Textbook of

Oyster Biology and Culture in India

K A Narasimham
and
V Kripa

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INDIAN COUNCIL OF AGRICULTURAL RESEARCH
NEW DELHI

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Published by
Directorate of Information and Publications of Agriculture
Indian Council of Agricultural Research
New Delhi 110 012

PRINTED : JULY 2007

Project Director (DIPA) : Dr T.P. Trivedi
Incharge (English Editorial) : Dr R.P. Sharma
Editing : Reena Kandwal
Chief Production Officer : V.K. Bharti
Technical Officer (Production) : Punit Bhasin
Senior Artist : B.C. Mazumder

ISBN No. : 81-7164-070-2

Price : Rs 400

Published by Dr T.P. Trivedi, Project Director (DIPA), Indian Council of Agricultural Research, Krishi Anusandhan Bhavan I, Pusa, New Delhi 110 012; Lasertypeset at M/s Print-O-World, 2579, Mandir Lane, Shadipur, New Delhi 110 008, and printed at M/s Chandu Press, D-97, Shakarpur, Delhi 110 092.

Preface

OYSTERS, an important group among the bivalve molluscs are highly esteemed as seafood in many temperate countries where consumption of raw oysters is popular. Oyster is probably the most studied invertebrate and marine aquaculture may have begun with oysters. Oyster farming has a long history and it has been reported that the Chinese practiced oyster culture before the Christian era while in Europe the Romans farmed oysters since the beginning of the first century B.C. by adopting the simple method of relaying the oyster seed in suitable grow out areas. In late 1920s the Japanese developed the 'hanging culture' and by 1950s made rapid strides by adopting the raft and long line oyster culture in depths upto 30 m. The latter half of the 20th century ushered in the spread of oyster culture to several parts of the world and there is growing interest in tropical countries, which have the advantage of cheap labour and producing market size oysters in a short period of 6-10 months against about 2 years or more in temperate countries, depending upon the method of culture and the species. The noted oyster biologist Dr.Gary Newkirk stated that oysters are cultured in all the continents except in the Antarctica. As per the FAO statistics, the world aquaculture production of molluscs in 2003 was 1,22,84,758 mt and among them the oysters accounted for 44,96,609 tonnes (36%). These figures highlight the importance of oysters in the global perspective. China emerged as a world leader in oyster production with about three-fourth production as its share.

In India, the first attempt to farm the oysters on scientific lines was made in 1910 by the British Biologist Dr. James Hornell. Realizing the importance of oyster culture, the Central Marine Fisheries Research Institute initiated a Research Project on oyster culture at its Tuticorin Research Centre in late 1970s by collecting natural spat. A devoted band of scientists under the able leadership of Shri K. Nagappan Nayar, followed by others, have successfully developed the technology of seed collection from nature, farming systems using racks for holding trays and oyster rens and also large scale hatchery production of seed. During 1993-95 several programmes were taken up by the CMFRI to assess the suitability of various sites in several states for oyster culture by using both hatchery and natural spat. These studies showed that several places in the four southern states are suitable for oyster culture, and the most important being the Ashtamudi lake in Kerala which emerged as a highly suitable site both for spat collection and grow-out culture. In the mean time, significant contributions on various aspects of oyster culture have come from

the College of Fisheries, Mangalore. After nearly two decades of research and development by the CMFRI, the first commercial oyster farm came up in 1996 at Dalavapuram in the Ashtamudi lake. Since then, with active support, in imparting training, technology transfer and continuous interaction in the field with the oyster farmers by the CMFRI scientists, coupled with the involvement and participation of financial institutions, developmental agencies and others, oyster culture is fast picking up in Kerala, with the current production being 750-800 t. The average annual production of oysters by the harvest of wild stocks is 18,800 tonnes / year. A major constraint at this time is marketing, since in India oyster consumption is traditionally limited to a few coastal communities and oysters are practically unknown in the vast interior of the country except for a few metropolitan cities. The technology for the preparation of several products with oysters is readily available in the country. The availability of indigenously developed and time tested packages of oyster culture technology, a strong research base to optimise production, increased awareness among the prospective farmers about the economic benefits of oyster culture and the readiness of developmental and financial institutions to provide credit, augurs well for the rapid development of oyster culture in the country.

Dr. K.A. Narsimham, senior author rendered over 37 years of service in the CMFRI and has over 70 scientific papers to his credit. During his long association with this Institute, he made significant contributions on most groups of molluscs of commercial importance in India. He functioned as the Head of Molluscan Fisheries Division for over four years. He played a major role, in association with his colleagues, in identifying various sites suitable for oyster culture in India and in the transfer of oyster culture technology to the farmers. As Principal Investigator of the bivalve hatchery project, in collaboration with his colleagues, he achieved a major breakthrough in the large-scale hatchery seed production of various clam species. He is a recipient of Ind. Aqua 1993 award, in recognition of his outstanding contributions in developing complete package of technology for clam culture.

Dr. (Mrs.) V. Kripa, Senior Scientist and co-author of the book is working in the CMFRI for the last 20 years. She has worked on the clam, oyster, mussel and cephalopod resources of the south-west coast of India. She took the Ph.D. degree from Cochin University of Science and Technology for her thesis on the rock oyster *Saccostrea cucullata*. She also received National award in 2001 for her article in Hindi on "Molluscan Mariculture" under the non-Hindi speaking category. She is playing a significant role in the technology transfer of oyster culture with particular emphasis on women empowerment in this area.

This book, Oyster Biology and Culture in India contains 12 Chapters and after a general introduction to oysters in Chapter 1, oyster resources, their

distribution and ecology are dealt in Chapter 2. Biology, unwanted species, fisheries, seed production, technology of farming, economics of oyster culture and technology transfer are dealt in Chapters 3 to 9 respectively. Chapter 10 gives information on oyster culture practices in major oyster producing countries in the world and Chapter 11 on recent developments in oyster culture in the global perspective. In the concluding Chapter 12, the authors, after a critical examination of the current status of oyster resources and culture in India, underscore the strategies for developing oyster culture in the country. This book, although mainly targeted to meet the requirements of university teachers, researchers and students is also expected to cater to the needs of personnel from fisheries / rural development agencies, financial institutions, NGOs and entrepreneurs. I am confident that this book will stimulate further research and development initiatives in oyster culture in India.

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Acknowledgements

WE are thankful to the Indian Council of Agricultural Research, New Delhi for according sanction and providing financial assistance to write this book on OYSTER BIOLOGY AND CULTURE IN INDIA under 'University Level Text Book Writing Scheme'. It gives us great pleasure to place on record our thanks to Prof (Dr) Mohan Joseph Modayil, Director, Central Marine Fisheries Research Institute, Cochin for providing us all the facilities for successfully completing the work, encouragement, and for the keen interest evinced during the course of the work. We consider it a great privilege to place on record our deep sense of gratitude to Dr P Vedavyasa Rao, former Principal Scientist, CMFRI, who has spent considerable time by critically going through the manuscript, for several helpful discussions and constructive comments which have vastly contributed towards improving the quality of presentation of the material in various chapters. We are indebted to Dr KK Appukuttan, Principal Scientist and former Head of Molluscan Fisheries Division, CMFRI for providing us the facilities and support given in various ways, and for suggesting valuable improvements in the manuscript.

Several of our colleagues working in the CMFRI have extended help in various ways. We are thankful to Dr TS Velayudhan, Principal Scientist for literature and photographs, Dr KS Mohamed, Head, MFD, for going through the section on Probiotics, for suggestions, help rendered in taking photographs and for literature, to Dr P Jayasankar, Senior Scientist for going through the section on genetics and offering comments, to Dr VK Pillai, Dr CP Gopinathan, Principal Scientists and Dr PK Krishna Kumar, Senior Scientist for providing literature. We are also thankful to Dr P Muthiah, Principal Scientist for giving latest information on oyster culture. One of us (KAN) expresses his thanks to Dr H Mohamed Kasim and Dr (Mrs) S Sivakami, former Officers-in-Charge and Dr R Narayanakumar, Scientist-in-Charge, Dr AK Unnithan, Senior Scientist and the staff of the Kakinada Research Centre of CMFRI for facilities and help provided in various ways. The help rendered by Shri P Radhakrishnan, Shri Mathew Joseph, Shri PS Alloycious, Ms J Sharma and other staff of Molluscan Fisheries Division, CMFRI at Cochin is also gratefully acknowledged. We are thankful to Dr NGK Pillai, Principal Scientist and Head of Pelagic Fisheries Division, CMFRI for help rendered in several ways.

We express our thanks to Dr I Karunasagar, Professor, College of Fisheries, Mangalore for the help rendered in sending the latest literature on microalgal toxins and for the services put in by Shri KCS Kondala Rayydu, Ms Seema Shri BNP Raju and Fellows, for the assistance given at various times during

the course of the work. We also express our gratitude to the Senior Research Fellows, Mr Ramalinga, Ms R Jugnu, Ms Ani Kumari, Ms Leena Ravi, Ms R Sreejaya and Ms Anjana Mohan for the assistance given for literature collection and final compilation of the manuscript.

Dr KA Narasimham
December, 2006 Dr (Ms) V Kripa

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Chapter 1

Introduction

OYSTERS are bivalve molluscs occurring worldwide in temperate, subtropical and tropical seas. Generally they inhabit the coastal waters. Certain species of oysters also occur in lagoons, estuaries and backwaters. They are endowed with a pelagic larval life which ensures wider distribution. The larvae settle on hard substrates such as rocks, molluscan shells or on firm bottom areas, undergo metamorphosis and lead sedentary life. Oysters are filter feeders, feed low in the food chain and play a crucial role in the coastal ecosystem. The soft body parts of the oyster are enclosed within two shells which protect the animal from external disturbances. Oyster meat is nutritious and rich in protein and minerals.

From time immemorial, the oysters are traditionally eaten in many parts of the world and are currently among the high priced seafoods in many temperate countries where consumption of raw oysters is very popular. They are exploited from the natural beds and are also farmed on a large scale in many countries. In view of their economic importance oysters are the objects of intensive studies by a large number of workers. Angell (1986) stated that "The oyster is probably the most studied invertebrate organism and much is known about its biology". During 2003, the world production of oysters by the harvest of natural populations was estimated at 1,99,517 mt and through aquaculture at 44,96,609 mt. Among the oysters, *Crassostrea* (Sacco) is by far the most important genus. The Eastern oyster, also called American oyster, *C.virginica* (Gmelin) formed a significant portion (83.5%) of the production by the harvest of wild stocks while the Pacific oyster, *C.gigas* (Thunberg) is the most dominant among the farmed oysters accounting for 97.3% of world oyster production in 2003 (FAO, 2003a; 2003b).

The oyster fisheries in many parts of the world have declined due to habitat destruction, pollution, diseases and overfishing. Historically, the growth and decline of the Eastern oyster, *C.virginica* fishery in the Chesapeake Bay, USA is perhaps the best documented. The oyster catch peaked in Maryland at 6,15,000 t in 1884 and declined to 12,000 t in 1992. The decline was attributed to 'reduced water quality', diseases and fishing (see Rothschild *et al.,* 1994). Habitat destruction by using dredges for harvest and overfishing were considered as prime factors by Rothschild *et al.* (1994). For the recovery of the fishery these authors suggested a 4 - point strategy namely: (1) fishery management (2) replenishment (3) habitat replacement and (4) broodstock sanctuaries.

Oyster farming has a long history as reported by Guo *et al.* (1999), and the Chinese cultured oysters since more than 2000 years ago. Bardach *et al.* (1972), stated that "Marine aquaculture may well have begun with oysters, which were cultivated in Europe during Roman times". In Japan, oyster culture began in 1670 in the Hiroshima Bay (Imai, 1977). Newkirk (1991) stated that oysters are cultured on every continent except Antarctica. Oyster culture began by collecting oyster seed on stones and similar hard materials (cultch) and relaying the cultch on firm grounds. There was little management practice involved and the production was low. This was followed by the stick, stake and rack culture methods which were independent of the nature of substratum and gave higher production when compared to the on-bottom culture. By 1950s with most of the shallow coastal grounds used for oyster farming, the Japanese initiated raft and longline culture extending up to 30 m depth. When compared to rafts, longlines were found better suited to withstand the rough sea conditions in coastal waters. Extension of the farming grounds into deeper waters resulted in substantial increase in the production of oysters in Japan. Hatchery technology for oyster seed production was developed in 1950s.

China has emerged as the world leader in oyster farming accounting for 84% of production in 2003 followed by Japan (5.8%), Korean Republic (5.3%), France (2.6%) and the USA (2.4%). Several technological advances have been made in oyster culture in recent years, particularly in temperate countries. Following the success of oyster culture in these nations, and in the context of increasing demand of the commodity, the tropical countries also evinced keen interest to develop oyster culture where it is practiced as a small-scale activity. The tropical countries have the advantage of faster growth rate requiring only 6-8 months of culture against 2-4 years in many temperate countries. Besides, low production cost due to cheap labour is also a favourable factor. The major problems faced by the oyster culture industry include pollution, diseases and continuous high stocking density culture in the same site, exceeding the carrying capacity of the water body. Low domestic market demand is a constraint in some countries.

In India, the first attempt to bring together the available information on oyster resources was made by Alagarswami and Narasimham (1973) followed by Rao (1974). The Central Marine Fisheries Research Institute brought out a comprehensive account on oyster resources, biology and culture in a Bulletin entitled 'Oyster Culture: Status and Prospects' (CMFRI, 1987). Rao *et al.* (1992) described the technology of seed production and farming of *Crassostrea madrasensis* and James and Narasimham (1993) gave an account on oyster culture in a Handbook on farming of molluscs in India. Narasimhan *et al.* (1993) gave an overview of the molluscan resources of the country which included oysters. Joseph (1998) dealt on oyster culture in the tropics, which included India. Recently Appukuttan *et al.* (2000) gave an update account of

oyster culture along with the mariculture of other bivalves in the country while Muthiah *et al.* (2000) gave information on oyster culture. Kripa *et al.* (2004) described the development of oyster farming as a rural development program in Kerala especially as a group farming activity.

Among the Indian oysters, *Crassostrea madrasensis* is the most dominant, occurring in the estuaries, bays and backwaters along the east coast and south-west coasts (*Fig.1.*). Oysters are harvested at low tides in shallow waters by dislodging them with a chisel and hammer. Oyster fishing is a small-scale activity in the country. Many preparations are made with cooked oyster meat and it is also processed into several products. The oyster shell finds application in lime-based industries. The average annual production of oysters by fishing for the period 1995-1999 from the country was estimated at 18,800 tonnes (CMFRI, 2001). This reflects substantial increase in production when compared to mere 1000 tonnes/year reported for 1980s by Alagarswami and Meiyappan (1989).

Fig. 1. The oyster *Crassostrea madrasensis* with one valve removed to show the meat in shell
Courtesy: CMFRI, Cochin, Kerala

During 1970s work on oyster culture was taken up at the Tuticorin Research Centre of CMFRI, Tuticorin. Methods of natural spat collection, grow out culture by using trays and rens held on or suspended from racks were developed. With the setting up of the Shellfish hatchery in 1980 at Tuticorin, oyster spat were successfully produced in 1982 (Nayar *et al.,* 1984). This hatchery at Tuticorin played a significant role in providing oyster seed to undertake location testing studies to find out their suitability for culture, at

several places along the Indian coast. The very first attempt in 1993 to test the suitability of the Ashtamudi Lake in Kerala for oyster culture proved successful. In 1994, the CMFRI has set up a rack and ren oyster culture demonstration farm in the Ashtamudi Lake. This water body proved to be a very good site for oyster seed collection. The first commercial oyster farm was set up in 1996 by an enterprising farmer in the Ashtamudi Lake, close to the demonstration farm of CMFRI, followed by several villagers venturing into oyster culture in the estuaries of Kerala. Beginning in 1980s at Tuticorin and since 1995 at Ashtamudi, the CMFRI is conducting training programmes covering all aspects of oyster culture to farmers and others, lending technology support and is linking the farmers with developmental agencies for finance and marketing. The rack and ren method of farming is adopted by the farmers. The annual production of farmed oysters (*C.madrasensis*) in India is estimated to be between 750-800 tonnes.

In India, coastal aquaculture is at present mainly centered around shrimps, largely due to their high price, demand in the export trade and the technological advancements made in breeding, seed production and field culture. However, over the past decade, frequent disease outbreaks and negative environmental impact of their culture in coastal areas have greatly hampered the accelerated expansion and extension of this sector. In this context, entrepreneurs and farmers are attempting to diversify the farmed species, and oysters are among the most preferred species, in view of their biological characteristics, adaptive capacity to varying environmental conditions, growing demand in export market and enlarging acceptance by the domestic consumers. In this scenario, the foremost requirement of developing oyster culture on a scientific and sustained basis is the availability of information on different aspects of its culture and the related paradigm. This book on oyster biology and culture in India endeavours to meet this requirement. It is mainly written to cater to the needs of university teachers, researchers and students in India. It is also useful to a wide spectrum of personnel drawn from Fisheries / Rural Development Agencies, Financial Institutions, NGOs and entrepreneurs. In the chapters presented in this book the emphasis is chiefly on the status of oyster culture in India. Also the progress made in oyster culture in the major oyster producing countries of the world is briefly reviewed. The recent technological advances made in other countries in the hatchery production of seed and grow out culture have been dealt with. In the light of the developments in oyster culture in other countries, the gaps in knowledge, future research needs, constraints faced by farmers and the steps to be taken for the development of oyster resources and culture on a sustainable basis in the Indian context are highlighted.

The production of figures in tonnes by weight given in this book are in metric tonnes.

QUESTION

1. Write briefly on the development of oyster culture in India

CHAPTER 2

Oyster Resources, Distribution and Ecology

OYSTERS are placed under the Class Bivalvia which encompasses aquatic molluscs that show a fundamental bilateral symmetry. Oysters inhabit the littoral and shallow subtidal areas. Their distribution extends to wide range of ecosystems including the coral reefs, mangroves and rocky shores. The species identification of these bivalves has been very difficult due to exceedingly variable morphological features of the shell, influenced by the environmental variation and the nature of substratum. In the last two decades considerable effort has been put in to revise the taxonomy of oysters based on the external shell morphology, anatomical characters of soft body parts and electrophoretic studies. Another thrust area of molluscan research is to evaluate the ecological significance of oyster assemblages. Studies have shown that oyster reefs play a critical role in enhancing the species richness of the habitat and are now considered as Essential Fish Habitats (EFH). A brief description on the taxonomy, distribution and ecology of oysters is given below.

TAXONOMY

Considerable work has been done on the taxonomy of oysters (Thomson, 1954; Carreon, 1969; Stenzel, 1971; Ahmed, 1975; Carriker, 1976; Torigoe, 1981; Angell, 1986; Harry, 1986; Arakawa, 1990). About one hundred species of living and five hundred species of extinct oysters were recognized initially (Korringa, 1952). Later it was realized that most of the species were not valid. In 1955, the International Commission on Zoological Nomenclature (ICZN) stated that the nominal species *Gryphea angulata* was not the type species of any nominal genus and the generic name *Crassostrea* (Sacco, 1897) was available for use for that species. Consequent to this many important oysters were placed under the genus *Crassostrea*.

Stenzel (1971) in his treatise on the systematics of oysters recognized eight living and fossilized genera. Several generic names have been introduced in recent years. Harry (1985), after an exhaustive study based on the morphology of shell and soft parts of oysters, found it necessary to extend the classification beyond that proposed by Stenzel (1971). This revised classification has resulted in the synonimyzation of names of oysters in several geographic regions that are simply different populations of one species. Recently electrophoretic

investigations on the population genetics of several species of oysters have been attempted (Buroker *et al.,* 1983; Newkirk, 1980; Hedgecock and Okazaki, 1984; Klinbunga *et al.* 2000).

Diagnostic characters

The shell is irregular in shape, more or less inequivalve, and is permanently attached to the substrate. Unlike the mussels and scallops which attach by byssus threads, the oysters are cemented by the left valve to the substrate. This sedentary mode of life has led to atrophy of foot and byssal gland. Oysters are characterised by single adductor muscle, hinge without teeth, pallial lobes free with marginal tentacles and pallial line without sinus, obscure or absent.

Classification

Oysters come under Phylum Mollusca, Class Bivalvia (also called as Pelecypoda, Lamellibranchiata or Acephala), Order Mytiloida, Super Family Ostracea.

Currently the living species of oysters are grouped into two families, Ostreidae and Gryphaeidae. The identifying characters of these two families are given in Table 1 (Fig.2).

Table 1. Distinguishing characters of Gryphaeidae and Ostreidae

Gryphaeidae	Ostreidae
Shell structure vesicular	Shell structure not vesicular
Adductor muscle circular	Adductor muscle scar oval or kidney shaped
Adductor muscle placed closer to the hinge than to the ventral margin	Adductor muscle median in position or placed nearer to the shell margin
Chomata long, sinuous and branched	Chomata if present short and simple

The oysters coming under the family Ostreidae are grouped into three subfamilies namely Ostreinae, Crassostreinae and Lophinae. The species coming under Crassostrinae have a promyal passage, are non incubatory and the shell is chalky. In Ostreinae and Lophinae the promyal passage is absent and they incubate the young ones for a short period. The shell is chalky in Ostreinae while in Lophinae it is not chalky.

Based on the shell characteristics, shape, size, colour and the anatomical features of the promyal chamber, gill ostia, heart, gut and breeding habits, the various genera and species are identified. The identification characters of some of the important oyster genera coming under Ostreidae and Gryphaeidae as described by Quayle and Newkirk (1989) and FAO (1998) are given below.

Crassostrea: Chomata absent. Adductor muscle scar reniform and variously coloured according to the species. Chalky deposits often present on the shell. Promyal chamber present. Fairly large oysters upto 200 mm having wider

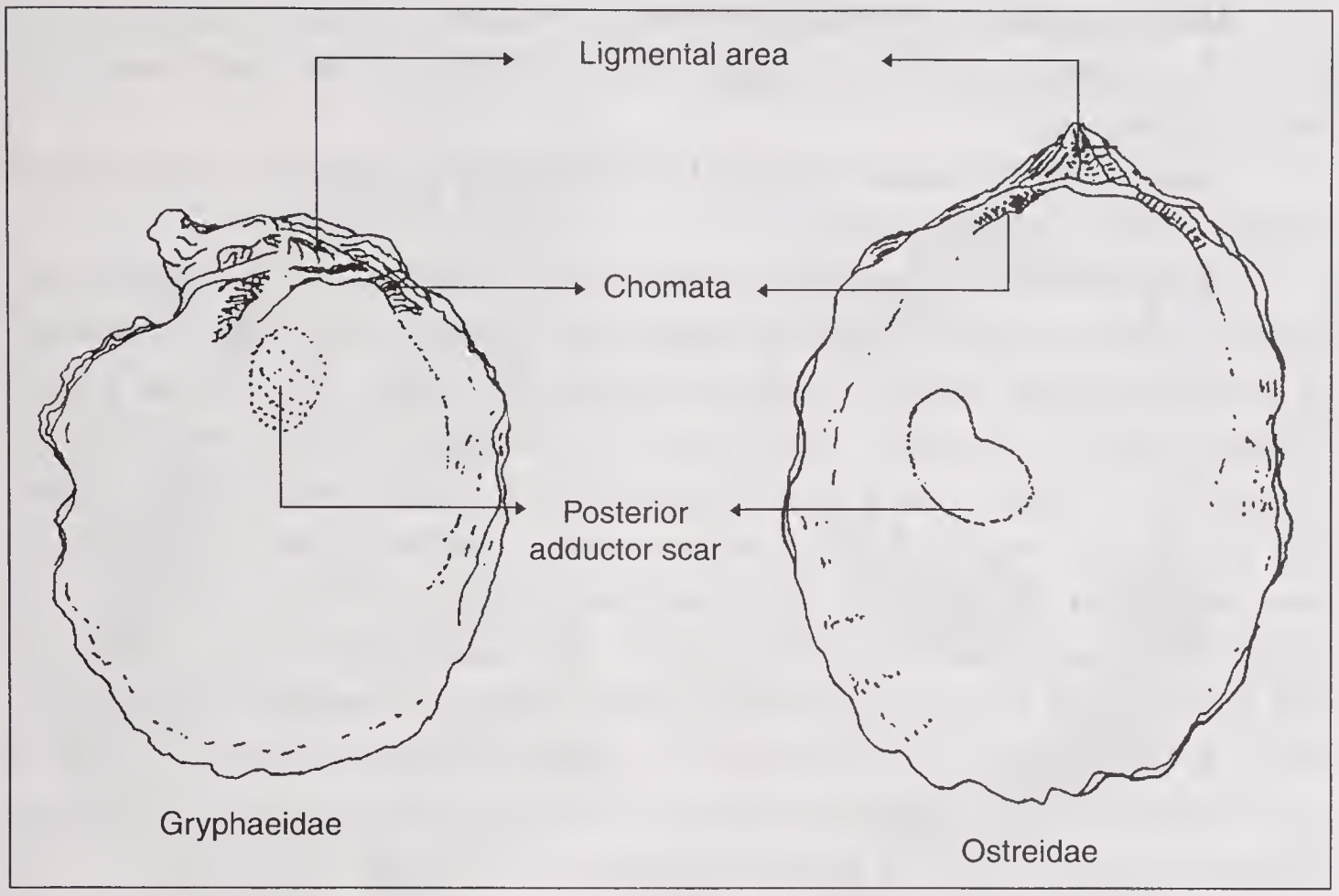

Fig. 2. Internal shell characteristics of Gryphaeidae and Ostreidae

distribution than the flat oysters and have the ability to tolerate wide variations of the environmental conditions.

Ostrea: Small and inconspicuous chomata present near hinge region. Right valve usually flat, left valve with small radial plicae. The nacre often coloured, scar reniform, promyal chamber absent. Moderate to large size. Less tolerant to salinity variation than *Crassostrea.*

Saccostrea: Chomata present, often completely around the periphery. Left valve plicate. Muscle scar reniform and generally coloured. Promyal chamber present. Medium sized oysters. Habitat similar to *Crassostrea.*

Tiostrea: Chomata present in the young but disappears with age. Adductor muscle scar reniform. Medium sized oysters. Larviparous oysters.

Striostrea: Characterized by full left valve attachment. The right valve with brittle lamellae. Large, elongate and chomata present. Large oysters upto 200 mm. Found in shallow subtidal areas.

Hyotissa: Oysters with thick valves. Promyal chamber present. Posterior margin deeply folded. Large oysters growing upto 200 mm. Widely distributed in subtidal tropical rocky regions and coral reefs.

Lopha: Surface of both the valves roughened by numerous small low and rounded protruberances arranged in obscure radial rows. Imbricating scales absent.

Dendostrea: Surface of both valves without small low and rounded protuberances, imbricating growth scales often present. Left valve with recurved spines forming clasping shelly extension for attachment of shell to extraneous object.

Alectyronella: Valve margins strongly plicate, chomata forming 2 to 4 rows of numerous pustules in right valve only; fingerprint shell structures generally present.

Planostrea: Chomata restricted to the dorsal half of the internal shell margins. Valve margin smooth.

In the last century considerable effort was made to identify and place the living oysters in south-east Asia in appropriate taxonomic position. In the Gulf of Thailand and the Andaman sea, nine species of oysters viz. *Hyotissa hyotis, Parahyotissa (Parahyotissa) imbricate* (Gryphaeidae), *Crassostrea belcheri, Crassostrea iredalei, Saccostrea cucullata, Saccostrea forskali, Striostrea (Parastriostrea) mytiloides, Lopha cristagalli* and *Dendostrea folium* have been identified by Yoosukh and Teerapang (1998). Genetic diversity and species-diagonostic markers of *C.belcheri, C.iredalei, S.cucullata, S.forskali* and *S.mytiloides* were investigated by the randomly amplified polymorphic DNA- RAPD analysis (Klinbunga *et al.*, 2000). Nine species-specific markers in *C.belcheri*, 4 in *C.iredalei* and 2 in *S.cucullata* were identified. Genetic distances between pairs of oyster samples were between 0.105 and 0.011. A neighbour joining tree indicated distant relationships between *Crassostrea* and *Saccostrea* oysters, but closer relationships were observed between the latter and *Striostrea mytiloides*. The commercially important species are mostly in the family Ostreidae.

Indian oyster resources

Along the Indian coast, oysters were identified and studied since the beginning of the 20th century. One of the first records on the taxonomy of Indian oysters is by Hornell (1910 a). Since then a series of reports on the taxonomy of Indian oysters were made by Annandale and Kemp (1916); Preston (1916); Gravely (1941); Satyamurthi (1956); Durve (1968); Rao (1974); Rao (1987) and Rao *et al.* (1992). The Indian oysters were originally referred to the genus *Ostrea*, but later included under the genus *Crassostrea*. Apart from this, occurrence of another oyster genus *Saccostrea* was also recorded. The generic characters of *Crassostrea* and *Saccostrea* have been described above. In India, four species of oysters have been considered as economically important (Rao *et al.*, 1992), which come under the subfamily Crassostrinae. They are *Crassostrea madrasensis* (Preston), *Crassostrea gryphoides* (Schlotheim), *Crassostrea rivularis* (Gould) and *Saccostrea cucullata* (Born). The detailed description of the four species based on the above mentioned literature are given below.

Crassostrea madrasensis (Preston, 1916): Shell valves usually elongate, and very irregular in shape. Outer surface of shell with numerous foliaceous laminae with sharp edges. Left valve is deep and slightly concave. Hinge narrow and elongate; sometimes elevated with a median depression. Adductor

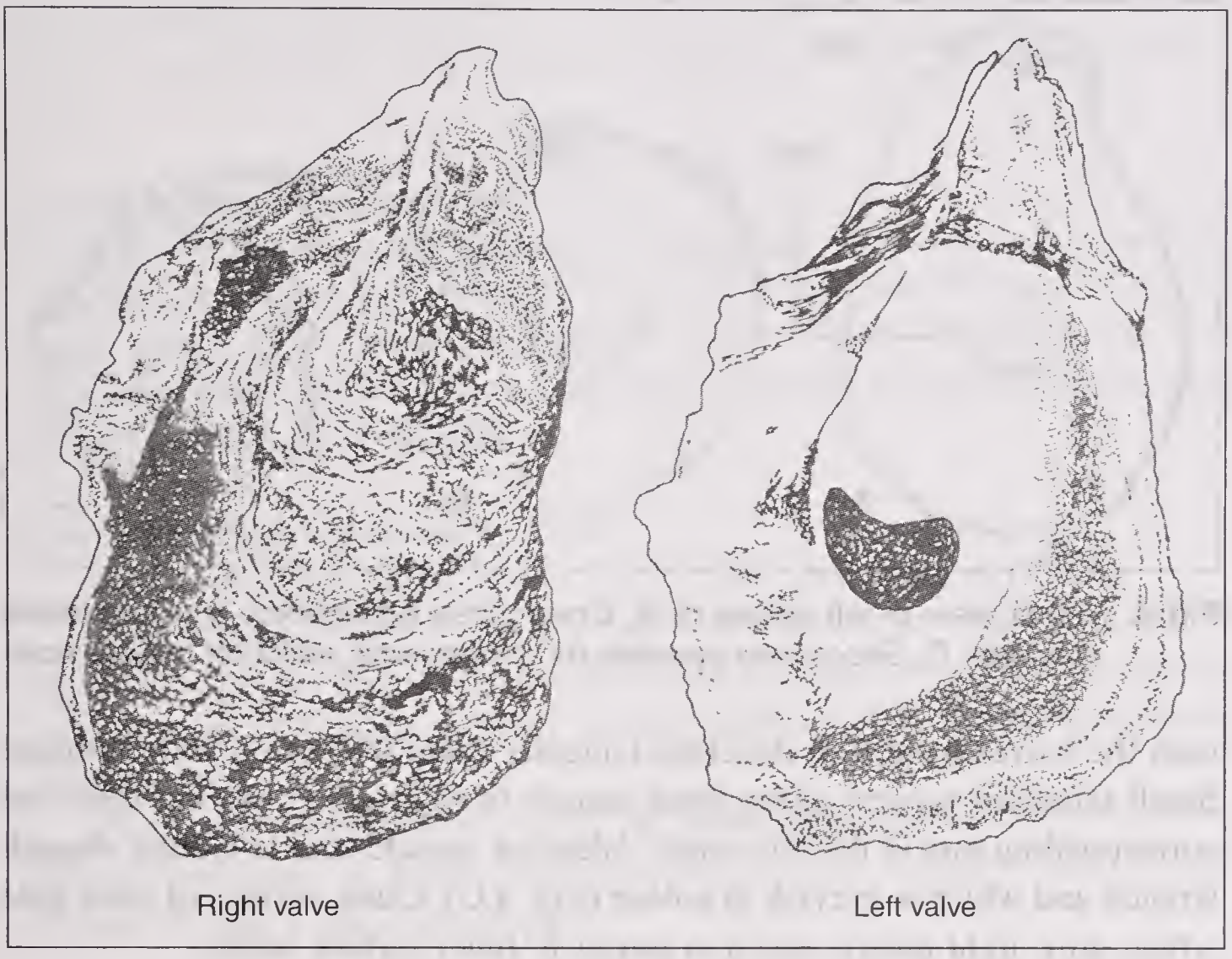

Fig. 3. Left and right valves of *Crassostrea madrasensis*

muscle scar situated subcentrally, reniform and dark purple in colour. Colour of outer surface of shell grey, green or light purple (ecophenotypic variations). Inner surface of valves is smooth, glossy and white in colour with purplish black colouration along the margin of the valves. (Fig. 3)

Crassostrea gryphoides (Schlotheim, 1813): Shell valves elongate and thick. Left valve cup like, hinge area well developed with a deep median groove with lateral elevations. Denticles not present on the inner margin of valves. Adductor muscle scar is broad, more or less oblong (Fig. 4.A). Striations on the scar are obscure or absent. Inner surface of valves and adductor muscle scar pearly in colour .

Crassostrea rivularis (Gould, 1861): Shell valves large, roughly round and flat. Shell cavity is shallow. Left valve is thick and slightly concave and the right one is almost the same size or slightly larger. Adductor muscle scar is oblong and white or smoky white in colour (Fig. 4.B). Inner surface of valves is white and bright.

Saccostrea cucullata (Born, 1778): Shell valve hard and stony, trigonal or pear shaped. The left valve is deep or moderately deep. Right valve is flat or slightly convex. Hinge straight, umbonal cavity well developed. Margins of

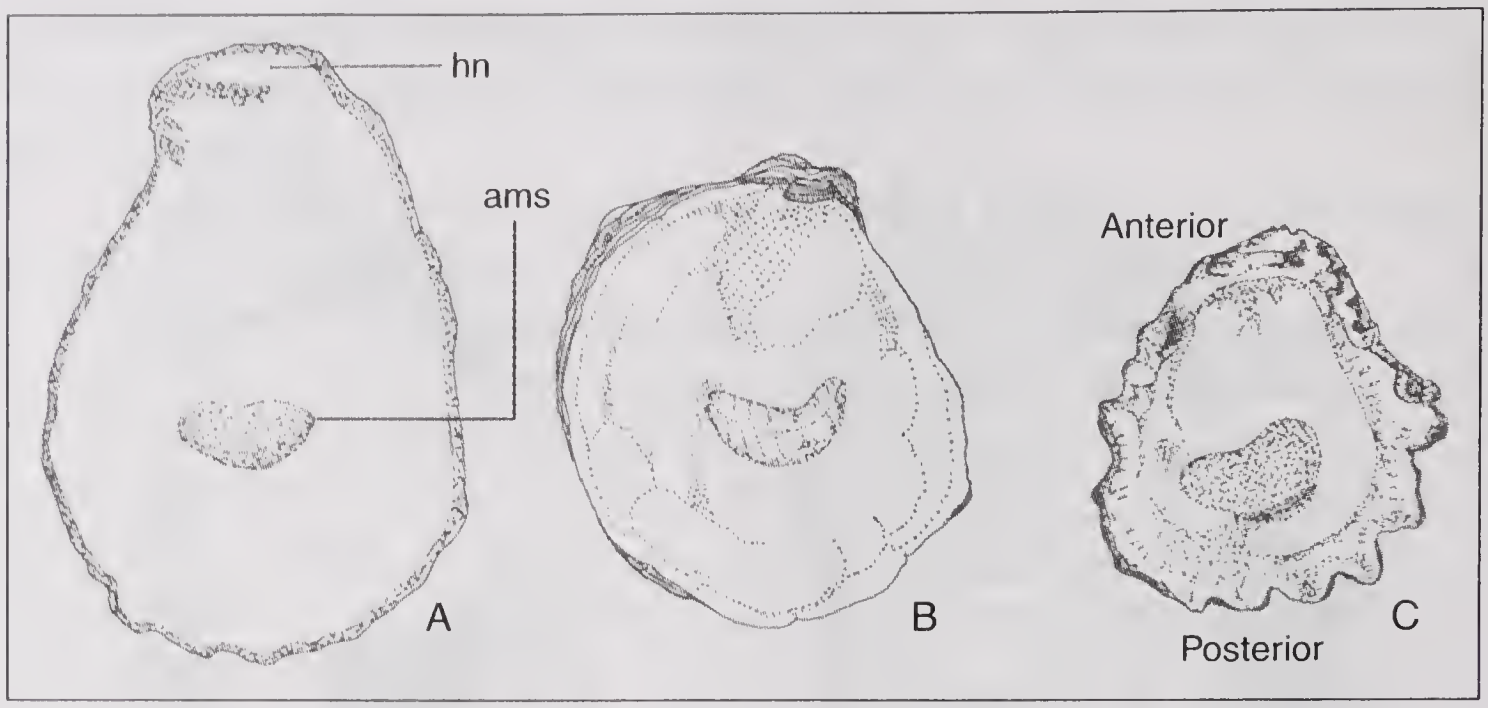

Fig. 4. Inner view of left valves of *A, Crassostrea gryphoides;* B, *Crassostrea rivularis*; C, *Saccostrea cucullata* (hn, hinge; ams, adductor muscle scar)

both the valves have well developed angular folds sculptured with laminae. Small tubercles present along inner margin of the right valve and there are corresponding pits in the left valve. Adductor muscle scar is kidney shaped, striated and white or greyish in colour (Fig. 4.C). Outer surface of shell pale white, grey, light brown, green or purplish. Inner surface white.

Rao *et al.* (1996) have mentioned that *Crassostrea rhizophore* (Guilding) occurs in stray numbers in the mangroves of Tamil Nadu. In addition to these five species of oysters coming under the family Ostreidae, one species under Gryphaeidae has also been reported from India. The Giant oyster, *Hyotissa hyotis* (Linnaeus) with large robust shell is found in the coral reefs. Incubatory or larviparous oysters have not been reported from Indian waters (Rao *et al.*, 1992).

As mentioned earlier, in the absence of well established taxonomic status of different species of oysters, there exist varying opinions as regards the nomenclature, identity and synonymy of the species by different workers. Rao (1987) has listed the synonyms of the Indian oysters. For further synonyms and discussions on this aspect the readers may refer to Stenzel (1971), Torigoe (1981) Harry (1985), Coan *et al.* (1995) and Carriker and Gaffney (1996). Torigoe (1981) considered *C.rivularis* and *C.ariakensis* as the same species, but this is probably incorrect usage (Coan *et al.*, 1995). Harry (1985) concluded that *rivularis* is a junior synonym of *pestigris* and placed *pestigris* in the new genus *Planostrea*.

DISTRIBUTION OF OYSTERS

Oysters are widely distributed in the temperate and tropical waters. Though they are common in the shallow intertidal and subtidal zones of coastal waters (Galtsoff 1964; Mahadevan 1987) their occurrence in deeper areas has also

been reported. *Neopycnodonte cochlear* commonly known as deepsea oyster or spoon oyster lives in depths extending from 27 to 2,100 m (Harry, 1985).

Commercially important oysters

Some of the commercially important oysters and their distribution summarized from Quayle and Newkirk (1989) and Carriker and Gaffney (1996) are given below. The taxonomic designations are mainly based on the most commonly used species names as found in literature and should not be taken as the last word on nomenclature.

Crassostrea gigas (Thunberg, 1793)

Common name: Giant Pacific oyster, Miyagi oyster, Magaki

Distribution: Indo-west Pacific from Pakistan to Japan and Korea and the Philippine Islands, Borneo and Sumatra, all along the China coast . Introduced to west coast of Canada, United States, Mexico, Chile, Korea, Taiwan and New Zealand.

Economic Importance: One of the most important food oyster; widely farmed especially in Japan, Korea, west coast of United States, Canada Europe, Brazil, Chile and Ecuador.

Crassostrea rivularis (Gould, 1861)

Common name: Chinese oyster

Distribution: Japan, China, Pakistan, India

Economic Importance: Cultured in China

Crassostrea belcheri (Sowerby, 1871)

Common name: Malaysian oyster

Distribution: Southeast Asia

Economic Importance: A large rapidly growing oyster and experimentally cultured. Principal commercial species in Southeast Asia .

Crassostrea iredalei (Faustino, 1932)

Common name: Slipper shaped oyster, talabang, tsinelas

Distribution: Philippines, Southeast Asia

Economic Importance: Important fishery on east coast of Malaysia, widely cultivated in Philippines; a commercial species in Southeast Asia .

Crassostrea madrasensis (Preston, 1916)

Common name: Indian backwater oyster

Distribution: Sri Lanka, India, South China sea coasts, Pakistan

Economic Importance: Commercial species in India, commercially farmed in India (Appukuttan *et al.*, 2000).

Crassostrea virginica (Gmelin, 1791)

Common name: Eastern oyster

Distribution: Western Atlantic from Gulf of St. Lawrence in Canada to Gulf of Mexico, Carribbean and coasts of Brazil and Argentina

Economic Importance: Occurs naturally in some areas as extensive reefs on hard to firm bottoms; commercially important; extensively exploited; widely farmed.

Crassostrea columbiensis (Hankey, 1845)

Common name: Columbian oyster

Distribution: Eastern Pacific from Chile north to Gulf of California.

Economic Importance: Commercial species from the Gulf of California to Panama, cultured in Mexico.

Crassostrea rhizophorae (Guilding, 1828)

Common name: Mangrove oyster

Distribution: Gulf of Mexico, Caribbean, Brazil

Economic Importance: Cultured on the Caribbean coasts. In Brazil cultivated on a pilot scale by family enterprises.

Crassostrea gasar (Adanson, 1757)

Common name: West African mangrove oyster

Distribution: Central West Africa, Senegal to Angola .

Economic Importance: Economically important in Gambia. Harvested from wild. Experimentally cultured in Senegal .

Crassostrea angulata (Lamarck, 1819)

Common name: Portuguese oyster

Distribution: Eastern Atlantic from equater north to Mediterranean and Atlantic coast of Iberian peninsula, Japan, China, Pakistan, India

Economic Importance: Widely cultivated in southern Europe

Crassostrea paraibanensis (Singarajah, 1980)

Distribution: Northern Brazil

Economic Importance: Was previously confused with and still locally called *C.brasiliana*. Cultured commercially in north-eastern Brazil.

Dendostrea folium (Linne, 1758)

Common name: Bronze oyster, Cox-comb oyster, flat oyster, leaf oyster, imbricated oyster

Distribution: Widely distributed in Indo-Pacific region.

Economic Importance: Experimentally cultured in Malaysia; some harvesting from wild populations in Morocco to Gabon area of western Africa.

Hyotissa hyotis (Linne, 1758)

Common name: Honey comb oyster, hyoid oyster, giant oyster

Distribution: Tropics of Indo-West Pacific and eastern Pacific

Economic Importance: Commercial species in the tropics. Harvested from wild populations

Lopha cristagalli (Linne, 1758)

Common name: Cock's comb oyster

Distribution: Mediterranean Indo-west Pacific, east coast of Africa and Red sea to Ryuku Islands, Philippines, Indonesia and rare in northern Australian waters.

Economic Importance: Associated with coral reefs at depths of a few meters.

Ostrea edulis Linne, 1758

Common name: Edible oyster, European flat oyster

Distribution: Eastern Atlantic from Norway and British Isles to Morocco and Mediterranean and Black seas, Aegean and Marble seas .

Economic Importance: Cultivated since ancient Roman times; farmed in France, Netherlands, United Kingdom and Spain.

Saccostrea commercialis (Iredale and Roughley, 1933)

Common name: Sydney rock oyster

Distribution: East coast of Australia, New Zealand and Thailand

Economic Importance: Widely farmed in eastern Australia and New Zealand. Introduced to Hawaii.

Saccostrea cucullata (Born, 1778)

Common name: Bombay oyster, Indian rock oyster, Red sea oyster

Distribution: Tropical coast of west Africa and offshore islands, around Cape of Good Hope, Indo-west Pacific to southern Japan, southern and Western Australia, northern New Zealand, all along Chinese coast, and Philippines .

Economic Importance: Commercial species in Indian Ocean and South-east Asia.

Saccostrea echinata (Quoy and Gainard, 1834)

Common name: Black bordered oyster

Distribution: South-east Asia, Japan, Australia, Indian Ocean and Western Pacific Islands.

Economic Importance: Widely cultivated in Indian Ocean and South-east Asian countries.

Saccostrea glomerata (Gould, 1850)

Common name: New Zealand rock oyster

Distribution: New Zealand, Hong Kong, Pakistan and Arabian Sea

Economic Importance: It is the main commercial species in New Zealand

Striostrea prismatica (Gray, 1825)

Distribution: Mexico and Pacific coast of Columbia

Economic Importance: Cultured experimentally in the Pacific coast of Columbia.

