chance.

MAHADEVAN, S. 1980. Taxonomy and ecology of cultivable molluscs. *Proc. of the Summer Institute in Culture of edible molluscs*, C.M.F.R.I., 40-54.

Pearl oyster species in India and their diagnostic characters have been mentioned.

MALUPILLAY, C. 1962. A survey of the maritime meteorology and physicochemical conditions of the Indian pearl banks off Tuticorin in the Gulf of Mannar from December 1958 to May 1959. *Madras J. Fish* 1 (1) : 77-95.

The fluctuations in the surface temperature of sea water observed from 31 rocky beds (paars) follow closely those of the overlying temperature. Salinity touches a low in December-February due to probably current direction and discharge of freshets from major rivers during North east monsoon rains. Dissolved oxygen was high and silicate content fairly rich (14.3 gm at/L). Data on other chemical and physical characteristics have been furnished.

MALUPILLAY, C. 1962. A review of the physico-chemical environmental conditions of the pearl banks and chank beds off Tuticorin in the Gulf of Mannar during April 1960 to March 1961. *Madras J. Fish.*, 1 (1) : 102-104.

Both S.W. and N. E. monsoons affect the hydrographical conditions of the pearl banks. Good mixing of water has been characteristic feature of these areas as revealed by the absence of marked vertical gradients of temperature, salinity and oxygen.

NARAYANAN, K. R. AND M. S. MICHAEL. 1968. On the relation between age and linear measurements of the pearl oyster *P. vulgaris* (Schumacher) of the Gulf of Kutch. *J. Bombay Nat. Hist. Soc.*, 65 (2) : 44-42.

Based on the annual growth ring studies of 2 oysters the authors infer that the oysters life span can extend beyond 8 years, although normally not so. The increase in length, breadth and hinge length in relation to age does not appear to be uniform. Growth arrest in summer and quick growth during November to February have been noticed. The thickness of hinge and hinge-width appear to be proportionate to the age of oysters and hence these two factors are more dependable in age determination.

NAYAR, K. NAGAPPAN. 1980. Present status of molluscan fisheries and culture in India. *Proceedings of the Summer Institute in Culture of edibleMolluscs held at Tuticorin* (C.M.F.R.I.) : 31-39.

Mention has been made of the great success achieved in pearl culture at Tuticorin in 1973 and also a pilot scale project on pearl culture started by Kerala Government at Vizhinjam since good settlement of oysters was brought to light in 1974.

NAYAR, K. NAGAPPAN AND S. MAHADEVAN. 1967. The pearl and chank fisheries—a new outlook in survey and fishing. *Souvenir : 20th anniversary of C.M.F.R. Institute*

Thoroughne ss and greater efficiency of the exploitation by following aqualung diving calls for introduction of this method in the exploitation of chanks and pearl oysters. CMFRI can impart training to fishermen so that aqualung diving can become popular and profitable.

PETER DEVADOSS, D. D., N. V. CHOODAMANI, R. VENKATARAMAN, S. THIAGARAJAN, S. MAHADEVAN AND A. D. ISAAC RAJENDRAN. 1958. Observations on the pearl fishery off Tuticorin—1957 in the Gulf of Mannar. *Proc. 45th Ind. Sci. Congress*, Pt. III, Session VII, Abst. No. 90 : 373-374.

Totally 7 paars were inspected prior to the fishery, getting 2,000 samples of oysters. The analysis showed that the oysters can be fished at once and population of fishable was estimated to be 12.7 million aged 3-4½ years. The pearl fishery which followed yielded 11,175,214 oysters in 51 days of fishing. The Government realised a revenue of Rs. 166,366.87.

PRASHAD, B. AND J. L. BHADURI. 1933. The pearl oysters of the Indian waters. *Rec. Ind. Mus.*, 35 : 167-174.

Systematic account of the five species of pearl oysters of India *P. vulgaris*, *P. maragaritifera*, *P. chemnitzii*, *P. anomioides*, and *P. atropurpurea* has been given indicating diagnostic features for their identification.

PHYLLIS, S. SUNDERARAJ. 1955. Pearl fishery at Tuticorin. *Illustrated Weekly of India* : 5-6.

The ritual of the divers' fishing day has been described to show their enthusiasm and efficiency. The oyster purchasing public respond with equal expectancy to become owners of valuable pearls, purchasing the oysters either in auction or from divers' lot.

PANDYA, J. A. 1974. Pearl oyster resource and culture experiments in Gujarat. *Proc. of the Group Discussion on Pearl Culture* held at Tuticorin (CMFRI) : 25-27.

Pearl oyster reefs, 42 in no. occupying 24,000 hectares coour between Sachana to Ajad. Handpicking of oysters is done during southwest monsoon. The last pearl fishing of 1968 yielded 30,000 oysters. Culture experiments were started in 1956 at Sikka but did not produce desired results.