Distribution of oysters in India

The distribution of oysters along the Indian coast shows a distinct pattern (Fig. 5). *C.madrasensis* is the major oyster species found along the east coast, except West Bengal, from Orissa to Tamil Nadu (Mahadevan, 1987; Das, 1993; Narasimham *et al.*, 1993; Rao *et al.*, 1996). Along the west coast it is more dominant in the south than in the north (Mahadevan, 1987). *C.gryphoides* is the main oyster species in the north-west region especially in the Gulf of Kutch. Mixed populations of *C.gryphoides* and *C.rivularis* are seen along the north-west coast (Chhaya *et al.*, 1993). One interesting observation is that though distribution of *C.gryphoides* is restricted to north-west region, occurrence of its fossils has been recorded from Calcutta (Durve, 1986). *Saccostrea cucullata* has wider distribution and is found along with all the

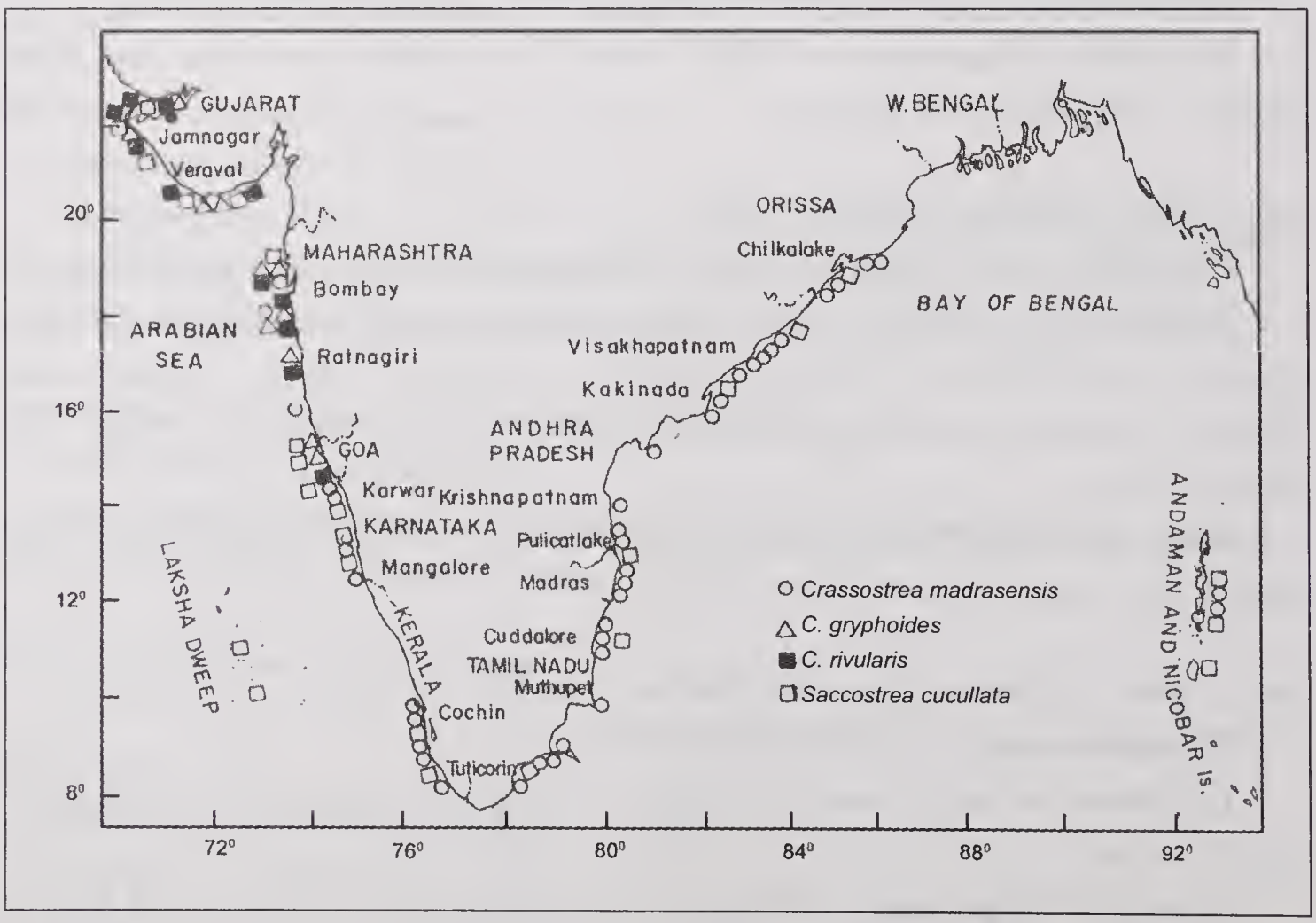

Fig. 5. Locations showing the distribution of commercially important oyster species in India (after Rao *et al.*, 1992)

species of the genus *Crassostrea* occurring in India (Mahadevan, 1987; Joseph and Joseph, 1988; Sundaram, 1988; Rao *et al.*, 1996). Along the east and south-west coast, it coexists with *C.madrasensis* (Rao *et al.*, 1996) while along the north-west coast it is seen along with *C.gryphoides* (Chhaya *et al.*, 1993). Apart from this, oyster populations dominated by *S.cucullata* are also seen especially in Karnataka (Joseph and Joseph, 1988), Maharashtra (Sundaram, 1988) and Gujarat (Chhaya *et al.*, 1993). This species is also widely distributed in the inshore waters of Andaman and Nicobar islands.

C.madrasensis has been found to be morphologically similar to the American oyster. Durve (1986) has critically analyzed the distribution of *C.madrasensis*, its morphological and biochemical similarity to the other major *Crassostrea* species and vis-à-vis commented "it thus could be conjured that *C.madrasensis, C.gigas, C.gryphoides, C.virginica* are all closely related and may have emerged as independent species by geographic separation and subsequent isolation." He also hypothesized that the extension of distribution of *C.gryphoides* and *C.rivularis* to the south-west coast of India might have been prevented by the now extinct land bridge from India to Madagascar.

Horizontal zonation

Within an estuary, horizontal zonation of different oyster species in a population has been observed. In most estuaries, *Saccostrea cucullata* is found more in the marine environment (Rao, 1987). In the Ashtamudi Lake in Kerala, near the barmouth, *S.cucullata* occurs in dense concentrations contributing to 81.7% of the total oyster density, the rest being *C.madrasensis*. Towards the estuarine region, the density of this species becomes thin and forms only 15 to 19% of the total oyster population. *C.madrasensis* dominates in the estuarine region and, towards the river side *S.cucullata* is completely absent (Kripa, 1998). This zonation pattern from marine to brackishwater can be due to the better adaptive capacity of *C.madrasensis* to low saline condition than *S.cucullata,* i.e. due to the difference in the lower threshold of their salinity tolerance. In the intermediary zone between the two extremes of marine and estuarine conditions the two species occur together..

Density of oysters

High densities have been observed in the natural beds during the spat fall season. In the Pulicat Lake and Ennore backwaters, the density of spat has been found to range between 300 to 1500 nos/ m^2 and 90 to 1800 nos/ m^2 respectively. The density of oysters in different estuaries along the Indian coast is given in Table 2.

Relative abundance of oyster resources

The magnitude of oyster resources shows wide variation along the Indian coast mainly due to seasonal variations in the hydrographic conditions of the

Table 2. Oyster densities (nos/ m^2) in different oyster beds along the Indian coast

State	Location	Species	nos/ m^2	Reference
Gujarat	Sikka	*S. cucullata*	142	Chhaya *et al.* (1993)
Maharashtra	Bandra	*S. cucullata*	576-1,792	Sundaram (1988)
	Worli	*S.cucullata*	256-1,536	
Karnataka	Kalinadi estuary	*S. cucullata*	12 -150	Ramachandran (1988)
		C.madrasensis	nil-0.7	
	Chendia creek	*S. cucullata*	20	
		C.madrasensis	0.5	
	Mulki estuary	*S.cucullata*	15 to 320	Joseph and Joseph (1988)
Kerala	Ashtamudi Lake	*C.madrasensis*	14-104	Kripa (1998)
		S.cucullata	43-258	
Tamil Nadu	Muttukadu backwaters	*C.madrasensis*	60-320	Sarvesan *et al.* (1988)
	Pulicat Lake	*C.madrasensis*	7 - 298	Thangavelu and Sanjeevaraj (1988a)
		C.madrasensis	300-1,500	Rao *et al.* 1996
	Ennore estuary	*C.madrasensis*	90-190	Rao *et al.* 1996
Pondicherry	Chunnambaru estuary	*C.madrasensis*	160 -3,010	Rao *et al.* 1996

oyster beds (Rao *et al.,* 1996). During 1987 –90, the Central Marine Fisheries Research Institute (CMFRI) made an effort to assess the standing stock along the south-east and south-west coasts of India through planned surveys (Rao *et al.,*1996). Apart from this, information on the resource abundance of selected regions of Orissa, Karnataka, Maharashtra and Gujarat is available from the works of Ramachandran (1988), Sundaram (1988), Das (1993) and Chhaya *et al.* (1993). From other states information on oyster resources is not available. Following is a brief report on the oyster resources of different maritime states of India.

Orissa: The Bahuda estuary near Sonapur harbours a rich bed of *Crassostrea madrasensis*. Mahadevan (1987) has indicated that oysters were seen in approximately 5 ha area in Sonapur. Recently, Das (1993) stated that the oyster beds extend to an area of 128 acres.

Andhra Pradesh: The total area of the oyster beds in this state, spread in 11 estuaries is 28.54 ha (Table 3). *C. madrasensis* is the main resource. *Saccostrea cucullata* formed 30 % and 10% of the oyster population in Kakinada harbour area and Kandaleru estuary respectively. The Pennar estuary has the richest oyster bed of 3.2 ha with a population of 727 t followed by Peddapatnam Revu and Kandaleru estuary. Rao *et al.* (1996) have commented that oyster resources at certain localities in this state are limited due to turbidity and fast water flow.

Table 3. Estimated standing stock of oyster in Andhra Pradesh during 1990

Location	Total area of beds (ha)	Total stock (tonnes)	Length range (mm)
Uppada creek	20	17.6	12-117
Kakinada harbour	0.74	60	NA
Kakinada Port	0.60	60	NA
Peddapatnam Revu	0.25	486	NA
Machilipatnam creek	0.40	16.8	28-59
Mudugondi estuary	1.26	85	NA
Gundalakamma estuary	0.27	4.1	NA
Pennar estuary	3.20	727	NA
Kandaleru estuary	1.80	88.7	NA
Swarnamukhi estuary	NA	7.3	NA
Konderu estuary	0.02	1.8	NA
Total	28.54	1,554.3	

Source: Rao *et al.* (1996)

Tamil Nadu and Pondicherry

The total standing stock was estimated at 19165.6 t in 243.6 ha area. *Crassostrea madrassensis* is the major resource in most of the estuaries though in some estuaries like Uppanar, Gadilam, and Alambau, *Saccostrea cucullta* formed 10 to 32 % of the population. *Crassostrea rhizophore* was found in the Coleroon estuarine complex attached to the roots of mangroves. The Ennore estuary had the richest oyster beds with an estimated standing stock of 14, 379 tonnes spread over 45.8 ha (Table.4). In Pondicherry, the Chunnambaru estuary had the maximum oyster resource, 2219.6 tonnes in 54.4 ha. In almost all the estuaries large size *C.madrasensis* (>100 mm) were seen. Rao *et al.* (1996) have attributed the reasons for such abundance to low rainfall and moderate current action in the vicinity of oyster beds. These conditions are favourable for breeding, spatfall and growth of oysters. In a survey conducted during September-December 1986 Sarvesan *et al.* (1988) the stock of *C.madrasensis* in 3.61 ha beds at 545 metric tonnes in Muthukadu backwaters. Sreenivasan *et al.* (1996) reported that a survey conducted on 13 and 14 September 1995 revealed the presence of *C. madrasensis* stock of 3,712 metric tonnes in 25.2 ha oyster beds. They measured 35-141 mm in length.

Kerala: The standing stock of oyster was estimated as 3938 tonnes in 30. 8 ha spread in 11 estuaries (Table 5). Though *C. madrasensis* was the major resource, *S.cucullata* formed 21 to 35% of the oyster population in estuaries like Shriya, Murad, Beypore, Chaliyam, and Nileswar. Most of the estuaries had limited oyster resource. Korapuzha estuary is the richest with 3,664 tonnes in 27 ha contributing to more than 93% of the State's oyster resource. The length, total weight and meat weight of the oysters recorded in most estuaries was smaller than that of Tamil Nadu. While the length of

Table 4. Estimated standing stock of oyster in Tamil Nadu and Pondicherry during 1988 –1990

Location	Total area of beds (ha)	Total stock	Length range (mm)	Average total weight (g)	Average meat weight (g)
Pulicat Lake	10.3	10.4	18-167	77	5.3
Ennore estuary	45.8	14,379	24-208	95	6.2
Kovalam backwaters	3.1	4.2	22-143	68	4.9
Edayar backwater	2.0	3.5	36-177	89	5.6
Alambaru estuary	11.0	715	30-77	36	2.1
Chunnambaru estuary	54.4	2219.6	12-128	76	3.4
Gadilam estuary	8.9	29.5	29-126	71	3.1
Uppanar estuary	18.7	147.1	31-109	58	4.2
Vellar estuary	50.1	456.9	27-123	70	3.4
Coleroon estuary	30.5	391.5	14-148	75	4
Vellayar estuary	2.4	5.0	58-163	148	4-12
Vettar estuary	1.4	2.6	31-121	52	8
Transquebar	0.6	25.6	55-124	76	8
Athankarai estuary	1.7	380.8	61-138	128	8
Kanjirangudi estuary	0.2	3	19-123	46	8
Kallar estuary	0.1	1	61-103	85	5
Karapad creek	0.5	84.9	71-122	143	9
Korampallam creek	1.1	272	70-133	136	9.5
Palayakayal estuary	0.2	2.6	75-136	131	8
Pinnakayal estuary	0.6	31.4	28-133	-	11
Total	243.6	19,165.6			

C.madrasensis in Tamil Nadu ranged between 12 to 208 mm in Kerala it was 17 to 118 mm. Similar difference was observed in the case of *S.cucullata* also, the length ranges being 15 to 70 mm in Tamil Nadu and 13 to 52 mm in Kerala.

Karnataka: Several estuaries in Karnataka harbour resources of C. *madrasensis* and *S.cucullata.* Mahadevan (1987) has reported that Nethravathi, Sharavathi and Kali estuaries, have oyster beds ranging from 1 to 5 ha. Ramachandran (1988) has estimated the standing stock of the Kalinadi and Chendia estuaries of Karnataka as 1.2 and 2.2 tonnes in 0.65 ha and 2.0 ha area respectively. The population is composed of both *C.madrasensis* and *S.cucullta.*

Goa: Oyster settlement has been reported from Ribander, Siolim and Curca (Mahadevan, 1987). However, the extent of the oyster beds and their abundance has not been studied in detail.

Maharashtra: *C.gryphoides* has been reported from Dahanu creek, Boiser, Satpuri, Palghar, Kelwa, Malad, Navapur, Utsali, Dahisar, Mahim creek, Alibag, Purnagad, Ratnagiri, Jaytapur, Malwan, Worli, Versova, Marve, Gobbunder, Cuff Parade, Bandra, Madh, and Bhate Bunder. In Mahim, Ratnagiri and Jaytapur *C.rivularis* occurs along with *C.gryphoides. S.cucullata* is also reported to occur along with these oysters. Sundaram (1988) has reported that

Table 5. Estimated standing stock (in tonnes) of oyster in Kerala in 1987

Location	Total area of beds (ha)	Total stock	Length range (mm)	Average total weight (g)	Average meat weight (g)
Chandragiri estuary	0.5	65	26-62	17	2
Shiriya estuary	0.2	23	20-45	NA	NA
Nileshwar	0.4	40	36-102	10-150	6
Azhikkal	0.4	16	38-118	147	5
Murad estuary	0.5	30	26-55	NA	NA
Korapuzha estuary	27	3664	55-99	NA	NA
Beypore estuary	0.2	13	NA	NA	NA
Chaliyam estuary	0.4	50	17-94	NA	NA
Periyar estuary	0.7	17	21-61	20	2
Thottapilly estuary	0.2	5	40-75	20	4
Kayamkulam estuary	0.3	15	31-73	21	NA
Total	30. 8	3,938			

NA= Not Available
Source: Rao *et al* (1996)

S.cucullata is the major species in the intertidal area of Worli and Bandra and he estimated the stock at 335 tonnes in 8.75 ha.

Gujarat: *C gryphoides* is the dominant oyster species in Gujarat, followed by *S.cucullata* and *C.rivularis*. Chhaya *et al.* (1993), have observed that the oyster resource is very negligible in most parts of the coast. In some regions the density is low, with about one oyster per m^2 while the maximum has been found to be 142 nos per m^2. From the density of oyster beds, it can be inferred that moderately rich oyster beds occur in Harshad Medha creek, Navibandar and Sikka regions. Details are given in Table 6.

Andaman Nicobar Islands: *C.madrasensis* is found in Port Blair, Havelock Island, Mayabunder and Dighlipur regions (James and Narasimham, 1993)

ECOLOGY OF OYSTER BEDS

Oysters live in a highly dynamic environment. With their sedentary habit they are particularly vulnerable to the environmental perturbations. However, through an array of physiological and behavioral mechanisms they have established themselves as one of the successful estuarine species. The effect of environmental variations such as salinity changes on oysters depends on the range of fluctuations and the abruptness of these changes (Hand and Stickle, 1977). The ecology of some of the oyster beds of India has been studied and the parameters such as temperature, salinity, turbidity and food availability have been considered as most important and have received the maximum attention (Hornell, 1910a; Paul, 1942; Rao, 1951; Rao and Nayar, 1956; Durve and Bal, 1962; Mahadevan and Nayar, 1987; Thangavelu and Sanjeevaraj, 1988a ; Yavari, 1994; Kripa, 1998).

Table 6. Distribution of oyster resources in Gujarat during 1988-92

Location	Resource	Area surveyed (ha)	Total oysters (Nos.)
Katlwada	*C.gryphoides*	7.5	10,000
Namathi creek	*C.gryphoides*	0.5	1100
Sikka	*S.cucullata*	0.05	66,456
Gagawa	*C.gryphoides*	1.17	200
	C.rivularis		
Harshad Medha creek	*C.gryphoides*	41.55	90,000
Navibandar	*C.gryphoides*	22.50	75,000
Samadhiyani	*C.gryphoides*	3.50	3500
Datardi	*C.gryphoides*	1.0	6000
Umargoan	*C.gryphoides*	10.0	10,000
Khalwada	*C.gryphoides*	7.5	10,000

Source: Chhaya *et al.* (1993)

Temperature

Virtually every aspect of the oyster biology including feeding, respiration, utilization of stored food reserves, reproduction, disease interactions, growth and distribution is affected by temperature and salinity. Temperature variations (range) observed in oyster beds along the east coast are : 27.5 to 34.5^{0}C during 1975 –1976 at Athankarai (Rao *et al.*, 1987); 25.2^{0}C to 31.93^0 C at Tuticorin (1992-93) (Yavari, 1994) and 22.8^0 to 33.6^0 C at Kakinada Bay during 1985-86 (Narasimham, 1987). In the Ashtamudi Lake in Kerala, the temperature ranged between 28.2 to30.8^{0}C during the period 1994 to1996 (Kripa, 1998). The water temperature variations between 22.8 and 34.5^{0}C are within the normal distributional range of *C.madrasensis.* In high temperatures (> 41^{0}C) the oysters suffered mortality and weight loss (Fingerman and Fairbanks, 1955,1957).The oysters were found to survive in intertidal temperatures of 46 to 49^{0}C when immersed at low tide. Frequently inhibited pumping activity was observed with rise in temperature. In some instances though the oysters kept their valves open, the pumping rates were highly reduced (Shumway, 1996).

It has been observed that the combined effects of two or more environmental variables can have profound biological consequences than any one of the factors acting independently. In some estuaries along the east coast in summer, the combined effect of high temperature and salinity and resultant desiccation have caused oyster mortality (Mahadevan and Nayar, 1987; Rao *et al.*, 1987; 1996). In south-west Louisiana and Texas the combination of high salinity and temperature have caused mass mortalities of *C.virginica* (Owen, 1953).

Salinity

Butler (1949) has suggested that the single most important factor which affects the oyster population is salinity. Salinity variations in estuaries may be diurnal, seasonal, or spatial and changes may be abrupt or gradual.

How salinity influences the reproduction of oysters is described in Chapter 3. The annual variation of salinity in the oyster beds along the east coast has been found to range between 3.49 and 35.01 ppt in Kakinada Bay during 1985-86 (Narasimham, 1987); 26.5 to 37.31 at Tuticorin during 1992–93 (Yavari, 1994). During 1975-1976 when the barmouth was closed, the salinity reached as high as 71.62 ppt in Athankarai estuary (Rao *et al.*, 1987). Large scale mortality of oysters due to continuous exposure to high salinity (>40 ppt) has been reported by Rao and Nayar (1956) in Adayar estuary. Lowering of salinity due to prolonged flooding during the north-east monsoon in certain years has been reported to cause large-scale mortalities of oysters (Mahadevan and Nayar, 1987). However, the recolonization of oysters and revival of oyster beds have been observed in the subsequent years (Rao *et al.*, 1987).

Along the west coast, the oyster beds are more affected by low saline conditions. The freshwater incursion into the estuaries during south-west monsoon causes drastic changes in the oyster population. The annual variation in salinity of the oyster bed was between 7.2 to 34.1 ppt during 1994-95 in Ashtamudi Lake (Kripa, 1998). However, this has not caused mass mortalities. In Cochin backwaters, very high mortality of oysters has been observed when the salinity of the oyster bed remains below <1 ppt for a prolonged period (Purushan *et al.*, 1983). Similar changes in oyster populations take place in the estuaries of Karnataka due to salinity variation (Joseph and Joseph, 1988).

The tolerance of oysters to withstand changes in salinity is enhanced by their ability to close the shell valves when exposed to extreme conditions. Valve movements and water transport were abnormal and growth inhibited when the eastern oyster was exposed to low saline conditions (0 to 5 ppt) (Loosanoff, 1953). Galtsoff (1964) observed that the oyster responded to low salinity by partial or complete closure of the valves and slowing or cessation of water current through gills. Exposure to an abrupt reduction from 27 ppt to 20, 15, 10, and 5 ppt resulted in decrease in pumping rate of 24, 89, 91, and 99.6% respectively for 6 hrs after transfer. Thereafter normal activity resumed and there was no long-term effect on pumping rate.

Turbidity

Turbidity is another important ecological factor which has significant influence on the tropical oyster beds (Yavari, 1994). Even if the productivity of the oyster bed is high, the food cannot be filtered by the oyster in turbid condition. High turbidity has been found to reduce the feeding rates, reduce the growth and even lead to mortality in *C.madrasensis* beds along the east coast (Rao *et al.*, 1996). Continued occurrence of turbid waters for more than a week has been found to affect the oyster spat more than the adult oysters. Along the west coast, the growth and survival of *C.madrasensis* populations are adversely affected by high silt load in the habitat during the monsoon period. High turbidity and low salinity affect the oyster population along the west coast (Purushan *et al.*,

1983, Rao *et al.*, 1996), though quantitative estimates of mortality have not been mentioned. Loosanoff (1962) observed an average reduction of 57 to 94% in the pumping rate of *C.virginica* in concentrations of 100 to 400 mg/l of silt and no pumping at all at higher concentrations. Suspended particles reduce oyster gill functions and metabolic efficiency by increasing pseudofaeces production. Oysters exposed to sediments have decreased growth and reproductive efficiency, while mortality and disease susceptibility also increase (Heral *et al.*, 1983). Hsia (1950) observed that in very turbid waters when the silt was allowed to settle on the oysters, there was an immediate cessation of shell movements for 16 to 19 hrs. The oysters subsequently attempted to reopen the valves in an effort to remove the silt. If the silt deposits remained for more than 3 days, mortality of oysters was observed. Siltation also reduces the quality and quantity of suitable habitat for oyster 'spat' settlement (Keck *et al.*, 1973; Bahr, 1976; Mackenzie, 1983; 1989).

Food availability

Food availability is another important ecological factor which affects the oyster population. Rao and Nayar (1956) have suggested that food availability is probably the most important factor affecting the growth of *C.madrasensis* in Adayar estuary. Chlorophyll-*a* concentration can be taken as a suitable indicator of available food for oysters. For the Indian oyster *C .madrasensis*, diatoms have been identified as the major food component. Yavari (1994) has experimentally proved that chlorophyll-*a* and turbidity are critical parameters which affect the growth of *C.madrasensis*. Apart from growth, favourable phytoplankton blooms have been observed to induce spawning in *C. gigas* in Spain (Ruiz *et al.*, 1992).

Though very little is known about the optimum density and species composition of the oyster's plankton food source, some studies have indicated that phytoplankton density influences the growth rate. In *C.rhizophorae,* Wright *et al.* (1990) found that when the phytoplankton density was 56.9 ± 15.2 cells/ml the growth was 0.10 mm/day, while it was 0.58 mm/day in an area where phytoplankton density was 178.9±100.9 cells/ml. Brown and Hartwick (1988) have estimated 12 g chl-a/ml as the optimum level of food availability for *C.gigas*. In the Ashtamudi Lake, where dense beds of *C .madrasensis* and *Saccostrea cucullata* are seen, the average number of phytoplankton cells has been found to be 255±155 cells/ml. Species belonging to 6 genera of Cyanophycea, 19 genera of Bacillariophyceae, 8 genera of Chlorophyceae, 2 genera of Dinophyceae, 2 genera of Euglenaceae and 1 genus of Rhodophyceae were found to occur in different densities in the oyster beds (Kripa, 1998).

pH

The annual variations in pH in the oyster beds at Tuticorin were observed as 7.99 and 8.39 (Yavari, 1994) and 7.75 and 8.22 at Ashtamudi Lake (Kripa,

1998). Mortalities due to variation in pH have not been reported from Indian waters. Studies conducted by Loosanoff and Tommers (1948) have shown that pH affects the pumping rate of oysters. Oysters kept in waters of 4.25 pH pump only 10 % as much water as control animals at 7.75 pH, even though the oysters kept the valves open for about 75% of time.

The influence of biotic factors on oysters is given in detail in Chapter 3.

OYSTER REEF

Oysters occur as single oysters or in groups or may be scattered across dense beds of accumulated shell, mud and sand (Winslow, 1882; Galtsoff, 1964; Bahr and Lanier, 1981; Dame, 1996). Oyster settlement in an ecosystem is not accidental (Keck *et al.*, 1973) and it is related to current speed, bottom roughness (Wildish and Kristmanson, 1979) and hydrology (Hedgpeth, 1953). The ability of oysters to cement to other oysters has lead to the formation of oyster reefs. An oyster reef is an aggregation of live oysters and empty shells occupying the bottom of an estuary (Galtsoff, 1964). The term is used interchangeably with oyster bottoms, oyster beds, oyster banks, oyster rocks and oyster grounds (De Alteris, 1988).

Oyster reefs are formed by continuous settlement, growth and death of oysters in the same location over a period of time. The physical dimensions and their structural variation or growth of the oyster reefs in the temperate countries have been studied in detail. Bahr (1976) indicated that the development of intertidal reefs of Georgia was an extremely slow process. De Alteris (1988) has calculated that one oyster bed in the James River accrete vertically at a rate of 0.5 m 100 yr-1.

Some of the oyster reefs in Chesapeake Bay are extensive. Mc Cornick-Ray (1998) observed that in Chesapeake Bay, the widest reef was 2.3 km, the longest 8.3 km, and largest 7 km^2.The length of oyster reefs in India have not been studied in detail. However, it has been observed that in certain estuaries of east coast like Chunnambaru estuary, the oyster beds may extend to 750 m in length and 60 to 200 m in width. Occurrence of multi- tier dense and massive oyster heaps has been observed in Gadilam estuary, Vellar estuary, Ennore estuary, Peddapatnam Revu creek, and Korapuzha estuary (Rao *et al.*, 1996). In some oyster beds, along with the live oysters, dead oyster shells are present. In the Athankarai estuary, Sarvesan *et al.* (1988) have observed that in some patches the live oysters form only 31 to 42% of the oyster population. In Pulicat Lake, the oyster beds have both live and dead oysters, the former contributing to 36.2-76.4% of the total oyster density (Thangavelu and Sanjeevarj, 1988a). In Mudasudai- Chinnavaykal area extensive oyster beds are seen in which live oysters formed 30%.

Oyster reefs are important components of the ecosystem. The benthic structure caused by the horizontal and vertical expansion of oyster beds influences the particle transport, biological organization, nutrient trapping and

sedimentation in the estuaries and coastal region (Mc Cornick- Ray, 1998).The functional and structural role of oysters in the ecosystem has not been very well understood. Mc Cornick- Ray (1998) has related the size of oysters during different time frames to size of sedimentary particles as in Wentworth scale (Ritter, 1986). The fertilized oyster egg which is 40-50 μ m (Galtsoff, 1964) has the size of a clayey-silt particle, the veliger 200-300 μ m, is equal to the size of very fine sand particle initially and later develops to the size of a fine sand particle (248-400 μ m) (Carriker, 1996). After settlement, it passes through the sizes of coarse sand (1000 μ m), very coarse sand (2000 μ m) to reach the size of gravel at 90-150 mm. At this stage the oysters may be harvested, but in certain unexploited beds the oysters continue to grow and reach 260-350mm (Galtsoff, 1964; Haven *et al.*, 1978; Stanley and Sellers, 1986; Ritter, 1986), which is equivalent to the size of a boulder.

Oyster reefs and their significance in the ecosystem have been the subject of study in many parts of the world. It is now well documented that they provide the following ecosystem services (Coen *et al.*, 1997)

- Filter the water and curtail excessive turbidity and occurrence of phytoplankton bloom.
- Help in benthic-pelagic coupling.
- Create feeding habitats for juvenile and adult mobile species.
- Provide substrata for sessile species (epifauna) and
- Provide nesting habitat.

Oyster reefs are considered as Essential Fish Habitat (EFH). They provide habitat for ecologically, commercially and recreationally important finfish and shellfish species (Coen *et al.*, 1999). Oyster bed is a typical example of 'biocoenosis' or a social community of living beings, a massing of individuals with ideal conditions governing their existence (Mobius, 1883) The shells of oysters are natural abodes of many plants and sedentary animals which attach to the shell surface (foulers) or bore through it (borers) to provide themselves a well protected residence. Apart from these there are parasites which harm the oysters while some others live within the dead oyster shells purely for shelter. It has been observed that these reefs attract and sustain fishes of many trophic levels (Harding and Mann, 1999).

In Pianktank River in Virginia, recreationally and commercially valuable piscivorous finfishes including striped bass (*Morone saxatilis*), bluefish (*Pomatomus salathrix*) and weakfish (*Cynoscion regalis*) have been found to be an integral component of trophic networks that depend on oyster reefs (Harding and Mann, 1999). Further, Harding and Mann (1999) have observed 32 finfish species representing 26 families on or near the oyster reef in 1996-1997. These pelagic fishes use oyster reefs as both feeding and breeding ground.

The population structure and associated fauna in the oyster beds in the Indian coast has shown seasonal variation largely dependent on the salinity of

the environment and the submergence time.The major variations seen in the intertidal and subtidal oyster beds are given in Table 7.

The oyster beds in India have a wide variety of foulers, borers and other fauna and flora. Barnacles, chiefly of the genus *Balanus* are probably the most ubiquitous of all the fouling organisms. *Balanus amphitrite* is the main species recorded followed by *B.tintinnabulum,* and *Cathamalus stellata*. Another dominant fouler is the calcarean polychaete worm *Hydroides* sp. During the monsoon season, these two foulers suffer mortality and several seaweeds and bivalves succeed them. Seaweeds like *Chaetomorpha, Ulva, Enteromorpha, Gracilaria, Cladophora* and *Gelediella* are associated with the oyster population along the Indian coast (Rao and Sundaram, 1972; Muthiah *et al*., 1987; Sundaram, 1988; Kripa, 1998). Bivalves like *Modiolus striatula, M.undulata, M.metacalfi, Anomia sp* and *Perna virdis* are dominant in the estuarine region. (Details about foulers, borers and predators of oysters are given in Chapter 4)

Table 7. Variations in the oyster population structure observed in the marine intertidal, estuarine intertidal and estuarine subtidal beds in Ashtamudi Lake

Marine intertidal	Estuarine intertidal	Estuarine subtidal
Oyster population dominated by *S.cucullata* forming 81.7% of the population.	*C. madrasensis* and *S. cucullata* (15 to 19%)	Oyster population dominated by *C. madrasensis* (>95%), mostly live oysters.
Nature of oyster bed is more like a reef; approximately one meter thick with dead oyster shells forming 40 to 50 % of the population. Live shells only on the surface of the reefs.	Thickness of oyster bed less than half a meter ; dead oyster shells only 5-10% of the population	Oysters occur as clumps formed by the attachment of three to four shells; occurrence of dead oyster shells negligible.
Barnacles are the main epifauna throughout the year.	Fouling by barnacles low, seasonal variation in associated fauna such as calcareous polychaetes, *Modiolus* sp.	Bivalves such as venerid clams and mussels are the main associated fauna.
Presence of seaweed low	Different types of sea-weeds are attached to the oysters during late monsoon and post monsoon period.	Presence of seaweed low.
Polydora infestation low; boring by sponges high.	*Polydora* infestation and boring by sponge moderate.	*Polydora* infestation high, boring by sponge moderate to low.

In Ashtamudi Lake, the shell surfaces and the cavities created by empty dead shells have gastropod and fish egg cases. Juveniles of crustaceans and finfishes are found to use the oyster beds as shelter, while several finfishes frequently visit the sites for feeding on the foulers encrusting the oyster shells. In the subtidal regions, oysters were associated with venerid clams like *Meretrix casta* and *Paphia malabarica*. The empty clam shells are used by the oysters for settlement (Kripa, 1998). In Pulicat Lake, *Marphysa gravelyi*, *Eunice* sp, *Polynoe* sp, *Gammarus*, polychaete larvae, amphipods, isopods such as *Sphaeoma* sp, *Lignio* sp, *Cirolina* sp, nematodes, crabs and shrimps are associated with the oyster beds (Thangavelu and Sanjeevaraj, 1988b). In the oyster beds in Maharashtra, Sundaram (1988) has observed snails like *Planaxis sulcatus, Nerita* spp, *Certhium* sp, and *Cellana radiata*, polychates, small crabs, anemones and sponges. To the same site, the mud skipper *Boleophthalmus* sp. and *Therapon* sp. are found to be occasional visitors.

Severe damages to the oyster reef by human activities such as intense fishing, construction works and environmental degradation by chemical pollution have been observed. Environmentalists, research and government agencies are therefore taking several steps to revive these beds and restore their species richness. Restoration of oyster habitats is now considered as an important part of estuarine ecosystem management. In 1997 in Choptank and Patuxent rivers in Maryland, fossil oyster shells were deposited at five sites in a configuration of 2.5 acre flat areas and on mounds of 3 to 4 m height. Some of these areas were planted with hatchery reared spat (1 million/ acre) while the rest were left unplanted (Koles and Paynter, 1999). The planted spat showed vigorous growth rate and spat settlement was noted on the unplanted mounds.

In India, in certain regions like the Ennore estuary, heavy fishing of oyster shells is prevalent. However, the damage caused by such fishing activities has not been studied. Similarly the role of oyster reefs in the estuarine ecosystem has not been investigated. Their significance as an essential fish habitat serving the resident fauna and transient species remains to be critically studied.

QUESTIONS

1. What are the major oyster species in India? Write on their distribution and abundance?
2. Describe oyster reef/bed and associated fauna and flora.

Chapter 3

Biology

DURING the past one and half century, considerable research has been done to understand the biology of oysters and refine the farming techniques. The biological and physiological processes of oysters especially the feeding mechanisms are better understood with the application of microcinematographic techniques. Oysters live in an environment, which has wide seasonal fluctuation, and efforts were made to apply the concepts of physiological energetic in an environmentally realistic context. During the past five decades, research has also targeted to identify the causative factors responsible for mass mortalities of oysters which had lead to virtual destruction of highly productive oyster beds.

In India, molluscan researchers were intrigued by the changes taking place in the natural oyster beds and several studies have been conducted on the biology. In this Chapter, the anatomy of oyster is described followed by a brief summary of available information on the biology of Indian oysters.

External Morphology of Shell

The structure of the oyster shell has been described by several workers (Baughman, 1947; Galtsoff, 1964; Stenzel, 1971; Breish and Kennedy, 1980). Detailed studies about the microstructure, biochemistry and formation and mineralization of shell have also been made (Wilbur, 1976; Carriker *et al.*, 1982; Wilbur and Saleuddin, 1983; Watabe, 1984, 1988; Simkiss and Wilbur, 1989; Crenshaw, 1990; Carriker, 1996). A general description of the external morphology and the oyster shell is given below.

The narrow end or apex of the shell is called the umbo or the beak and this represents the oldest part of the shell. The soft body of the oyster is enclosed within two shells, a larger lower left valve and an upper smaller right valve. The left valve is usually cup shaped and cemented to the substratum. Juvenile oysters attach their left valve to the substrate using fibrous organic matter secreted from the foot (Cranfield, 1975). As they grow they begin to cement themselves onto rocks or other hard surfaces using a part of the surface of their lower left valve. The upper right valve is never involved in cementation under natural condition. The thickness and strength of the shell valves are highly variable and those grown under unfavorable condition are often thin and fragile.

Shell morphology

The shell morphology of the oyster is extremely variable. Nature of the bottom, salinity, temperature, current velocity, turbidity, direct sunlight, calcium concentration and chemical pollution are some factors suspected to be involved in the modification or changes in the shell morphology of oyster (Galtsoff, 1964; Carriker, 1996). The shape of oyster is determined by the contours of substratum in which it grows and this phenomenon is called xenomorphism.

It has been observed that the oysters assume the following shapes when grown on different substrata.

- Smooth and elongated when grown individually on soft substratum.
- Corrugated and circular shell with lower valve deep when grown on hard bottom such as gravel.
- Irregular shape when grown with oysters.
- Circular/elongated with reduced cupped nature when grown fixed to a firm substratum.

The highest commercial grade oysters come from areas where the bottom is firm and non-shifting.

Biochemical composition of shell

The shell is composed of three layers: an outer thin periostracum, central thick chalky layer and inner nacreous layer which is often thin, shiny, lustrous and hard.

Calcium carbonate embedded in a protein mass is the main component of the shell. The periostracum is almost all protein. Calcium carbonate constitutes more than 95% by weight of the shell of *Crassostrea virginica* (Galtsoff, 1964). The conchiolin of the oyster shell is rich in aminoacids (Table 8). Apart from this the shell is composed of a variety of minerals (Tables 9-11). Carriker *et al.,* (1991) conducted a study with proton induced X-ray emissions on the distribution and concentration of 15 chemical elements (sodium to strontium in the periodic chart of elements) of the shell of rapidly growing *C.virginica*. Concentration of elements was calculated as percent by weight of the total 15 elements analysed. Concentration of calcium ranged between 908 ppt to 981 ppt. Titanium, chromium, manganese, iron, copper, zinc and bromine varied from 0.01 to 4.78 ppt; sodium, magnesium, aluminium, silicon, sulphur, chlorine and strontium ranged from less than 0.50 to 31.41 ppt. (for more details, see also Carriker, 1996).The central layer and nacre have different crystalline structures giving different appearances and texture. The oyster larval shell which is 'D' shaped is termed Prodissoconch I and as it grows it is termed Prodissoconch II. The adult calcareous shell formed after settlement is termed Dissoconch.

On the inner side of the shell valve is the adductor muscle scar which is the place of attachment of the adductor muscle. This muscle scar is the most conspicuous area of the oyster shell and may be highly pigmented, light or

Table 8. Amino acids from the conchiolin of two species of oysters in parts of 100 parts of protein

Amino acids	*Crassostrea angulata*	*Ostrea edulis*
Arginine	0.45	2.90
Histidine	-	0.65
Lysine	3.55	4.30
Glycine	15.70	15.70
Leucine	0.51	-
Tryptophane	-	0.48
Tyrosine	3.27	3.05
Valine	0.95	-
Cystine	-	0.98
Methionine	1.77	1.62

Source: Roche and Lafon (1951)

Table 9. Chemical composition of oyster shells in percent of shell weight

Constituents	Range	Constituents	Range
Al	0.043 - 0.045	Zn	NEG-0.0009
Ca	38.78 - 38.81	Cl	0.0034-0.0035
Cu	NEG- 0.0025	CO_3	57.19
Fe	0.09-0.11	Fl	-
Mg	0.183 - 0.189	N	0.196
Mn	0.009	As	-
P_20_5	0.073-0.075	Organic matter[1]	1.41-1.51
SiO_2	0.570 -0.580	Water[2]	0.27-0.28

[1]Loss above 110°C. Ignited; [2]Loss to 100°C.: NEG-Negligible

Source: Hunter and Harrison (1928)

Table 10. Chemical composition of *C.virginica* dredged from Galveston Bay

Constituent	Concentration (%)	Constituent	Concentration (ppm)
Calcium (CaO)	54.6	Organic Carbon as CH_4	400
Carbon (CO_2)	43.5	Chlorine (Cl)	340
Sodium (Na_2O)	0.32	Aluminium (Al)	200
Magnesium (MgO)	0.33	Iron (Fe)	180
Sulfur (SO_2)	0.16	Phosphorus (P)	116
Silicon (SiO_2)	0.16	Manganese (Mn)	110
Strontium (SrO)	0.12	Fluorine (F)	54
Moisture (H_2O)	0.58	Potassium (K)	30
Total	99.8%	Titanium (Ti)	12
		Boron (B)	5
		Copper (Cu)	3
		Zinc (Zn)	2
		Bromine (Br)	1
		Iodine (I)	0.5

Source: Smith and Wright (1962)

Table 11. The percentage of calcium and strontium in shells of oysters

Species	Calcium	Strontium	Carbon dioxide	Organic matter	Atom ratio Sr/Ca x 1,000
O.lurida	38.6	0.085	42.5	1.68	1.01
C.virginica	33.7-37.8	0.92-0.107	41.8-42.4	2.16-2.34	1.25-1.29
C.gigas	34.6-36.2	0.097-0.100	32.6-42.5	1.33-1.71	1.26-1.28

even absent. A narrow band of dark elastic material called the ligament which has a purely mechanical function is situated along the edge of the hinge between the two valves. It helps the adductor muscle to open and close the two shell valves. The anterior margin of the shell is the hinge side and the posterior margin is the opposite.

Shell dimensions

The commonly used terminologies to describe the dimension of oysters are length, width and thickness (Quayle and Newkirk, 1989) (Fig. 6). The axis or the orientation of shell and the corresponding terminologies used are given in Table 12

Table 12. The terminologies used to describe the shell dimensions

Axis/orientation	Dimension	Common usage
Anterio-posterior axis	Height	Length
Maximal distance between ventral and dorsal margin parallel to hinge axis (dorsoventral axis)	Length	Width
Maximum distance between outer surface of closed valves measured at right angles to the plane of closure of valves	Width / Depth	Thickness

ANATOMY

Detailed description of anatomical features of oysters is available from the works of Moore (1898), Brooks (1905), Churchill (1920), Galtsoff (1964) and Eble and Scro (1996). The salient features of the different systems are given below.

Mantle

The body of the oyster (except the adductor muscle area) is covered by a soft fleshy fold of tissue called the mantle or the pallium. The left and right folds of mantle join together at the dorsal edge where it forms a cap and covers the mouth. The mantle edges are also fused at the posterior margin (in the region of the cloacal chamber). The remaining edges of the mantle are free. The large cavity bounded by the mantle lobes is the pallial cavity or mantle cavity which

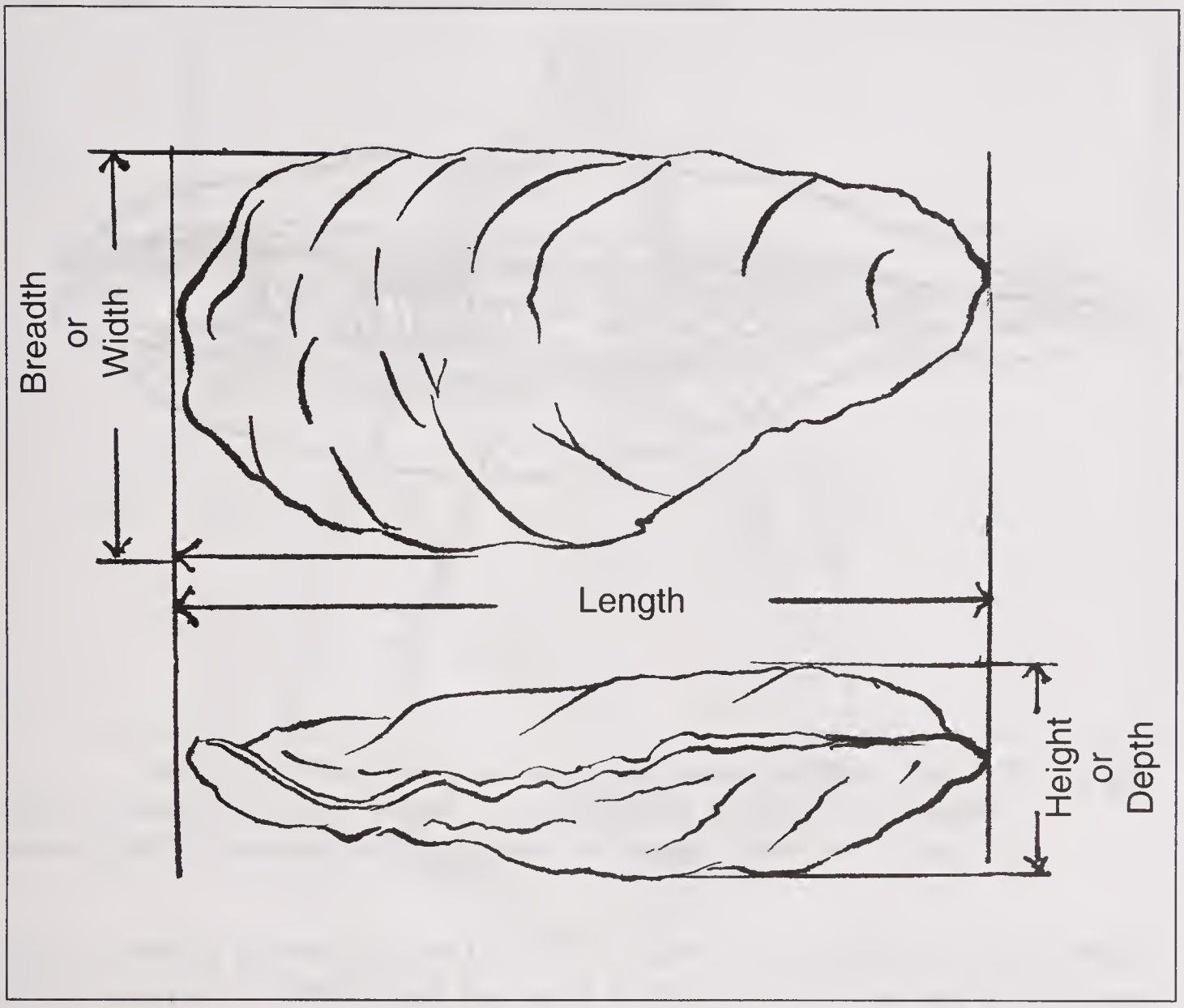

Fig. 6. Diagram showing the shell dimensions of oyster

is usually filled with water. This seawater which contains various products of oyster's metabolism and mucous is called 'shell liquor' and it helps the oyster to survive in the intertidal zone. For oysters in the sub-tidal region, the shell liquor helps to tide over the unfavourable situation caused by floods or temporary presence of toxic or irritating substance in water which forces the oyster to keep its shell closed. The mantle is always in contact with the valves, but is not attached to them.

The mantle cavity contains the palps and gills on one side and the rectum on the other. The rectum opens dorsally to a special portion of the dorsal pallial cavity known as the cloacal chamber. The right lobe of the mantle is separated from the visceral mass to form the promyal chamber (Fig. 7); the left lobe is fused to the visceral mass (Eble and Scro, 1996). The pallial cavity is subdivided into two chambers. The cavity formed by the fusion of the mantle dorsally with the visceral mass and ventrally with the bases of the gills is known as epibranchial chamber. It continues posteriorly as the cloacal chamber. The large cavity containing the gills and bounded by the two mantle lobes is the hypobranchial chamber.

The border of the mantle is divided into three lobes – the outer or shell lobe is narrow and lies in contact with the margin of the shell. The middle lobe

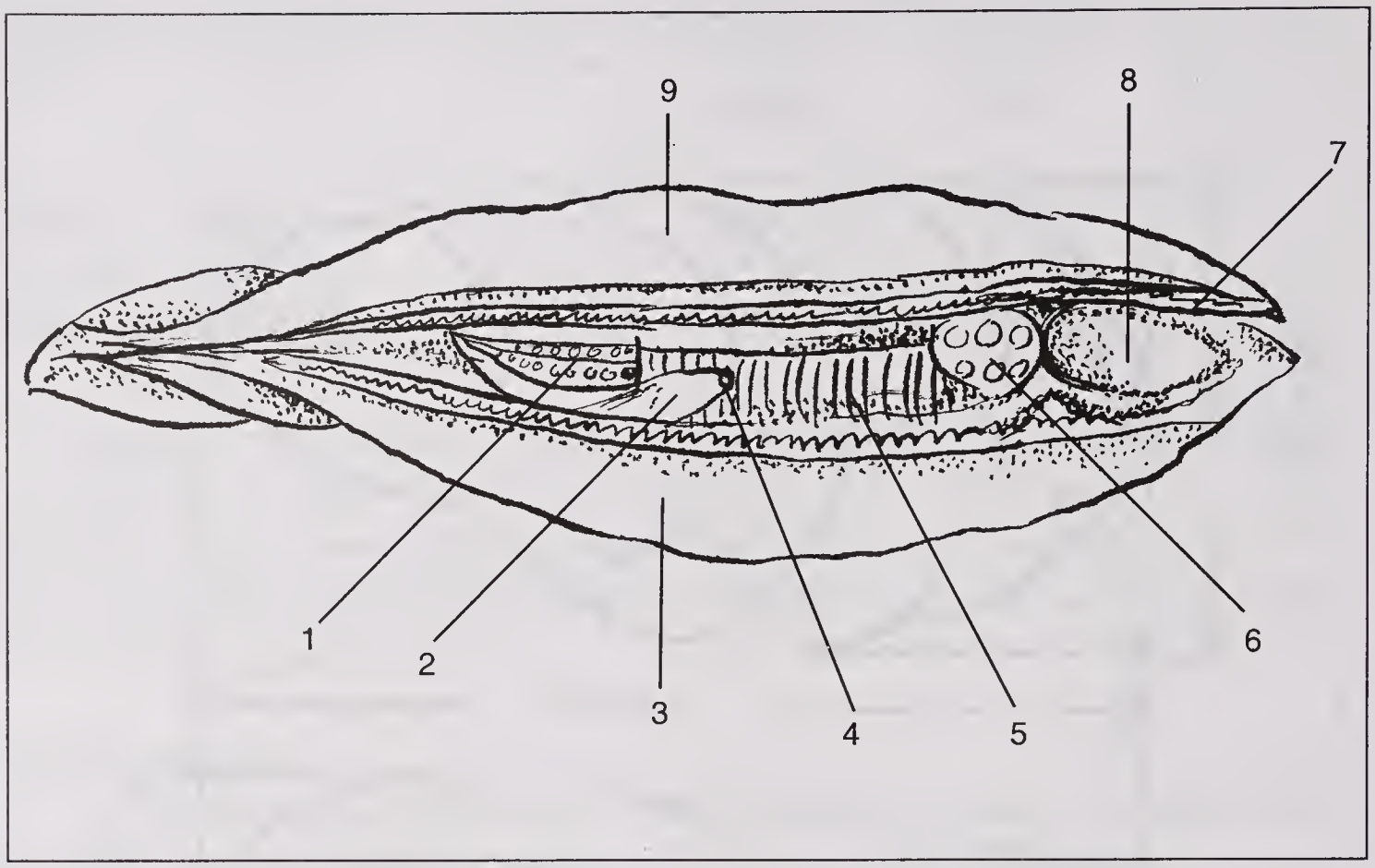

Fig. 7. Promyal chamber viewed from the posterior side of an oyster
1. Promyal chamber 2. Rectum 3. Left valve 4. Anus 5. Adductor muscle
6. Cloacal chamber 7. Mantle 8. Hypobranchial chamber 9. Right valve

bears sensory tentacles and is separated from the shell lobe by a deep cleft, the periostracal groove (Galtsoff, 1964; Eble and Scro, 1996). The inner lobe is called the pallial curtain (Nelson 1938). It bears long, thick tentacles. By interlocking the long tentacles of both sides of the pallial curtain, the entrance to the mantle cavity can be sealed. Even if the valves are open, no exchange of water can take place where the pallial curtain is sealed. Instead of completely closing the pallial curtain, the oyster can selectevely open certain regions. By contracting the adducter muscle, the oyster can eject strong jets of water from the mantle cavity. A ligamental ridge, which secretes ligament, is also situated in dorsal region of the mantle. The main organs of *Crassostrea* sp. as seen after removal of right valve is given in Fig.8.

The main functions of the mantle are:

- Formation of shell and secretion of ligament.
- Reception of sensory stimuli and conveying them to the nervous system.
- Shedding and dispersal of eggs and sperm.
- Respiration.
- Storing of reserve material like glycogen and lipids.
- Excretion by discharging blood cells with waste material.

Muscular system

The single adductor muscle is the main muscular part of oysters and it is located about two thirds of the distance from umbo or nearer to umbo. It's

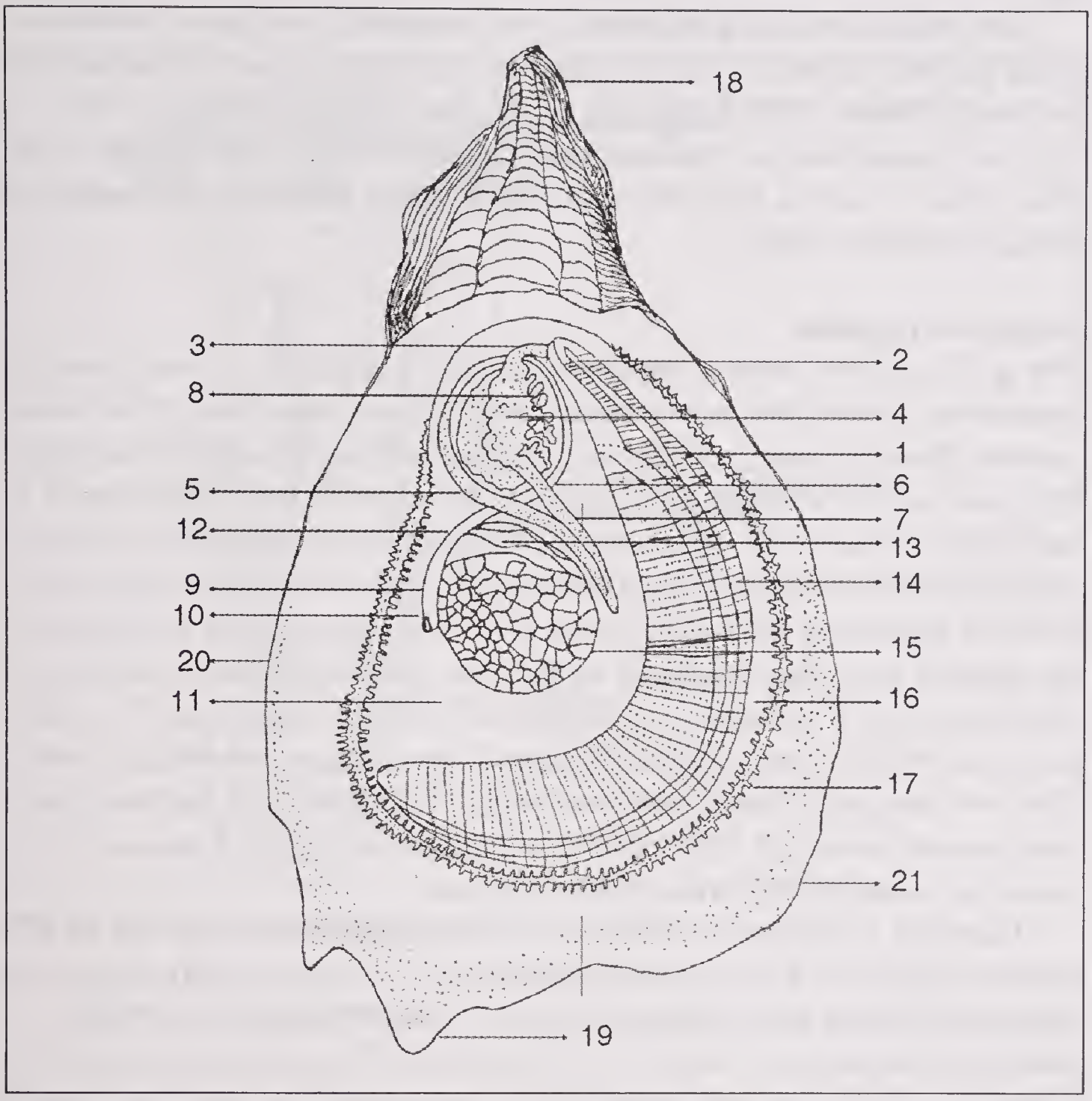

Fig. 8. Organs of *Crassostrea* sp. after removal of right valve 1.Outer labial palp 2. Passage to mouth 3. Oesophagus 4. Stomach 5. Ascending intestine 6. Descending intestine 7. Style sac – midgut 8. Liver diverticula (digestive gland) 9. Rectum 10. Anus 11. Cloacal chamber 12. Pericardial chamber 13. Heart 14. Outer gill 15. Adductor muscle 16. Left mantle 17. Sensory tentacle (papilla) 18.Anterior side 19. Posterior side 20.Dorsal 21.Ventral side.

major function is to control the opening and closing of the valves. In most oysters, it accounts for 20 to 40 % of the total weight of the tissue. Adductor muscles are composed of long, narrow uninucleate muscle cells called fibers (Morrison, 1996). The adductor muscle consists of two sections, a large anterior beige coloured area called the 'quick muscle' which is responsible for the main opening and closure of the valves and a smaller white coloured section called the "catch" muscle which can hold the valves in a set position for long periods with little expenditure of energy. The adductor muscle works continuously against the pressure of the hinge ligament which pushes to open the valves. The power of the adductor muscle varies with the size and condition of the oyster. A pull of over 9 kg is required to open the shell of a good American oyster of 7.5 to 10 cm size.

The mantle, including the lobes is very contractile and can be withdrawn inside the shell (Galtsoff, 1964). In the mantle the radial muscles extend from the visceral mass of the mantle edge. They are also present in the lobes. A layer of circular muscle is present near the pallial surface at the base of the lobes. There is also a layer of small muscle fibres just below the epithelial surface (Carriker, 1996).

Respiratory system

The gills perform several important functions and play a major role in respiration, to which the mantle contributes a minor share. They create water currents, filter the water, collect food particles, and move them to labial palps. They also serve for dispersal of gametes and incubate the fertilized eggs in larviparous oysters. The gills consist of four folds (demibranchs) of tissue suspended from the visceral mass and occupy much of the ventral and ventro-posterior portions of the mantle cavity (Fig.9). In cross section the gills have the shape of four V's, a double V on the right and another on the left side of the oyster. Each V is known as a demibranch and each arm of the V is called a lamella, with an inner descending lamella and an outer ascending lamella. Thus two marginally folded lamellae constitute a demibranch and two joined demibranchs form a gill. Each lamella is composed of vertical filaments which in turn are clustered in vertical folds or plicae.

Each gill is attached to the body of the oyster at the open end of VV known as gill base. The projected end of the VV is known as gill margin and it projects into the mantle cavity (Galtsoff, 1964; Eble and Scro, 1996)

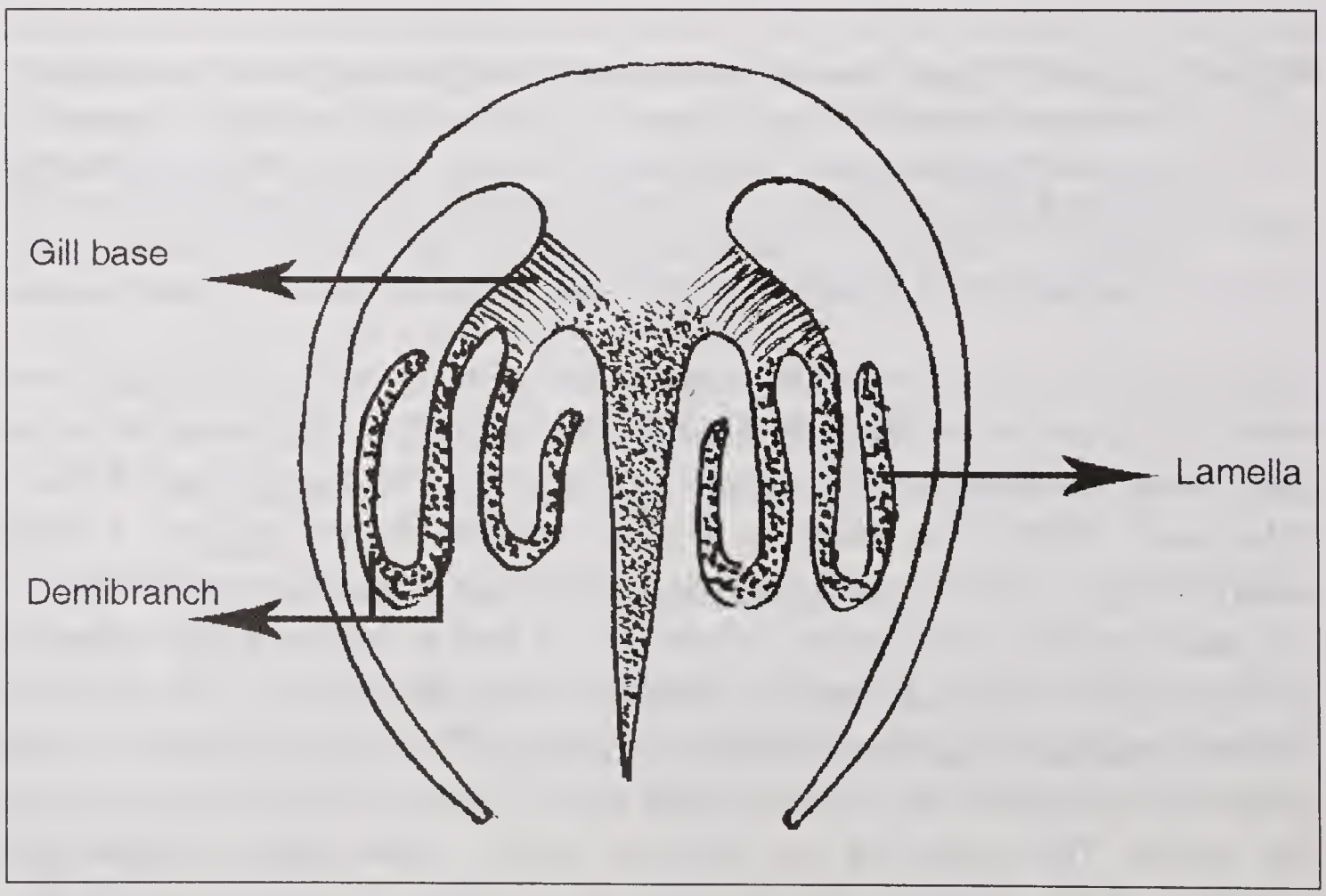

Fig. 9. Diagrammatic representation of the gills of Ostredae

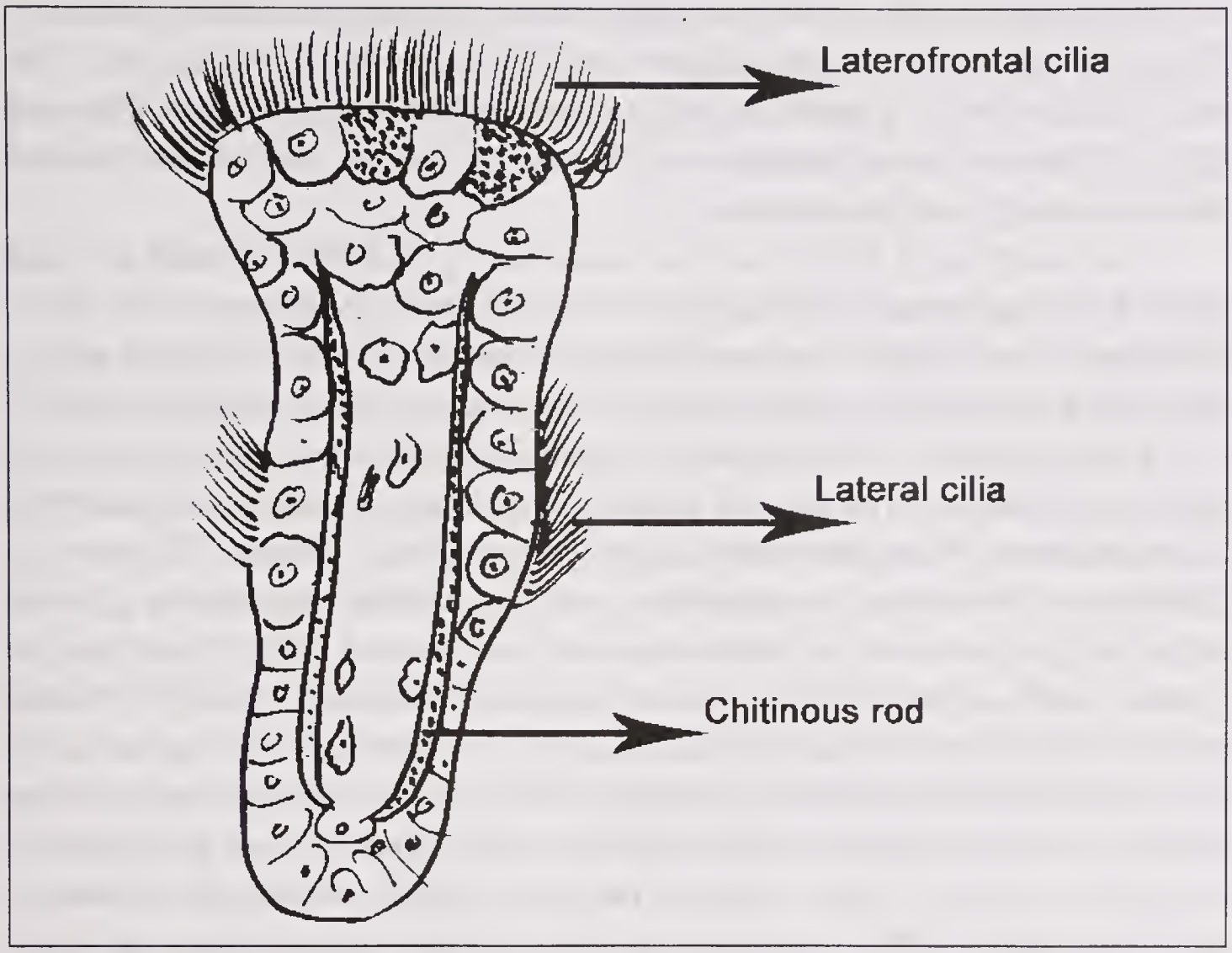

Fig. 10. Section of a gill filament of oyster

The inner two demibranchs are joined together at the central axis of the gills under the common efferent vein. The structuiral unit of a gill is a tubular filament supportd by chitinous rods. The filament has laterofrontal and lateral cilia (Fig.10).The space in the central part of the filament is periodically filled with blood as gill plates expand and contract. The cilia are of various sizes and beating of the cilia aids in maintaining current which helps in gaseous exchange for respiration. The mantle participates in respiration by providing direct exchange of gases between surface of the oyster and the surrounding water.

In *Crassostrea*, the exhalent system is modified by the presence of promyal chamber. The gills filter the water and collect food particles which are sorted and separated from incoming current of water. The filtered water is passed out through the area behind the adductor muscle and also through the promyal chamber. The water current also helps in dispersing the gametes during spawning.

Digestive system

The digestive system of oysters consists of a mouth, short oesophagus, stomach, crystalline style sac, digestive diverticulam, midgut, rectum and anus. The mouth is a compressed U- shaped opening between the two lips, the labial palps (Fig. 8). The labial palps lie at the extreme anteroventral side of the body just under the oral hood of the mantle. The broad bases are attached to the

visceral mass dorsally while the slightly curved margins extend posteriorly to the point where they are in juxtaposition to the free edges of the gills. The mouth is lined with a stratified, tall, ciliated columnar epithelium (Eble and Scro, 1996) and opens into the oesophagus, which is a short funnel shaped dorso-ventrally compressed tube.

The oesophagial epithelium has unicellular glands that contain acid and neutral mucopolysaccharides (glycosaminoglycans) (Beninger *et al.*, 1991; Eble and Scro, 1996). The oesophagus enters the anterior chamber of the stomach at the junction of the latter with the caecum (Shaw and Battle, 1957).

The stomach is a large sac-like organ that is divided into anterior and posterior chambers. The anterior chamber gives rise to anterior and posterior caeca and two primary ducts that lead to the digestive diverticula. The posterior chamber of the stomach is separated from the anterior chamber by a broad ridge that projects into the lumen from the mid ventral wall. It also has the gastric shield, a plate-like, translucent structure embedded in the left ventral wall. It consists of two main lobes joined by a narrow neck. Just posterior to the gastric shield, the posterior stomach leads into an elongated outpouching called the style sac-midgut (Eble and Scro, 1996). The style sac produces the crystalline style and rotates it against the gastric shield releasing the contained carbohydrates into the lumen of the posterior stomach. The midgut is separated from the style sac by the greater and lesser typhlosoles (Shaw and Battle 1957; Galtsoff, 1964). The next significant part of the digestive system is the intestine consisting of ascending, median and descending portion. The ascending limb of the intestine arises at the common posterior chamber of the style sac and midgut. Near the anterior extremity of the visceral mass, the ascending limb descends ventrally to form the median limb. The descending intestine runs posteriorly in the ventral portion of the visceral mass, then crosses obliquely to the left and runs along the dorsal margin of the pericardial sac before opening into the rectum. The rectum runs dorsally over the adductor muscle and ends in the anus that is located in the cloacal chamber.

Another important component of the digestive system is the digestive gland. Three primary ducts leave the stomach, two from the anterior chamber and one from the posterior chamber; they divide into many secondary ducts, which in turn branch into the pretubular ducts. These lead directly to digestive tubules.

Circulatory system

The circulatory system consists of heart, arteries, veins and open sinusus. The heart is situated close to the adductor muscle on the anterior side. It is suspended obliquely in the pericardial coelom. The pericardial coelom is a thin walled chamber between the visceral mass and the adductor muscle. It protects the heart. The systemic heart is three-chambered consisting of two atria and a common ventricle.

The pear shaped ventricle is larger than the two auricles. Its walls are formed by thick bundles of non-striated muscle fibers. The auricles are dark coloured due to the presence of pigment cells in their walls. The degree of pigmentation varies from light brown to almost black (Galtsoff, 1964). The walls of the auricle are thinner and lighter than those of the ventricle. The ventricle is separated from the atria by a constriction, the atrioventricular junction (Eble, 1996).

Lack of continuity between the arteries and veins due to the presence of sinuses is the characteristic feature of the open circulatory system of bivalves. The spaces which function as capillaries have no distinct walls, are of irregular shape and appear as slits in the tissue (Galtsoff, 1964). Two large arteries, the anterior and posterior aorta emerge from the posterio-dorsal side of the ventricle. The arterial system consisting of several arteries like the pericardial, visceral, rectal, circumpallial, subligamental, cephalic and labial arterie which supply blood to different parts of the oyster. The venous system comprises the sinuses, afferent and efferent veins and small vessels of the gills. Most oysters also have an accessory heart which is a paired tubular structure fixed to the mantle near the cloacal chamber. They project into this chamber. This helps in moving the blood through the mantle. Oscillation of the blood in the mantle is the primary function of the accessory hearts.

The mantle and the gills are the two main organs for oxygen exchange with the environment. Eble (1996) after giving a detailed account of the arterial and venous systems has described the physiology of circulation. According to Eble (1996) the systemic heart pumps haemolymph to the visceral mass and adductor muscle. The haemolymph from various organs in the visceral mass is collected by veins and delivered to the gills. Haemolymph in the adductor muscle flows mainly into the gills, secondarily into the kidney. Accesory hearts pump haemolymph from the kidney to the mantle. Haemolymph circulates through gills before returning to the heart. Large veins in the mantle collect haemolymph which is returned to the heart.

Excretory system

The kidney is a tubular gland that lies in a large haemolymph sinus called the renal sinus. The anterior limbs of the kidney lie anterior to the heart, embedded in Leydig cell connective tissue just under the mantle. The main part of the kidney lies under the heart and adductor muscle, extending the entire width of the animal (Eble and Scro, 1996).

The excretory system consists of nephridia situated on either side of the visceral mass (Fig. 11). The nephridia are markedly asymmetrical, the right being larger than the left. Each nephridium consists of a central portion, the body with its short wide duct, and two limbs, an anterior and a posterior. The body of the nephridium encloses a large lumen and communicates with the nephridium of the other side through a transverse canal. Both the limbs of the

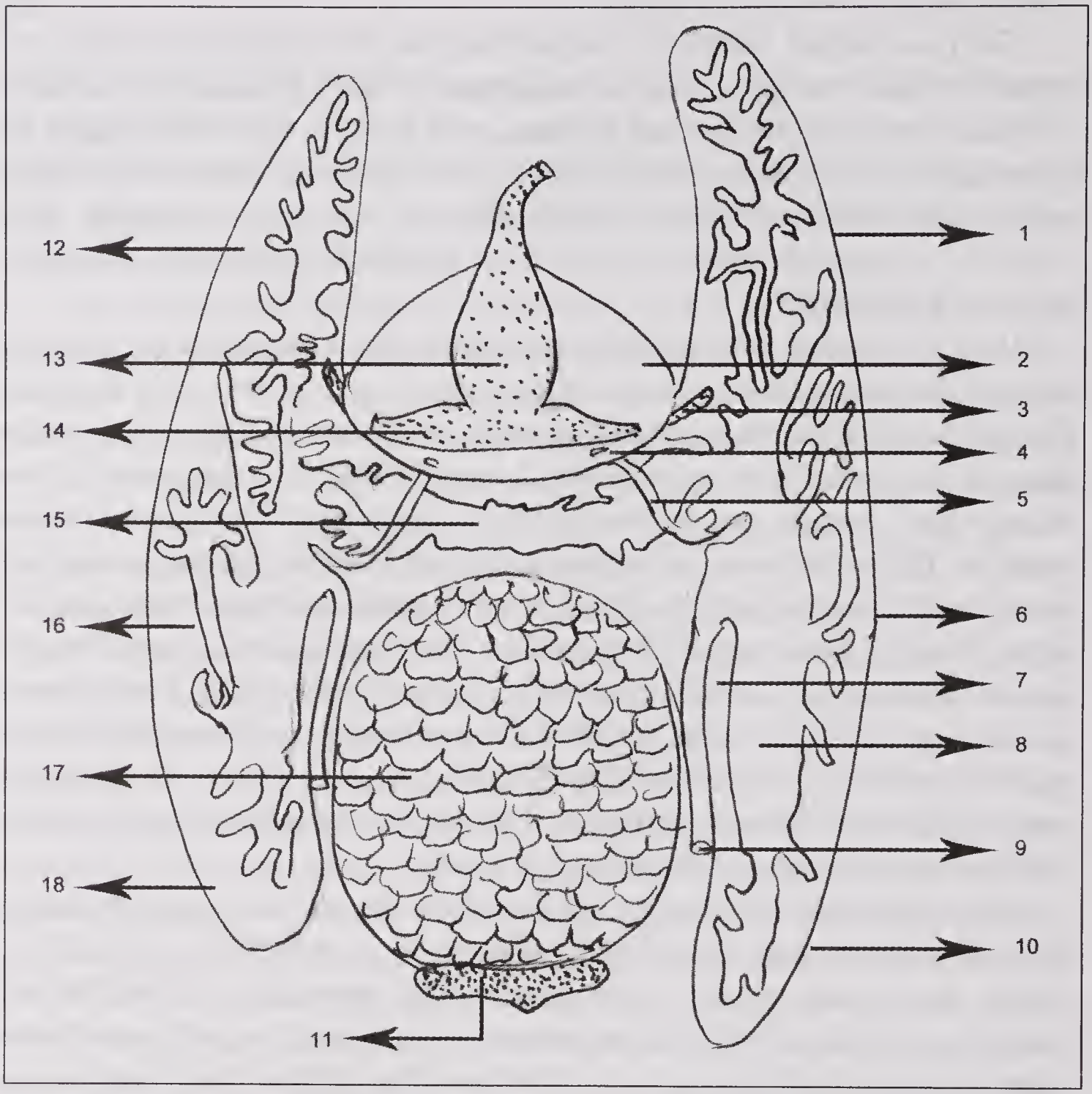

Fig. 11. Excretory system of oyster. 1. Anterior right limb of nephridium 2. Pericardium 3. Efferent vein 4. Renopericardial opening 5. Renoperi-cardial canal 6. Right nephridium 7. Renal duct 8. Reservoir 9. Renogonadial vestibule 10. Posterior right limb of vestibule 11. Visceral ganglion 12. Anterior left limb of nephridium 13. Ventricle 14.Auricle 15. Inter-nephridial passage 16. Left nephridium 17. Adductor muscle 18. Posterior left limb of nephridium

nephridium are formed by numerous branching and twisted tubules lined with excretory cells. Most of the posterior limb of the nephridium is occupied by a wide vesicle or reservoir for storage of urine. A short renal duct leads from the reservoir to the outside and opens into renogonadal vestibule through which both reproductive and excretory products are discharged. In addition to nephridia, pericardial glands, wandering amoebocytes and the mantle epithelium also perform excretory function (Galtsoff,1964)

Eble and Scro (1996) have stated that in the eastern oyster, the pericardial gland is reduced to mesothelial granular cells that line the pericardial coelom and are also present as 'brown cells' associated with atria. The structure and function of brown cells as well as renal filtration and physiology are described

by Eble (1996). The wandering phagocytes are found throughout the tissues of the visceral mass and gills. They accumulate on the surface of the body by diapedesis and are discarded. Mucus or goblet cells on the surface epithelium also help in excretion.

Nervous system

Oysters do not have a major control centre like the brain. The nervous system is simple, comprising of two main ganglia, the visceral and the cerebral ganglia (Galtsoff, 1964). They are joined by the cerebro-visceral connectives (Fig. 12). The U-shaped cerebral commissure goes around the oesophagus and the circumpallial nerve extends along the mantle's edge. Several nerves originate from the ganglion and extend to different parts of the body. The

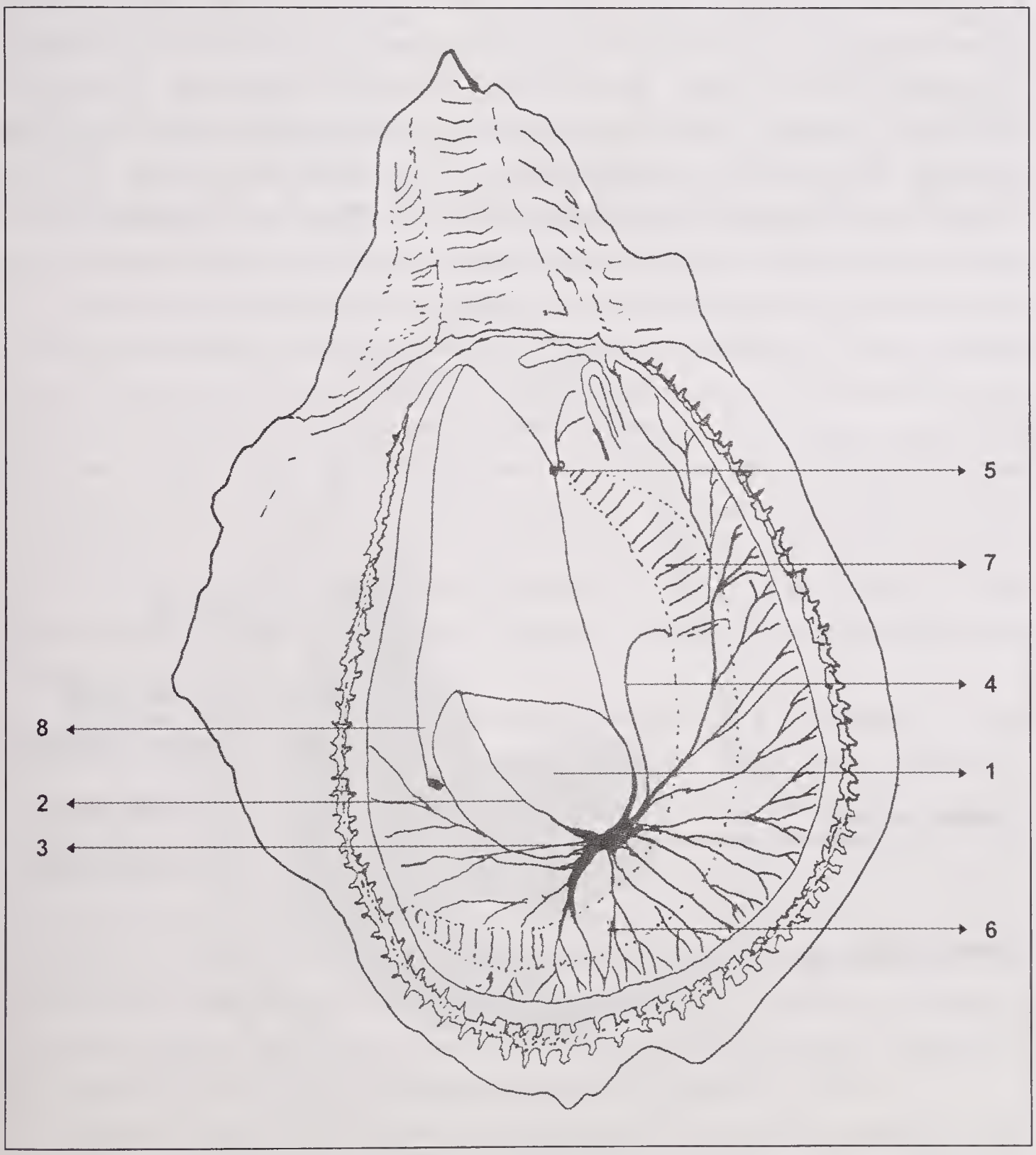

Fig. 12. Nervous system of *Crassostrea* sp. seen from right side. 1. Adductor muscle 2. Adductor muscle nerve 3. Visceral ganglion 4. Branchial nerve 5.Cerebral ganglion 6. Lateral pallial nerve 7. Gills 8.Rectum.

pedal ganglion is absent. The tentacles along the edge of the mantle and the pallial organ inside the cloaca are the only sense organs of the oyster. The tentacles are highly sensitive to illumination, temperature and chemical changes of the surrounding water. The function of the pallial organ is not well understood. Eyes are present in fully grown larvae, but absent in adult oysters.

Reproductive system

The sexes are generally separate (heterosexual) though hermaphroditism has been recorded. The reproductive organ is the gonad situated in the visceral mass between the digestive gland and the mantle. It originates at the region of the oesophagus, extending the length of the visceral mass to the pericardial area where it bifurcates into a dorsal lobe that extends towards the rectum and a ventral lobe extends to the posterior extension of the visceral mass. During the resting phase the gonad cannot be distinguished grossly from the surrounding vesicular connective tissue. The outline of the gonad is indistinct. When fully developed the gonad measures several millimeters thick and has many branching channels, the gonoducts which are clearly visible on the surface (Fig. 13). The sex cells are discharged through the gonoducts into the urinogenital grove

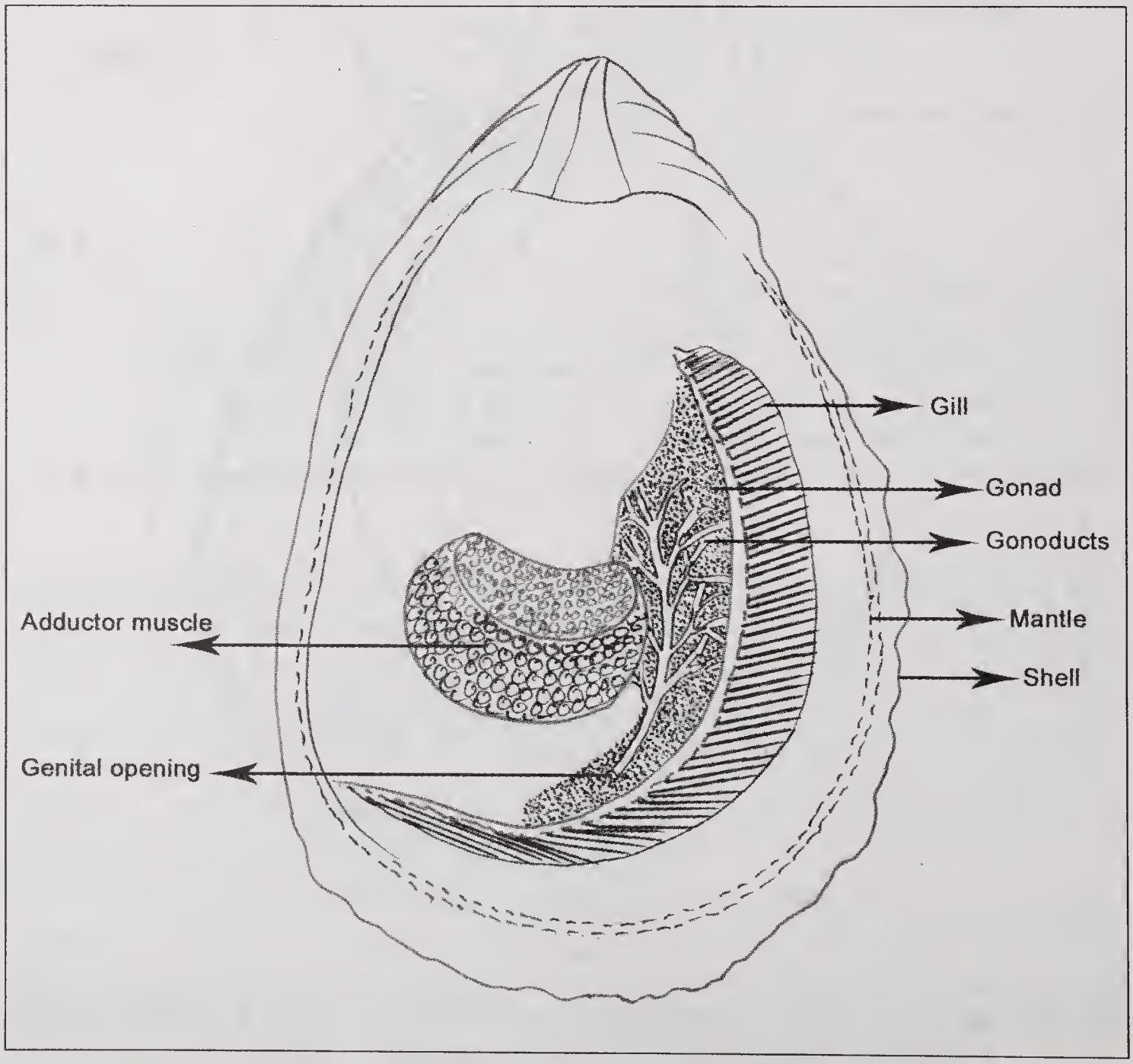

Fig. 13. Ripe gonad of oyster

(vestibule) and from there they are passed to the outside through the epibranchial chamber. The sex of the oyster cannot be differentiated externally.

FOOD AND FEEDING HABITS

Oysters are filter feeders capable of filtering and utilizing the phytoplankton and organic detritus suspended in the water. The food particles are moved mainly by the ciliary action of the gills. With the application of new microcinematographic techniques it has been possible to understand the various feeding structures of bivalves *in vivo* (Newell and Langdon, 1996). Ward *et al.* (1994), observed previously undetected tract along the most anterior margin of the demibranch that serves to carry excess particles away from the basal gill-palp junction.The food particles in the incurrent water pass through the gills and get entrapped, bound in mucus and are directed towards the labial palps. The labial palps play an important role in sorting and selecting the food. They either direct the particles towards the mouth or reject it as pseudofaeces. Bernard (1974) has stated that the ciliated ridges on the palps reject the entire mucous - particle load if the size of particle is large. Considerable discrepancies exist in the results of studies on retention efficiency and particle size. Haven and Morales-Alamo (1970) and Palmer and Williams (1980) reported that *C.virginica* can retain particles in between 3 to 6 µm size range with efficiencies as high as for particles larger than 6 µm. Conversely, Riisgard (1988) reported that *C.virginica* can retain particles smaller than 6 µm with lower efficiency than that reported for many other bivalve species. The mucus enmeshed particles which enter the oesophagus mix with enzymes released by the crystalline style and extra- cellular digestion of starch takes place. By a combination of ciliary pathway in the sorting pouches and in the stomach itself, small and partially digested particles are carried to the tubules of the digestive gland where intracellular digestion of fat and protein takes place (Quayle and Newkirk, 1989).

Digestive tubules of *C. madrasensis* are found to be monophasic, *i.e.* at a particular tidal phase almost all the tubules have a homogenous structure. During high tide these tubules are used for digestive and absorptive phases while during low tide the disintegrating and reformative phases are dominant (Hameed and Paul Pandian, 1987). Histological study of the digestive tubules of intertidal and subtidal *C.virginica* showed that the intertidal *C.virginica* responds to tidal cycles by losing or reconstituting the crystalline style concomitant with changes in tubule morphology. In contrast, in subtidal oysters the digestive tubules are not affected by normal tidal cycles, supporting the contention that they are continuous feeders (Winstead, 1997).

Yonge (1926) reported that protein and fat digestion occurred only intracellularly within the wandering phagocytes, and the starch was digested only extracellularly by the action of thyliamylase. Phagocytosis mainly occurs in the digestive diverticula. The oyster is also capable of absorbing dissolved

organic matter in the water through the surface of gills, palps and mantle (Owen, 1974). Apart from this, blood cells capable of engulfing the food also ingest and digest individual particles of food.The granular haemocytes in the alimentary canal of oysters have wide range of digestive enzymes including amylases, lipases, esterases and proteases (Yonge, 1926; Takatsuki 1934; Mathers, 1973). Haemocytes containing digested material in the haemocoel surrounding the digestive tubules have also been observed (Yonge, 1926; Morton, 1971). There are important enzymes in the stomach which help in the digestion of starch and glycogen. Digestive enzymes have been observed in the digestive diverticula (Mathers, 1973; Onishi *et al.*, 1985; Brock *et al.*, 1986) and midgut (Mathers, 1973). He also observed different polymerases and oligomerases in the stomach contents, stomach wall, style sac and style of oysters.

Several studies have been made on the gut microflora of oysters *Cristispira* spp. A colourless gram negative spirochaete has been observed to live in the matrix of the style of oysters (Dimitroff, 1926). These can be distinguished by the presence of a ridge or crest-like structure called the 'crista' (Tall and Nauman, 1981). Dimitroff (1926) has stated that a smaller spirillum, *Spirillum ostreae,* may also be present in the style. It is believed that these contribute to the style's production of enzymes. However, Mayasich and Smucker (1987) have inferred that the enzymes in the crystalline style of oysters are produced endogeneously and that *Cristispira* spp. and the bacteria do not contribute significantly to the production of enzymes. Crosby and Reid (1971) have suggested that the gut microflora play a significant role in extracellular digestion of cellulose, but they have not been able to determine the relative importance of endogenous versus exogenous cellulases of bacterial origin.

The unwanted materials are directed by the caeca along a special path called typhlosole, to the opening of the intestine, where these are compacted into solid strings and are ejected out in the exhalent water current *via* the anus. The faecal ribbons of the oysters contain many live cells-diatoms, dinoflagellates, yeasts and others which are not digested by the gastric and intestinal juices.

Filtration rates

The oysters, as mentioned earlier, are filter feeders and the water currents produced by the ciliary action of the gills serve both respiratory and feeding functions. Exogenous factors like water currents (Grizel *et al.*, 1992), seston concentration (Higgins, 1980a; 1980b), temperature, salinity (Rajesh *et al.*, 2001) are some of the factors which influence the feeding processes of oysters. The rate at which suspended food is filtered from the suspension is determined by the pumping or the ventillation rate (rate at which water is transported through the gills) and the retention efficiency (the efficiency with which particles are retained by the gill) (Malcouf and Bricelj, 1989). The retention efficiency is found to depend on the particle size and particle concentration.

It has been clearly observed that all the material retained is not utilized by oysters and part of it is eliminated as pseudofaeces (Langdon and Newell, 1996). The combined production of pseudofaeces and faeces (material that is ingested but cannot be absorbed or metabolically utilized) is referred to as biodeposition rate.

The physiological measurements of filtration rate (FR), clearance rate (CR), pumping rate (PR) and ingestion rate (IR) are generally used to study the ecological energetics. The CR is defined as the volume of water filtered completely free of particles per unit time. Pumping rate is the volume of water flowing through the gills per unit time. When all the suspended particles are removed by the gills with 100% retention efficiency, clearance rate is the same as the pumping rate. The IR or feeding rate is defined as the number of algal cells an organism consumes per unit time (Malcouf and Bricelj, 1989). Direct measurements of pumping rates have posed several practical difficulties. Hence indirect methods have been proposed and instead of pumping rates, clearance rates have been determined (Iglesias *et al.*, 1998). There are two methods to measure the clearance rate.

a) Measurements in closed or static systems that are based on the rate of depletion in particle concentration due to filtering activity. This method is called Coughlan method. (Coughlan, 1969).

b) Measurements made in an open or flow through system. Here the percentage of reduction in particle concentration that occurs in a water mass when flowing through the chamber with one or more bivalves inside is measured. Both these methods have been found to give comparable results. When the particle concentration is high and the oyster produces pseudofaeces, then the rate of particle rejection is also measured. Then ingestion rate = filtration rate (FR) - rejection rate (RR). The only way to measure rejection rate is by the direct quantification of produced pseudofaeces, which can be easily performed by quantitative collection followed by gravimetric determination of collected matter (Iglesias *et al.* 1998).The FR and IR are calculated using the following formulae (Ali, 1970; Walne, 1972).

$$\text{The filtration rate, (F ml/hr) } F = V \times \frac{\log \text{conc. } t_o - \log \text{conc. } t_1}{\log e\, t} \times 60$$

Where V = volume (ml of algal solution used); conc. t_o = initial concentration and conc. t_1 = algal concentration after time t.

$$\text{Ingestion rate (I, cells/hr/animal) } I = \frac{C_1 - C_2}{nt} \times V \times 60$$

Where C_1 = initial algal concentration; C_2 = final algal concentration after time t; t = duration of the experiment in minutes, V = volume of water and n = number of oysters.