RADHAKRISHNAN, N., I. NALLUCHINNAPPAN AND DANIEL SUDHANDRA DEV. 1980. *Seminar on Coastal and Inland Fish Culture in Tamil Nadu*, Abstr. 29.

Mortality of the pearl oyster in the farm at Tuticorin due to sudden fall in salinity has been mentioned.

RAO, K. VIRABHADRA. 1968. Pearl oysters of the Indian region. *Proc. Symp. Mollusca*, Mar. Biol. Ass. India, 3 : 1017-1028.

The identity, synonyms and distribution of six peatl oyster species under the genus *Pinctada* have been deart with. *Pinctada sugillata* has been recorded for the firsl time from Indian coasts.

RAO, K. VIRABHADRA AND K. SATYANARAYANA RAO. 1974. Pearl oysters. In : The Commercial Molluscs of India. *Bull. Cent. Mar. Fish. Res. Inst.*, 25 : 84-105.

The field identification of shell characters of Indian species of pearl oyster have been given. The criteria for recognising the different species are : (1) Presence or absence of hinge teeth, (2) nacreous border (3) width of nacreous layer, (4) shape and positions of anterior and posterior ear and (5) shell colour and markings.

SAMBANDAMURTHY, P. S. 1962. Surface plankton of the pearl banks, Thollayiram paar, off Tuticorin. *Madras J. Fish.*, 1 (1) : 75-76.

20 important plankters have been reported as occurring in the waters although seasonal fluctuating in abundance. This indicative of the oceanic conditions influencing the primary productivity in this area. The presence in good number of larval forms of fishes shows that the zone may be a nursery for pelagic species.

SAMBANDAMURTHY, P. S. 1966. On a survey of the pearl banks of Tuticorin, Gulf of Mannar in 1961-62. *Madras J. Fish.*, 2 : 71-77.

Results of survey of 10 paars showed the waning oyster population after the last fishery. Only 964 oysters were collected in 65-66 mm size, which according to the author should belong to 5 year age group.

SILAS, E. G., K. ALAGARSWAMI, K. A. NARASIMHAM, K. K. APPUKUTTAN AND P. MUTHIAH. 1982. Country Reports—India. In : F. Brian Davy and Michael Graham (Eds.) Bivalve culture in Asia and the Pacific. *Proc. Workshop held in Singapore*, 16-19. Feb. 1982 : 34-43, I.D.R.C., Ottawa.

A short review of pearl fishery in India is given. The paper gives a resume of the progress made in India of oyster farming, mussel farming, cockle farming and about the potentialities of clams in India. The paper points out the need for organised development, proper extension, availability of seed for large-scale culture, finding out low cost technology and developing post-harvest technology and quality control. Future plans like developing economic data base, cost benefits study of culture of oysters and promoting R and D efforts are envisaged.

SIVALINGAM, S. 1963. Bibliography on pearl oysters. *Dept. of Fisheries, Bull.* 13, *Fisheries Res. Station, Ceylon :* 1-21.

678 references pertaining to work on pearl oyster from all parts of the world are listed.

SUDHAKAR, K. AND FREDA CHANDRASEKARAN. 1968. Note on the veliger larvae in plankton collected from Thollayiram paar. *Madras J. Fish.*, 4 : 38-44.

200 veligers from plankton collected over the paar ranged in size 24.3μ-36.5μ and have been considered to be pearl oyster larvae based on their resemblance to those described by Herdman (1906) and Hornell (1922).

THOMAS, H. S. 1884. A report on pearl fisheries and chank fisheries. *Madras Government Publication :* 34 pp.

The bearings and names of important paars of Mannar coast of India have been given in addition to chronology of inspection of paars and fisheries conducted.

THURSTON, E. 1889. The Tuticorin pearl fishery. *Nature*, London, 40 : 174-176.

The conduct of the pearl fishery and the results were given.

VARMA, R. PRASANNA. 1960. Flora of the pearl beds off Tuticorin. *J. mar. biol. Ass. India*, 2 (2) : 221-225.

The algal flora of pearl beds is rich. In the four zones where collections were made by diving as many as 69 species had been reported in Zone IV, 15 in Zone III, 61 in Zone II and 25 in Zone I. The algae are mostly of the types found in coral beds, irrespective of depth. Majority of green algae inhabiting deep waters are siphonales. Blue green algae was totally absent in the collections. The presence in good quantity of brown algae in the paar area is interesting. Red algae *Gracillaria* and *Hypnea valentiae* are also commonly seen in Zone IV which is off Tiruchendur.

VENKATARAMAN, R. AND S. T. CHARI. 1956. Chemical investigations on the formation of pearls in the Indian pearl oyster (*Margaritifera vulgaris*). *J. Sci. and Ind. Res.*, 15-C, 99 : 212-213.

The iron content of the meat without pearl formation is 7 times that of the meat with big pearls. The aminoacid make up of the protein from different portions of meat does not show variations.