The FR of *C.madrasensis* is influenced by the salinity. It was highest at 20 ppt salinity than at 10 and 32 ppt (Rajesh *et al.*, 2001). The FR of *C.madrasensis* of two different size groups 65-70 mm and 100-105 mm was compared and FR of larger animals was found to be significantly ($P<0.05$) higher. The FR of 65-70 mm and 100-105 mm was 15.509 l/hr/animal and 21.389 l/hr/h animal respectively in an algal cell concentration of 7.5×10^4 cells /ml at 20 ppt. During the last decade efforts have been made to apply the concepts of physiological energetics of bivalves in an environmentally realistic context (Navarro *et al.*, 1991; Hawkins *et al.*, 1996). Recently Hawkins *et al.* (1998), have observed that bivalves are able to selectively enrich the organic content of ingested matter relative to filtered matter, preferentially rejecting inorganic matter prior to ingestion as pseudofaeces. In a natural system the efficiency of selection varied positively with both the mass of seston filtered per hour and organic content of filtered matter. Accordingly, when the food available was high, the mass of seston filtered per hour was greatest and more than 60% of the organic matter ingested per hour resulted from selective processes.

REPRODUCTION

Reproduction in oysters is controlled by endogenous factors such as stored nutrients and neuroendocrine compounds and by exogenous factors such as salinity, temperature and pheromones (Stephen, 1980; Joseph and Joseph, 1988; Littlewood and Donovan,1988; Mane and Nagabhushanam, 1988; Thompson *et al.*, 1996).

The seasonal changes in gonad development and the principal exogenous factor which stimulate spawning in *C.madrasensis* have been studied (Hornell, 1910a; Panikkar and Aiyar, 1939; Paul 1942; Rao 1951, 1953, 1956; Rao 1974; Stephen 1980; Joseph and Madhyastha 1982; Rajapandian and Rajan 1983; Narasimham 1987; Joseph and Joseph 1988). Stephen (1980) and Joseph and Joseph(1988) have investigated the changes in biochemical levels of the adductor muscle, mantle and gonad with the gametogenic cycle of *C.madrasensis*. Durve (1965) and Mane and Nagabushanam (1976, 1988) have described the gametogenic cycle of *C.gryphoides* along the Maharashtra coast. The annual reproductive cycle of *S.cucullata* has been studied by Sukumar and Joseph (1988) and Kripa (1998).

In *Crassostrea* species the eggs produced by the female gonad and the sperms by the male are discharged externally into the open environment where fertilization takes place. During spawning, the sperm is discharged as a steady stream in the exhalent water through the genital pores. The spawning in female is slightly different; the exhalent opening of the mantle is closed, the valves are kept open and most of the inhalent area except for small opening in the posterior ventral region is also closed. The released eggs are collected in the inhalant chamber as they cannot be discharged through the exhalent

chamber which is closed. The adductor muscle then contracts rapidly and the cluster of eggs is forced out through the small opening along the mantle edge curtain.The eggs are ejected about 30 to 60 cm away from the oyster thereby ensuring the dispersal. Depending on the species, the maturity of the gonad and the environmental conditons, the entire spawning may be completed at a stretch within a short period or with short pauses or may extend for days or week (Galtsoff, 1964; Quayle and Newkirk, 1989).

In oysters of the genus *Ostrea* the eggs are retained within the inhalant chamber of female and the sperms from the adjacent spawning male enter the female with the inhalant water current and fertilize the eggs. The fertilized eggs are incubated in the chamber for 10 days and are released as half grown larvae (Quayle and Newkirk, 1989) by the female.

Hermaphroditism

Oysters have no secondary sexual characters and their sex can be recognized only during the reproductive periods by microscopic examination of gonads. The oviparous species of oysters of the genus *Crassostrea* usually are not functional hermaphrodites. Specimens in which functional eggs and sperms are found together are rare (Galtsoff, 1964). In the viviparous Chilean oyster, *Triostrea chilensis* of Northern New Zealand, simultaneous hermaphrodite oysters have been reported (Jeffs *et al.*, 1997). Hermaphroditism has been noted in different populations of *C. madrasensis* along the east and west coasts. Rao (1953, 1956) recorded hermaphroditism in *C. madrasensis* throughout the year while Rajapandian and Rajan (1987) and Narasimham (1987) noted hermaphroditism only in stray instances in spent and recovering stages along the east coast. (Fig 14f)

Sex change

In *C. madrasensis*, young oysters of '0' year group are functional males upto 78 mm size. In one year old and above (118.5 mm), 72% of the population were females (Rajapandian and Rajan, 1987). In *Ostrea* the sex may alternate once or several times within one breeding season depending on temperature and food conditions. In general, the proportion of males and females remains approximately equal in spite of these sex changes (Quayle and Newkirk, 1989).

Fecundity

The fecundity of the oysters of the genus *Crassostrea* is about 100 million eggs (Quayle and Newkirk, 1989). The size of the ova when spawned is about 70 µm and the sperm head is about 3 µm. The eggs of *C.madrasensis* measure 48 – 60 µm in diameter. The fecundity of this species is 10 to 15 million eggs (Rajapandian and Rajan, 1987).

Sexual maturity and Spawning season

Seasonal gonadal changes can be studied by gonadal smear or histological preparations (Quayle and Newkirk, 1989). The gonadal changes can also be evaluated by visual - observation. Gonadal smears are prepared by making a small cut on the surface of the body of the oyster with a scalpel at a point half way between the position of the mouth and the adductor muscle. The smear taken should be examined immediately. Histological preparations provide reliable assessment of the gametogenic state of the oysters. It is common to divide the reproductive cycle of the oyster into 5 stages (Table.13 and Figures 14 and 15)

Table 13. Distinguishing features of maturity stages of the oyster gonad

Stage	Condition of gonad
Indeterminate	Difficult, if not impossible, to determine sex, follicles absent.
Maturing	Beginning of gametogenesis with the appearance of follicles; primary sex cells seen on the follicle walls.
Ripe	Follicles enlarged and gametes capable of fertilization and sperms active.
Partially spent	Recently spawned with follicles partially collapsed, few mature ova and sperm also present.
Spent	Completely spawned with follicles collapsed without ova or sperm. This is followed by accumulation of Leydig tissue and back to stage 1 or 2.

The development of gonad in an individual is a continuous process in each follicle. It has been observed that the gonad forms about 30 to 40% of the total body weight, exclusive of shell.

The males of *C.madrasensis* and *Saccostrea cucullata* attain maturity as they reach a size of 12-14 mm and 18-22 mm respectively. The majority of females of the former species mature at 24-26 mm and the latter at 20-22 mm (Joseph and Joseph, 1988; Kripa, 1998). Along the Indian coast, it has been observed that the majority of the oysters in a population reach maturity at the same time and spawning is triggered through interactions between the oyster and the environment resulting in synchronous spawning during the peak spawning period. The spawning trigger for the Indian oysters has been attributed mainly to variation in salinity (Hornell, 1910a; Moses 1928; Paul, 1942; Rao, 1951; Durve, 1965; Stephen, 1980; Joseph and Madhyastha, 1982; Kripa, 1998). The spawning season and periodicity has been found to differ for the Indian oysters (Table 14).

Along the east coast, at Madras Harbour, *C.madrasensis* has been reported to have year round spawning, while north of this in Kakinada Bay the species has a restricted spawning and does not spawn during July-December when the salinity is low. Down south, at Tuticorin, two spawning periods have been

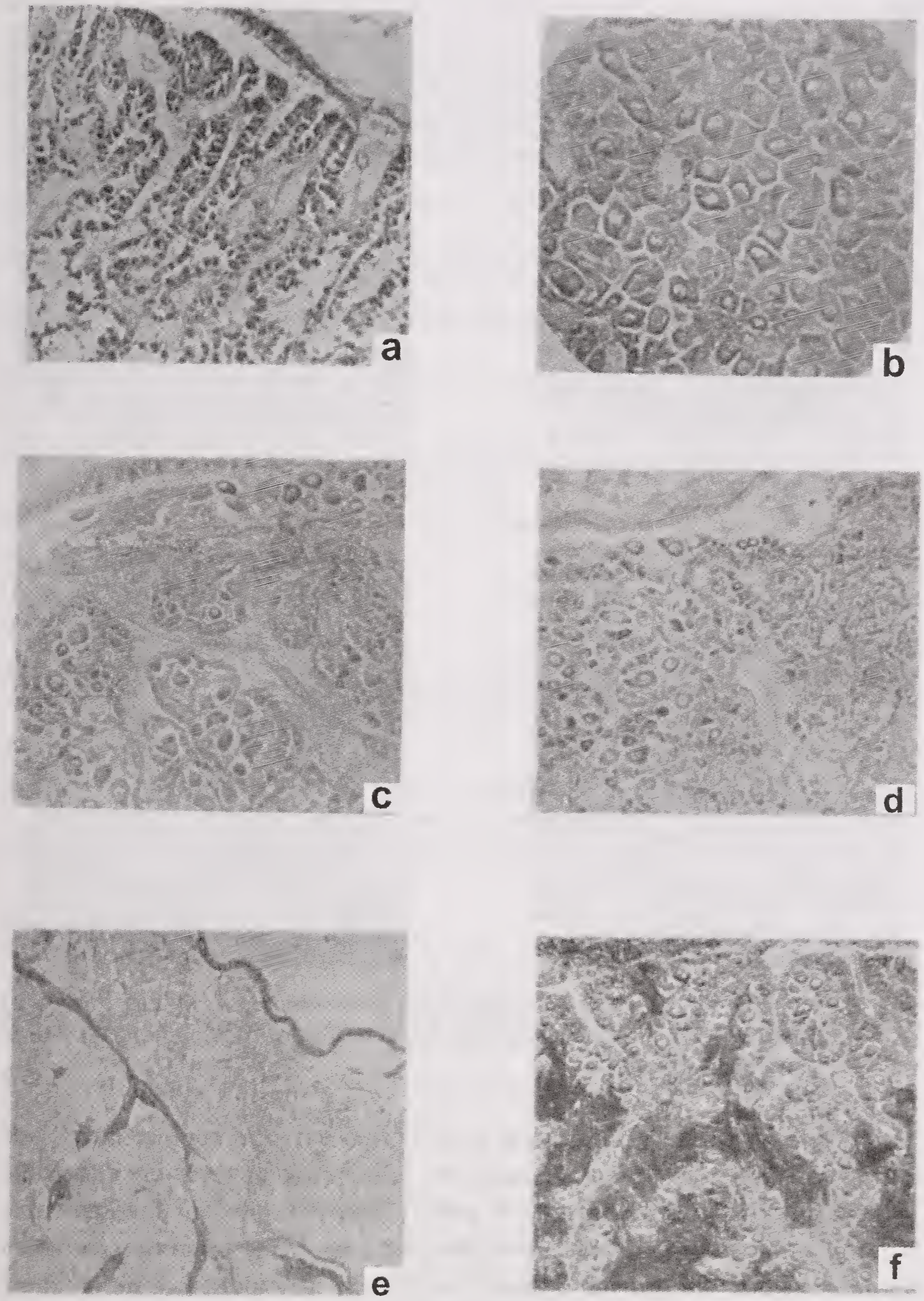

Fig. 14. Maturity stages of *Crassostrea madrasensis* a) Maturing female b) Ripe female c) Partially spawned female d) Spent female e)Indeterminate stage f) Hermaphrodites (after Rao, 1958)

observed. Along the Indian west coast, in Kerala, *C.madrasensis* spawns during the post monsoon period (Nov –Dec) when the salinity and temperature of the coastal waters increase. Minor spawning has been observed during the summer months also. In Karnataka, the same species has a peak spawning

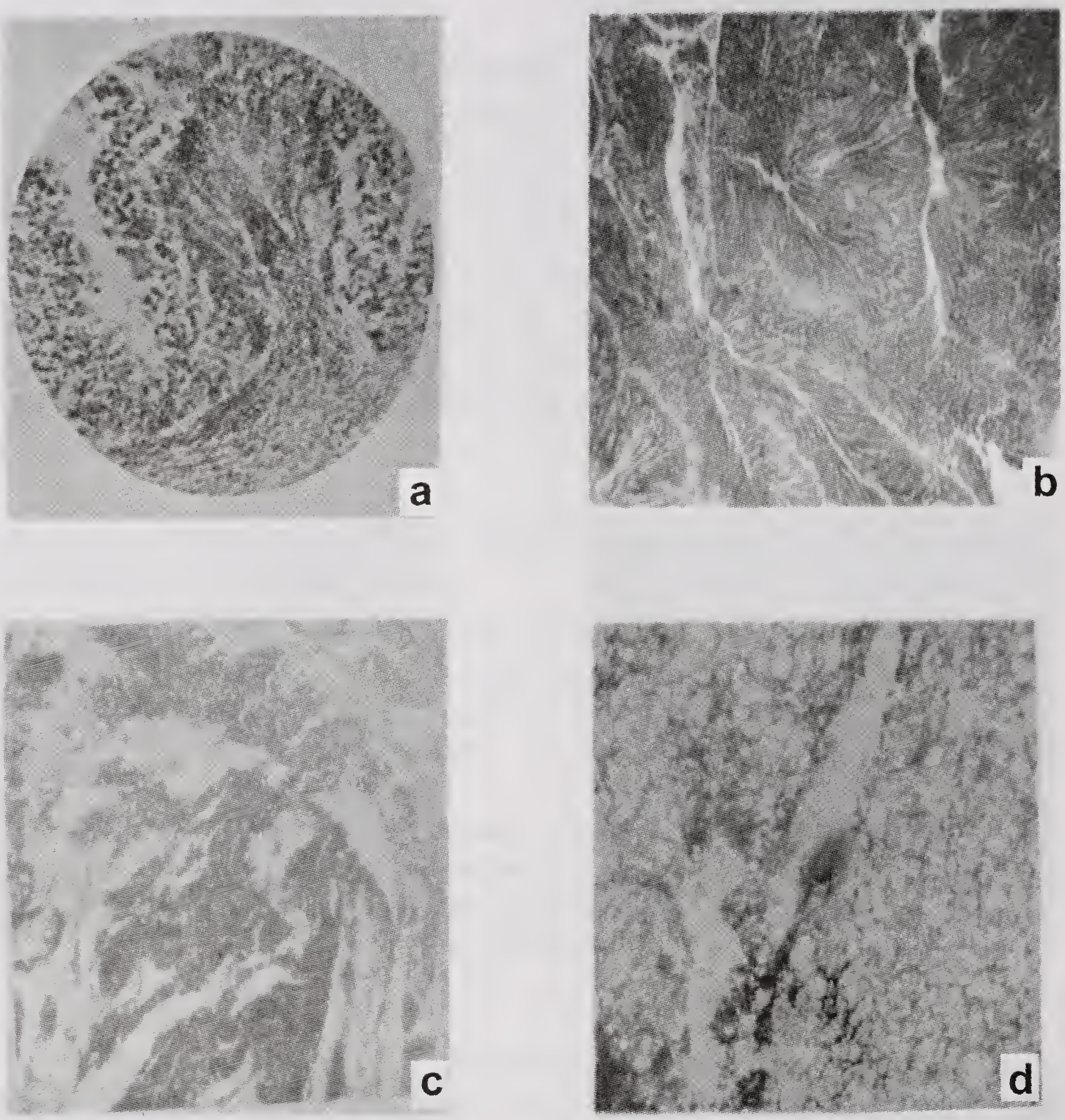

Fig. 15. Maturity stages of male *Crassostrea madrasensis* a) Maturing male b) Ripe male c) Partially spawned male d) Spent male (after Rao,1956; Narasimham, 1987)

period just during the premonsoon period (Apr-Jun) and another minor one during postmonsoon. However, under low salinity and temperature during the monsoon, the spawning activity is greatly reduced. Though the spawning season of *C.madrasensis* along both the coasts has been found to vary, it can be inferred that the spawning takes place when the salinity of the ambient water is between 20 and 30 ppt. Generally spawning occurs when the salinity increases. Hornell (1910a) was the first to draw attention to the relationship between sexual activity of oysters and salinity. This pronounced relationship prompted Stephen (1980) to term this relationship as 'Hornel's Rule'. Apart from salinity variation, diurnal variations in temperature have also been suggested as favorable for spawning in *C.madrasensis* along the east coast (Rajapandian and Rajan, 1983; 1987). Spawning has also been related to a combination of rising water temperature and salinities (Narasimham, 1987).

Table 14. Spawning season of oysters along the Indian coast

Location	Peak spawning period	Environmental factors triggering spawning	Reference
C.madrasensis			
Kakinada Bay	Jan – June	Rising temperature and salinity	Narasimham(1987)
Madras harbour	Throughout the year	Variation in salinity	Paul (1942)
Adayar estuary	Oct- Dec, Mar – Apr	Variation in salinity	Rao (1951), Rao and Nayar (1956)
Tuticorin	Jul-Sep, Feb- Apr	Diurnal variation in temperature	Rajapandian and Rajan (1983)
Mulki estuary	Apr- Jun, Nov	Variation in salinity	Stephen (1980) Joseph and Madhyastha (1982), Joseph and Joseph (1988)
Ashtamudi	Nov-Dec	Rising temperature and salinity	Velayudhan *et al.* (1995)
C.gryphoides			
Kelwa back waters	July -Sep	Salinity ranging between 13 and 28 ppt	Durve (1965)
Bhatia creek	Sept -Nov	Increasing salinity	Mane and Naga-bhushanam (1988)
S.cucullata			
Ratnagiri	Oct-Jan	Rising salinity and temperature	Mane and Naga-bhushanam (1988)
Someshwar	June –Sep, Nov-Dec	Rising temperature and salinity	Sukumar and Joseph (1988)
Ashtamudi Lake	Nov- Feb, May-June	Temperature and salinity	Kripa (1998)

C.gryphoides has two different spawning periods along the Maharashtra coast. The spawning period is from July to September in Bhatia creek, while towards south along the Ratnagiri coast, the spawning season is during September-November. Mane and Nagabhushanam (1988) have analyzed the hydrographic changes occurring in the oyster beds and found that for *C.gryphoides,* the optimum salinity range for spawning in the Bhatia creek and Ratnagiri is 13-28 ppt and 23.5-31.2 ppt respectively. Desai and Nimavat (1983) based on neuroendocrine studies have reported that salinity and temperature influence the reproduction of *C.gryphiodes* and *C.rivularis.*

For *S.cucullata*, the major spawning period is during the post monsoon in the different populations along the west coast (Sukumar and Joseph, 1988; Kripa, 1998).

Development

Several investigations have been made to study the development of oyster eggs and larvae (Brooks, 1880; Galtsoff, 1964). Following description is mainly summarized from Quayle and Newkirk (1989) and Rao (1983).

The eggs are viable for about 24 hours in the temperate countries while in the warm tropical waters, the fertilizing power of both egg and sperm lasts only for 3 to 4 hrs. The embryonic and larval stages are given in Figs. 16, 21 and 22. After fertilization the cells divide rapidly and the first polar body is observed within 20 to 40 minutes; subsequently the second polar body is formed. The first cleavage occurs immediately after this and the cells in the animal pole divide resulting in the 8 -celled stage. After further cell division, a roughly spherical morula stage is reached. In *C. madrasensis* in about 2½ hrs after fertilization, blastula with cilia is formed and it shows rotatory movements. This is followed by gastrulation partly by epiboly and partly by invagination. At the end of 20 hrs, a definite swimming organ called the velum is formed and these larvae are called 'veligers'. The velum has a ciliated part that protrudes outside the open shell and is used for swimming as well as for food collection. These larvae have limited mobility and move about horizontally by the water currents. In the first few days, the larvae have a D shape and they are often called D shaped or straight hinge larvae. The veliger larvae have alimentary canal, foot and adductor muscle and begin to feed on minute phytoplankton. Soon, protruberances on the straight hinge line develop and the larvae become rounder with the formation of umbones. This stage is called early umbone. Oesophagus, stomach, intestine, digestive gland and rudimentary gills are formed. In later larval stages, the oysters have two adductor muscles. The larval shell is different from that of the adult, being less dense and transparent. This stage is termed the mid umbo stage. Further development results in the eyed larvae with the formation of an active foot, a cement gland and black eye spot on each side. The pediveliger is the final larval stage which is competent to metamorphose and get attached. The pediveliger stage is characterized by the presence of functional foot, velum, alimentary canal, eyespot, heart, gill rudiment and two adductor muscles. These larvae can swim and also descend to the bottom by crawling. This is known as swimming creeping stage (Carriker, 1961b).

If the pediveliger larva finds a solid substrate, it crawls on it with the help of foot. If the site is unsuitable the larva continues swimming. On suitable substrate the pediveliger larva forces from its cement gland a minute drop in which it crawls and settles with the left valve in the cement. This act of attaching on a solid substrate is called setting or spatting. The spat is also known as the seed. Once the spat sets, it is fixed and undergoes several changes. The foot and the cement gland are detached, the velum is lost, the body becomes twisted, the anterior adductor muscle is lost and the posterior adductor muscle is retained and it moves more to the center of the shell. The

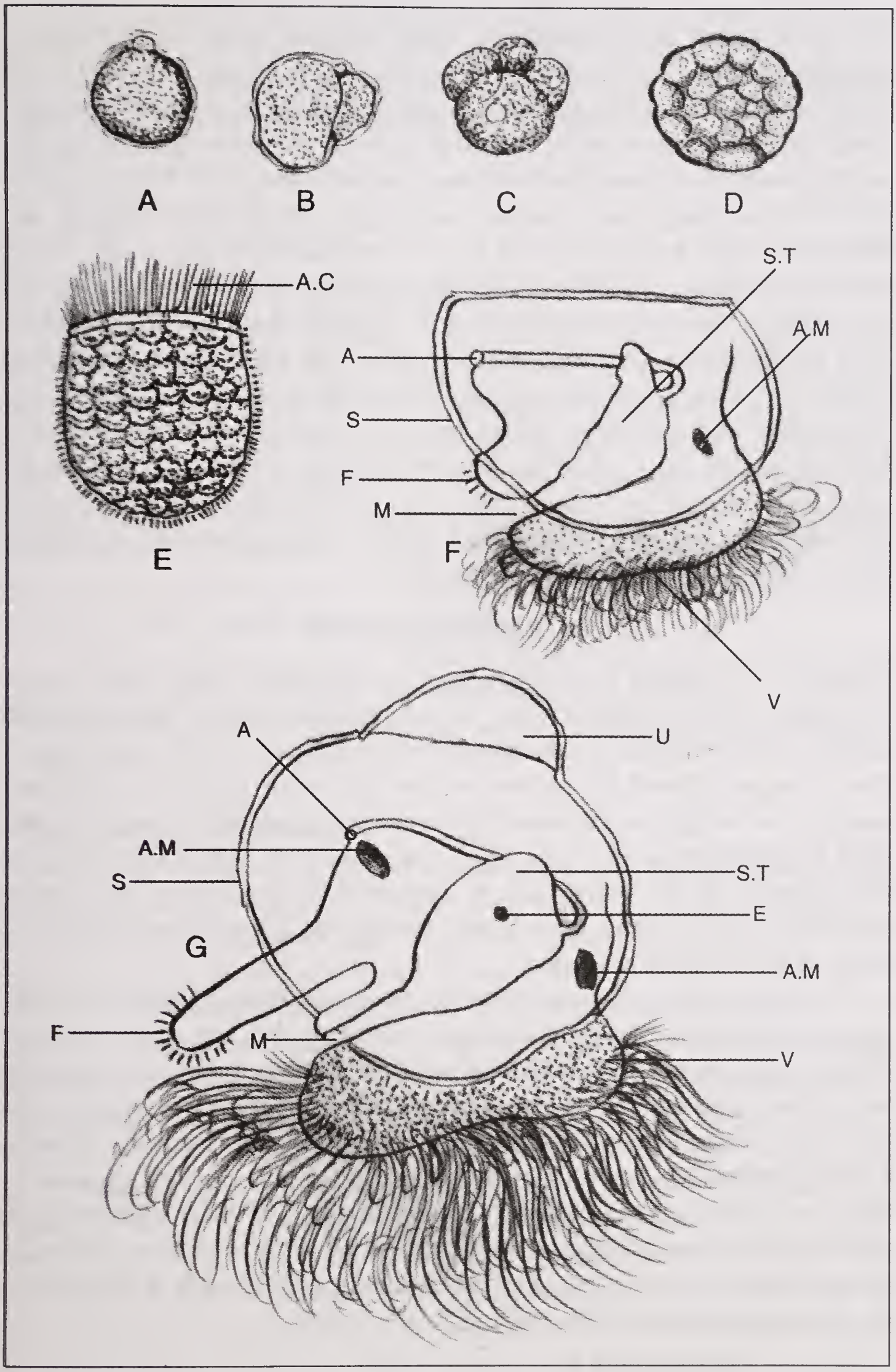

Fig. 16. Embryonic and larval stages of oyster A. Fertilised egg with first polar body B. Two-celled stage C. Four celled stage D. Blastula E. Trochophore F. Veliger G. Pediveliger. (Abbreviations: AC-Apical cilia, AM-adductor muscle, E-eyespot, F-foot, M-mantle, S-shell, ST – Stomach, V- Velum, U-umbo

new shell called the dissconch is quite different from the larval shell (prodissoconch). The position of umbones of the larvae is used for the identification of the oyster genera. *Crassostrea* larvae have prominent umbones which are opisthogyrate, being twisted posterior to the centre line of the hinge, while *Ostrea* larvae have broad umbones that are orthogyrate, being centrally placed on the hinge line. *Tiostrea* larvae have no umbones (Quayle and Newkirk, 1989). Polyspermy will lead to irregular cleavage of egg. In the brooding chambers of incubatory Osterid species such as *Tiostrea lutaria*, all the stages of larval development such as gastrula, trochophore and veliger have been observed. Attempts were made to rear them outside the parent oysters. Ex-parent rearing has not been successful for early larval stages, but both veliger and pediveliger stages responded to elevated temperature and food and settled. In *O. edulis* the developing larvae are incubated within the inhalant chamber of the mantle cavity of females for approximately 7 days at 20^0C, and are released as fully shelled, pelagic veligers into the surrounding water where the development is completed.

AGE AND GROWTH

Growth is the change in weight/size of an organism or the mean size of population over a period of time. Growth and survival are the two major factors, which control the production of a culture unit. Growth can be evaluated from changes in linear dimensions, volume (in oysters usually the condition index) or as weight measurement of the whole animal, its live meat weight, shell weight or dry meat weight (Quayle and Newkirk, 1989). Depending on the objective of the study such as estimation of production and quality assessment, the variables are selected. Usually the linear measurements are taken and the growth estimated.

Growth can be expressed either as absolute or relative terms. Absolute growth indicates the change in size while relative growth rate gives the rate of change over a period of time (Wilbur and Owen, 1964). When the size of the animal over a definite unit of time is plotted, the slope of the time relating size with time (or age) is the absolute growth rate or velocity of growth (Warren, 1971). Although this gives a growth rate it does not give any indication about the growth of the animal relative to its size. To account for the difference in the size, relative growth rate is used and the commonly applied expression is the instantaneous growth rate. The dimensionless coefficient K is obtained by the following equation (Malcouf and Bricelj, 1989).

$$K = \frac{[\log_e L_2 - \log_e L_1]}{[t_2 - t_1]}$$

where L_1 = the initial length (or other measurement of size)

L_2 = the final length

$t_2 - t_1$ = the elapsed time (usually in days)

The K coefficient may be multiplied by 100 to express growth as percent per day. If the growth increment ($L_2 - L_1$) is small and the time interval ($t_2 - t_1$) is short, an adequate approximation of instantaneous growth rate may be obtained from the average relative growth rate (ARGR) (Warren, 1971) which is calculated as

$$ARGR = \frac{L_2 - L_1}{(L_2 + L_1)\ 0.5\ (t_2 - t_1)}$$

where L_1, L_2 and $(t_2 - t_1)$ are as given above.

Growth in oysters depends on several factors such as variations in temperature and salinity, the availability of food, the time of submergence, presence of foulers, the degree of crowding and the presence of pollutants (Galtsoff, 1964; Quayle and Newkirk, 1989; Kennedy, 1996). As the oysters grow, the cementation of the shell is continued. At the place of cementation, the prismatic structure of the outermost shell layer is modified to a ridge-and-furrow structure (Yamaguchi, 1994). The furrows are ultimately filled by the shell material. At the site of ongoing shell cementation, the mantle margin presses the shell margin onto the substrate.

Growth in shell length and width of oysters originates from the outer surface of the outerfold of the mantle edge while the outer surface of the whole mantle secretes the inner shell surface or nacre, thereby increasing the thickness of the shell.

Methods of age determination

Growth may be studied by comparing the progression of modal size groups over a time in the successive length frequencies of a random sample of population or by measuring the marked or tagged oysters over a period of time. The first method is useful only when the breeding season is short and a new brood enters the population as a well defined group with a limited size range. In such cases each age group appears as a distinct mode in a length frequency distribution. If the oysters have an extended breeding season, the offsprings of different broods growing at different rates may mix and it will be difficult to distinguish the modes. In the marking or tagging method the oysters are marked by gluing a tag to one valve with a water proof glue or by drilling a small hole in the umbo of the left valve and tying a tag. A number can be etched on the shell by an electric drill and protected by covering it with a transparent plastic. However, in the tropics during certain season due to severe fouling the number on the tag may not be visible or there are chances of loosing the tag when the foulers attached on it are removed.

Though length is the most commonly used measurement, other linear parameters such as width and depth are also periodically observed. Variations in total weight, meat weight and dry meat weight and their relationship to length are useful to oyster farmers to plan the harvest.

Dimensional and Length-Weight Relationship

Variation in the shell dimensions of *C.madrasensis* along both the Indian coasts has been studied. For studying the relationship between length and weight and other linear measurements, the regression equation Y = a+bX is used after logarithmic transformation if required (Somasekar *et al.*, 1982; Narasimham, 1987; Kripa, 1998). The logarithmic values of observed length and corresponding log weights showed a linear relationship (r=0.82; P=0.1 %) for *C.madrasensis* in Vellar estuary (Somasekar *et al.*, 1982). For the same species and for *S.cucullata* the length-weight and morphometric relationships observed by Narasimham (1987) and Kripa (1998) respectively are given in Table 15. Along the west coast in Cochin estuary, it was observed that the height and length approximated in oysters of less than 3.5 cm in height resulting in spat of orbicular shape (Nair and Nair, 1985) while along the east coast it was 2.5 cm (Rao and Nayar, 1956). In the oyster of shell height 3.5 cm to 8 cm, increase in height was faster, leading to an oval shape and above 8 cm the oyster became further elongated (Nair and Nair, 1985).

Table 15. Length-weight and linear relationships in *C.madrasensis* and *S. cucullata*

Species	Parameter (dependent variable)	a	b	r
C.madrasensis	Total weight*	-3.2421	2.6498	0.96
	Shell weight*	-3.3963	2.6678	0.95
	Wet meat weight*	-3.9245	2.4110	0.92
	Width	7.5634	0.5823	0.84
	Depth	5.0008	0.2080	0.65
S.cucullata	Total weight*	-7.5144	2.7649	0.7421
	Meat weight*	-9.3594	2.5586	0.7877
	Dry meat weight*	-11.1044	2.6002	0.6953
	Width	6.8760	0.5310	0.7421
	Depth	2.1466	0.4083	0.6387

*after logarithmic transformation
Source: Narasimham (1987) and Kripa (1998)

Growth Rates of Indian Oysters

The first report on the growth of *C.madrasensis* was made by Hornell (1910a) from Pulicat Lake near Chennai. Further studies on the growth of *C.madrasensis* have been made by Paul (1942), Rao and Nayar (1956), Somasekar *et al.* (1982), Nayar and Mahadevan (1983), Reuben *et al.* (1983), Joseph and Madhyastha (1982), Joseph and Joseph (1983, 1985), Nair and Nair (1985), Narasimham (1987), Yavari (1994) and Velayudhan *et al.* (1995, 2000).

Durve and Bal (1962) investigated the growth characteristics of *C.gryphoides* in Kelwa backwaters. Aspects related to biotic potential of *S.cucullata* along Karnataka has been reported by Joseph and Joseph (1988),

while Kripa (1998) has described the age and growth of this species occurring along the Kerala coast.

The growth of three species of Indian oysters namely *C.madrasensis*, *C.gryphoides* and *S.cucullata* reported by various authors based on the studies on natural populations and experimental culture in different water bodies are given in Table 16.

Table 16. Growth rates of oysters in different water bodies along the Indian coast

Species	Location	Source	Length attained (mm)	Period (months)	Reference
C.madrasensis	Bhimunipatnam	Ec	80	12	Reuben *et al.* (1983)
C.madrasensis	Kakinada Bay	Nb	58-66	12	Narasimham (1987)
C.madrasensis	Kakinada Bay	Ec	66 72	8.5 12	Rao *et al.* (1994)
C.madrasensis	Adayar estuary	Nb	36.8 50.6	6 12	Rao and Nayar (1956)
C.madrasensis	Pulicat Lake	Nb	74.2 6	92 12	Thangavelu and Sanjeevaraj (1985)
C.madrasensis	Vellar estuary	Nb	49 85 112	12 24 36	Somasekar *et al.* (1982)
C.madrasensis	Vellar estuary	Ec	82	12	Patterson and Ayyakkannu (1997)
C.madrasensis	Tuticorin	Ec	80	12	Nayar and Mahadevan (1983)
C.madrasensis	Mulki estuary	Nb	70 91.5 142	7 12 24	Joseph and Joseph (1985)
C.madrasensis	Cochin	Ec	60	5	Purushan *et al.* (1983)
C.madrasensis	Ashtamudi Lake	Ec	65.9	6	Velayudhan *et al.* (1995)
C.madrasensiss	Sikka	Nb	29	12	Chhaya *et al.* (1993)
C.gryphoides	Kelwa backwaters	Nb	37.2 47.9	6 12	Durve and Bal (1962)
S.cucullata	Ashtamudi Lake	Nb	36.2 51.1 57.2	12 24 36	Kripa (1998)

Ec = Experimental culture; Nb = Natural bed

Among the three species, *C.madrasensis* has been found to have the highest growth rates along both the coasts. Growth studies based on samples collected from the natural bed are few. It has been observed that the growth of oysters is faster during the initial stages immediately after settlement. Along

the east coast, in the natural bed *C.madrasensis* in Vellar estuary is reported to reach only 49 mm in one year while in Kakinada Bay it grows to 58-66 mm during the same period. At both the places suspended experimental culture studies indicated faster growth rate (Table.16). Along the west coast, in Karnataka, *C.madrasensis* reaches 91 mm in one year indicating a comparatively higher growth rate than the east coast oyster population. Even in estuaries where the fresh water influx is high like the Cochin backwaters, the oysters reach 60 mm in 5 months. The studies in the experimental culture indicate that *C.madrasensis* attains about 60 mm length in 6 months and 80 - 90 mm in about one year. However, considerable seasonal variation in growth rate is observed in all oyster populations. Extreme low salinities during peak monsoon have been observed to arrest shell growth. Only when the conditions become favourable, the oysters start their somatic growth and gonad build up. Factors like high siltation during the monsoon slow down the growth. *C.gryphoides* is a slow growing oyster. It reaches only 47.9 mm length in one year which is almost half that of *C.madrasensis*. *S.cucullata* is a small sized oyster with maximum length of < 60 mm.

CONDITION INDEX

Condition of oyster indicates the degree of fatness of an oyster or the extent to which the meat fills the cavity. Condition indices are regarded as useful measurements of the nutritive status of the bivalves. Several studies have been conducted to measure these variations, which have been reviewed by Walne (1970). Condition index may also be employed as an assay for monitoring various pollutants and diseases (Scott and Middaugh, 1978; Scott and Vernberg, 1979; Scott and Lawrence, 1982).The first definable quantitative condition index (CI) equation based on the shell cavity has been described by Higgins (1938). Subsequently, various indices of condition have been proposed. Atleast six different condition index formulae are currently in use (Crosby and Gale, 1990). Some of the methods used are given below.

Walne (1970) defined a method based on the shell cavity volume

$$CI = \frac{\text{dry soft tissue wt (g)} \times 1000}{\text{internal shell cavity volume (ml)}}$$

Walne and Mann (1975) modified the method and used dry tissue weight as a function of dry shell weight.

$$CI = \frac{\text{dry tissue weight (g)} \times 1000}{\text{dry shell weight (g)}}$$

Lawrence and Gordan (1988) proposed the following method

$$CI = \frac{\text{dry soft tissue weight (g)} \times 100}{\text{internal shell cavity capacity (g)}}$$

Hawkins *et al.* (1987) gave another method of determining CI using shell cavity capacity.

$$CI = \frac{\text{dry soft tissue weight (g)} \times 1000}{\text{internal shell cavity capacity (g)}}$$

The shell cavity capacity is determined by subtracting dry shell weight (g) in air, of a cleaned animal from its total whole live weight (g) in air. The method using the shell weight is not a measure of how much space is utilized and does not account for possible variations of internal cavity due to overall shape and shell thickness variability. It is instead a body component index, which compares the proportions that soft body tissue and shell weight compose of the total dry bivalve weight. It cannot be used as an index to evaluate the nutritive status of the oyster. The method of determining the CI based on volume or shell cavity gravimetric capacity should be used for ascertaining the nutritive status of oysters or to determine whether the animals are under stress. Crosby and Gale (1990) have recommended that the method described by Hawkins *et al.* (1987) as the future standard method for determining bivalve condition index.

Apart from the numeric or the calculated value of CI, it is very important to evaluate the condition of the oyster by visual observation (Quayle and Newkirk, 1989). The general size of the meat, colour and appearance of the body surface and mantle thickness are significant parameters. The condition is good when the colour of the oysters', body is white to cream (the dark digestive gland should not be visible) and the mantle is thick.

In the Indian oysters the condition index, determined by the shell cavity method, is closely linked with the somatic and gametogenic growth. In *C.madrasensis* in Mulki estuary, condition index values were moderate (> 20 <70) during the gonadal growth while high values (>70) were recorded during somatic growth and fattening period (Joseph and Madhyastha, 1982). For the same species, the CI values were very high (120 -150) during March –April and August – September in Tuticorin. It was observed that the CI values were high when the diurnal variation in temperature was high (Rajapandian and Rajan, 1983). In oyster farming, condition index in the above range is considered to be good for harvest and less than 70 as unsuitable. In Kakinada Bay, the condition index was high when the oysters were in the partially spent stage (April-June) and low when the oysters were in the 'spent' condition (Narasimham, 1987). Durve (1964) observed that in *C.gryphoides*, the seasonal variations in condition were related to the gonadal cycles and that the oysters were in the best condition during October-June when they were not in the spawning condition.

BIOCHEMICAL COMPOSITION

Venketaraman and Chari (1951) and Easterson and Kandasami (1988) studied

the biochemical composition of *C.madrasensis* of Ennore backwaters and Tuticorin oyster farm. The range of variation for three components (in percentage) is given below.

	Ennore backwaters	**Tuticorin Farm**
Moisture	76.7 to 85.0	77.9 to 82.6
Ash	1.01 to 2.06	3.96 to 6.6
Lipid	1.49 to 2.71	0.20 to 2.20
Protein	6.93 to 13.31	8.09 to 16.00
Glycogen	0.44 to 5.63	*0.9 to 8.6

*Total carbohydrate value determined and hence higher value

QUESTIONS

1. Describe the basic anatomy of an oyster.
2. Write on food and feeding habits of oysters.
3. Write on types of reproduction and the various larval stages in the life history of oyster.
4. What is condition index and describe the various methods used in its study?
5. Write short notes on: a) Filter feeding b) D-larva c) Pediveliger larva d) Condition index e) Oyster shell

CHAPTER 4

Unwanted Species

THERE are several unwanted species which compete for food, space, weaken the shell by drilling, prey upon oysters and cause diseases resulting in oyster mortality. They are dealt in this chapter.

FOULERS

Biofoulers are the unwanted flora and fauna which attach and grow on the cultured species and on the farm structures. The intensity of fouling varies depending on the location and the season. Foulers are usually considered as a nuisance in oyster farming and are called pests. They compete for food and space with the oysters, and in extreme cases cause mortality.

The main effects of intense fouling on oyster culture are:

1) low settlement and high mortality rates of oyster spat;
2) reduced growth rate;
3) increased weight of the farm stock and structures and related floatation problem;
4) hinderance in harvest and post harvest processes and
5) limitation in marketing as single oyster.

In India, reports on the fouling of oyster beds have been made by several authors (Rao and Sundaram, 1972; Muthiah *et al.*, 1987; Thangavelu and Sanjeevaraj, 1988b; Sundaram, 1988 and Kripa, 1998). The commonly encountered foulers on oysters are given below.

Algae

Seaweeds like *Chaetomorpha*, *Ulva*, *Enteromorpha*, *Gracilaria*, *Cladophora*, *Polysiphonia* and *Gelediella* and blue green alga, *Oscillatoria* are associated with the oyster population along the Indian coast (Rao and Sundaram, 1972; Muthiah *et al.*, 1987; Thangavelu and Sanjeevaraj, 1988b; Sundaram, 1988 and Kripa, 1998). At Tuticorin, *Gracilaria* has been found to grow densely on the oyster cages and affected the water flow (Muthiah *et al.*, 1987). Along the Kerala coast, seaweeds are found in abundance during the monsoon and postmonsoon seasons (Kripa, 1998). In the mangrove oysters, apart from these genera other seaweeds like *Acanthophora spicifera*, *Caulerpa racemosa*, *Derbesia vaucheriaeformis*, *Cladophoropsis membranacea*, *Struvea anastomosans* and *Dictyota* sp. have been reported to occur from the Caribbean (Littlewood, 1991).

Porifera

Along the east coast of India sponges such as *Haliclona* sp and *Hyatella* sp. have been observed on *C.madrasensis* (Thangavelu and Sanjeevaraj, 1988b). *Reniera tubifera*, *Pleraphysillia* sp., *Haliclona* spp, *Dysidon fragilis*, *Mycale* sp., *Ulosa hispidu*, *Darwinella rosacea* have been noted to foul on *C.rhizophorae* (reviewed by Littlewood, 1991). Sponges may be encrusting or attach solitary.

Coelenterata

Coelenterates, *Garveia cerula* and *Aiptasia tagetes* are known to foul on the oyster *C. rhizophorae* in Cuba while at Puerto Rico, coelenterates like *Pennaria* sp, *Bougainvilla* sp. and *Alcyonium* sp. occur on the same oyster species (Littlewood, 1991).

Bryozoa

Bryozoans are commonly called moss animals. They are colonial. The encrusting bryozoans are usually less than 1 mm in thickness, but one colony may completely cover an adult oyster shell (Quayle and Newkirk, 1989). They are not very harmful to adult oysters but may at times grow over the spat. Seven species of bryozoans were noted on the oysters in Mulki estuary (Joseph and Joseph, 1988). In Pulicat Lake, Thangavelu and Sanjeevaraj (1988b) observed that *Scrupoecellaria* sp., *Schizoporella* sp. and a few unidentified species formed 3.4% of foulers on *C.madrasensis*.

Annelida

The polychaetes *Marphysa gravelyi, Eunice* sp and *Polynoe* sp are found in the crevices between oysters in Athankarai estuary (Rao *et al*., 1987). Calcarean polychaete worms *Hydroides lunulifera*, *Spirorbis* sp., and *Pomatoceros* sp. are the common tube dwelling polychaetes observed on *C.madrasensis* in Pulicat Lake and Ashtamudi Lake (Thangavelu and Sanjeevaraj, 1988b; Kripa, 1998). *Sabellastarte magnifica*, *Sabella* sp., *Spirobis* spp., *Branchiomma nigromaculata*, *Pseudobranchiomma emersoni*, and *Megalomma* sp. are the common foulers on mangrove oysters (Littlewood, 1991). Avault (1998) has mentioned that in the Hiroshima Bay during a population explosion of *Hydroides elegans*, 6000 oyster rafts were affected and the production dropped by 60%.

Bivalves

Byssal attaching molluscs and cementing species other than the oyster sometimes foul the oyster shells. In India, bivalves like *Modiolus striatulus*, *M.undulatus*, *M.metacalfie*, *Anomia* sp. and *Perna virdis* are the dominant foulers. In Pulicat Lake, *Modiolus* sp. formed 8% of the foulers on *C.madrasensis* (Thangavelu and Sanjeevaraj, 1988b). In Ashtamudi Lake,

they are the dominant foulers during the postmonsoon period in the intertidal zone (Kripa, 1998). In the tropics *Isognomon*, *Chama* and *Spondylus* have been considered as foulers (Quayle and Newkirk, 1989).

Crustacea

Barnacles, chiefly of the genus *Balanus,* are probably the most ubiquitous of all the fouling organisms. *Balanus amphitrite* is the main species recorded followed by *B.tintinnabulum*. In Pulicat Lake barnacles formed 69.5% of the foulers, mainly dominated by *B.amphitrite* (Thangavelu and Sanjeevaraj, 1988b). At Worli in Maharashtra, Sundaram (1988) observed the conical barnacle *Cathamalus stellatus* in the *S.cucullata* beds. Barnacles compete for food and space in oyster beds. Dead shells provide space for secondary attachment of foulers. Adult barnacles even prey on oyster larvae (Steinberg and Kennedy, 1979). In India, barnacles are a menace to spat collection. Their breeding period almost coincides with that of oysters. Hence spat settlement gets affected (Kripa, 1998). Sometimes barnacles first settle and the oyster spat which settles on them easily fall off as they grow. They also affect the postharvest processes. In Ashtamudi Lake, the barnacles are the dominant foulers on the oysters in the lower reaches of the Lake.

Chordata

Tunicates or ascidians are known to foul on oyster. Individual tunicates adhere to the shell by a broad holdfast and the body is enclosed within a test or envelope. The colonial types of ascidians consist of small tunicate bodies enclosed in a fleshy encrustation upto 1 cm thick (Quayle and Newkirk, 1989). Their occurrence is rare in the oyster farms of India where estuarine conditions prevail. Ascidians like *Botrylloides nigrum*, *Symplegma* sp, *Diplosoma listeranum*, *Lisscolinum abdominale* are common in mangrove oysters (Littlewood and Donovan, 1988).

BORERS

Borers are generally considered as pests of oysters as they do not kill the oyster but may severely affect their condition and marketability. The shell of the oyster is bored by these animals and they reside within the shell. They make the shell brittle, cause blisters on the nacre and make the oysters easy prey to other predators.

Algae

Algae such as *Hyella caespitosa*, *Mastigocoleus testarum* and *Gomontia polyrrhiza* penetrate the periostracum and then branch into inner layer of oyster shells (Galtsoff, 1964). Reports on the perforating algae infecting oysters in India are not available.

Sponges

This group forms one of the commonest borers in oysters. Boring by the sponge *Cliona* sp. has been found to be more in the oysters inhabiting the marine regions of an estuary. Boring is found to be comparatively low in the oyster population where salinity is low for a long duration. In Ashtamudi Lake low salinities prevail for prolonged period at the culture sites and hence, severe damage to the shell has not been observed in both *C.madrasensis* and *Saccostrea cucullata*. Along the east coast also, boring by *Cliona* has been observed in *C.madrasensis* (Thomas, 1979; Thangavelu and Sanjeevaraj, 1988b). *Cliona celata, C.vastifica, C.carpenteri,* and *Aka minuta* are the species of sponges recorded in oysters along the south-east and south-west coast (Thomas, 1979). Among these *C. celata* was seen both on *C.madrasensis* and *S.cucullata* while *C.carpenteri* was seen only in *S.cucullata* and *A.minuta* on *C.madrasensis* alone. The boring *Cliona* creates a honey comb of tunnels in the calcareous shell and the numerous holes they make on the shell increase the brittleness of the shell (Thomas *et al.*, 1993).

Annelids

The polydorid polychaete worms are found in almost all species of oysters and are more abundant in low saline, muddy environments. The larvae of these worms usually settle on the surface of the oyster shell and slowly penetrate into the shell.

In Pulicat Lake, 9.2% of oysters were found to be infested by *Polydora ciliata*. The number of worms in the infested oyster ranged from 2 to 54. Maximum number was seen in 70-79 mm oysters. The size of worms ranged from 3 to 42 mm (Thangavelu and Sanjeevaraj, 1988b). Stephen (1978) observed that in the *Crassostrea madrasensis* population in Mulki Estuary the mud worm infestation was very low, almost nil during the monsoon months. He attributed the reason for low infestation to the almost fresh water condition of the estuary during monsoon period indicating that continued submergence in fresh water conditions for prolonged period is detrimental to the mud worm. Fresh settlement of mudworm was observed with the increase in salinity.

The rate and intensity of *Polydora* infestation in natural and farmed oysters (*C.madrasensis*) in Kerala was studied by Ghode and Kripa (2001). In the natural oyster beds of Ashtamudi Lake, 80% of oysters in the age group less than 6 months were not infested by the mud worms *Polydora ciliata,* while only 44 % farmed oysters of same age were uninfested. In oysters between 12 to 15 months age, the percentage of uninfested oysters was 48 and 17.4 in natural bed and in farmed oysters respectively. All farmed oysters above 2 years had *Polydora* infestation while in the natural bed 2% were still uninfested.

The intensity of infestation was found to increase with age in both natural bed and farmed oysters. Severe infestation (> 50 % of the internal shell

surface as mud blister) was not observed in small oysters (less than 6 month) in the natural bed while in the farm 8% of the same age group was severely infested. In the farm, the percentage of oysters with severe infestation increased from 14.3 in the first year to 46.5 after 24 months. At the same time in the natural bed in oysters above 24 months only 38% were severely infested

Bivalves

Lithophaga sp. was found to make long and cylindrical burrows in the shell of *C.madrasensis* in Pulicat Lake (Thangavelu and Sanjeevaraj, 1988b).

PREDATORS

In spite of the presence of a hard protective shell, the oysters are preyed upon by several vertebrate and invertebrate organisms. The mode of predation varies from simple crushing to paralyzing the oysters. The common predators are gastropods, crabs, starfishes and fishes. Some flatworms are also known to predate upon these bivalves.

Flat worms

The turbellarians of the genus *Stylochus* and *Pseudostylochus* attack both spat and adult oysters. They are also known as 'oyster leaches' (Galtsoff, 1964) and "oyster wafers" (Menzel *et al.*, 1958). It was reported that they caused 30 to 90% oyster mortality along the west coast of Florida during 1916 and 1917. Extensive mortalities due to flatworms have occurred under typically crowded mariculture conditions (Provenzano, 1961). *P.ostreophagus*, a Japanese species, is found to drill an oval perforation of the oyster spat upto 1 cm in diameter and is capable of causing considerable mortality (Quayle and Newkirk, 1989). Flatworms of the genus *Stylochus* enter the oyster through their partially gaping valves.

Gastropods

Certain gastropods commonly known as 'drills', are common predators of oysters. They have extensible and flexible proboscis to which is attached a radula having horny teeth. Associated with this apparatus is an accessory boring organ whose secretion softens the shell and then with the rasping action of the radula the shell is scraped to reach the flesh (Carriker, 1961a). The mechanical radular movements used for drilling are termed "band-over-pulley" method (Butler, 1954; Gunter, 1979). Cymatid gastropods, *Cymatium martinanium* and *C.muricinum* are not drilling gastropods; instead they insert their proboscis between the valves of the oysters and squirt a highly acidic toxic secretion which is believed to anaesthetize the prey. *Melongena corona*, the crown conch feeds on the oysters without drilling the shell.

In India, *Thais rudolphi* has been observed to attack young *C.madrasensis* in Athankarai estuary (Rao *et al.*, 1987). In the Tuticorin oyster farm of

CMFRI, *Cymatium cingulatum* has been reported to cause 13% mortality to oysters (Muthiah *et al.,* 1987). *Thais tissoti*, *Bursa granularis* and *Drupa tuberculata* are the predatory gastropods recorded in *S.cucullata* beds in Maharashtra (Sundaram, 1988).

In temperate countries, oyster drills cause considerable damage in the commercial farms. *Urosalpinx cinerea*, *Eupleura caudata* and *Thais haemastoma* are some of the major destructive gastropods (Galtsoff, 1964; Hofstetter, 1977). The conch *Melongena corona* and the lightening whelk *Buscycon contrarium* are also predators of oysters (Hathaway, 1958; Menzel and Nichy, 1958; Avault, 1998). In some seasons, the losses have been estimated at 50% in Louisiana, 85% in Alabama and 90% along Pacific coast of the United States (May and Bland, 1969; Hofstetter, 1977). The density of the oyster drills has been found to be highest where salinity is high and most active in regions of high salinity.

Crustacea

Scylla serrata, the mud crab, has ben observed in the oyster beds of Athankarai estuary (Rao *et al.,* 1987). In the Tuticorin farm, *S.serrata* and *Pagurus* sp. have caused mortality to spat settled on tiles and rens but loss due to this predation was negligible (Muthiah *et al.*, 1987). Crabs are known to cause considerable mortality in natural oyster population (Krantz and Chamberlin, 1978; Bisker and Castagna, 1987). The stone crab *Menippe mercenaria*, the mud crab *Panopeus herbstii*, rock crab *Cancer irroratus* and the blue crab *Callinectes sapidus* are the common predators of oysters (White and Wilson, 1996; Bisker and Castagna, 1987). The blue crabs use different methods to open the oysters depending on the size of the prey; small oysters are crushed, while the adult oysters are devoured by chipping of their shell edge (Krantz and Chamberlin, 1978). They feed on oyster spat by cracking the shell. Spat set on collectors have been destroyed by crabs. Hermit crab, *Eupagurus berhardus* is known to attack and devour oysters whose shells have been damaged during declustering. One method of eradication of predatory crabs is to lay baited traps around intertidal spat collectors and cultivated oysters. In some regions where the blue crabs are consumed, it may be an additional source of income to the farmer.

Echinoderms

Sea stars are a menace in the oyster farms in the temperate region. Greatest harm is done when the oysters are grown by the on-bottom method and also during the spat collection period (Galtsoff, 1964). *Asterias forbesi* is an important predator. An oyster, between 75 and 100 mm in length may be devoured by a starfish in less than 24 hours (Quayle and Newkirk, 1989). Starfish predation has not been reported in the oyster farms in India.

Fishes

Striped burrfish *Chilomycterus schopfi*, the goby *Gobiosoma bosci*, the toad fish *Opsanus tau*, the cow-nosed ray *Rhinoptera bomasis*, Summer flounder *Paralichthys dentatus*, Puffer fish *Diodon hystrix*, skates *Raja* spp.prey on oysters (Hoese and Hoese, 1967; Littlewood, 1991; White and Wilson, 1996). The black drum *Pogonias cromis*, the diamond sting ray *Dasyatis dipterurus* are predators of oysters. These fishes use their powerful teeth to crush the oyster shell.

Birds

Blue bills, *Nyroca marilla* and *Nyroca affinis* and the white winged scoters, *Melamita deglandi* prey upon oysters (Galtsoff, 1964). Bird predation of oysters has not been reported from India.

Size related predation

Predation by gastropods and crustaceans is related to the size of the oyster. The blue crab *Callinectes sapidus*, the stone crab *Menippe mercenaria* and the common rock crab *Cancer irroratus* are noted for the size related predation. It has been observed that rock crab, mud crab and the American lobster *Homarus americanus* could not attack larger oysters (> 30-35 mm) (Elner and Lavoic, 1983). Similarly, flatworms also have shown preference for small oysters. *Stylochus ellipticus* preferentially attacks small oysters, but large flatworms can kill oysters as large as 6 cm (Landers and Rhodes, 1970). Size of the predator influences the intensity of destruction of the oyster bed. Adult starfishes have been found to cause more mortality than younger ones (MacKenzie, 1970). Fishes have also shown size related predation. Nearly all oyster predators are limited to consuming smaller oysters but drumfish and cow-nosed ray can prey upon oysters above 8 cm (Smith and Merriner, 1978). It has been reported that the conch *Thais* sp. could eat almost 100 small oysters per day. Although they attack large oysters, they prefer the oyster spat (May and Bland, 1969; Hofstetter, 1977).

Thangavelu and Muthiah (1983) observed that *C. cingulatum* attacked oysters of size 25 to 85 mm and the modal size of oysters killed was 53.3 mm. Nearly 75% of the oysters were in the size group 40-65 mm. Muthiah *et al.* (1987) observed that size of *C.cingulatum* was also related to the size of oyster which is preyed upon. They noted that gastropods of size 45 mm preyed upon oysters of 39 to 64 mm with a mean size of 49.7 mm. *Cymatium* of 74 mm shell length preyed upon oysters of mean size 68.5 mm.

CONTROL OF FOULERS, BORERS AND PREDATORS

Fouling can be controlled by physical, chemical and biological methods. Physical methods involve manual removal of foulers or moving of the oyster string/oysters away from the site. It is labour intensive and increases the

operational expenditure of the farming systems. Chemical methods indicate dipping the rens in chemical solution for a fixed period. Though the method is effective, care should be taken to choose right chemical (Table 17). It should be non-toxic and should not affect the oyster meat. After understanding their ecological impact and other fauna they can be used to control fouling.

By placing a few dogwhelks (*Nucella lapillus*) in the oyster trays, fouling by mussels is reduced since they prefer to prey on small mussels. Most snails under Tritinidae do not have pelagic larvae and it is suggested by some workers that the best method to control these gastropods is to collect them when they aggregate for breeding and egg deposition. It has been observed that the rock crab *Cancer irroratus,* when present in the oyster trays, fouling was low. A species of *Haliphthoros* has been proposed as a possible candidate for biological control of the oyster drill. The probable effects it may have on other fauna are not known. Oysters prefer light settlers while barnacles prefer dark (Avault, 1998). The different methods used for controlling the foulers, borers and predators of oysters are presented in Table 17.

In India, experiments were conducted to eradicate mud worms by dip treatments in formalin, chlorine and freshwater (Ghode and Kripa, 2001). Formalin treatments in three different doses, 1000,500 and 250 ppm for 30 minutes, 1 hour and 2 hours respectively resulted in removing 79.6%, 69.1% and 69.6% worms from oysters with low mortality (6.6, 1.6 and 0% mortality). Eradication treatment using chlorine at doses 1000, 700 and 500 ppm for 3, 5 and 6 hours were successful in eliminating 78.3%, 65.1% and 57.7% worms respectively from shells with test oyster mortality of 15%, 11.6% and 3.3%. Freshwater treatment for 3, 6, 9 and 12 hours and aerial exposure after brushing the oysters with formalin were not effective in eradicating mudworm.

PARASITES AND DISEASES

Parasites and diseases cause large-scale mortalities of oysters in several parts of the world. During the last three decades, a multidisciplinary approach towards understanding the causes of major oyster mortalities that occurred in Europe, the United States and Japan has been made. In some cases (eg. Dermo disease) it has been possible to identify the etiological agent and document its life cycle, mode of transmission, effects of disease on the host, the defense mechanism and the influence of the environment (Sindermann, 1990; Ford and Tripp, 1996). Several publications have summarized the known diseases and parasites of oysters (Lauckner, 1983; Sparks, 1985; Sindermann and Lightner, 1988; Fisher, 1988; Elston, 1990, 1993; Sindermann, 1990; Perkins, 1993; Bower *et al.*, 1994; Ford and Tripp, 1996). Not much work has been done on oyster pathology in India. A brief description of the commonly found parasites and the principle infectious diseases of oyster are given further.

Table 17. Physical, chemical and biological methods generally employed to control the foulers, borers and predators of oysters.

Control method	Organism controlled	Remarks
Suction devices	Predators and competitors	Removes the buried predators
Mops made of iron beams with bundles of rope yarn	Removes mainly starfishes by entangling	Harmless to oysters
Flaming: passing a flame over oyster shell after drying	Removes foulers	Harmless to oysters
Air drying: exposure to sun	Destroys early stages of sponge, tunicates and algae/seaweeds	Harmless to oysters: but controls only to small extent.
Scraping, scrubbing and jet washing	Larval stages, egg cases and larger foulers	Controls only to certain extent
Chlorinated hydrocarbon	Oyster drills and other predators	Uptake by oysters may affect their quality, regulation set by FDA and EPA
Dip treatment in rock salt solution followed by aerial exposure	Predators	Harmless to oysters
Quicklime applied through pumps @ 300 kg/ha	Controls starfish	Harmless to oysters
Dipping in hot water (55-60°C) for 10 to 15 sec; in fresh water for 30 to 50 hours, dipping in brine solution	Controls foulers and borers	Harmless to oysters
Avoiding placing spat collectors during breeding season of foulers	Avoidance of large scale settlement of barnacles, *Modiolus* and calcareous polychaetes	Information on the ecology and breeding of foulers is essential to employ the method
Growing other compatible species which can eliminate the fouler (biological control)	General fouling organism	Selection of compatible species and understanding of their mode of action are essential

Parasites

Not much information is available on the parasites and diseases of the tropical oysters. Oysters are infected mostly by parasitic helminths and crustaceans. These are internal parasites and usually their effect on the host is considered as sublethal. Molluscs are sometimes encountered as ectoparasites.

Helminth parasites. Trematodes, Cestodes and Nematodes are the Helminth parasites of molluscs. Among these, trematode larvae are considered

as the most important. They use molluscs as the first intermediate host (with sporocyst, redial and cercarial stages) or as second intermediate host (metacercarial stage). In some instances, the mollusc may act as host for both the stages (Sindermann, 1990). *Bucephalus haimeanus*, *B.cuculus and B.longicornutus* are known to infect oysters (Howell, 1966; Sindermann, 1990). Sporocysts and cercariae of Bucephalidae are parasitic in oyster, metacercaria in small fish and adults in predatory fish. Sporocysts of the genus *Bucephalus* occur in the gonads and digestive gland of the oyster and may spread to gills, mantle and even adductor muscle. They are known to cause sterility to the host. Menzel and Hopkins (1955) observed that early infection temporarily stimulated growth of the host, but more severe infections retarded it. Metacercaria of *Gymnophalloides tokiensis* (whose definite hosts are marine birds) and *Protoeces ostreae* are found in Japanese oysters (Ching, 1972). Larvae of *Protoeces maculates* are reported in European oysters. Massive infestation by the larvae of *Acanthoparyphium spinulosum*, with an average of 45 worms per oyster has been observed in American oysters (Little *et al.*, 1966).

It has been observed that some of the trematodes which infect the oyster are hyperparasitized by haplosporidians. Howell (1967) has described *Urosporidium constantae* from *Bucephalus longicornutus* parsitizing *Ostrea lutaria*. The haplosporidean completely destroyed embryonic cercariae within the sporocyst system. Another hyperparasite is the microsporean *Nosema dollfusi* of *B.cuculus* in *C.virginica* (Sprague, 1964).

In India, trematode parasites have been observed in *C.madrasensis* (Samuel, 1976; Joseph, 1978; Stephen, 1978; Thangavelu and Sanjeevaraj, 1988c). Samuel, (1976) observed infestation by the cercaria of *Bucephalopsis haimeanus*, a trematode on *C.madrasensis*. He observed that in the infected oysters, the gonads externally appear well developed and mature, but internally they were devoid of eggs or sperms; the only contents were the cercaria and tissue fluids. The parasites were densely packed in a system of ramified tubules. In two of the infected oysters, the flesh weight was higher (gigantism) compared to that of the uninfected one of the same size group. Only 1 % of the oyster population was infected. Stephen (1977) has reported that 0.61 % of oysters from Mulki estuary were infected by the larvae of *Bucephalopis* sp. The primary site of infection by larval trematode, *Bucephalus* sp. in *Crassostrea madrasensis* was the mantle (Joseph, 1978). The infection seemed to spread to digestive gland, normal site of gonad, gills, and finally the labial palps. The adductor muscle was never infected. The sporocysts were long, tubular, multibranched and tangled, measuring from 24 to 368 µm in width. Signs of total inhibition of gametogenesis were evident in all the infected oysters (Joseph, 1978). Infestation by trematodes *Bucephalopsis haimeanus* was observed in the gonads of *C.madrasensis* in Pulicat Lake (Thangavelu and

Sanjeevaraj, 1988c). Initially the infection was found in the gonads of oyster and later it was found to invade other tissues such as mantle, gill and digestive gland. Infection was more in partially spent and spent oysters than in fully ripe and developing gonads. In infected oysters, the gonads were quickly resorbed and thus the oysters were castrated, leading to indeterminate stage. Almost all sizes of oysters from 20 to 129 mm were infected. The extent of infection varied with size groups. Oysters of 60-69 mm and 100-109 mm size groups were more heavily infected. The parasites were observed to die at a salinity of 2-3 ppt. Thangavelu and Sanjeevaraj (1988c) observed strong influence of salinity on the infection by trematodes in oysters. They found that when infected oysters are exposed to low salinity of 4.52 ppt, the percentage of gonad infection was reduced from 12.7 to 0.84 after a fortnight. On further exposure for a fortnight to low salinity (3.92 ppt), the oysters were completely devoid of infection.

Oyster populations in several regions of the world are parasitized by larval cestodes. The coracidium of the *Tylocephalum* was reported in the stomach and gills of American oysters. The response of the host when infected by parasites has been studied in some instances. The parasite *Tylocephalum* sp. does not seem to damage the host significantly, but a thick fibrous cyst is formed around the metacestode. Cheng (1996) showed that the host did not respond appreciably while the parasite penetrated the gut wall, but reacted to it when came in contact with the underlying connective tissue by enclosing it with a complex capsule of brown cells, connective tissue fibers and haemocytes. Stephen (1978) has observed the larvae of the cestode *Tylocephalum* in *C.madrasensis*.

Nematodes are an inconspicuous group of parasites in oysters. They occur as larvae. *Echinocephalus sinensis* (=*Echinocephalus crassostreai*) was reported from *C.gigas* (Ko *et al*., 1975)

Crustacean parasites. The common crustacean parasites of oysters are copepods and crabs (pinnotherid). They are not considered as very significant pathogens, but may cause occasional mortalities under unfavourable environmental conditions. Among the copepod parasites, *Mytilicola orientalis*, known as the red worm or *le cop rouge*, is an intestinal parasite which occurs in the host's gut. This species was first observed in *C.gigas* in Japan (Mori, 1935) and it was introduced to U.S. when the oyster seed were imported from Japan. From then it even spread to the native oyster species *O.lurida* (Chew *et al*., 1964). The parasitic copepods were introduced to France also when seed and adult oyster (*C. gigas*) were imported from Japan and North America (Sindermann, 1990). The infected oysters had a lower condition index than the uninfected one. *Mytilicola orientalis* has been found to affect the gut of *C.gigas*. Normal tall columnar epithelium was reduced to squamous or cuboidal epithelium and cilia were lost from cells in contact with the parasite. In some

cases, the parasite penetrated into the gut wall destroying the mucosa (Sparks, 1962). In *C.glomerata*, *Pseudomyicola spinosus* causes haemocytosis in the connective tissue beneath the epithelium of the gut wall where appendages of parasite are inserted (Dinamani and Gordan, 1974).

The pinnotherid crabs, commonly called the pea crabs inhabit the mantle cavity of oysters. They are cited as the main cause for the unusual mortalities that occurred in Delaware Bay in 1941 (Stauber, 1945). Atleast 90 % of the oysters were reported to harbour four to six crabs. However, in the following years, the abundance declined considerably. They were reported to cause the gill and palp lesions, weight loss, and reduce the filtering ability of the oyster (Haven, 1959). In Madagascar, Poisson (1946) reported that a characteristic irritating flavour developed in oysters which were parasitized by the pinnotherid crab. However, he speculated that this flavour might be due to the coelenterate *Sertularia* which often grows on the shells that contain *Pinnotheres*. They have also been considered to have symbiotic relationship with oysters rather than parasitic (Quayle and Newkirk, 1989).

The pea crab *Pinnotheres* sp. has been reported in *Saccostrea cucullata* (Awati and Rai, 1931), in *C. gryphoides* (Durve, 1964) and in *C.madrasensis* (Narasimham, 1987; Joseph and Joseph, 1988).

Molluscan parasites. The ectoparasitic gastropod *Boonea impressa* attaches its proboscis to the oyster's mantle and then pierces the host's gut wall with a buccal stylet and sucks the body fluids. They may occur in high densities; nearly hundred snails have been reported on a single oyster (Robertson, 1978). Ward and Langdon (1986) found that *B.impressa* reduced the energy available to oysters for growth and maintenance.

Diseases

In the last century, the natural oyster populations and the farmed stock in many parts of the world have been affected by catastrophic mass mortalities bringing the oyster industry to a stand still for many years. One of the earliest mass mortalities of oysters reported in scientific literature was the *maladie du pied* which occurred in the Arachon Basin, France in 1877 affecting the oyster *Ostrea edulis*. In Europe, mass mortalities *of O. edulis* were reported during 1919 to 1923 due to an unknown causative factor (Korringa, 1952). In 1930, the shell disease caused by the fungus *Ostracoblabe implexa* was responsible for mass mortalities of *O. edulis* and *C. angulata*. These two species were again affected by another disease, the digestive gland disease caused by ascetosporan, *Marteilia refringens* and the gill disesase in the1960s and 70s. In 1979, extensive stocks of the European flat oyster were destroyed by the disease-bonamiasis caused by the protozoan *Bonamia ostreae*. Mortalities due to this disease reached 80% in the French oyster growing areas (Poder *et al.*, 1982.).

The natural populations of oysters have been supporting well established fisheries in many countries. These natural oyster beds have witnessed severe outbreaks of diseases. The *C. virgina* population of Canada was hit by the Malpeque Bay disease (1915 – 1939, 1955). The impacts were so severe that it took nearly 20 years to return to the previous level of abundance (Logie, 1956). Mortalities due to the protistan parasite *Dermocystidium marinum* (now called *Perkinsus marinus*) in the Gulf of Mexico began in late 1940's (Mackin *et al.*, 1950). The annual mortalities were more than 50% in this region (Ray *et al.*, 1953). In the following decade, *Haplosporidium nelsoni* caused extensive mortalities accounting for above 95% leading to drastic decline in the fishery (Farley, 1968). In New Jersey waters of Delaware Bay the production which fluctuated around 2724 tonnes during the late 40's and early 50's declined to 75 tonnes in 1960.

In Asia, the *C.gigas* population in different regions of Japan viz. Kanasawa Bay, Miwura peninsula, Hiroshima Bay and Matsushima Bay suffered large scale mortalities during 1915 to 1960 due to unknown reason (Sindermann, 1990). The cause for the mortalities were related to metabolic disturbances associated with spawning (Mori *et al.*, 1965). Koganezawa (1975) related these mass mortalities to the developments in hanging methods of oyster farming. Further information on these mass mortalities of oysters in different regions is available in the reports of Gross and Smith (1946) and Sindermann (1968a, 1968b, and 1990). In India large-scale mortalities in oyster population due to diseases have not been reported.

The common symptoms of disease in oysters as summarized by Galtsoff (1964), Quayle and Newkirk (1989), Sindermann (1990) and Ford and Tripp (1996) are: retarded growth, failure to fatten resulting in thin watery meat, lack of gonad development, recession of mantle, slightly gaping valves and discolored dirty green or brown body. A brief outline of the main diseases is given below.

Viral diseases: The first report of viral disease in oysters was by Farley *et al.* (1972) on a herpes-type infection in *C.virginica*. Since then considerable work has been done on oyster mortalities which seemed to have a viral etiology (Farley, 1978; Sparks, 1985). The major viruses reported to infect oysters are given in Table 18. Sindermann (1990) has commented that "the viral agents are latent in the natural population but may become patent under conditions of environmental stress".

A major viral disease is the gill disease, also known as *maladie des branchies*, which was responsible for severe mass mortalities of *C.angulata* on the French coast in 1996. This resulted in 70 % mortality of oysters in culture areas. An iridovirus resembling lymphocystis virus of fish was identified as the disease agent (Comps and Duthoit, 1976). These were found to affect the gill and palp tissues leading to destruction of filaments, gill erosion and necrosis.

Ovacystosis is another viral disease which is caused by Papovavirus in *C.virginica* (Farley, 1973; Meyers, 1981). They cause massive hypertrophy of gametocytes and eggs. The larvae of *C.gigas* have suffered large-scale mortalities (upto 50 %) due to the attack of icosahedral virus. This is known as the Oyster Velar Virus Disease (OVVD). They occur in the velar epithelial cells of larvae and cause velar and mantle erosion (Elston and Wilkinson, 1985).

Table 18. Viruses reported to infect the commercially important oysters.

Host	Virus type	Effect on host	References
Ostrea edulis	IPN-like virus	Experimental infections caused necrosis of digestive tissue, with infiltration of hemocytes; general tissue edema; increased mortality rates in experimental populations.	Hill and Alderman (1979)
Crassostrea virginica	Herpes-type	Mortalities when animals stressed by high temperatures. Dilated digestive diverticula, and aggregation of cells in connective tissue surrounding blood sinuses.	Farley *et al.* (1972)
	Papovavirus	Lysis of infected cells; low prevalence. Isolates	Farley (1973) Meyers (1979)
	Reo-like virus	were cytopathogenic for fish cell lines, but no oyster pathology was reported.	Meyers and Hirai (1980)
Crassostrea gigas	Herpes-type (presumptive)	Associated with enzootic "summer disease" of *C.gigas.*	Alderman (1980)
	Icosahedral virus	Velar and mantle erosion; epizootic with mortalities of larvae of up to 50%; called oyster velar virus disease (OVVD).	Elston (1979, 1980)
	Iridovirus	Gill erosions, similar to those seen in *maladie des branchies* of *C.angulata,* but of lesser severity than in that species	Marteil (1968)
	Icosahedral virus (presumptive)	Causes grayish discoloration of visceral mass	Comps (1978)
Crassostrea angulata	Iridovirus	Identified as cause of *maladie des branchies*, causes gill erosion and necrosis, hypertrophy of gill epithelial cells.	Comps and Duthoit (1976)

Fungal diseases: Diseases caused by fungi are only a few and, in the natural population, they mainly attack the shell. Fungal attacks occur in oyster

hatchery but they are not as severe as the bacterial infection.The "shell disease" (*maladu du pied*) also known as the foot disease of *O.edulis* is one of the most severe diseases of oysters and has been recognized for more than a century. Its etiological agent was first described as a bacterium but further studies disclosed the common occurrance of a fungus. The infection occurs in the shell under the adductor muscle attachment where it causes blisters on the shell and degeneration of the adjacent muscle tissue. The muscle becomes detached as irregular cysts were formed. A disease characterized by the formation of green or brown pustules caused by *Monilia* was also reported (Sindermann, 1990).

Cole and Hancock (1956) have described two distinct diseases in European oysters, the typical one characterized by greenish rubbery warts and knobs inside the shell particularly in the region of muscle attachment, and an atypical form in which young oysters had thickened margins with numerous white patches but had no deformation of the muscle attachment area. Alderman and Jones (1967) have identified the etiological agent as a phycomycetes fungus (*Ostracoblabe implexa*) possibly a member of Saprolegniaceae, which is present in the shells of diseased oysters.

In India, Durve and Bal (1960) reported on the occurrance of a shell disease in *C.gryphoides*. Another fungus described as *Ostracoblabe implexa* was isolated from shell lesions of the rock oyster *S.cucullata* by Raghukumar and Lande (1988). Direct shell-to-shell transmission was possible under experimental condition.

Bacterial diseases

Larval vibriosis. Larvae of oysters have been found to be more susceptible to bacterial diseases than adult oysters. Experimentally it has been proved that adults can tolerate high population of bacteria but larvae succumb to disease (Guillard 1959; Tubiash *et al*., 1965). Vibriosis or bacillary necrosis has been recognized as an important disease of bivalve larvae in hatcheries. An exotoxin produced by *Vibrio* sp. has been reported to cause 100% mortality of oyster larvae (Sindermann, 1990). Pathogenic strain of *Pseudomonas* has also been responsible for larval mortalities.

Commercial oyster hatcheries have often faced rapid epizootic mortalities in the larval culture due to vibriosis (Tubiash *et al*., 1965). Two species have been identified, *Vibrio anguillarum* and *V.alginolyticus* (Tubiash *et al*., 1970). The bacterial cells are gram-negative rods, 0.6 to 10 μm long, and motile with polar monotrichous flagella (Elston, 1990). Though the larvae can be treated with antibiotics, routine application is not recommended because of the potential for developing resistant strains (Brown and Losee, 1978; Elston, 1984). The disease outbreaks can be minimized by reducing the stress factors such as overcrowding, high temperature, insufficient food, or inappropriate oxygen tension (Tubiash, 1975; Elston, 1984).

Juvenile oyster disease (JOD): Juvenile Oyster Disease has caused high mortalities in hatcheries in United States where the juveniles of *C.virginica* are reared in extensive systems. The mantle and hinge ligament are affected. In some oysters, the attachment of the adductor muscle to the shell degenerates. The most characteristic symptom of JOD is the presence of an anomalous organic deposit inside one or both valves. It is formed between the mantle and inner shell and is usually raised into a ridge around the mantle edge (White and Wilson, 1996). The etiological agent of JOD has not been confirmed.

A protistan parasite is considered to be associated with JOD (Farley and Lewis, 1993). It has also been suggested that rapid secretions of conchiolin layer is a reaction to same type of irritant (Bricelj *et al.*, 1992). The toxic blooms caused by the dinoflagellates *Gymnodinium sanguineum,* and the red-tide causing ciliate, *Mesodinium rubrum* were investigated, but no direct relationship to JOD was observed (Bricelj *et al.*, 1992). High densities of *M.rubrum* and *Gymnodinium* spp. frequently lead to bacterial blooms (especially *Vibrio*). The bacteria use nutrients from the decaying plankton (Romalde *et al.*, 1990). It is assumed that a combined effect of these factors may be the cause for JOD. A bacterial etiology has also been suggested. In tissue section, bacteria were found in mantle lesions and anomalous conchiolin deposits of some oysters (Bricelj *et al.*, 1992). Although the causative agent has not been identified, the disease can be transmitted in the laboratory to unaffected oysters by proximity to disease bearing individuals (Lewis, 1993). The control measure suggested was to increase water circulation in rearing containers of juvenile oysters (Bricelj *et al.*, 1992; Ford, 1994)

Bacterial infections have been observed in adult oysters also. *Vibrio*-induced cardiac edema was reported in low prevalence in oysters of Chesapeake Bay (Tubiash *et al.*, 1973). The isolates of pericardial fluids contained high densities of *V.anguillarum* which are pathogenic experimentally to oyster larvae, but adults were not affected. In Japan, mass mortalities of *C.gigas* in Hiroshima Bay in the early 1960's occurred due to "summer disease" (Numachi *et al.*, 1965). Similar sporadic mortalities of *C.gigas* have occurred in North America since the early 1960's. *Pseudomonas enalia* and *Vibrio parahaemolyticus* have been isolated from the dying oyster (Colwell and Sparks, 1967; Lipovsky and Chew, 1971). However the general conclusion about these summer mortalities is that this disease is probably of bacterial etiology, possibly aggravated by physiological stresses of spawning and high water temperatures (Sindermann, 1990). A bacterium of the genus *Nocardia* has been linked with summer mortality (Friedman and Hedrick, 1991).

Protozoans: Some oyster diseases which were responsible for collapse of natural oyster population are caused by the protozoan parasites. The etiological agents for the Delaware Bay disease (MSX), the seaside disease (SSO), the Dermo disease, aber disease and bonamiasis are protozoans. The principal

protozoan pathogens of oysters are listed in Table 19. The salient features of the major protozoan diseases in oysters are given below.

Table 19. Principal protozoan pathogens of oysters

Host	Disease name	Pathogen	Effect on host
Crassostrea virginica	Delaware Bay disease, MSX disease	*Haplosporidium nelsoni*	Mass mortalities upto 95% occurred in North America in late 1950s
C.virginica	Seaside disease (SSO)	*Haplosporidium costale*	Causes early summer mortalities with sharp peaks
Ostrea edulis	Digestive gland disease, Aber disease	*Marteilia refringens*	Mass mortalities up to 90% on French Atlantic coast
O.edulis	Bonamiasis, hemocyte	*Bonamia ostreae*	Epizootics and continuous mass parasitosis mortalities began in 1979 and spread quickly to all growing areas
C.virginica	Dermo disease	*Perkinsus marinus*	Mortalities since the 1940s in the Gulf of Mexico; persistent annual mortalities in high salinity waters

Dermo disease The extensive oyster mortalities in the Gulf of Mexico were caused by the Dermo disease. The etiologic agent was first thought to be a fungus, *Dermocystidium marinum* (Mackin *et al.*, 1950). Later, based on its similarities to parasitic coccidians, it was placed in the phylum Apicomplexa and renamed as *Perkinsus marinus* (Levine, 1978). Recent studies using small subunit ribosomal RNA sequences, suggest that *Perkinsus* spp. may be more closely related to dinoflagellates (Fong *et al.*, 1993; Siddal *et al.*, 1995). Prevalence of this parasite is more than 50 % in most of the oyster growing areas of Gulf of Mexico (Craig *et al.*, 1989). The oysters may get infected through feed (Perkins, 1988) or by parasites released into water by disintegration of dead oysters and also through faeces of live oysters (Bushek *et al.*, 1994). It has been observed that the haemolymph sucking snail *Boonea impressa* acts as a vector in the transmission of *P.marinum* in other live oysters.

In the infected oysters, several biochemical and biological changes have been observed. Decrease in tissue amino acid concentration (Paynter *et al.*, 1995) and an increase in the taurine – to - glycine ratio, similar to that reported for molluscs stressed by other infectious and non-infectious diseases (Soniat and Kaenig, 1982) have been observed. Shell and soft tissue growth retardation and decrease in the percent of gonad area were some of the biological changes observed (Ray *et al.*, 1953; Dittman, 1993). The host responds to Dermo disease by increasing the circulation of haemocytes and their infiltration into the affected area.

High temperature (>25 °C), and salinity (>9 to 10 ppt) have been found to increase the activity of the parasite (Ford and Tripp, 1996). The severity of the disease is increased by the parasitism by the snail *Boonea impressa* (White *et al.*, 1987) and by some chemical pollutants in the environment (Winstead and Couch, 1988; Wilson *et al.*, 1990). The control measures suggested are avoiding planting of infected oyster in new areas and by using cycloheximide (Calvo and Burreson, 1994).

MSX disease: The mass mortalities of oyster in North America in 1957 and 1959 were due to a disease commonly known as MSX with a protozoan as the etiological agent (Haskin *et al.*, 1965). It was given the acronym MSX because it was found as multinucleated (plasmodial) stage with unknown affinity, thus named multinucleated sphere X (Haskin *et al.*, 1965). Later it was identified as *Haplosporidium* (formerly *Minchina*) *nelsoni* a spore forming pathogen (Levine *et al.*, 1980). In the last decade, phylogenic comparision using 16S (small subunit)-like ribosomal RNA gene sequences suggested that haplosporidians are more closely related to alveolates (ciliates, dinoflagellates and apicomplexans) than to other spore forming protozoans such as microsporidian (Siddal *et al.*, 1995). The mode of transmission is not known. Despite many attempts, it has not been possible to transmit the disease in controlled condition. The portal of entry of *H.nelsoni* is through gill and palp epithelia (Ford and Tripp, 1996) while *P.marinus* and *H.costale*, other two major parasites invade the host through the lining of digestive system.

The growth of infested oysters is retarded (Matthiessen *et al.*, 1990), the condition index lowered (Barber *et al.*, 1988; Ford *et al.*, 1988) and clearance rate reduced to half (Newell, 1985). Variation in biochemical composition has been reported with low levels of lipid glycogen and protein.Temperature and salinity affect the infection of *H.nelsoni* (Ford and Haskin, 1982; Andrews, 1964). High temperature and low salinity were correlated with reduction of infection (Andrews, 1983). Metabolic effects of MSX on oysters are aggravated by other stressors such as concurrent infestation by *Polydora websteri* (Littlewood and Ford, 1990). The most effective method to control the infection is by using disease resistant strains produced in the hatchery (Ford and Tripp, 1996).

SSO disease: The SSO disease ("SSO" for seaside organism) is reported to occur in *C.virginica* in North America. The causative agent is a protozoan, *Haplosporidium costale* which is closely related to *H.nelsoni*. The method of transmission of this parasite is not known. It has not been possible to infect fresh uninfected oysters by feeding and injection of spores. It has been observed that oysters become infected only during exposure periods when sporulating *H.costale* are found in previously infected oysters. The entry into the oyster is through the digestive epithelium. Development of the pathogen is enhanced in salinities greater than 30 ppt. The development of lethal

infection by *H.costale* requires exposure during a well-defined 2-month period followed by an incubation period of nearly a year (Ford and Tripp, 1996). The oyster farmers plant and harvest the oyster by avoiding the periods of high mortality.

Digestive gland disease: The digestive gland disease or Aber disease is caused by the ascetosporan *Marteilia refringens*. The disease was responsible for the mass mortalities of *O.edulis* (upto 90 %) on French Atlantic coast in 1967. It has been reported to affect oysters in Spain and Holland (Sindermann, 1990). The pathogenic parasite mainly affects the intestine and digestive gland tubules. In infected oysters, the digestive gland becomes pale and the meat becomes thin (Morel and Tige, 1974).

Bonamiasis: The ascetosporan parasite *Bonamia ostreae* is the etiological agent for the disease Bonamiasis. The *O.edulis* population in France suffered large scale mortalities due to the attack of this parasite in 1979. The disease spread to Netherlands when infected oysters were imported from France (Grizel and Tige, 1982; Balouet *et al.*, 1983). Consequently, in Netherlands, an extensive programme to remove all oysters from the infected areas was implemented and this curtailed the disease (van Banning, 1982, 1985). The infected oysters get a yellow discolouration. Presence of gill lesions and "microcells" has been reported (Sindermann, 1990). Another species of the genus *Bonamia* has been reported to cause mortalities upto 63 % in wild population in 1986 (Dinamani *et al.*, 1987).

In India, samples collected and analysed from the natural oyster beds around Tuticorin in 1984-85 indicated the occurrence of *Perkinsus marinus*, which ranged from 10 to 60%. The weighted incidence ranged from 0.05 to 0.36 (Muthiah and Nayar, 1988).

Other protozoan parasites: Mass mortalities of rock oysters, *S.commercialis,* in Australia have been reported during the 1970's. The causative agent of this has been identified as an ascetosporan *Marteilia sydneyi* (Wolf, 1972; Perkins and Wolf, 1976). Necrosis of the digestive gland epithelium and retardation of gonad development have been observed in infected oyster.

Apart from the protozoan parasites which caused large scale mortalities, the occurrence of other protozoa in different species of oysters has been reported (Ford and Tripp, 1996). *Hexamita nelsoni* is a cosmopolitan flagellated protozoan infecting oysters, especially the haemocytes of *C.virginica*, *C.gigas*, *S.commercialis*, *Ostreola conchaphila* and *O.edulis* (Schlicht and Mackin, 1968; Sprague, 1970).

Remarks

Although appreciable strides have been made on the oyster diseases in certain European and western countries, information on this aspect with regard to the Indian oysters is scanty. This is because, oysters are mostly exploited at present in the country from the wild and they are yet to be farmed intensively.

Nevertheless, oyster culture is bound to develop soon on a large scale in view of its great potential and its role in sea food production. It would, therefore, be prudent that steps are taken now itself to initiate mission oriented research on oyster diseases and cognate aspects of screening, monitoring, quarantining, internal transmission of diseases and control measures, so as to ensure the development of oyster culture on a sound and sustainable basis.

QUESTIONS

1. Give an account on oyster foulers, borers and predators. What are the control measures?
2. Write on parasites and diseases of oysters.
3. Write short notes on: a) Barnacles, b) Boring sponges, c) Gastropod predators of oysters, d) Larval vibriosis, e) Juvenile oyster disease, f) Dermo disease, g) MSX disease, h) SSO disease.

Chapter 5

Fisheries

OYSTERS which abound the coastal and estuarine regions have been considered as a prized food and fished by man in appreciation of their delicate flavour since pre-Christian era. In addition to its flavour, oyster meat is also considered to have medicinal properties. Hornell (1916) has observed "The oyster meat is a tonic of the first order and a complete food, most beneficial to weakned patients and those in whom appetite is deficient". It has been reported that the ancient Romans served large quantities of oysters at the banquets and even used them as a monetary unit the *denarius* equal in value to one oyster. Over the years the oyster stocks in several areas were overfished, leading to the verge of extinction by intervention of mankind and by natural disasters.

In India, currently the oyster fishery is a small scale activity at subsistence level. Indian oyster meat is yet to make an entry into the international market. However, oyster shell powder has been exported from India and in 2000, 1378 tonnes of shell powder, valued at Rs 4 million, was exported from the country (MPEDA, 2000). In the last decade, oyster production by the harvest of wild stocks has shown substantial increase. A brief description of the world oyster fisheries, the fishing methods and the status of Indian oyster fisheries is given in this chapter.

WORLD OYSTER PRODUCTION

The world oyster production by harvest from the natural beds during the period 1994 to 2003 ranged between 1,58,187 tonnes in 1999 and 2,49,647 tonnes in 2000 with an average of 1,88,183 tonnes. In 2003, 1,99,517 tonnes of oysters were landed. America was the foremost producer contributing 59.9 % of the landing followed by Mexico (24.9%) and Korea (10.1 %) (FAO, 2003a). A decline in the oyster fishery in some of the countries was witnessed during this period. Thailand had contributed to the world oyster production in the last decade but failed to make significant contribution in the subsequent years. The principal geographic area which supports the oyster fishery is the North-west and Western Central Atlantic Coast.

Crassostrea virginica singly contributed to more than three-fourths of the global oyster landing during the year 2003. The production of this important resource was mainly from America, Mexico and Canada. The second dominant

Table 20. World oyster production (in tonnes) during 1994 to 2003 (FAO, 2003a)

Oyster	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
American cupped oyster	1,28,472	1,58,534	1,48,540	1,44,707	1,35,222	1,32,207	2,21,553	1,75,042	1,59,168	1,67,378
Chilean flat oyster	18	-	-	5	1	6	9	202	7	25
Cupped oysters nei	1,799	4,097	3,957	4,539	4,211	6,244	5,142	4,504	3,440	3,636
European flat oyster	4,753	4,340	3,456	3,598	2,765	2,456	880	964	1,523	2,372
Mangrove cupped oyster	4,847	5,701	4,589	3,722	4,896	3,906	3,228	5,244	2,229	3,610
New Zealand dredge oyster	584	1,077	1,931	2,172	1,000	995	766	832	816	852
Olympia flat oyster	.	.	.	.	.	6	7	8	11	8
Pacific cupped oyster	23,691	20,141	25,160	25,692	12,101	12,272	17,983	11,240	17,781	21,536
Slipper cupped oyster	107	324	291	152	89	95	79	96	97	100
Total	1,64,271	1,94,214	1,87,924	1,84,587	1,60,285	1,58,187	2,49,647	1,98,132	1,85,072	1,99,517

Source : FAO, 2003a

Table 21. Oyster production (in tonnes) in Asia during 1994 to 2003

Country	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Indonesia	657	1,331	1,596	1,678	2,029	2,025	2,281	1,194	198	640
Korea, Republic of	20,710	18,262	18,259	17,210	9,905	11,609	15,939	10,056	16,678	20,201
Philippines	107	324	291	152	89	95	79	96	97	100
Taiwan Province of China	2	7	-	-	-	-	-	4	-	-
Asia Total	21,476	19,924	20,146	19,040	12,023	13,729	18,299	11,350	16,973	20,941
Asia's % in Total production	13.07	10.26	10.72	10.31	7.50	8.68	7.33	5.73	9.17	10.50

Source : FAO, 2003a

species was *C.gigas* contributing to 10.8 % (21,536 tonnes) of the world oyster landings. Korea was the major producer of *C.gigas* (20,201 tonnes) followed by USA (1,225 tonnes). Rest of the production came from United Kingdom-95 tonnes, France-8 tonnes, Equador-5 tonnes and Portugal-2 tonnes. The mangrove oyster, *C. rhizophorae* was fished from Venezuela, Cuba and Dominican Republic, the production being 4,197.2 tonnes. Several other species of *Crassostrea* are fished commercially in south-east Asia and Brazil. These are reported collectively in the FAO Fishery Statistics under the designation *Crassostrea* spp. Details of the species wise landings during 1994 to 2003 are given in Table 20.

The group of flat oysters under the genus *Ostrea*, mainly *O. edulis*, *O.lurida*, and *O.chilensis* formed < 5% of the landings. New Zealand, Ireland, Denmark, United Kingdom and Turkey are the major producers of flat oysters. Production of oysters under the genus *Saccostrea* was negligible. Though this group is known to contribute to subsistence fishery in several South-east Asian countries, it has not been documented.

The oyster production from Asia in 2003 was 20941 mt (10.5 % of the world landing, the main contributors being Korea (96.4%), Indonesia(3.04%) and the Philippines (0.48 %) (Table 21). Korea's oyster fishery showed wide fluctuations during the period 1994 to 2003. The production from Thailand which was 1399 tonnes in 1989 was negligible during the subsequent years. Among the oyster resources, *Crassostrea gigas* was the dominant species, followed by *C. iredalei*. The oyster production from India is not reported to the FAO.

OYSTER PRODUCTION IN INDIA

In India, oysters are fished and utilized in all the maritime states though the magnitude of fishery and utilization is varied. Reports by Hornell (1910a, 1916, 1917, 1949), Rai (1928, 1932), Rao (1958, 1963, 1966, 1974), Jones (1968), Alagarswami and Narasimham (1973), indicate that oyster fishing is traditionally practiced by Indian coastal villagers since the last century. The oyster production was low till the early 1990s, but since then it has improved. The average annual landing of oysters during 1995 -99 is estimated as 18,800 tonnes (CMFRI, 2001). Based on the annual landings and the biomass estimated through different planned surveys along the coastal regions of maritime states, the potential yield of oysters was estimated as 33,962 tonnes (CMFRI, 2001) indicating further scope to step up production.

The main fishing areas along the Indian coast, the species contributing to the fishery and the resource utilisation pattern is given in Table 22. The available information on oyster fishery is presented below.

North-east zone

Very little information is available on the oyster resources of West Bengal.

Oyster is locally known as 'Kakada' in Orissa. The main fishing area is the Bahuda estuary in Ganjam district of Orissa. Oysters were fished even during the pre-independence period. The fishery is mainly for the shell but live oysters are also used by the local people. Since the late 80s the Department of Mines leases out the fishing area annually instead of the Department of Fisheries. During 1992-93 the lease amount realised was Rs 82,000 (Das, 1993). Annually about 1,500 tonnes of oysters are fished from this region.

South-east zone

The standing stock of oysters from this region (Andhra Pradesh, Tamil Nadu and Pondicherry) has been estimated as 20,719 tonnes (Rao *et al.*, 1996). Though the oyster landings are not monitored, information collected during the survey conducted by CMFRI has shown that the local fishers seasonally exploit the oysters. Along the Andhra Pradesh coast oysters are fished from Machilipatnam creek, Sarada estuary, Bhimunipatnam backwater, Upputeru canal (Kakinada), Krishnapatnam and Gokulapalli. Tamil Nadu and Pondicherry have the richest oyster resource in the country. In Ennore estuary and Pulicat Lake, intense exploitation of oysters has been observed. The annual shell-on-oyster production from Ennore estuary varied from 1062 to 7115 tonnes (Rao *et al.*, 1996). In Gadilam estuary the oyster meat is also used as bait in the hook and line fishery. Rao *et al.* (1996) have indicated that oyster meat is collected from Kovalam backwaters and supplied to Chennai city. The shrimp hatcheries in this zone also use oyster meat as a feed for brood stock. There is only limited exploitation of resources in most of the estuaries.

South-west zone

In all the three maritime states of this region viz. Kerala, Karnataka and Goa oysters are fished mainly for their meat by the local fishers. In Kerala, well-established oyster fishery has been reported in Korapuzha estuary, Puthuponnani, Pozhikkara and in Ashtamudi Lake (Rao *et al.*, 1996; Kripa, 1998). During the last five years, oysters from Kerala were even marketed in Maharashtra especially in Mumbai. The coastal villagers believe that oyster meat is good for nursing mothers and also to people who suffer from rheumatism.

In Kerala, the oyster fishery is influenced by several social and biological factors. In most coastal villages, the number of fishers involved in oyster fishing is highly variable. When there are more remunerative employment opportunities in other fishing sectors such as trawling or fishing in the coastal or near shore waters, the effort in oyster fishing declines considerably. The market/consumer preference for other bivalve resources such as clams and mussels in the same areas also affects the production. In Ashtamudi lake, when the local fishing agents give indication of export order for the clam *Paphia malabarica*, the traditional oyster fishers switch over to clam fishing.

Similarly when the oysters are in the spent or watery condition, the fishers generally refrain from fishing resulting in low oyster catch. Preference for land based occupation in the coastal villages, close to the developing urban area, also affects the oyster fishery. The oysters are marketed in the nearby villages either as shell-on oysters or as oyster meat. The price in Kerala ranges from Rs 40/- to 45/- for 100 no. of shell-on oysters (Rao *et al.*, 1996; Kripa, 1998).

North-west zone

During the early part of last century, oysters were plenty in the estuaries of Maharashtra. These were fished by the local people and marketed at various places in the state (Alagarswami and Narasimham, 1973; Rao, 1974). However, in recent years due to deteriorating water quality of the oyster beds near Mumbai the production has declined (Sundaram, 1988). In Gujarat, oyster fishery is of a very low magnitude and Chhaya *et al.* (1993) have reported that the resource is so sparse that no fishery can be developed based on the available stock.

OYSTER FISHING METHODS

Because of the sedentary habit of oysters, the main fishing gears used are simple (Korringa, 1952). In the temperate countries, oysters are fished by simple gears such as rakes and tongs. In some areas they are just hand picked during low tide from shallow areas. Rakes have long handles and long, slightly curved teeth. Raking is done by hand in sloping oyster beds upto 8 m depth. Tongs are hand operated and used on level bottoms usually upto 5 m depth. Tongs consist of a pair of rakes attached to long wooden scissor-like handles which are joined approximately one-third of the distance from the end of rakes. The teeth of the rakes point inward and some tongs have baskets attached to both ends. With a series of short lifting movements, the oysters are scraped off the bottom. Tonging is a time consuming operation and can be done only when the water is calm. Patent tongs are also used for fishing oysters. The metal part is similar to that of hand tong, they are hinged so that they open, as they are lowered and close when lifted. Another oyster fishing method of fairly recent origin is dredging. The dredge or the drag is a large rake-head backed with a bag attached to a strong rope in place of a handle. It is usually used for harvesting oysters in deeper areas and is towed over the bottom by a powered boat and hoisted either by a mechanical or motor-driven force. Dredging is considered harmful to the ecosystem and is not usually permitted.

After fishing the oysters are usually culled (separated) by a culling hammer. The hammer usually has a measuring gauge and undersized oysters and empty shells are returned to the oyster beds. Predators such as starfish and rock crabs, taken incidentally are also destroyed. In the Chesapeake Bay, the

Table 22. Important fishing areas along the Indian coast and the utilization of oysters

State	Resource	Main Fishing areas	Utilization
Orissa[1]	*Cm*	Bahudi estuary near Sonapur and at the mouth of the Chilka Lake	Cement industries and poultry feed.
Andhra Pradesh[2]	*Cm*	Sarada estuary, Bhimuni-patnam backwater, Upputeru canal (Kakinada) Krishna-patnam and Gokulapalli	Cement industries; shrimp feed.
Tamil Nadu and Pondicherry[3]	*Cm*	Gokulapalli, Ennore, Muthupet swamps Killai backwater, Pazhayar, Vaigai and Tambaraparni estuaries, Pulicat and at Tuticorin	Cement industries; shrimp feed; human consumption.
Kerala[3]	*Cm, Sc*	Korapuzha estuary, Ashtamudi and Vembanad Lakes, Cochin backwaters, estuaries and the creeks of Dharmadam, Valapatnam, Nileswaram and Chandragiri	Human consumption; Cement industry.
Karnataka[2]	*Cm*	Nethravathi, Mulki, Udayavara, Venkatapur, Coondapoor and Kali estuaries	Human consumption; Cement industry.
Goa[4]	*Cm, Cg, Sc*	Ribander, Siolim, Curca	Human consumption; Cement industry.
Maharashtra[4]	*Cg, Sc*	Alibag,Ratnagiri,Jaytapur, Malad, Boisar, Satpuri, Palghar, Kelwa	Human consumption; Cement industry.
Gujarat[5]	*Cg*	Sikka	Cement industry.
Andamans[2]	*Sc*	Port Blair, Havelock Island, Mayabunder and Dighlipur	Human consumption.

Source : 1-Das, (1993); 2-James and Narasinham, (1993); 3-Rao *et al.,* (1996); 4-Alagarswami and Narasimham, (1973); 5-Chhaya *et al.,* (1993)
Cg : *C.gryphoides*; Cm : *C.madrasensis;* Sc : *S.cucullata*

oysters are fished by all the gears mentioned above. Conflict between mechanized and non-mechanized fishing gear operation is also seen in oyster fishery. In North America, disagreement between the tongers and dredgers became so fierce and bloody that it was called '**Oyster war**'. In 1868, the Maryland Oyster Navy, a special police force, was established to bring law and order to the Chesapeake Bay and Potomac River. These oyster wars came to a formal end only when laws were passed by the Government in 1962 indicating when and where the dredgers could work. In India, the main fishing method is by hand picking or by detaching the oyster clumps with a chisel or

knife. Mechanical dredging as seen in some parts of the temperate countries is not practiced in India.

FISHING SEASON AND SPECIES COMPOSITION

Oysters are fished throughout the year along the west coast except during the peak monsoon period. The fishers themselves are good judges of the oyster quality and have good knowledge of the period during which the oyster meat is watery. In some estuaries like the Vembanad Lake in Kerala, oyster fishermen change the fishing grounds based on season. They pick the oysters from the deeper areas like the seaward navigation channels during the monsoon, since the intertidal population will be mainly dead oyster shells or those live will be of very poor quality (Kripa, personal observation). Along the north-west coast, in the creeks of Maharashtra the oysters are fished by diving, the peak fishing season being November-December. In these regions also the effort and number of fishing days are found to have wide monthly variation (Alagarswami and Narasimham, 1973).

In most estuaries or open coastal regions, the larger *Crassostrea* spp. and the smaller *Saccostrea cucullata* contribute to the fishery (Rao *et al*., 1996; Kripa, 1998). In Ashtamudi Lake, 92% of the oysters landed are *C.madrasensis*, the rest being *S. cucullata*. In Vembanad Lake and in the estuaries of north Kerala, *C. madrasensis* contributes to more than 98% of the catch. This is mainly because the fishing grounds are more in the brackishwater region than in the marine region, and *C. madrasensis* population thrives well in brakishwater. The catch per person ranges from 20 to 40 kg /day. During 1994 -1995, the peak fishing season was observed during the premonsoon period, March to May, when the monthly landing was estimated as 7 tonnes. The lowest of 1.6 tonnes was in August. From September to January, the fishery progressed steadily from 2.4 to 6.3 tonnes. During June - July, the landings were low (Kripa, 1998).

SIZE AND AGE COMPOSITION

In most estuaries of Kerala, only oysters above 50 mm are harvested. Smaller oysters of length range 35 to 50 mm are culled and left in the subtidal region, which later reach harvestable size. The fishery in Ashtamudi Lake is mainly supported by *C. madrasensis* of 70 to 90 mm and *S. cucullata* of 30 to 50 mm. Oysters targeted to metro hotels are usually above 70 mm while for the local markets smaller oysters are also included. The length range of oysters in the natural bed in some of the major oyster beds is given in Chapter 2.

Oyster fishery is comparatively of a smaller magnitude when compared to clam fisheries. The population characters of *S.cucullata* in Ashtamudi Lake have been studied by Kripa (1998). By the Response Surface Analysis and the Automatic Search Routine, the Lα was estimated as 61.5 mm and K at 0.89

per month. The study indicated that the oysters have a life span of 3 to 5 years and they grow to 36.2, 51.1 and 57.2 at the end of 1, 2 and 3 years respectively. The fishing mortality in Ashtamudi Lake is comparatively higher when compared to the almost negligible values in the oyster beds near Worli in Maharashtra. But the high density has been found to restrict the space available for growth at these sites.

The length at first capture Lc of *S.cucullata* was 32 mm, since it was observed that this is the smallest size group fully represented in the catch. The instantaneous rate of total mortality Z was estimated as 2.15 using the length converted catch curve. The natural mortality M was estimated as 0.87 and the fishing mortality F 1.28. The various parameters of *S.cucullata* population in Ashtamudi Lake are given in Table 23. The exploitation ratio U was 0.59. The yield Y was estimated as 4.53 tonnes which is the average of the annual catch during 1994 - 96. Applying the values of Y and U, the total annual stock was estimated as 7.68 tonnes and the average annual biomass as 3.54 tonnes.

Table 23. The population and fishery parameters estimated for *S.cucullata* in Ashtamudi Lake, Kerala.

Z	M	F	U	Y (tonnes)	Y/U (tonnes)	Y/F(tonnes)
2.15	0.87	1.28	0.59	4.53	7.68	3.54

Lr	Lc	Tr (yr)	Tc (yr)	Tmax (yr)	Lmax (mm)	Wmax (g)
10 mm	32 mm	0.4	0.7	3.4 yrs	58.2	48.13

Source : Kripa (1998)

SUBSOIL SHELL DEPOSITS

C. madrasensis shell deposits along the south-east coast are fished and used as raw material in fertilizer, calcium carbide, lime, cement and poultry feed industries. The main fishing areas are Bahuda estuary in Orissa and Ennore estuary in Tamil Nadu. Apart from this the subsoil shells are fished in several estuaries along the east coast. Mahadevan (1987) has reported that the mining of subsoil deposits by lessees in estuaries like Kali River, Athankarai and Bahuda river yield nearly 15,000 tonnes of shells annually.

In Orissa, the Government used to lease out the oyster beds and the harvested shells are utilized for manufacturing poultry feed (Alagarswami and Narasimham, 1973). More recently Das (1993) has reported that annually about 1,500 tonnes of oysters are exploited from the Bahuda estuary. In Ennore estuary, Alambaru estuary and Kovalam backwaters, the subsoil deposits are collected in large quantities. In Kovalam backwaters, once in four years about 80 % of the oysters are removed for manufacture of lime which is used in building construction (Rao *et al*., 1996). Rao *et al*. (1987) described the fishery and exploitation of molluscan shell deposits along the Pinnakayal -

Valinokkam coast. At Mariyar and Valinokkam, the shell deposits of the clam *M. casta* (94%) and *C.madrasensis* (6%) occur at a depth of 0.2 to 1.0 m. These deposits are of recent origin. Many of these areas were taken on lease by salt companies for construction of salt pans. The loosely occurring shells of 40–180 mm length are removed by digging and hand picking. At Kovangad, the shell deposits are at about 0.5 m below the water surface and are about 2.0 m thick. Here also, the fishing method is manual by pushing rectangular wooden panels into the earth, removing the mud and sand present inside and collecting the shell. This is done by marginal agriculture farmers, when they do not have work in the fields. The State Government leases out the exploitation right to different individuals who employ the farmers. The annual production has been reported to range between 300 and 400 tonnes. Fishing is done throughout the year except in the north-east monsoon months (October to December).

In the Gulf of Kutch, regular exploitation of both lime and oyster shells was done by a cement industry in Sikka which had obtained long term lease for lifting the sand. This has led to drastic decline in oyster population (Chhaya *et al.*, 1993).

MANAGEMENT OF OYSTER FISHERY

Oyster production from natural beds has shown wide fluctuation during the last one and half centuries. Severe depletion of stocks in the major oyster beds either due to overfishing, disease outbreak or environmental degradation has been reported (Sinderman, 1990; Carlton and Mann, 1996). In some areas a combination of one or two of these factors were implicated (Rothschild *et al.*, 1994)

In Europe, commercial exploitation of oysters over the years has led to virtual destruction of natural resources. The flat oyster beds were repeatedly closed for fishery due to overfishing and stock depletion in Germany, Denmark and Netherlands (Schlauch, 1999). Another typical example of overfishing and resource mismanagement is the oyster fishery of Willapa Bay in North America. Due to the development of shipping industry, the oyster landings increased to 13,000 mt in 1890. Then they declined rapidly to a level of less than 5,000 tonnes in 1920. Parasites and diseases were considered as responsible for the collapse of the fishery. (More details are given in Chapter 4.) The bluff oyster (*Tiostrea chilensis*) fishery in New Zealand collapsed in the mid-late 1980's due to Haplosporidian *Bonamia* sp. (Keogh *et al.*, 1997). Apart from this, industrialization and deterioration of water quality have also contributed to the destruction of oyster beds such as the oyster industry in south Puget which flourished during the 1920's and dwindled due to pollution from a paper and pulp mill. Historically one of the best recorded oyster industry is that of Chesapeake Bay which peaked at 6,15,000 tonnes in 1884, declined to

about 12,000 tonnes in 1992 mainly due to environmental degradation, fishing pressure and disease outbreaks (Rothschild *et al.*, 1994; Harding and Mann, 1999). Thus areas which were once famous for oyster production became shadows of their past.

In an effort to revive the natural oyster fishery, attempts were made to transplant or introduce either *C.gigas* or *C.virginica* and these were partly successful (Beattio *et al.*, 1982). In some regions they failed to establish self reproducing populations. In addition to these transplantations, regulations and programmes based on the inferences drawn from the ecobiological research, projects on oysters were formulated, and these were strictly enforced. The results were encouraging proving that by appropriate regulations the natural resources can be protected.

Rothschild *et al.* (1994) have attributed the cause for long - term decline of oyster to habitat loss associated with intense fishing pressure. To effect the recovery of the ailing Chesapeake Bay oyster stock, a 4-point management strategy was prepared by the authors.

- Fishery management steps to control size specific fishing mortality.
- Repletion strategy - a) Placing shell on existing substrate to effect habitat replacement, increase the growth and survivorship of oysters. b) Transplanting recruited spat into areas of improved growth and survivorship.
- Habitat replacement strategy - building new substrate to create additional suitable oyster habitat for recruitment of spat, growth and survivorship of new recruits. As it takes decades to create an oyster reef naturally, engineering replacement habitat with artificial structures in optimum growth and survival areas seems to represent a viable alternative.
- A broodstock sanctuary - would include the designation of 'no - fishing' restriction in specific areas where production of larvae and spat settlement are known to be high.

In an effort to restore native oysters in Chesapeake Bay, citizen volunteers are involved in a unique partnership with Government management agencies. In 1996, these volunteers helped to transplant approximately 7,50,000 large wild caught oysters onto a one acre broodstock sanctuary. Spawning by these oysters resulted in a 10 to 200 fold increase in juvenile abundance in 1997 (Braumbaugh *et al.*, 1998). This growing consciousness among the people about the need to regulate fishing, increase of oyster habitat and provide broodstock sanctuary is a positive sign pointing towards a sustained fishery for the future. Fishery management measures curtailing fishing activity during the breeding season has been in vogue in the USA for the last two decades. For C. *virginica,* in Chesapeake Bay, the minimum size of capture was regulated to 76 mm in 1990. An interactive relationship has been observed between the

reproductive behaviour, fishery and the population equilibrium of *C. virginica*. This oyster is weakly protandric hermaphrodite, i.e. some older males become females. (Galfstoff, 1964; Kennedy, 1983). When the fishing pressures on such population increases (i.e, decline in female proportion) the production of eggs per adult biomass (spawning efficiency per unit biomass) is reduced much more than in a non hermaphroditic population. Rothschild *et al.* (1994) have critically analyzed the causes for the decline in Chesapeake Bay oyster population and have commented that an increase in size of first capture to 122 mm would be able to double the yield per recruit and quintuple the spawning stock biomass. This would be more effective than decreasing the fishing pressure.

Another typical example where management measures have helped revival of fishery is at Long Island Sound. Oyster production from this region rose from 85 tonnes of meat in the 1960s to 1000 tonnes in 1975 (Mackenzie, 1989). This 10-fold increase in production resulted as the oyster companies increased the planting of oyster shells on the beds from 6,200 m^3 to about 8,000 m^3 in a year and by controlling mortalities of seed oysters from predation by gastropods and suffocation by silt. The gastropod predators were removed by suction dredges and starfishes by catching them with mops or by killing them with granulated quicklime. Mortality due to siltation was avoided by placing them when the spat were less active (Mackenzie, 1981).

In India, though the oyster beds are extensive the demand for oyster meat is low and hence their exploitation is by and large remaining at a low level except at a few places. This low level of exploitation has not necessitated formulation of management measures regulating fishing activity. To increase the utilization of this resource, management measures should be directed towards developing proper marketing channels. Quality assurance to consumers along with wide ranging awareness campaigns about the nutritive value of oysters is urgently required. This leads to demand driven fishing effort, resulting in increased production from the currently under exploited resources.

Chhaya *et al.* (1993) have indicated that the oyster fishery cannot be developed in the existing oyster beds in Gujarat owing to the very thin oyster densities (< one number/ m^2). The slow growth of the local oyster species (*C.gryphoides*) also does not contribute to the growth of oyster stock. With the objective of developing the oyster resource of Gujarat, the faster growing *C.madrasensis* spat produced in CMFRI hatchery in Tuticorin was transported by road and air to Jamnagar within a transit period of 36 hrs. Though the first trial in 1988 was not successful, the second consignment of 5,500 oyster spat of 10 mm length showed more than 90% survival during transportation. The spat grown in cages in the intertidal region showed a growth of 2.9 cm in one year. This growth rate of *C.madrasensis* reared in cages is far from satisfactory. However further studies are needed to evaluate the performance of *C.madrasensis* in this region.

Intense exploitation has been reported at Ennore estuary, Pulicat Lake, Kovalam and Korapuzha estuary. Rao *et al.* (1996) have suggested that the heavy exploitation of live oysters from Ennore and Kovalam should be regulated. It was also observed that the density of spat was very low in most of the estuaries. Measures have to be taken to increase the spat fall in areas where oysters are regularly fished. From the foregoing brief account the management measures required to develop a sustainable oyster fishery in the country are:

- Market development of oyster meat by creating awareness about the nutritive value of oyster.
- Quality assurance to the consumer by making depuration of fished oysters mandatory and also pollution monitoring of waters in areas where oysters are regularly fished.
- Fishery restriction in areas of intense exploitation.
- Placing additional empty shells (shelling) for increasing the spat settlement in areas where commercial fishery exists.

Development of oyster culture in areas suitable for augmenting production.

QUESTIONS

1. Describe oyster fishing methods, season and species.
2. What are the strategies for the recovery of oyster fisheries?
3. Write on oyster production, important species in the world and in India.

Chapter 6

Seed Production

THROUGHOUT the world natural spat collection forms the basis of most oyster culture industries. Along the Pacific North-west USA coast, hatchery produced seed are used in the cultivation of the Pacific oyster, *Crassostrea gigas*. Natural seed collection is cheaper when compared to the cost of seed produced in the hatchery.

NATURAL SPAT COLLECTION

The substrate provided to the oyster larvae for attachment is known as cultch or collector. It should be clean and hard. In the temperate waters, oyster or scallop shell is widely used as cultch. More recently tubular plastic mesh (Netlon) is used for packing shell cultch. Quayle and Newkirk (1989) have stated that roughened surfaces appear to be more suitable for spat settlement, the colour of the cultch has no significant influence on the setting behaviour of the oyster larvae and that the presence of a bacterial film on the cultch for the setting of the eyed larvae is not essential, at least for the genus *Crassostrea*. They have also stated that the larvae tend to settle more readily on surfaces on which there are already some spat.

The selection of the cultch material depends upon the type of culture. For example, in the production of individual oysters (unattached) for the half-shell market, lime-coated tiles give good results as it is easy to remove the oyster spat from the tiles for further rearing. For the ren method of culture, strings made of oyster shells with spacers inserted between the shells are hung usually from racks. The grow out culture is often carried by using the same rens. For the stake culture the common method is to drive the bamboo or the wooden poles (stakes) into the substratum and the stakes act as spat collectors; the grow out culture is carried on the same stake. For the on-bottom oyster culture, oyster shells, stones, and concrete panels laid in the shape of inverted 'V' on the substratum are some of the materials used as cultch.

It is necessary to have a good knowledge about the biology of the oyster, particularly on reproduction for the collection of spat. Laying the cultch in the water at appropriate time is critical for successful spat collection. There are four methods to predict the time of spatfall (Nair *et al.*, 1993) namely, study of gonad maturity stages, eyed larval counts from the plankton samples, regular examination of test panels or cultch materials held in the spat collection

areas, and observations on the locally occurring substrates for oyster spat. Successful spawning, as determined by gonadal studies, need not necessarily result in good spat settlement because of unfavourable conditions such as heavy silt load, hyper or hyposalinity, and drift of the larvae by water currents away from the area of spat collectors. Spatfall forecast based on the abundance of eyed larvae in the plankton has its own drawbacks. It is extremely tedious (Clarke *et al.,* 1991) as it involves sorting of oyster larvae from large number of the larvae of other groups of animals and more importantly the difficulty in the identification of the oyster larvae. Quayle and Newkirk (1989) stated– Identification of bivalve larvae is one of the more difficult aspects of shell-fish biology to master. Use of test panels made of glass, commonly experimented in biofouling studies or cultch materials such as oyster shells hung at different places and depths is perhaps the best method for oyster spatfall prediction in the tropical waters. Observations on the occurrence of spatfall on the locally available substrates which include oyster shells, submerged rocks, fish traps, cage floats, piers etc. can be an effective indicator for suspending cultch. However, spat size should be < 2 mm to indicate recent spawning (Nair *et al.*, 1993).

NATURAL SPAT COLLECTION IN INDIA

Several studies have been conducted to determine the availability, duration and intensity of the spatfall of oysters from Indian coastal waters.

Crassostrea madrasensis

The cultch materials used include oyster, mussel, windowpane oyster and coconut shells, asbestos sheets, roofing tiles, velon screens, polyethylene liner sheets, PVC tubes, wood pieces, concrete pieces and slabs, bamboo frames, automobile tyres and close meshed plastic buckets. Thangavelu and Sundaram (1983) described the process followed in giving lime coating to tiles. After an initial coating of lime, a secondary coating, comprising 3:4 ratio of lime and fine sand mixture is given to the tiles (Figure 13). Several authors (Thangavelu and Sundaram, 1983; Muthiah, 1987; Sarvesan *et al.,* 1990; Patterson and Ayyakkannu, 1997) reported that in the cultch laid horizontally, the lower concave surface received more spatfall than the upper convex surface. Sarvesan *et al.* (1990) stated that 71 % of spat was set on the lower concave side and the rest on the upper convex side. Silas *et al.* (1982) mentioned the spat settlement ratio as 1:5 on the upper convex and lower concave surfaces respectively. This disparity is generally attributed to silt deposition on the upper surface which is not conducive to spatfall (Quayle and Newkirk, 1989).

Thangavelu (1988) stated that in the Pulicat Lake, the veliger larval abundance was high in November 1980 but the spatfall was poor, while in April 1981, the larval abundance was less than moderate but the spatfall was high. He further stated that the low salinity of 0.37 ppt in November 1980

Fig. 17. Lime-coated tiles in trays held on racks in the Tuticorin Bay for oyster spat collection. *Courtesy:* CMFRI, Cochin, Kerala

would have affected the survival of the larvae resulting in low spatfall and the high salinity of 34.83 ppt in April 1981 would have resulted in successful spat setting. This study highlights the difficulties faced in spatfall prediction based on larval abundance. Kripa and Salih (1999 a) mentioned that in the Ashtamudi Lake the spatfall observed in May is prone to mortality due to dilution of water caused by the monsoon in the following months.

From Table 24 it is obvious that biannual spatfall is more common and was observed in the Bheemunipatnam backwaters, Pulicat Lake, Muthukadu backwaters, Vellar estuary, Athankarai, Tuticorin bay and the Mulki estuary. At a given centre between the two seasons, one is marked consistently with high intensity spatfall than the other. In general, March - April and October - December are the seasons of spatfall for *C. madrasensis* (Table 24).

Spatfall throughout the year or for the major part of the year was observed at Bheemunipatnam, Kakinada, Athankarai and the Ashtamudi areas.

At Tuticorin and Ashtamudi, spat collections on oyster shell rens were made continuously for 5 years or more (Figure 18). The average spat settlement at Tuticorin was 5.8 to 7 nos/ oyster shell and at Ashtamudi it was > 23 nos/ oyster shell. This indicates that the Ashtamudi Lake is highly productive for spat collection. In fact the abundance of seed and the demonstration of the oyster farming technology by the CMFRI scientists in the Ashtamudi Lake

Table 24. Spat collection of *C. madrasensis* along the Indian coast

Area of study	Spatfall particulars	Author
Andhra Pradesh		
Bheemunipatnam	Throughout the year. Peaks in March and October. Close meshed plastic buckets 4-50 nos/ 10 cm^2. In October-December '79 intense spat fall of 100-200 nos/ 10 cm^2 occurred.	Reuben *et al.*, 1983.
Kakinada Bay	March-September.	Rao *et al.*,1994.
Tamil Nadu		
Adayar estuary	November-January/ February.	Rao and Nayar, 1956.
Pulicat Lake	Peak October-December with average of 4.7 nos/ 100 cm^2. Secondary settlement March-April with 0.29 nos/ 100 cm^2.	Ramakrishna, 1988.
Pulicat Lake	Spat settlement high in May and low in November. Veliger larvae abundance in plankton coincided with high spatfall.	Thangavelu, 1988.
Muthukadu backwaters	Peak September-November and low intensity in February-April. Other months no spatfall. Spat 8-109 nos (average 55/tile).	Sarvesan *et al.*, 1990.
Vellar estuary	Peak in August-September and minor peak in April-May, lime coated tiles most efficient. Average density 21.4 nos at 80 cm depth and 54.2 nos at 100 cm depth per tile (11 x 3.8 cm).	Patterson and Ayyakkannu, 1997.
Athankari estuary	Major spatfall in January-April; minor June-December, Average 0.2 nos/ oyster shell.	Rao *et al.*, 1983.
Karapad creek (Tuticorin)	April-May. Up to 100nos/ tile. Average 40 nos/ tile of 24 x 15 cm. Total 6,00,000 spat collected in 45 days.	Nayar and Mahadevan, 1983.
Tuticorin	Intense March-April, less intense September-October. Maximum 105 nos/ tile of 20 x 12 cm. Maximum 517 nos/ corrugated asbestos sheet of 30 x 30 cm. Average 393 nos/ sheet.	Thangavelu and Sundaram, 1983.
Tuticorin	Major April-May, secondary August-September. In 1979 Tuticorin Bay 316 nos/ m^2, 76 nos/m^2 in Karapad creek, and 92 nos/m^2 in natural bed on lime coated tiles of 24 x 15 cm. In 1980 average spatfall: 7 nos/ oyster shell, 5 nos/ mussel shell, 1 no/ coconut shell, 4 nos/ asbestos sheet of 120 x 80 cm, 87 nos/ velon screen of 4.25 x 16.5 cm, 215 nos/ polythene lined sheet of 4.25 x 16.5 cm, 30 nos/ PVC	Muthiah, 1987.

Area of study	Spatfall particulars	Author
	tube of 30 cm diametre and 1 m length and 33.5 nos/ tile of 24 x 15 cm size. During 1981 through 1984, spat settlement of 12, 15.6, 29 and 15 nos/ tile of 24x15 cm. Average spatfall ranged from 5.8 to 6.5 nos/ oyster shell.	
Kerala		
Ashtamudi Lake	During October 1993-September 1994 spatfall 10 months except in June and September. Peak December-January. Average 24.6 nos/ oyster shell.	Velayudhan *et al.*, 1995.
Ashtamudi Lake	In December 1994-February 1995, average spatfall 24 nos/ oyster shell.	Velayudhan *et al.*, 1998.
Ashtamudi Lake	At bar m-outh and estuary throughout the year. Intense during November-January at both sites. Minor peak in May. From June to August negligible spat settlement. Maximum settlement 35 nos/ test panel of 20 cm x 20 cm.	Kripa and Salih, 1999 a.
Cochin backwaters	January-February.	Purushan *et al.*, 1983.
Karnataka		
Mulki estuary	Peak November-December; minor March-April.	Joseph and Joseph, 1983.

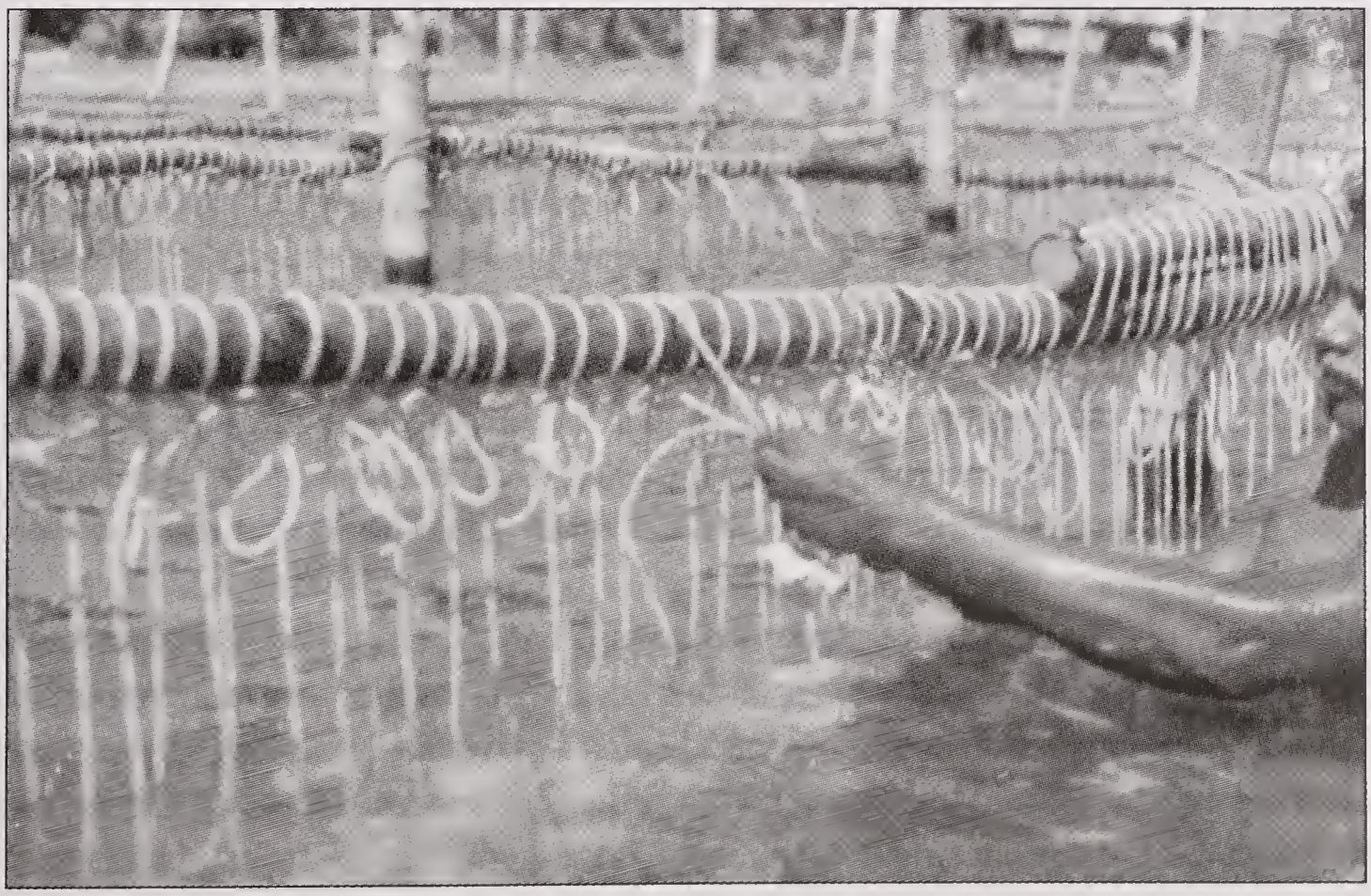

Fig. 18. Oyster strings suspended from a rack for natural spat collection in the Ashtamudi Lake. Note the strings are closely set
Courtesy: CMFRI, Cochin, Kerala

resulted, for the first time in India, in the emergence of commercial oyster farming by the villagers.

Crassostrea gryphoides

In the Kelawa backwaters near Mumbai spatfall begins in July and extends till September (Durve and Bal, 1962).

Saccostrea cucullata

Along the Bombay (now Mumbai) coast, Awati and Rai (1931) observed spat settlement throughout the year except during the monsoon (mid June-September). Joseph and Joseph (1983) stated that the spat settlement in the Mulki estuary is heavy throughout the year except during July-August (monsoon). In a brief study during January - March 1986 near Mumbai, Sundaram (1988) observed the occurrence of spat during these three months. In the Ashtamudi Lake, Kripa and Salih (1999 b) monitored the spatfall on test panels of 20 x 20 cm size. They observed spatfall throughout the year and at the bar mouth this species dominated (81.7 %) of the total oyster spat. The density on the test panel varied from 258 in February to 43 spat in September.

S.cucullata generally occurs along the open coast and close to the mouth of the estuaries where salinity variations are in a narrow range. The studies indicate the spatfall throughout the year.

SEED PRODUCTION IN THE HATCHERY

Attempts to raise oyster seed under controlled conditions were made towards the end of the 19th century. Brooks (1880) studied the eggs and early larval stages of the American oyster *Crassostrea virginica*. Wells (1926, 1927) succeeded in rearing the larvae of *C. virginica* to spat in glass jars. The earlier workers failed in their attempts in larval rearing and spat production mainly due to the poor quality of the seawater used and for not providing suitable micro algae as food. Since 1950's, Loosanoff and Davis (1952a,b; 1963), Walne (1956, 1974), AQUACOP (1977), and Dupuy *et al.* (1977) have standardised the oyster seed production technology in hatcheries. This development has paved the way not only for the commercial production of oyster seed for oyster culture but also for researches in oyster genetics.

The selection of suitable site for oyster hatchery is of utmost importance and many factors are to be taken into consideration. Uninterrupted supply of good quality seawater, free from industrial and sewage pollution is required. The suspended particles and silt load in the water should be low. Sites close to river mouths should be avoided, since during monsoon, flooding dilutes the seawater salinity, rendering it unsuitable for seed production. It is advantageous to select a site which is close to the oyster farm and natural oyster beds. The site should be easily accessible for the transport of men and materials throughout the year.

HATCHERY PRODUCTION OF OYSTER SEED IN INDIA

In India the larvae of *C. madrasensis* were reared in the laboratory up to the straight- hinge stage by Samuel (1983) while Rao (1983) succeeded in inducing spawning and rearing the larvae till settlement. A breakthrough in the induction of spawning, larval rearing and mass production of *C.madrasensis* spat was achieved by Nayar *et al,* (1982, 1984) at the Shellfish Hatchery of the CMFRI, Tuticorin. The various stages in the oyster seed production were standardised by Nayar *et al.* (1987 b, 1988 b) and Rao *et al.* (1992). The hatchery operations are divided into five phases namely, selection and conditioning of broodstock, induced spawning, fertilisation and early development, larval rearing, preparation of cultch materials and production of spat, and culture of algal food.

Hatchery Facility at Tuticorin

Building: The main hatchery complex is a 15 x 10 m shed, half of which is roofed with translucent FRP sheets and the other half with asbestos sheet. Air vents, exhaust fans and glass-panelled large windows are provided. Concrete flooring is given and a pair of closed drains run along the entire length of the hatchery to collect the water drained from the rearing tanks. In the asbestos roofed section are provided four identical rooms of 4 x 2.5 m size for microalgae culture, broodstock conditioning, duty room and analytical laboratory. The translucent portion of the hatchery is used for larval/spat rearing and mixed algal food production. The algal culture and broodstock conditioning rooms have thermocool ceiling and are air conditioned.

Seawater Supply: It comprises an intake point, a draw well, sedimentation tanks, filter bed, water sump, overhead tank and delivery lines to the hatchery (Figure 19). Seawater is drawn into the well through a 15 cm diameter PVC pipe by gravity and is pumped by 1 HP pump set to the sedimentation tanks where large particles in the water settle. The supernatant water is passed into the filter bed. The latter consists of river sand at the top followed by charcoal, pebbles and finally small granite stones at the bottom. It effectively filters particles above 10-20 µm (Nayar *et al.* 1984). The filtered seawater is collected in a storage sump (capacity 20,000 l) and is pumped by 7.5 HP pump to overhead tank (capacity 10,000 l). Standby pumps are kept for emergency. Water is drawn to the hatchery from the overhead tank through 12 mm diameter PVC pipes. The receiving end in the hatchery is plugged by surgical cotton to prevent still smaller particles from entering into the rearing tanks. This facility can supply 10,000 l filtered seawater daily to the hatchery. The nannoplankters up to 10 µm are passed into the rearing tanks in the hatchery. Recently high pressure mechanical filter was installed in the hatchery which facilitates effective filtration. The annual variation of the water temperature is from 23.5-32.6^0 C, salinity 34.11 to 36.32 ppt and pH 7.76 to 8.20 (Nayar *et al.,* 1987 b).

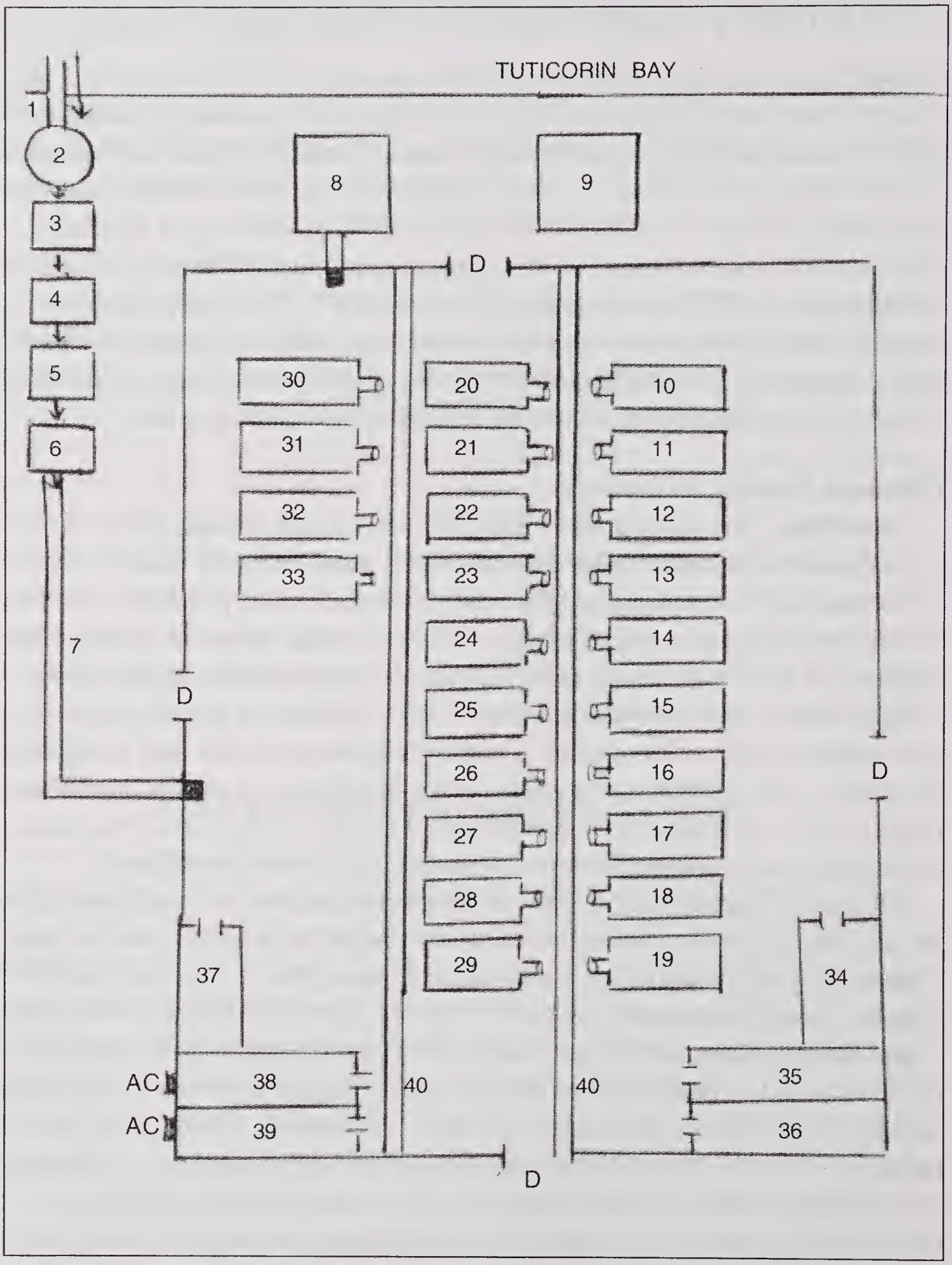

Fig. 19. Schematic diagram of oyster hatchery of CMFRI at Tuticorin. 1. Seawater intake pipe 2.Draw well 3. Sedimentation tank 4.Filter bed 5.Storage sump 6.Overhead tank 7.Seawater supply pipe to hatchery 8.Generator 9. Air Compressor 10-19. Larval rearing tanks 20-29. Spat rearing tanks 30-33. Algae culture tanks 34. Spawning tanks 35. Analytical room 36. Duty room 37. Stores 38. Conditioning room 39. Axenic algae culture room 40. Drain; AC- Airconditioner D- Door

Air Supply System: This consists of air compressors, filters, PVC air grid, polythene aeration tubes, diffusion stones and air regulators. Air compressor

of rotary vane model with attached storage tank and run with 1 HP electric motor is used. The air flow is regulated and passed through a series of filters to remove oil and moisture. Air is supplied to the rearing tanks through 25 mm diameter PVC pipes. Air is drawn at the required places from the pipe lines through nozzles fixed to the pipes. Air is supplied to the tanks through polythene tubes and diffuser stones. Air supply to the tanks can be adjusted with the help of a gate valve connected to the polythene tubes. A standby compressor helps in effective management of air supply to the hatchery.

Generator: A generator of 10 KVA, operated by a 16 HP diesel motor is installed for use in case of interruption in the power supply.

Rearing Tanks: The rearing tanks comprise FRP tanks of 75 x 50 x 25 cm for conditioning the oysters, one 100 l capacity perspex tank for spawning the oysters, 20 FRP tanks of size 200 x 100 x 50 cm for rearing larvae and spat (Figure 20), four FRP tanks of 200 x 100 x 50 cm for outdoor algae culture and five perspex tanks of 100 l capacity for indoor algal culture.

Other Equipments: Sieves of different mesh sizes, compound microscope, haemocytometer, plankton counting chamber, pH meter, thermometers, salinometer, oxygen analyser, autoclave, glassware and plasticware.

Selection and Conditioning of Broodstock

The word conditioning is used to denote the process by which the gonad maturation of the oysters is hastened so that the gametes become ripe for spawning. The process involves manipulation of environmental conditions

Fig. 20. Oyster hatchery at Tuticorin showing the larval and spat rearing tanks
Courtesy: CMFRI, Cochin, Kerala

and nutrition. In temperate countries, the spawning season of bivalves is of short duration, limited to about 3 months. During the non-spawning period the maturity process is accelerated in the hatchery by keeping the bivalves at elevated temperatures with suitable food. During the summer, holding the mature bivalves at lower temperatures prevents spawning. Thus by conditioning, bivalves in ripe condition can be made available for most of the year (Loosanoff and Davis, 1963; Dupuy *et al.,* 1977).

In India conditioning the oysters about 5^0 C below the ambient water temperature with suitable algal diets accelerated the gonad development, resulting in sexually ripe oysters. The oysters are selected based on the condition factor and age. Selection of a mixed and heterogeneous stock of oysters from several areas will give better results. It is also desirable that the salinity regime of the area from where the oysters were collected is comparable to that of the water salinity in the hatchery. Otherwise the oysters should be acclimatised before they are conditioned. The prevailing temperature of the collection area is recorded since, based on this manipulation of temperature it is effected for conditioning the oysters.

C. madrasensis of the length range 60-90 mm are considered as ideal and it is preferable that 30 % of them belong to '0' age group (60-75 mm) in order to be assured about the presence of males in the broodstock (Nayar *et al.,* 1987b). The maturity stage of oysters is ascertained by the examination of gonad tissue smears under a microscope. Oysters which show dominance in 'maturing stage' of gonad development are preferred since the conditioning period will be relatively short when compared to the spent/ indeterminate stage oysters.

The selected oysters are cleaned thoroughly with wire brush to remove the plants and animals adhering to the shell. A batch of 25 oysters are placed on a synthetic twine-knit PVC frame in 100 l, FRP tank (75 x 50 x 25 cm), and raw seawater pre-cooled at 20-22^0 C, is filled in the tank. Aeration is provided. The tanks holding the oyster broodstock are cleaned daily to remove dirt, faeces and pseudofaeces and filled with fresh raw seawater. After cleaning, the water level in the tank is maintained at half the height of the tank and 15 litres of mixed phytoplankton, cultured in outdoor tanks using inorganic fertilisers as medium are added twice during a day, between 09-00 and 17-00 hrs at 4 hours interval. The average cell concentration of the algae is 1.0 million cells/ ml. Thus the oysters are conditioned by holding them in the conditioning room at about 5^0 C below the ambient water temperature. They attain full maturity in 10-20 days (Nayar *et al,* 1987 b). The raw seawater used for broodstock conditioning contains supplementary food and in a subsequent study Nayar *et al.* (1988 c) gave mixed microalgae at the rate of 3 liter / oyster / day.

Palaniswamy and Sathakkathullah (1992) conducted experiments at Tuticorin to spawn the oyster, *C. madrasensis* outside the spawning period. They maintained batches of the oysters in the broodstock conditioning room

at the rate of 15 nos/100 l tank. Water temperature was maintained at 20 ± 1^0 C and salinity 32-33 ppt. Mixed algal diet of *Chaetoceros* sp., *Skeletonema* sp. and *Nitzschia* sp. of 35 l (cell concentration 0.75 to 1.0 million cells/ml) was given daily, after water change. Every fortnight 15 oysters were subjected to 29 ± 1^0 C temperature shock to induce spawning. During August-September (secondary peak in spawning) between 73.3 and 79.9 % of oysters spawned. In the following five months (no spawning or feeble spawning in the natural bed) 20-60 % of oysters spawned. This study shows that spawning in *C. madrasensis* can be induced, to a certain extent, outside the spawning period, by manipulating temperature and providing suitable food to the oysters.

Palaniswamy and Rajapandian (1997) fed six species of microalgae namely *Tetraselmis gracils, Chaetoceros calcitrans, Chromulina freibergensis, Isochrysis galbana, Dicrateria icornata* and *Chlorella salina* individually, to *C. madrasensis* in a 24 hr study, after the oysters were starved for a day. In all cases, in the first one hour, filtration was the highest. The authors suggested that it is better to provide the food to the oysters at intervals rather than giving it at one time.

Nayar *et al.* (1988 c) conducted a study by feeding *C. madrasensis* with mixed phytoplankters viz, diatoms, comprising *Chaetoceros affinis, Skeletonema costatum, Thalassiosira subtilis and Nitzschia closterium* and phytoflagellates, *Isohysis galbana* and *Pavlova* spp. at the rate of 3 l per oyster per day. The average cell concentration of the algae was 1 million cells/ml. After conditioning at 22-24^0 C for 10-20 days (average 14.5 days) 40.4 % of the oysters spawned. In oysters fed exclusively with *Chlorella salina* (1-1.2 million cells/ ml) at the rate of 3 l/oyster/day, spawning resulted in 13.6 % of oysters and in the oysters fed with boiled corn flour at the rate of 400 mg corn flour/ oyster/ day spawning was induced in 17.6 % of the oysters (Nayar *et al.*, 1988b). This study shows that mixed phytoplankton is the preferred diet for broodstock conditioning. The algal diets given to the broodstock should always contain two to three species for better results (Utting and Millican, 1997).

In Thailand it was found that fish or shrimp earthen ponds with their unusual phytoplankton blooms could provide excellent facilities for conditioning the oyster broodstock (Nugranad, 1991). Utting and Spencer (1991) described the broodstock conditioning techniques followed at Conwy, UK. The broodstock of the Pacific oyster (*Crassostrea gigas*) of 70 mm shell length and flat oyster (*Ostrea edulis*) of 65 mm shell diameter are held at 22 ± 2^0 C in tanks having water flow not exceeding 25 ml/ minute per adult oyster. Each oyster requires about 200 million cells of *Tetraselmis*, 2000 million cells of *Thalassiosira* or 1000 million cells of *Skeletonema* per day. A mixture of these species on a proportional basis gives better results than a single species diet. The authors recommended a food ration, equivalent to 6% of the initial dry meat weight of the broodstock in dry weight of algae per day.

Live algae are preferred when compared to diets of 100 % spray-dried algae (Utting, 1993). Spray-dried algae have often good potential in broodstock conditioning since they are convenient to use and provide carbohydrate source leading to glycogen reserves build up required for the *de novo* synthesis of lipid during gonad maturation (Utting and Millican, 1997).

The best diets are those high in Polyunsaturated Fatty Acids (PUFAs), eicosapentaenoic acid, 20:5 (n = 3) and decosahexaenoic acid, 22:6 (n = 3), because many adult bivalves are unable to produce these *de novo* from shorter chain pre-cursors (Chu and Greaves, 1991). Millican and Helm (1994) found that fecundity, dry meat weight and larval survival of *O.edulis* were higher when broodstocks were given diets containing 'Tahitian' *Isochrysis* than when *Dunaliella tertiolecta* was given, since the latter is deficient in PUFAs of chain length greater than 18 carbons. Of the two fatty acids considered essential for bivalve broodstock, 20:5 (n = 3) utilized potentially during embryo development (to provide energy) while 22:6 (n = 3) is conserved for structural function (Helm *et al.,* 1991; Marty *et al.,* 1992). The role of dietary protein for broodstock conditioning needs detailed study since protein supplies as much of the energy required during embryogenesis as lipid (Utting and Millican, 1997).

Induced Spawning, Fertilisation and Early Development

Fully matured bivalves can be induced to spawn by giving different kinds of stimuli like raising water temperature, addition of sperm suspension to a container holding females, mechanical stress, and addition of chemicals such as Hydrogen peroxide, Ammonium hydroxide, Sodium hydroxide and Tris buffer. In India, *C. madrasensis* is induced to spawn by thermal stimulation. Approximately 25 oysters, conditioned for about 10-20 days at about 5- 10^0 C below the ambient temperature are induced to spawn by transferring them to 100 l Perspex tank containing 50 l filtered seawater with temperature range of 2-4^0C above the ambient. A silica immersion heater and a Jumo thermometer are used to raise and monitor the water temperature in the spawning tank. Aeration is provided in the tank. The sudden change of water temperature (thermal shock) induces spawning during the first one hour. If spawning is not achieved, fresh sperms stripped from a sexually ripe male are added to the broodstock spawning tank and the sperm suspension induces spawning. The spawning oysters are immediately transferred to separate spawning trays (one oyster in each 3 litre glass tray) containing filtered seawater at ambient temperature. On completion of the spawning the oysters are removed from the trays. If the female is a heavy spawner and the water becomes highly murky, it is transferred to another tray to complete the spawning. It is essential to remove the oysters, on completion of spawning in the trays to prevent the oysters from filtering the gametes. The egg suspension from each spawning

tray is filtered through a 100 µm stainless steel or nylobolt sieve into a container. The sperms obtained from individual trays are mixed and the pooled sperm suspension is added to each tank containing eggs. This results in greater heterozygosity of the progeny. The gametes are mixed and mild aeration is provided.

Most of the eggs are fertilised within 60 minutes of spawning. The fertilised eggs settle at the bottom and aeration is suspended. The supernatant water, containing sperms, unfertilised eggs and debris is removed. Fresh filtered seawater is added and decanting is carried 3-4 times. This is followed by addition of fresh seawater and mild aeration. The fertilised eggs undergo first cleavage within 45 minutes.

Larval Rearing

At the end of 4 hrs after fertilisation, as a result of rapid cell divisions, the morula stage is reached and at the end of 20 hrs the straight-hinge, also called D-shelled larva or veliger larva stage is reached (Figure 21). The 'D' larvae actively swim and are siphoned from the tank and reared in 1 tonne FRP tank filled with filtered seawater and aerated. The D-larvae are semi-transparent; velum protrudes out and creates strong ciliary current which directs minute particles of food into the stomodaeum. The actively swimming larvae are separated by siphoning, leaving the sluggish in the tank. This culling process is continued for the first 2 days. The straight hinge larvae are stocked at a density of 5 larvae / ml of seawater in 1 tonne tank for further rearing. The

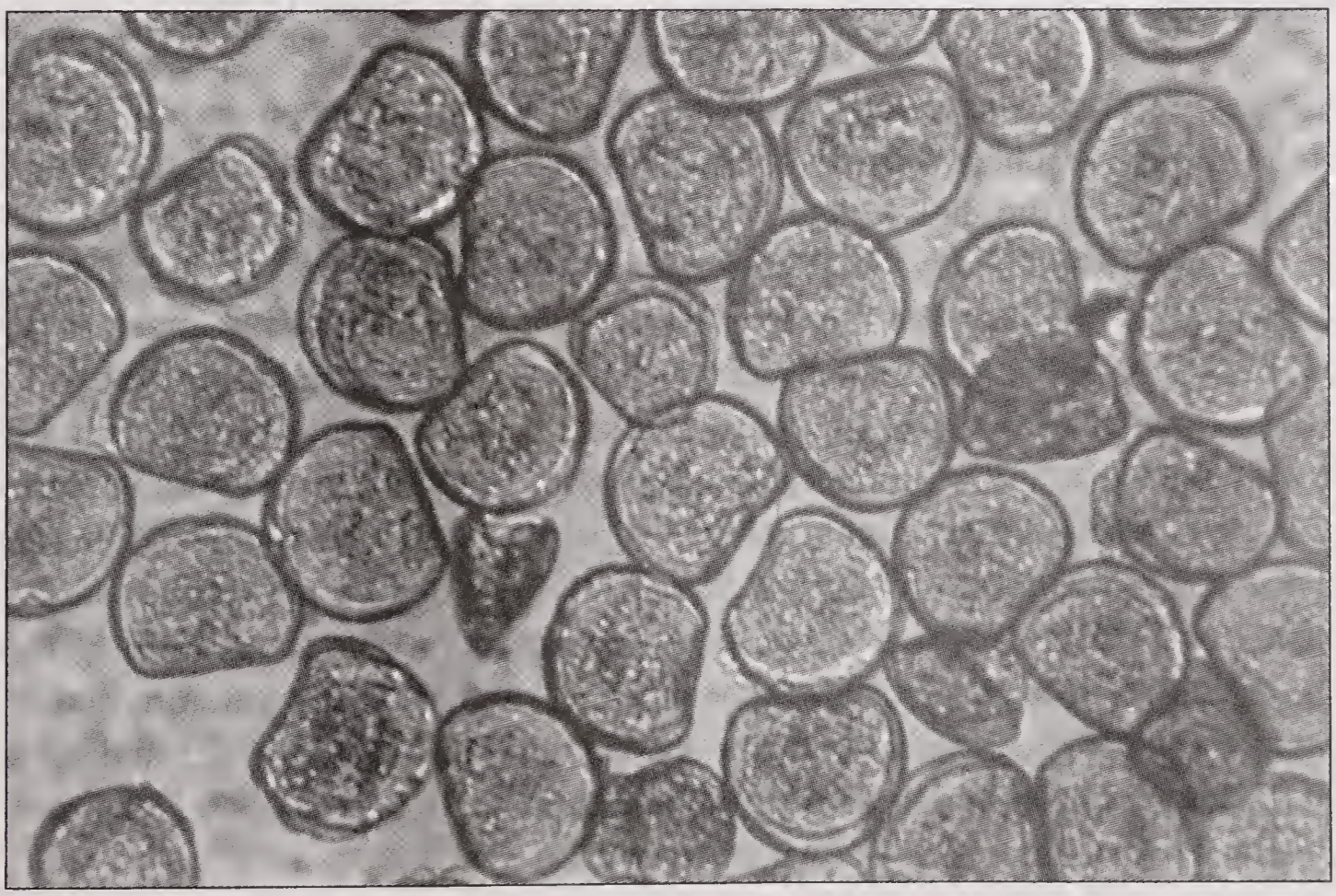

Fig. 21. D-larvae of oyster produced in the hatchery. Size 65 µm
Courtesy: CMFRI, Cochin, Kerala

larvae are fed with phytoflagellates, *Isochrysis galbana* and *Pavlova lutheri* at the end of 24 hrs from fertilisation. During larval rearing, the water in the rearing tanks is changed daily with fresh filtered seawater and then food is given. Aeration is provided. The sequence of the development of the larvae from the straight hinge stage to the pediveliger stage is given below.

Stage	Size µm	Hours / Days
Straight-hinge	60-70	20 hrs
Early umbo	100	3rd day
Mid umbo	150	7th day
Advanced umbo	260 to 270	12th to 15th day
Eyed larva	280 to 290	13th to 17th day
Pediveliger	330 to 350	14th to 18th day

The rearing density of the larvae at various growth stages and the feeding protocol with flagellates are given below. The nanoplankters measuring up to 10 µm pass through the sandfilter used for seawater filtration. As a result additional food is available to the larvae.

Stage of larvae	Number of larvae/ml	Algal cell concentration in nos/larva/day
Straight-hinge	5	3,000-4,000
Umbo	3	4,000-5,000
Advanced umbo	2	5,000-8,000
Eyed stage	2	8,000-10,000
Pediveliger	2	10,000-12,000

On the third day the larval shell is slightly oval in shape and the early umbo stage is reached. They are filtered through 80 µm sieve. On the seventh day the umbo on the shell is distinct and pronounced concentric rings are seen on the larval shell. Between 12 and 15 days the late umbo stage is reached (Figure 22). In 13 to 14 days the eyed stage is reached with the appearance of characteristic eye spot. The pediveliger larvae start setting within 24 hrs or sometimes it is prolonged by 2 to 6 days depending on the availability of favourable substratum. Before metamorphosis, the oyster larvae permanently cement themselves to a suitable substrate and this is called settlement. During larval rearing, mortality of 2 to 3 % per day was considered as normal by Nayar *et al.* (1984). In a study on the effect of salinity on the growth of D-larvae of *C. madrasensis* till settlement at 29.1 to 32.4^0 C temperature range, Nayar *et al.* (1988 c) observed faster growth rate, 20.1 µm/day at 25 and 19.5 µm/day at 30 ppt salinities when compared to 18.0 µm/day at 20 and 16.4 µm/day at 35 ppt salinities of the water medium.

Utting and Spencer (1991) stated that the D-larvae of C. *gigas* can be grown at densities of 15-20/ml but growth and survival have improved

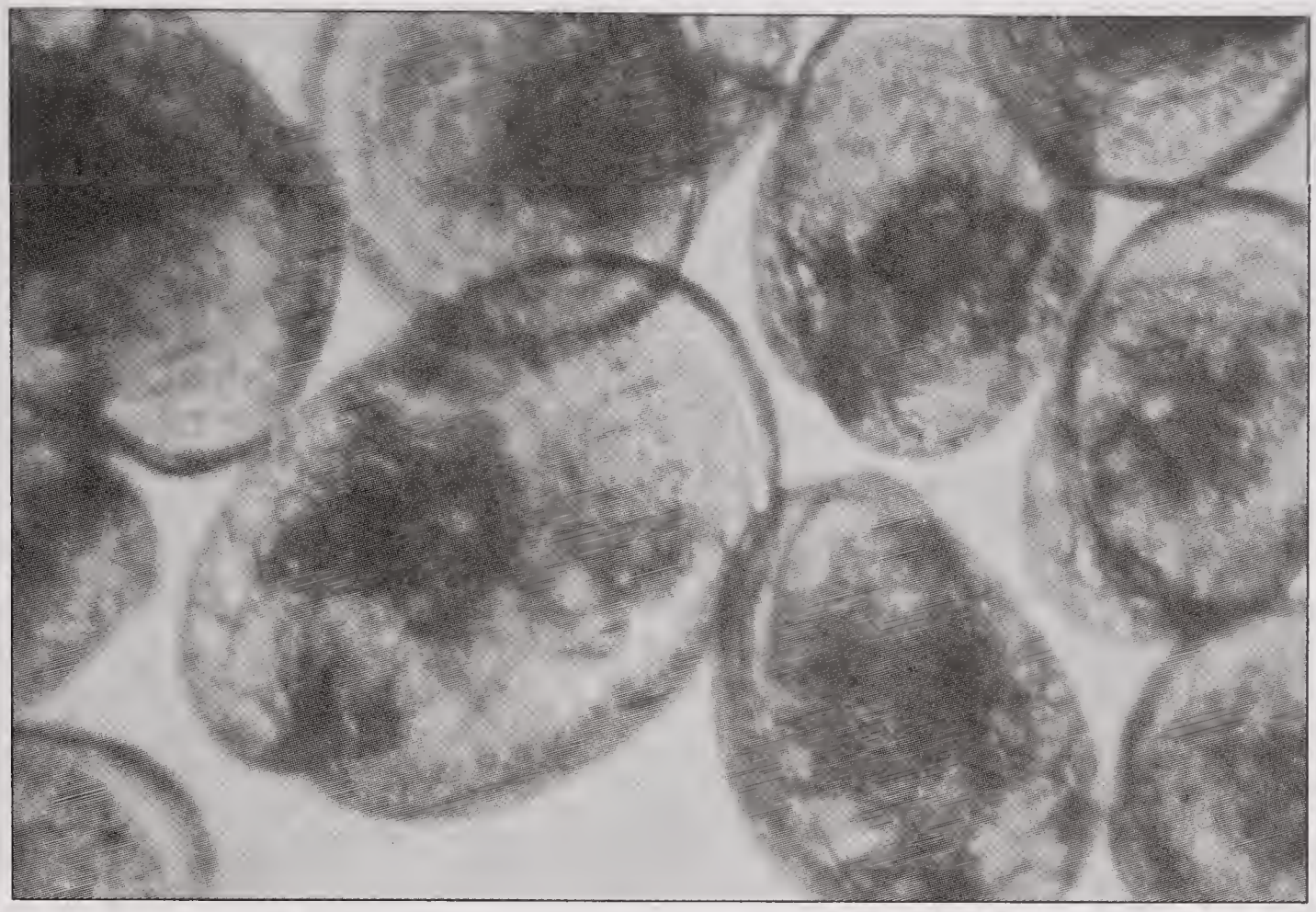

Fig. 22. Late Umbo stage of oyster larvae. Size 260 µm
Courtesy: CMFRI, Cochin, Kerala

considerably at densities below 10/ml. They stated that mixed algal diets are preferred and a suitable diet for the D-shelled larvae is a mixture of *Chaetoceros* and *Isochrysis*; the most suitable cell densities are 125 cells/ ml and 50 cells/ ml respectively. The number of algal cells/larva/day is higher than that reported from India. They suggested that with high densities of larvae, it is necessary to add the total daily ration in two or more feeding sessions. The larval culture is carried in static water systems (i.e., flow-through system avoided).

Preparation of Cultch Materials and Spat Production

The cultch materials used in the hatchery must be non-toxic and clean. They should be compact to allow sufficient water circulation in the rearing tank and hard enough to withstand handling. They should not alter the water quality. The most common materials used for the setting of oyster spat in the hatchery are oyster shells, shell grit and polythene sheet; the most preferred are oyster shells. A hole is drilled at the center of the shell, brushed well, washed in chlorinated water and pretreated by soaking and repeated washings in seawater. By this process the pH of the water in rearing tanks will not be affected. These shells are spread uniformly at the bottom of FRP tanks containing filtered seawater and several rows of shell rens are also suspended in order to increase the surface area for settlement in the tank (Figure 23), when majority of the larvae pass off the eyed stage (300-350 µm). In a 200 x 100 x 50 cm tank 400-500 oyster shells are laid (P.Muthiah, personal communication and Rao *et al.*,

Fig. 23. Shell collectors suspended in the larval rearing tanks in the hatchery for the collection of oyster spat
Courtesy: CMFRI, Cochin, Kerala

1992).The larvae are released into the tanks at a concentration of 2 larvae/ ml and the setting tank is well aerated. The larvae are fed with *Isochrysis* at the rate of 10,000-12,000 cells/ larva/ day. During the next few days the larvae set on the shells and majority of the larvae settle on the concave side of the shells. The spat settlement is 70 to 80/ oyster shell (Rajapandian *et al.,* 1993) and in a separate study Muthiah (personal communication) gave the average as 39 spat/ oyster shell (Figure 24). The production of attached spat for a 1 tonne tank holding 400 oyster shells is 15,630 (P.Muthiah, personal communication).

Oyster shell grit and polyethylene sheets are used for the production of cultchless spat. Oyster shell grit of 0.5 mm in size are washed thoroughly, sterilised in 10 ppm chlorine, washed once more in running filtered seawater and dried. The shell grit are uniformly spread at the bottom of one tonne capacity FRP tank and the larvae at setting stage are released. For setting on the polyethylene sheet the bottom and sides of the tank are lined with pretreated polyethylene sheet and the released larvae settle on the sheet. In the larval setting tanks, before feeding, water is completely changed on alternate days and half the water is changed on the other days. It takes 5-6 days for larval setting. The spat are reared for three weeks and are fed with mixed phytoplankters such as *Chaetoceros* sp, *Skeletonema costatum, Thalassiosira subtilis, Nitzschia* spp. etc. Average setting on polyethylene sheet is 4 spat/ cm^2 (Nayar *et al.,*1987b). In a study on the rate of spat setting, Nayar *et al.* (1988 c) observed that the D-larvae of *C. madrasensis*, reared at 29.1 to 32.4^0 C in the hatchery gave spat production of 2.6 to 7.9 % of the initial larval stock.

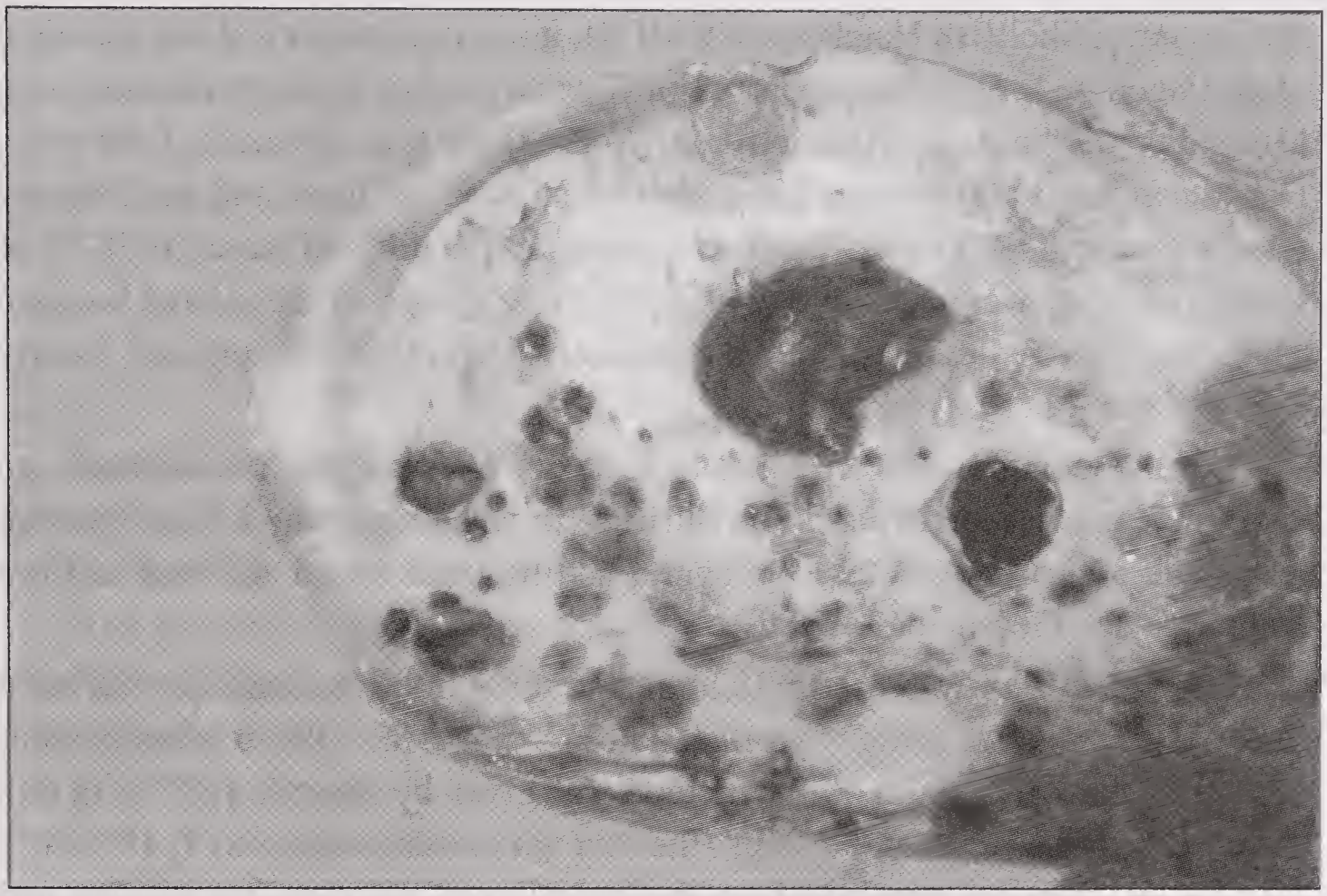

Fig. 24. Oyster spat, set on shell collector in the hatchery
Courtesy: CMFRI, Cochin, Kerala

The chemicals epinephrine and nor-epinephrine added at concentrations of 10^{-4} M - 10^{-5} M are said to induce oyster larvae to settle and metamorphose for the production of cultchless spat (Coon *et al.,* 1986).

For spat rearing, nursery upwelling systems are suitable for oysters, immediately after settlement (Utting and Spencer, 1991). Spat growth is largely dependent by the quantity of food available for feeding. The ration is calculated on dry weight of algae. One million *Tetraselmis* cells are equivalent to 0.2 mg dry weight. Feeding a ration of 0.4 mg dried algae per milligram (live weight) of spat per week provides good spat growth (Utting and Spencer, 1991). These authors gave the following dry weights of algae species commonly used in the hatcheries.

Dry weight (mg) per million cells

Species of algae	Weight
T - ISO	0.02
Skeletonema costatum	0.032
Chaetoceros calcitrans	0.007
Choromonas salina	0.13
3 H (*Tetraselmis pseudonana*)	0.02
Tetraselmis suecica	0.20

Culture of Algal Food

The success of hatchery operation largely depends on providing adequate quantities of suitable micro-algal food to the larvae and spat of the oysters. At

the Tuticorin Shellfish Hatchery of CMFRI, it has been observed that the ideal phytoflagellate for feeding the larvae of *C. madrasensis* is *Isochrysis galbana*, a member of the class Haptophycae. Apart from this, species of *Pavlova*, *Dicrateria* and *Chromulina* have also been tried as food and satisfactory results obtained. All these flagellates measure 7-8 µm and have 26-38 % of protein by body weight (Nayar *et al.*,1987 b). Once the larvae set and become spat, they are fed with mixed culture of micro-algae comprising mostly diatoms and other phytoplankters.

For the isolation of the required species of micro-algae five methods are in vogue namely, pipette method, centrifuge or washing method, by exploiting the phototactic movements, by agar planting, and serial dilution culture technique(see Gopinathan, 1982).

Serial Dilution Technique: In India, the serial dilution technique has been used for the isolation of the phytoflagellates (Nayar *et al.,* 1987 b ; Gopinathan, 1996). A detailed account of this method was given by Sournia (1971). In this method, mainly five dilution steps (the inocula corresponding to 1, 10^{-1}, 10^{-2}, 10^{-3} and 10^{-4} ml) are employed for the isolation of the required species and nearly 25 culture tubes (15 ml) are required. After filtering the seawater through 10-20 µm sieve, the filtrate is inoculated to five series of culture tubes in various concentrations. This is kept under sufficient light (1000 lux) with uniform temperature (25^0 C) conditions. After 15 days some discolouration is seen in the culture tubes due to the growth of micro-algae. This culture is further purified by sub-culturing it in 500 ml or one litre conical culture flasks. Once the culture is completely purified, it is transferred into 3 or 4 litre Haufkin culture flasks and maintained as stock culture. The stock culture can be maintained for 1-2 months.

After the isolation of the desired species in culture tubes, they are sub-cultured again in a few 50 ml test tubes. These test tubes form the base for the continuous supply of axenic live algae for the large-scale micro-algae production system in the hatchery.

Culture Media: For the successful culture of the micro-algae various chemical culture media are used. Although most algae are photoautotrophic and can grow in purely inorganic media, others require organic compounds and the requirements may be either absolute or stimulatory. Usually for culturing the flagellates the Conwy or Walne's medium (Walne,1974) is used at the Tuticorin shellfish hatchery for the maintenance of stock culture as well as mass culture (Nayar *et al.,* 1987 b).

Growth Phases of the Algae: During the laboratory culture of the micro-algae, increase in cell numbers follows a characteristic pattern comprising 5 phases. In the lag or induction phase, there will be no cell division for a few hours among the cells inoculated to a new flask. The exponential phase is characterised by rapid cell multiplication and growth which continues till the

culture reaches to a maximum level. In the declining phase, the growth and multiplication of the cells is arrested and slowly the cell numbers decline. After the arrested growth, the culture passes into the stationary phase, marked by the absence of further cell division for a few days. Actually this phase is prolonged in the case of flagellates and they may develop some cover, cyst or matrix around their body for thriving in the unfavourable conditions. Finally during the death phase the cells loose vitality and die, rendering the culture useless.

Stock Culture Maintenance: These are maintained in 3 or 4 litre Haufkin culture flasks. Autoclaved or boiled seawater, after cooling is provided into the Haufkin flasks and required nutrients (Walne's medium) are added. About 10 ml of the inoculum in the growing phase is transferred to the culture flask and the same is placed in front of two tube lights (1000 lux). The exponential growth phase usually peaks after 8-10 days and the illumination is reduced to one tube light. In the stationary phase the culture can be maintained for two months in the stock culture room under controlled light and temperature, and with or without aeration. At the peak exponential growth phase the culture turns dark brown in colour and the cells remain in suspension without movements.

Mass Culture: The mass cultures are raised indoors by using the fully grown inoculum from the stock culture in 10 l polythene bags, 20 l glass carbuoys, 100 l perspex tanks and 250 l cylindrical transparent FRP tanks. Nutrient medium is added to these containers. They are held on wooden racks and provided with light and aeration (Figure 25). The algal cells usually reach the maximum concentration in 4-5 days and are harvested. In the out door mass culture of diatoms and nannoplankters, commercial inorganic fertilisers are used along with the mixed phytoplankters from raw seawater (after filtering the zooplankters) from the inoculum (Figure 26).

Harvest: The fully-grown algal culture is harvested during the exponential phase, after determining the cell concentration. During the declining and stationary phases, the load of metabolites will be very high and the algal cells may not be in the healthy condition.

General Conditions: For the axenic cultures, the glassware are sterilised. Most flagellates require low light intensity during the stationary and declining phases. Twelve hours of light and 12 hours of darkness is maintained in the stock culture room and indoor mass culture facility. This is achieved by auto-time controlled switch. Normal room temperature of 28-30^0 C is not conducive for micro-algae culture. The temperature in the culture room is maintained at 23-25^0 C by air conditioners. It is essential to aerate the micro-algae holding containers as it promotes growth, keeps the culture in suspension, uniformly distributes the nutrients in the water column and supplies the carbon dioxide required for photosynthesis.

Fig. 25. Axenic culture of microalgae in the shell-fish hatchery at Tuticorin
Courtesy : CMFRI, Cochin, Kerala

Fig. 26. Outdoor culture of microalgae
Courtesy: Surya Hatcheries

TRANSPORTATION OF OYSTER SEED

The farmed oyster grow out areas are not always suitable for the collection

of seed in required quantities. In such situations live transport of oyster seed either from the hatcheries or from the sites where natural seed occur in abundance, is resorted. The best example is the long distance transport of the hardened seed of the Pacific oyster *C. gigas* from Japan to the USA by ship involving 10 days journey. This began in 1920s and continued till 1970s (with a break during second world war). This practice helped to build and sustain the oyster production along the U.S. Pacific coast. This species is not native to the USA, and apart from several introductions, the import of the seed resulted in the successful spawning and establishment of the populations of this species in areas around Hood canal and Wilapa Bay in the Washington state (Chew, 2001). Hardening involves periodical exposure to air and this is best done by keeping them in the midtidal zone in the coastal water. Further details on the hardening of *C. gigas* seed are given in Chapter 10. Hardening helps the seed to resist environmental stress resulting in higher survival during transport.

In India, hatchery raised and hardened *C. madrasensis* seed were transported to several places, mainly to assess the suitability of the sites for developing oyster culture. For hardening, the oyster seed are held in a container and covered by a wet piece of gunny cloth (soaked in seawater and excess water drained) for 24 hours. Then they are transferred to a container filled with filtered seawater and aerated for the next 24 hours. This process is repeated for about 10 days (Chellam *et al.,* 1988). Experiments conducted on the hardened and normal *C. madrasensis* seed showed that the former can be maintained in semi-arid condition up to 120 hours with 76% survival while in the latter the survival was 22% (Muthiah,1987).

For transportation, the hardened oyster seed are wrapped in seawater soaked gunny sheet, and transferred to either box-type cage of 40 x 40 x 10 cm covered with small mesh nylon cloth or tin container (about 16 l capacity). During the transit, once or twice, depending upon the journey time, the seed are transferred to plastic basins containing fresh seawater for a few hours and then repacked as before. The details of the transport of the hardened seed from the Tuticorin hatchery to different parts of the country are given in Table 25. Some adult oysters are also included in the consignments. The longest duration of the seed transportation was from Tuticorin to Jamnagar involving 36 hr journey. The mortality rate was low and varied from nil to 9 % except for one instance when there was total mortality (Table 25) and the reasons are not known.

Table 25. Particulars of *C. madrasensis* seed transported from Tuticorin to different places

S. No	Year	Sent to	Number of seed	Size (mm)	Mode of transport	Duration of transport (hrs)	Mortality %
1	1981-82	Madras	250	15-25	Road	17	0.4
2	1981-82	Narakkal	2,500	15-20	Road	14	Nil
3	1987-88	Jamnagar	5,800	8-38.5	Road and Air	36	9
4	1988-91	Jamnagar	5,500	9-60	Road and Air	36	100%
5	1988-91	Jamnagar	10,000	1-5	Road and Air	36	Nil
6	1992-93	Cochin	4,500	10-55	Road	10	Nil
7	1992-93	Calicut	4,500	10-55	Road and Train	18	Nil
8	1992-93	Mangalore	4,500	10-55	Road and Train	22	Nil
9	1992-93	Karwar	4,500	10-55	Road	30	Nil
10	1992-93	Madras	4,500	10-55	Train	15	Nil
11	1992-93	Kakinada	4,500	10-55	Train	30	Nil
12	1995-96	Pondicherry	1,500	1.4-42.6	Road	15	Nil
13	1995-96	Karwar	3,725	27.3-58.4	Road	28	Nil

Source : Chellam *et al* (1988) and Muthiah *et al* (2000)

QUESTIONS

1. Write on seasonal occurrence of natural spat of oysters at different places along the Indian coast.
2. Describe briefly the techniques used in induced breeding, larval rearing and spat production of oysters in the hatchery.
3. Give an account on the culture of micro algae in oyster hatchery.
4. Write short notes on: a) Oyster brood stock selection and conditioning in hatchery b) Preparation of cultch materials for spat collection c) Serial dilution technique for isolation of algae d) Transportation of oyster spat.

Chapter 7

Technology of Farming

IN India, Hornell (1910 b) initiated oyster culture experiments by laying lime coated tiles for spat collection in the Pulicat Lake, near Chennai on the east coast. Awati and Rai (1931) reported that the oysters collected during March-May were stocked in farm sites at Kelwa, Navapur and Utsali in Maharashtra. This was basically a holding practice till the oysters were marketed during October-May. Concerted efforts to develop the oyster farming technology have been made since 1970 's at the Tuticorin Research Centre of CMFRI. Initially natural seed were used. The development of hatchery technology for large-scale oyster seed production in 1982 at the Shellfish Hatchery of CMFRI, Tuticorin gave further impetus for oyster culture. Several location testing programs for oyster culture have been taken up at many centres along the Indian coast, using both the natural and hatchery seed. As mentioned in Chapter 6, the Ashtamudi Lake in Kerala has proved to be a good site for natural seed collection and farming the oysters, leading to small-scale oyster culture by villagers.

SELECTION OF FARM SITE

Several physical, chemical, biological and social factors are to be considered for selecting the site for oyster farming. Site selection also depends upon the type of oyster culture.

Water Depth and Type of Substratum

Intertidal and shallow subtidal areas are suitable for on-bottom culture but the bottom should be firm. For off-bottom culture (racks, stakes, rafts and long lines), the nature of the substratum is of little concern. For stake and rack methods of culture 1-3 m depth is suitable; the raft and long line culture systems are practiced in coastal waters where the depth is 5 m or more.

Tides

Tidal height is of no consequence in the raft and long line cultures. The rack and stake farms are generally located at subtidal areas, but short duration tidal exposure of the oyster stock in the intertidal areas renders farm maintenance easy. The water flow due to the tidal cycle is of little concern in the on-bottom culture but may cause movement of rens and trays in the suspended culture.

Protection from Wave Action

Areas prone to strong wave action are not suitable for oyster culture since they stir up sediments in shallow waters reducing feeding efficiency and damage the farm structures (Quayle and Newkirk, 1989). Experience in the raft culture of mussels in India showed that in the open coastal waters, the rough sea conditions do not permit year round farming and only a seasonal mussel crop of 5-6 months duration can be raised. Sheltered sites such as estuaries, bays and lagoons are preferred.

Water Quality

This includes temperature, salinity, dissolved oxygen, pH, nutrient salts, turbidity and productivity. All these factors show seasonal variations and a quantitative evaluation over a period of time will help in selecting the site. The critical levels of various factors differ from species to species selected for culture. For example among the Indian oysters, the rock oyster *Saccostrea cucculata* thrives well in marine environment whereas *Crassostrea madrasensis* and *C. gryphoids* are euryhaline, mostly inhabiting in backwaters. Temperature variations recorded in the different areas in the coastal regions are not much and are generally within the favourable range. High levels of turbidity interfere with the feeding of oysters, resulting in reduced growth. Based on the data collected from oyster farms in India the various parameters considered as suitable for farming the oyster *Crassostrea madrasensis* are: water temperature 25-31^{0}C, salinity 15-35 ppt, dissolved oxygen 3.0-5.0 ml/l, pH 7.5 to 8.8, gross productivity 2.0 to 6.7g C/m^3/day and net productivity 1.0 to 4.7g C/m^3/day.

Pollution

Three types of pollutants are of prime importance in oyster culture (a) pathogenic bacteria and viruses, (b) toxic algae, and (c) heavy metals and chemicals. The source of microbial pollutants and heavy metals/ chemicals are the untreated sewage and industrial wastes respectively. They enter the culture sites due to run off from the land. Blooms of toxic algae periodically occur in certain areas, and are reported from India. The oysters accumulate these toxins in their body and humans consuming them fall sick, sometimes resulting in death. Hence areas prone to pollution should be avoided.

Predation and Fouling

They are dealt with under Chapter 4 and a preliminary survey of the site helps to collect information about their presence. However, a site need not necessarily be rejected on this account since proper management of the farm takes care of them.

Conflicts with Other Users

Areas used by others such as for navigation and traditional fishing should be excluded so as to avoid possible conflicts.

Access

It is advantageous to have easy access throughout the year to the culture site since men and materials are to be transported to the farm and harvest to be carried back.

NURSERY REARING OF SPAT

Oyster spat are reared in nurseries by providing protection till they grow to a size of 25-30 mm. Nursery rearing ensures good survival of the spat and they are better off to withstand the adverse conditions and predation. There are several types of nursery systems, either land-based or located in the water body. In India, nursery rearing is felt necessary for the hatchery reared spat since it is expensive to maintain them in the hatchery till they reach 25-30 mm size for grow out culture. For the natural spat the nursery and grow out cultures are combined in India.

Natural Spat

In the rack and tray method of farming at Tuticorin, *C. madrasensis* spat are collected on lime coated tiles laid in box type cages and held on racks. Spat set on these tiles attain size of 25 mm in 2 months, and are scrapped from the tiles for further rearing in box type cages (Mahadevan *et al.,* 1980; Nayar, 1987).

In the rack and ren method of culture practiced at Ashtamudi, strings of oyster shells suspended from racks for spat collection are also used for grow out culture and no additional protection is provided to the spat in the early growth phase. Thus both nursery and grow out cultures are combined, more oyster shells are added to the strings, which are set much nearer to each other. This practice reduces the water flow and enables heavier spat set.

Hatchery Spat

Throughout the world, the hatcheries prefer to take out the spat at the earliest since it is expensive to maintain them longer. In the rack and ren method of culture followed at Tuticorin, the hatchery raised spat are cultured in the nursery. Each string of 1.5 m long having 6 oyster shells, with spat attached is taken out from the hatchery tank 15 days after the spat was set. In the nursery, 3-4 strings are held in a velon screen bag and these bags are suspended from racks (Figure 27). The velon screen bag is periodically cleaned to remove silt, foulers and predators. After 30-50 days of nursery rearing the bags are removed and the strings are transferred to the oyster farm for suspension from racks (Rao *et al.,* 1992; Rajapandian *et al.,*1993).

The stake is the support used for rearing the spat, which are usually set on the oyster shells. In this method the nursery and grow out cultures are carried from the same stake. Casuarina or eucalyptus stakes of 1-1.5 m length with a nail on the top end and two or three nails on the sides, close to the top end, are

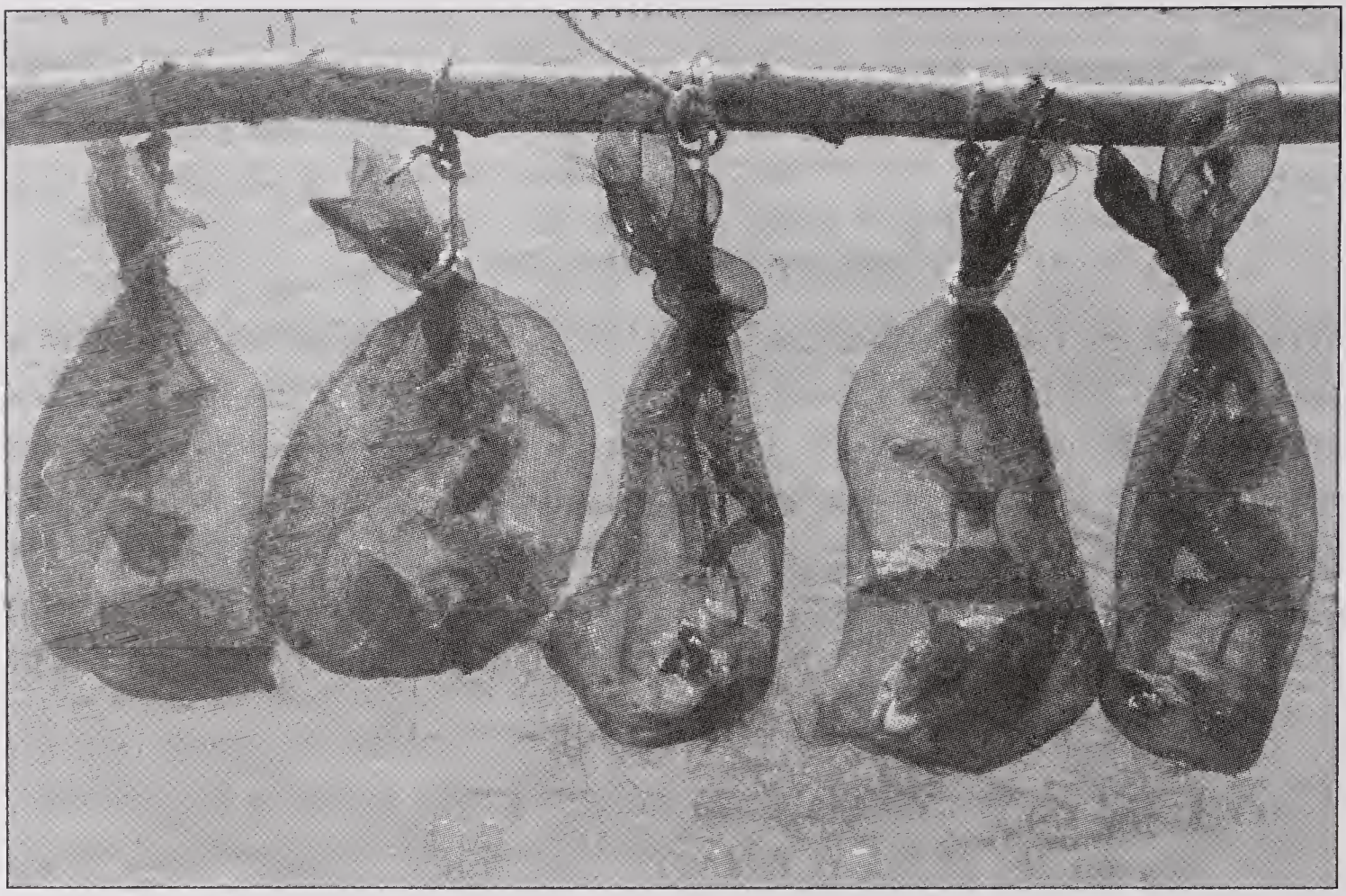

Fig. 27. Oyster shell strings with attached spat held in nylon bags for nursery rearing Courtesy: CMFRI, Cochin, Kerala

driven into the substratum. Each nail holds in place one oyster shell with hatchery raised spat of about 4 mm length set on it (P.Muthiah, personal communication). The top portion of the stake, holding the spat set on oyster shell, is covered with a piece of velon screen to protect the spat against predation. The velon screen is removed after 2-3 months of nursery rearing when the oysters attain 25-30 mm length (Rao *et al.,* 1992; Muthiah *et al.,* 2000).

GROW OUT CULTURE

There are several methods of farming the oysters and the details are given by Quayle and Newkirk (1989). Broadly they come under two categories namely bottom (also called on-bottom) culture and off-bottom culture. They are further divided as follows:

1. Bottom	(a) intertidal
	(b) subtidal
2. Rack	(a) tray
	(b) string
	(c) stick
3. Stake	
4. Raft and long line	(a) tray
	(b) string
	(c) stick

Those listed under 2, 3 and 4 come under off-bottom culture.

Bottom Culture

This is a very old method and it is low intensive both for capital and labour. It is practiced in intertidal or subtidal areas. A major requirement for this method of culture is a firm and stable bottom, with minimum siltation. This method of culture has been attempted in the Karapad creek and Korampallam canal by planting cultchless and attached spat, set on oyster shells. The oysters attained 75 mm average length at the end of one year (Nayar *et al.,* 1988 a).

Intertidal Bottom Culture: It is well known that the oyster populations in the subtidal areas grow faster than those in the intertidal region since the former have access to food without interruption. Greater tidal exposure results in proportionately slower growth (Summer, 1981; Spencer, 1990; Ruwa, 1990). Strong wave action during the tidal cycle may displace the oysters and may also cover them under sand or mud. High levels of turbidity created by wave action may affect the feeding. Predation by star fishes and rays is high on oysters grown intertidally. To protect the oysters from rays, in the Arcachon area in France stakes are planted in the oyster beds and in the Humboldt Bay in the USA the culture site is fenced (Quayle and Newkirk, 1989). An advantage of intertidal culture is the low fouling intensity. The shell cultch with attached spat are planted on the ground during low tide. Apart from predation, mortality results due to siltation and competition for space. The seed attached on cultch generally grow into clusters. It is necessary to decluster them into single oysters or small groups of oysters. In temperate waters this is done when they have grown to 3-5 cm length; declustering results in mortality up to 25% (Quayle and Newkirk, 1989). Management practice involves cluster separation, thinning if density is high, and removal of foulers and predators. Hand picking, raking or forking are the methods used for harvest.

Subtidal Bottom Culture: It is generally practiced in depths up to 5 m. This is similar to intertidal culture except that predation control is not easy and fouling is more intense. The main difference lies in harvesting for which dip nets, tongs and dredges are used. This method of culture is practiced in Long Island Sound in Eastern USA (Quayle and Newkirk, 1989).

Rack Culture

The rack is a fixed structure and is constructed either in intertidal or subtidal areas (Figure 28). The advantages of rack culture include a) independent of the type of substratum b) faster growth compared to bottom culture c) fewer predator problems and d) low silting mortality (Quayle and Newkirk, 1989). A variety of culture devices such as oyster shell strings, trays, tyres, different types of nets, tubing and sticks may be held on or suspended from racks.

There are several types of racks and in India single beam and parallel beam racks are mostly used. The single beam rack, as the name implies consists of a single beam (pole) placed horizontally and secured on several poles, vertically driven into the substratum. This rack is good for suspending

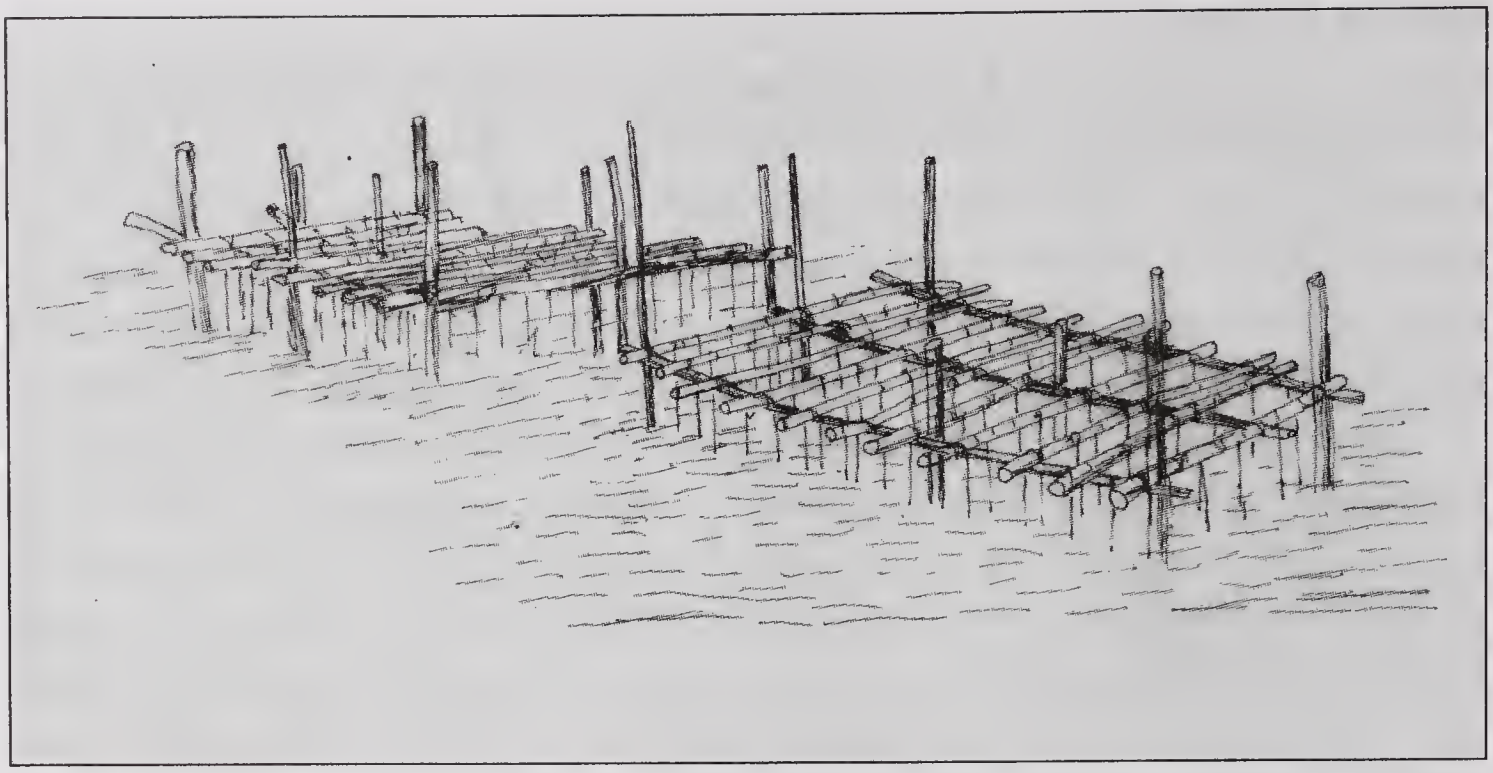

Fig. 28. Farm structure - Rack

strings or trays. Two single beam racks running parallel and connected by cross poles is known as parallel beam rack; it is suitable for tray culture. Casuarina, eucalyptus and bamboo poles depending upon local availability are used in the country for rack construction.

Rack and Tray Culture

The advantages of tray culture are rapid growth, production of single oysters with good shape and high quality meats, and control of stock. The disadvantages include high production cost, fouling and yield limited to single oysters. In India, large scale studies on the culture of *Crassostrea madrasensis* were initiated in 1978 by the rack and tray method in the Karapad creek and later in the Tuticorin bay (Mahadevan *et al*., 1980; Nayar and Mahadevan, 1983). The oyster farm is situated in the Tuticorin bay on the south--east coast of India (Figure 29). The racks were erected in the bay where the depth varies from 0.5 to 1.5 m and salinity from 29.4 to 35.3 ppt. Rarely in the monsoon season, due to heavy rainfall and discharge of fresh water from creeks in the area the salinity may drop to 15 ppt. The temperature ranges from 25-31^0 C. It is high during April-May (peak spawning season) and low during January-February when it varies between 25-28^0 C. The tidal range is 0.3 to 1.3 m.

The rack is constructed by driving six poles, each of 2.4 m in length into the substratum up to 60 cm depth. These poles are fixed in a line, 2 m apart and another set of six poles are driven parallel to the first row. These two rows of poles are connected by tying 2.4 m long cross poles. Above these cross poles, 8 poles of 5.5 and 6.5 m length are placed and tied to form a platform which is used for keeping oyster trays. Coir and 3 mm diameter synthetic ropes are used for tying the poles. Each rack covers 25 m^2 area and accommodates 20 rectangular trays. In 0.25 ha area 60 racks each of 25 m^2 can be erected (Nayar, 1987).

Fig. 29. Rack and tray culture of oysters at Tuticorin. Oyster trays are held on racks Courtesy: CMFRI, Cochin, Kerala

Lime coated curved roofing tiles of 24 x 15 cm size are placed at the rate of 50 tiles/ tray of 100 x 75 x 15 cm size. The tray is made of 5 mm iron rod and covered with 2-2.5 cm mesh synthetic twine. The tiles are placed with their convex side facing downwards. The trays with tiles are placed on the rack and remain submerged during spat collection (Thangavelu and Sundaram, 1983).

Spat, set on lime coated tiles are grown for two months by which time they reach 25-38 mm size and are scrapped for further rearing on racks. The detached single spat are reared in 40 x 40 x 15 cm box type cages made of 6 mm M.S.round rods and covered by 12 mm mesh synthetic twine. The cages with cultchless oyster spat (150-200 nos/ cage) are suspended from racks by 4 mm thick and 1.5 m long synthetic ropes. (Nayar, 1987).

After two months rearing, the oyster seed reach 50 mm length in suspended cages, and are stocked in 90 x 60 x 15 cm trays at the rate of 150-200 oysters/ tray. The frame of the tray is made of 6 mm welded steel and covered by 20 mm mesh synthetic twine. On a rack of 25 m^2, 20 trays are accommodated, holding 3000-4000 oysters. The oysters are reared, beginning from settlement for one year, when they attain 80-90 mm length (80-100 g shell-on weight with meat farming 8-10 %). During the rearing period, periodically the cages, trays and oysters are cleaned of foulers, and predators such as crabs and gastropods. The poles of the racks are replaced if needed (Nayar, 1987). The oysters are harvested when the condition factor (see Chapter 3) is high which occurs before spawning; soon after spawning the oyster meat looses weight, becomes thin and flabby, and is not tasty. Rajapandian *et al.* (1993)

recommended the harvest of oysters when the condition factor values range between 120-150. The oysters are harvested by collecting them from the rearing trays in to a dinghy and brought to the shore. By the rack and tray method the actual production was 27.5 tonnes shell-on / 0.25 ha/year. The yield of oyster meat from this farm was 2,475 kg at 9 % of shell-on weight (Nayar *et al.,* 1987a). In this farm 60 racks were accommodated and each rack covered 25 m^2 area, supporting 20 trays containing 4,000 oysters. In an earlier study Nayar and Mahadevan (1983) estimated the mortality of oysters as 5 % in the farm by this method. Rao *et al.* (1992) estimated the production of shell-on oysters at 120 tonnes/ ha/ year by rack and tray culture.

Since the environmental conditions are relatively stable and the farm site is protected from strong wave action in the Tuticorin bay, it is possible to culture the oysters for 12 months in a year, harvesting one crop. As the oysters are marketable from 60-70 mm size onwards it is worthwhile to investigate whether they can be harvested between 8-10 months culture and its affect on production. However, the condition factor of the oysters should be considered in such studies.

Rack and Ren culture: This method became popular in India and was adopted by the farmers. The CMFRI is maintaining rack and ren oyster farms for Research and Development for two decades in the Tuticorin bay, and in the Ashtamudi Lake since 1993. The racks used are the same types described earlier with slight modifications. The farming of oyster carried out at the Tuticorin bay and at the Ashtamudi Lake are as follows:

Tuticorin bay

For spat collection oyster shells are strung on G.1.(NO.10) wire of 1.5 m length. Each unit is called a ren. During the peak spawning season (April-May) the rens are laid horizontally on the racks at 100 rens/ rack. The number of oyster spat collected ranged from nil to 27 with an average of 7 nos/ shell (Muthiah, 1987). After spat settlement, fresh rens are prepared by providing inter spaces between the shells with attached spat. These rens have 5-6 oyster shells with inter spaces of 15 cm between adjacent shells and are suspended from racks. In one year the oysters grow to an average size of 85 mm (Nayar *et al.,* 1988a).

Rajapandian *et al.* (1993) have generated valuable data on the rack and ren method of oyster culture by operating a pilot project at Tuticorin. Hatchery raised seed of *C. madrasensis* were used and about 70-80 spat were set on each oyster shell cultch. The average spat set on oyster shell in the hatchery is 39 (P. Muthiah, personal communication). In a 1.5 m long nylon rope (5 mm thick), 6 shells with attached spat collected from the hatchery were strung by giving spacers and reared in the nursery for 30 days in velon screen bags . The velon screen bag is removed and strings are suspended from racks in the oyster farm for grow out culture. The farm area was 0.76 ha with 96 racks. Each

occupied 80 m^2 area and 80 strings were suspended from a single rack. The growth data and survival from the time of transfer from the hatchery to the time of harvest (12 months) are given in Table 26.

Table 26. Average growth of oysters in strings by weight and percentage survival in the rack and ren farm at Tuticorin. Each string has 6 oyster shells

Period of rearing in months	Average weight (kg) of one string with oyster spat	Average nos. of spat/ oyster string	Average weight of an oyster in g	Percentage survival
1	0.525	74.0	-	-
2	0.980	65.0	7.00	87.8
3	1.755	61.0	20.16	82.4
4	2.585	58.4	35.50	78.3
5	3.350	56.0	50.40	75.6
6	4.295	53.5	70.10	72.2
7	4.800	51.0	83.80	68.9
8	5.250	49.0	96.40	66.2
9	5.800	47.0	112.20	63.5
10	6.240	45.0	127.00	60.8
11	6.920	43.0	148.00	58.1
12	7.350	39.0	175.00	52.7

Source: Rajapandian *et al*, 1993.

The oysters have grown from 7.0 to 175.0 g shell-on weight during the culture period and at harvest the weight varied between 165-181 g/ oyster. Maximum mortality/ fallout was 12.2 % in the first month (Table 26). The survival rate at the end of the year was 52.7 %. The production from 3,655 shell rens harvested on four occasions resulted in 27.95 tonnes (Rajapandian *et al.,* 1993). This gives a production of 7.63 kg shell-on/ ren and the estimated production works out to 76.4 tonnes/ hectare/ year. These authors have stated that the oysters can be harvested at the end of 10 months. Rao *et al.* (1992) estimated the production rate as 80 tonnes/ hectare/ year. The oysters are manually harvested by untying the oyster rens from the racks and individual oysters are separated from the clusters. After cleaning, the oysters are depurated.

Ashtamudi Lake

Rack and ren method of *C. madrasensis* culture was initiated in the Ashtamudi Lake in October 1993.

Farm Site and Hydrography: The Ashtamudi Lake has 32 kın^2 water spread, and has extensive beds of *C. madrasensis* and *S. cucullata*. The Lake supports a wide range of bivalve fauna and the livelihood of more than 3000 villagers is directly or indirectly linked to these resources. The culture site is located at Dalavapuram, 3 km interior from the Lake mouth. It is well protected and has good tidal flow from the Arabian sea. The range of tidal amplitude is 0.07 to 1.29 m. The hydrography of the culture site during September 1994 to

August 1995 (Table 27) indicated that salinity varied from 9 to 15.5 ppt between July and October and 19 to 31.5 ppt in the remaining months, dissolved oxygen from 2.0 to 4.6 ml/ l, water temperature was stable from 28.0 to 30.1^{0}C, pH from 7.66 to 8.8, gross primary productivity 2.0 to 8.9 g C/ m^3/ day and net productivity 0.5 to 4.67 g C/ m^3/ day (Velayudhan *et al.*,1998).

Table 27. Hydrographic data of oyster farm at Ashtamudi Lake from September 1994 to August 1995.

Month	Salinity (ppt)	Oxygen (ml/l)	Temperature Atm (^{0}C)	Temperature water (^{0}C)	Productivity Gross (g C/m^3 /day)	Productivity Net (g C/m^3 /day)	pH
Sep. 1994	14.0	4.6	31.2	28.0	2.0	0.5	7.9
Oct.	9.0	2.0	29.0	28.0	3.59	2.46	8.0
Nov.	19.0	3.0	29.5	29.8	2.05	1.03	8.8
Dec.	24.0	2.6	29.0	30.1	3.05	1.54	8.74
Jan. 1995	31.5	3.1	30.1	29.9	6.1	4.6	8.10
Feb.	31.4	3.4	30.5	28.8	5.3	4.0	7.79
Mar.	30.1	3.8	31.0	28.0	4.6	3.5	7.85
Apr.	28.0	4.1	31.2	28.2	4.4	3.1	7.77
May.	24.0	3.6	31.3	28.2	8.9	1.3	7.70
Jun.	21.0	3.6	30.0	28.1	5.34	4.01	7.72
Jul.	10.0	4.0	30.0	28.0	6.68	4.67	7.66
Aug.	15.5	3.4	30.5	28.5	5.30	1.80	7.75

Source : Velayudhan *et al.,* (1998).

Nair *et al.* (1984) studied the primary production of the Ashtamudi Lake. At Neendakara, 3 km from the oyster culture site the annual mean net productivity in the surface and bottom waters was 74.37 and 75.08 mg C/ m^3/ hr and the gross productivity 148.09 and 157.60 mg C/ m^3/ hr respectively. They stated that the "Ashtamudi estuary is one of the extremely productive estuaries in the country….".

During 1993-94, two experiments on the rack and ren method of *C. madrasensis* culture were conducted at Dalavapuram by Velayudhan *et al.* (1995) and a third experiment was undertaken in the same farm site during January-August 1995 (Velayudhan *et al.,* 1998), to augment the data base generated by the earlier study. In experiment A (called 'A') 12 oyster rens, each holding six oyster shells with attached spat (total 471 spat and average length 28.2 mm) were transported from the Tuticorin hatchery of CMFRI to the Ashtamudi Lake in October 1993. They were suspended at 2 m depth from the horizontal platform of a Chinese dip net in the culture site. In experiment B (called 'B') a total of 125 oyster rens, each holding five shells were suspended in November 1993 from a rack of 30 m^2 constructed at a depth of 2-2.5 m, close to the site of the Chinese dip net platform of 'A'. In December 1993, a total of 15,374 natural oyster spat of average length 24.0 mm were

found on the rens, and the average number of spat per ren was 123 and per single cultch 24.6 (Table 28). For experiment C (called 'C') the oyster farm was expanded in December 1994 to cover 0.04 ha comprising 6 racks; the racks were 2 m apart to provide working space. A total of 825 rens with 4,950 oyster shells were suspended from the horizontal poles of this rack (Figure 30). The cleaned shell rens were treated with 5 % bleaching solution for 10 minutes, after removing the epifauna, to minimize slipping of the spat. In January 1995, the spat settlement rate was 144 nos/ ren.

Growth: From the initial average length of 28.2, 24.0 and 23.2 mm the oyster spat have grown to 47.8, 52.0 and 65.9 mm average length in 6 months in 'A', 'B' and 'C' respectively. The length after 12 months was 63.9 mm in 'A' and 68.0 mm in 'B' while in 'C' the growth was faster and the oysters

Fig. 30. Rack and ren oyster farm at Kerala. Ready to harvest oyster rens are taken out of the water for display
Courtesy : CMFRI, Cochin, Kerala

attained an average length of 68.3 mm in 8 months. The average total weight (shell-on) of the oysters after six months were 13.2, 25.3 and 44.4 g in 'A', 'B' and 'C' respectively. After 12 months the average shell-on weight was 38.3 g in 'A' and 41.0 g in 'B' while in 'C' the growth was faster and the shell-on weight was 43.5 g in eight months. The meat weight of the oysters showed a progressive increase during the first six months of culture but afterwards registered wide fluctuations. In 'A' the highest average meat weight of 4.9 g was recorded in July after eight months, in 'B' it was 5.1 to 5.2 g during June,September and November 1994 and in 'C' the highest average meat weight was 5.6 g in August, after eight months.

Survival: In 'A' the initial density of oysters was 69 nos/ m length of ren in October 1993 (Table 28). In the following month this number was reduced to 21 oysters indicating 69.5 % mortality. From November to February there was continuous natural spat settlement on the rens. As a result, the number of oysters per metre length of ren reached a maximum of 65 in February. Natural spat set on the rens was observed for 10 months except in June and August (Velayudhan *et al.*,1995). By the end of September 1994 the number of oysters were reduced to 42 per metre length of ren indicating 64.6 % survival. In 'B' the density came down from 147 to 70 oysters at the end of 12 months culture period with 47.6 % survival. Mortality was high till the end of April 1994. In 'C' from an initial density of 144 nos/ ren in January, there was a gradual reduction to 72 oysters in June. In July there was fresh spat settlement and density increased to 125 oysters, followed by a steep decline to 77 oysters/ m ren in August. The survival was 53.4 % for eight months. There was considerable recruitment of the spat during the duration of the culture and the freshly set spat were not excluded in the calculation of the survival rates.

Production: In 'A' the shell-on production per metre of ren was 1.4 kg (meat weight 230 g) in May '94, for 8 months of culture (Table 28). Thereafter it narrowly fluctuated to peak 1.6 kg shell-on weight in September, but the meat weight declined to 189 g. In 'B' the shell-on production per metre ren progressively increased from 296 g to 2.87 kg for a culture period of 12 months. The meat weight peaked to touch 392 g in June 1994 and there after it decreased. In 'C', the initial shell-on weight of 38 g per meter ren in January 1995 increased to 3.35 kg by August; the meat weight per meter of oyster ren increased from 2.74 g to 431 g in the same period (Table 28). However, the total shell-on and meat weights touched peak values of 3.52 kg and 525 g respectively in July, after seven months culture (Table 28). A total of 550 strings from 'C' were harvested on two occasions in August 1995 and a production of 1.842 tonnes shell-on (meat yield 230.1 kg) was obtained. The remaining 275 strings were maintained in the farm for further studies.

Table 28. Production of *C. madrasensis* per metre ren cultured in the Aashtamudi Lake

Month	Expriment A			Expriment B			Expriment C*		
	Total no.of oysters	Shell on wt.g	Flesh wt. g	Total no.of oysters	Shell on wt.g	Flesh wt. g	Total no.of oysters	Shell on wt.g	Flesh wt. g
Oct 93	69	-	-	-	-	-	-	-	-
Nov 93	21	119	25	-	-	-	-	-	-
Dec 93	33	227	42	147	296	45	-	-	-
Jan 94	45	324	81	137	917	160	144	38	2.74
Feb 94	65	559	147	106	911	190	137	329	38
Mar 94	49	646	156	90	945	198	127	1,015	141
Apr 94	48	974	182	80	1,168	304	120	923	207
May 94	48	1430	230	79	1,998	371	98	2,044	263
Jun 94	45	1431	220	77	2,387	392	72	3,197	301
Jul 94	44	1377	198	76	2,454	372	128	3,520	525
Aug 94	43	1470	176	75	2,595	352	77	3,350	431
Sep 94	42	1608	189	75	2,610	348	-	-	-
Oct 94	-	-	-	75	2,850	367	-	-	-
Nov 94	-	-	-	70	2,870	364	-	-	-

*Study period January-August 1995.
Source: Velayudhan et al., 1995 and 1998

Based on these studies, Velayudhan *et al.* (1998) indicated that a 300 m^2 rack and ren oyster culture unit, realised a production of 4.25 tonnes shell-on and 425 kg of meat. They indicated that in one hectare area, 24 racks, each of 300 m^2 can be accommodated and production of wet meat and shell per hectare is estimated at 10.2 and 81.6 tonnes respectively. They have also worked out the economics of oyster culture (see Chapter 8) and stated that it can be profitably carried out in the Ashtamudi Lake from November for a period of 7-8 months. The high intensity of spat fall observed in the Ashtamudi Lake suggests that it can be developed as a large scale spat collection center for commercial oyster farming in this area and also to supply seed for oyster culture at other places.

Rack and Stick Culture: This is a simple method and widely practiced in Australia and New Zealand (Quayle and Newkirk, 1989). In this system the oyster seed are collected on narrow sticks and are placed horizontally on racks for growth. The sticks can be arranged in bundles for seed collection. After the natural spat set on the sticks reaches under 2 cm length, the stick bundles are separated and individual sticks are secured on the racks. This method of culture is not practiced in India.

Stake Culture

In the stake culture the stake is the support for growing oysters while in the stick culture the stick is the cultch material for oyster spat. The stake culture

is suitable in shallow waters with muddy bottom. Studies on stake culture of oysters were conducted at Tuticorin and hatchery raised spat, set on oyster shell cultch, were used. The details of nursery culture were given earlier. Nursery and grow out culture are carried on the same stake. Casuarina poles of 6-7 cm diameter and 1-1.5 m length are driven into the substratum. Each stake holds 3-4 oyster shells with attached spat. The number of oysters on the cultch vary from 15-20/ stake. They are harvested at 70 mm length after 10-12 months (Figure 31). The production is 20-22 tonnes/ hectare with 93 % survival (Rao *et al.*,1992; Muthiah *et al.*,2000). Nayar *et al.*,(1988 a) indicated that the oysters grown by stake method reach 80-90 mm length in one year and production of 10-15 t/ ha.

Fig. 31. Oyster farm at Tuticorin showing stakes with oysters exposed at low tide Courtesy : CMFRI, Cochin, Kerala

Rafts and long lines

Rafts and long lines are used in the areas where the depth is 5 m or more. Rafts are floating structures consisting of wooden frame, supported by floats and are held in position by anchors laid on the substratum and usually connected by iron chains to the raft (Figure 32). Locally available wood such as bamboo or casuarina may be used for raft construction. The poles are placed in a parallel row and over this another row of poles are placed across. They are tied with nylon rope to make a rigid frame. In earlier days empty, sealed and painted 200 l oil barrels were used for flotation but now they are replaced by styrofoam barrels. The raft may be either rectangular or square in shape. In raft construction, the expected weight of the harvest should be considered for providing appropriate floatation. Quayle and Newkirk (1989) stated that a four barrel raft (each barrel 200 l capacity) with barrels secured at the corners of the wooden frame, can support nearly a tonne, less the weight of the wooden

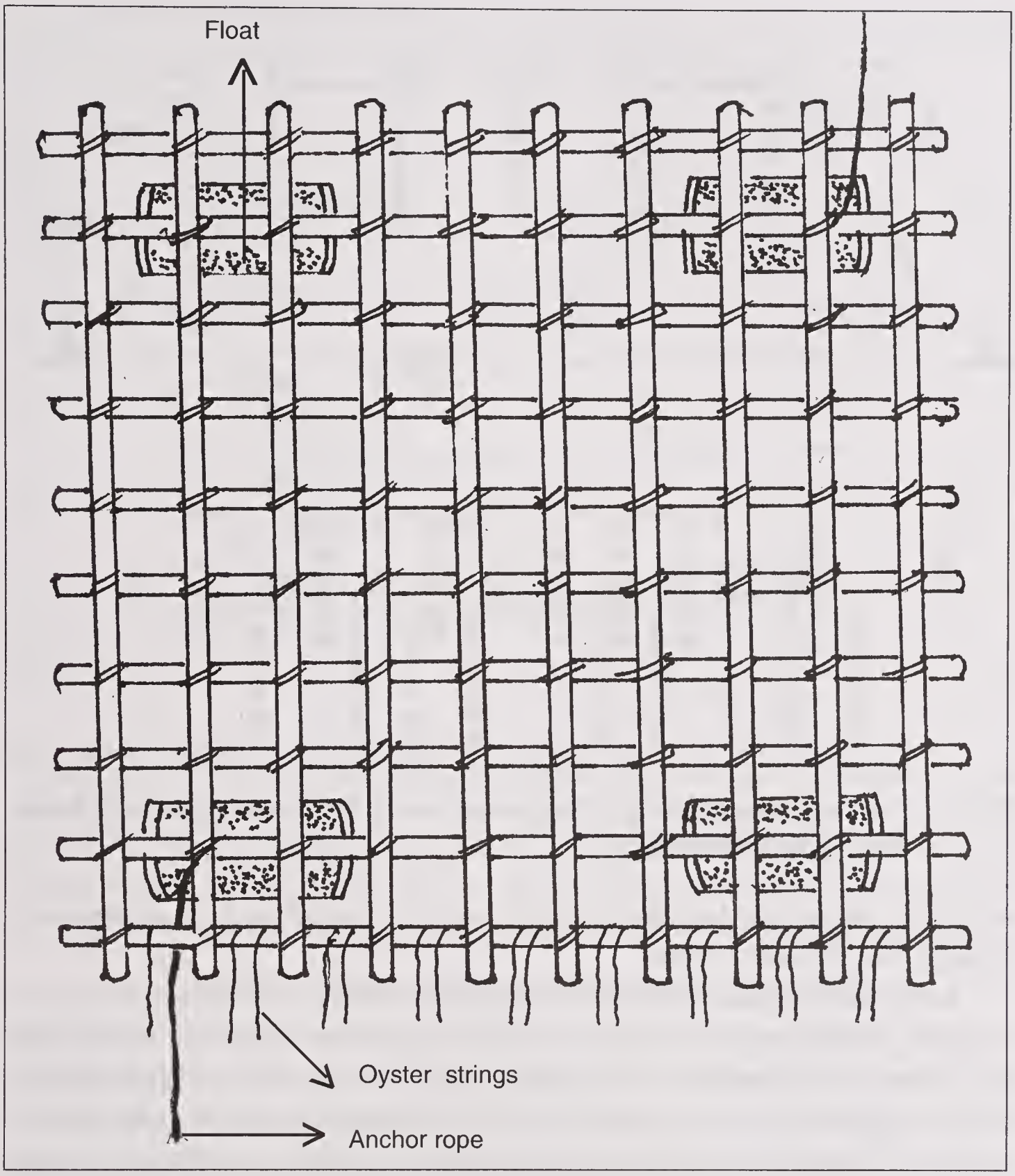

Fig. 32. Farm structure - Raft

frame. They have stated that the strings of oyster weigh about 5 times less in water than they do in air.

Like rafts, the long lines also float but can withstand the rough sea conditions far better than the rafts due to their flexibility. The long line unit comprises a main line (synthetic rope) of 12 mm or more in diameter, supported at intervals by floats and anchored at both ends (Figure 33). Oyster strings are hung from the main line at the rate of 3-4 nos/ m length. Long lines more than 100 m are often difficult to manage and 50-100 m units are considered as more suitable (Quayle and Newkirk, 1989). Oil barrels of 200 l can hold a double long line. On the assumption that a string of full-grown oysters (7-8 cm) weigh 2.3 kg in water, then 200 l barrel can support about 50

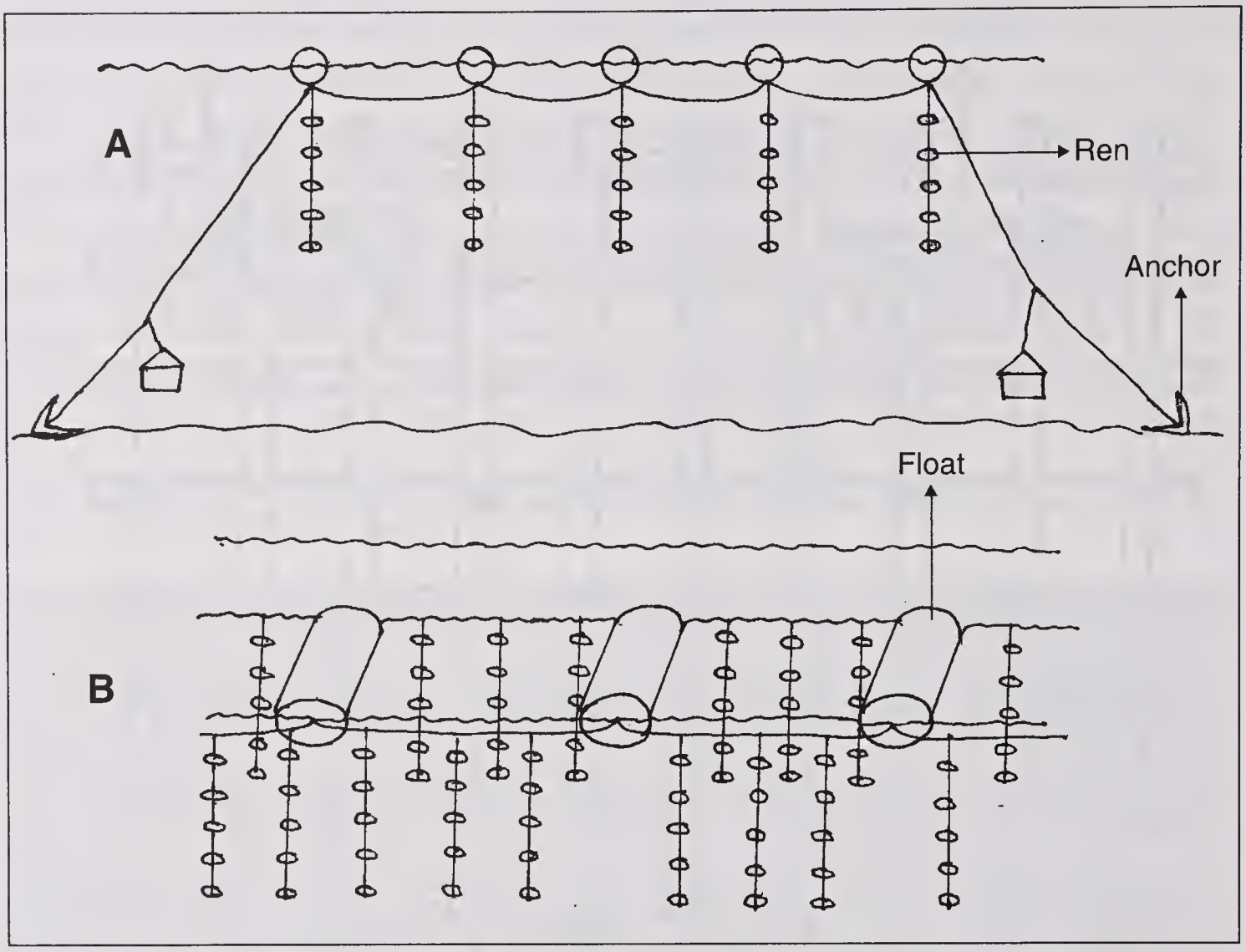

Fig. 33. Farm structure showing A. Single long line B. Double long line with floats and suspended strings.

strings/ m on double long line; barrels may be placed at 8-10 m intervals (Quayle and Newkirk, 1989).

Rafts and long lines are used for suspended culture of oysters held in trays or on the strings and sticks; they are similar to those used from racks. The main advantage of the rafts and long lines lies in the utilisation of greater depth of water column for oyster production when compared to rack or stake culture methods. This results in higher production per unit surface area when compared to other farming systems discussed earlier. In India, while pearl oysters and mussels have been cultured from rafts and a few experimental studies made on long line mussel culture, no attempt was made to farm the oysters from these units. This is mainly due to the rough sea conditions prevailing along the Indian coasts. Moreover *C. madrasensis* thrives well in sheltered estuaries and backwaters.

Location Testing For Oyster Culture

Based on natural and hatchery raised seed of *C.madrasensis* several studies have been conducted to assess the suitability of sites at Bheemunipatnam, Kakinada bay, Pulicat Lake, Muttukadu backwaters, Vellar estuary, Athankarai estuary, Cochin backwaters, Narakkal, Chettuva, Kunjithai, Dharmadam and Mulki estuary (Reuben *et al.,* 1983 ; Rao et al., 1994 ; Ramakrishna, 1988 ; Thangavelu, 1988 ; Sarvesan *et al.,* 1990 ; Patterson and Ayyakkannu, 1997;

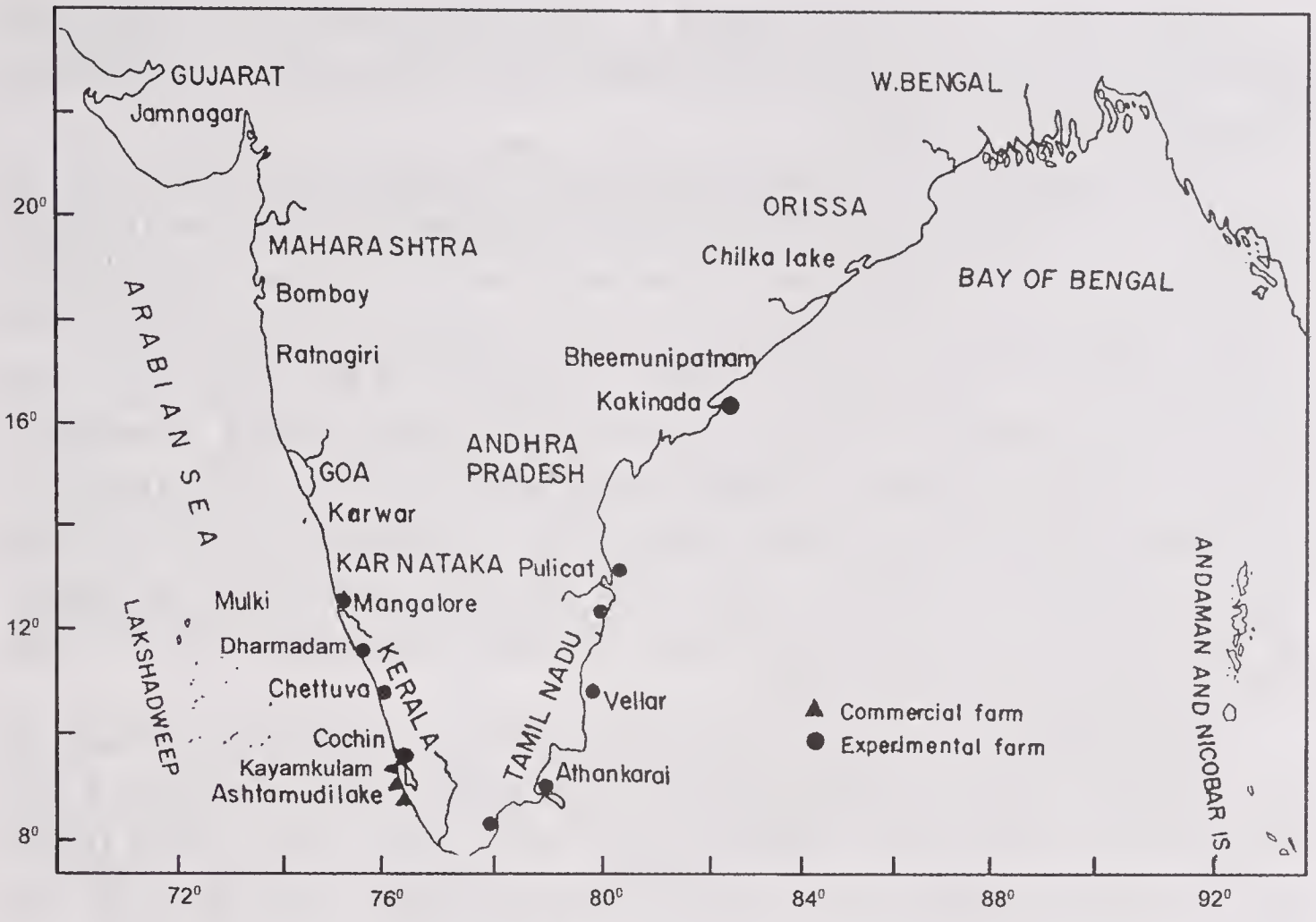

Fig. 34. Locations of experimental and commercial oyster farms of India

Rao *et al.,* 1983 ; Purushan *et al.,* 1983 ; Joseph and Joseph, 1983) (Figure 34). These studies have showed that the above mentioned sites are suitable for oyster farming and a seasonal crop of 6-8 months duration can be raised.

PURIFICATION OF OYSTERS FOR MARKET

During the course of feeding, several pollutants occurring in the aquatic environment are collected by the oysters and accumulated in their body. Consumption of these oysters by humans causes several diseases and at times proves fatal. Bivalves such as mussels, oysters and clams are used as sentinels to monitor aquatic pollution. The pollutants broadly come under three categories, namely (a) pathogenic bacteria and viruses, (b) toxins produced by algae and (c) heavy metals, pesticides and hydrocarbons.

Microbial Pollutants

The discharge of untreated sewage and land drain pollute the oyster growing areas with bacteria and viruses which in turn are accumulated by the oysters. The pathogenic bacteria usually found are coliforms (*Escherichia coli*), faecal streptococci and occasionally pathogens like *Salmonella, Shigella, Vibrio parahaemoliticus* and *V. cholorae* (Gopakumar, 1988). Some of these bacteria normally occur in the human digestive system, and their concentration increases due to the consumption of bivalves. Members of the salmonella group cause typhoid fever while coliforms and vibrios may cause stomach upsets or severe gastroenteritis.

The coliform groups, particularly *E. coli* are used as indicator organisms because they occur abundantly and generally reflect the possible concentrations of pathogens from sewage.

Bacteriological and toxicological analyses of oyster meat from the oyster farm of the Central Marine Fisheries Research Institute (CMFRI) at Tuticorin showed that *E. coli*, *Staphylococcus* and *Salmonella* were absent (Silas *et al.*, 1982). Faecal coliform count was very low and within permissible limits in the oyster *Crassostrea madrasensis* samples collected from the CMFRI farm and also from the natural bed at Tuticorin. Also the pathogenic bacteria, *Salmonella, Streptococci* and *Staphylococci* were absent (Pillai and Selvan, 1988). However, Abraham *et al.* (1998) reported that the oyster, *C. madrasensis* collected from the natural beds of Tuticorin coast were grossly contaminated by human pathogens such as *Salmonella, Vibrio*, *Staphylococcus aureus, Escherichia coli*, and *Enterococcus faecalis*.

Most common viral diseases associated with the consumption of bivalves are caused by pathogens such as Norwalk Like Viruses (NLV), hepatitis A and enteroviruses (Sindermann, 1990; Enriques *et al.,* 1992; Cliver, 1997). Direct detection of viral pathogens by using Polymerised Chain Reaction (PCR) will help to assess the quality of shellfish but the method is complicated and expensive for routine analysis (Granmo *et al.,* 2001). There appears to be no information available about the pathogenic viruses from the oysters from Indian waters.

Toxins from Algae

Of the 5,000 known phytoplankton species (Sournia *et al.*, 1991), some 300 may cause dense blooms and about 40 species produce toxins. Under favourable conditions such as upwelling of nutrient rich bottom water, some algae multiply fast and produce blooms and these are generally referred to as "red tides". The toxic blooms are mostly associated, with dinoflagellates. The important genera, as mentioned by Shumway (1990), are *Protogonyaulax, Gymnodinium* and *Pyrodinium* (vectors of Paralytic Shellfish Poisoning), *Dinophysis* (vectors of Diarrhetic Shellfish Poisoning), and *Ptychodiscus* (vectors of Neurotoxin Shellfish Poisoning). The diatom *Nitzschia pungens* is considered to be responsible for Amnesic Shellfish Poisoning by Smith *et al.* (1990). Certain regions in the temperate countries are prone to seasonal outbreaks of shell fish poisoning and *Protogonyaulax tamarensis* which causes PSP is the best documented among the toxic algae (Shumway, 1990). Mouse bioassay is commonly used to detect PSP.

From India, three instances of paralytic shellfish poisoning and few human deaths have been reported from Vayalur village, Tamil Nadu in 1981(Silas *et al.,* 1982), Kumble estuary, Karnataka state in 1983 (Karunasagar *et al.*1984) and from Vizhinjam, Poovar and Karumkulam, near Trivandrum in 1997 (Karunasagar *et al.,*1998). In the first 2 cases the PSP was due to the

consumption of the clam *Meretrix casta* and in the third instance due to the consumption of mussel, *Perna indica*. It was observed by Karunasagar *et al.* (1984) that the clams accumulate the PSP at higher rate and also detoxify at a faster rate when compared to the oyster, *S. cucullata*. There seem to be no reports of DSP, NSP, and ASP toxicity associated with bivalve consumption from India.

During a two year study in seven estuaries in Karnataka, Karunasagar *et al.* (1989) detected PSP toxicity in 5 bivalve species during April 1985 and March – April 1986. A sample of *Crassostrea* sp. collected from the Tadri estuary during April 1985 showed the presence of PSP at a low level of 320/ MU/100 g. However, during the last week of March 1986 some shell fish (species not mentioned) collected from Udyavara / Malpe area showed high levels, 1100-1200 MU/100 g. Sommer and Myer (1937) reported that sickness may result in humans at 1000/MU/100 g and death at about 2000/MU/100 g level. The DSP toxicity was noticed sporadically at 0.37 to 1.5/MU/g in the hepatopancreas of bivalves; the DSP symptoms in humans are manifested at 12/MU/g (see Karunasagar *et al.*, 1989).

From Mexico, Mee *et al.* (1986) reported on the death of 3 persons and 18 cases of illness due to PSP toxicity on consumption of oyster *Crassostrea iridescens*. Onoue *et al.*, (1980) gave information that 16 persons developed numbness of mouth due to PSP toxicity in Japan on consumption of *C.gigas*. The algal source in the first instance was identified as *Gymnodinium catenatum* and in the second as *Protogonyaulax catenella*.

Heavy Metals, Pesticides and Hydrocarbons

Lakshmanan (1988) studied the concentration of heavy metals Hg, Cu, Zn, Cd, Fe, Mn, Pb and Sn in canned and smoked in oil *C. madrasensis*. The products, packed in tin and aluminium cans were obtained from Cochin. The range in the mean values of various metals are Hg 89-101.5 ppb, Cu 46.6-68.6 ppm, Zn 154.6-202 ppm, Fe 69.4-386.5 ppm, Pb nil to 4.6 ppm, Cd 1.6-3.4 ppm, Mn 4.1-8.1 ppm, and Sn nil to 50 ppm. Mercury, lead and cadmium were below the permitted limits of the Indian Standards for heavy metals in canned fishery products. Copper and zinc were higher in oyster products.

From Cochin area, Sankarnarayanan *et al.* (1978) have studied the concentration of copper and zinc in *C. madrasensis* and from Goa, Zingde *et al.* (1976) on the zinc concentration in *Crassostrea* sp. Sankaranarayanan *et al.* (1978) have reported the range of copper and zinc concentration in *C.madrasensis* at 70 to 205 µg / g and 2,450 to 12,500 µg / g respectively while Zingde *et al.* (1976) obtained 323-2800 µg / g of zinc in *Crassostrea* sp. These authors reported higher values for these metals when compared to the values obtained in the study by Lakshmanan (1988). The results obtained by Pillai *et al.* (1986) on the levels of copper and zinc in fresh oysters from Tuticorin are comparable with those reported by Lakshmanan (1988).

Mercury poison causes damage to humans through progressive and irreversible accumulations as a result of ingestion of small amounts repeatedly. This causes sub-lethal or even lethal effects to the humans (Chichester and Graham, 1973). Jasmine *et al.* (1988) studied the mercury content of oysters *C. madrasensis* collected from the Tuticorin bay. On dry weight basis, mercury content varied from 0.0024 to 0.17 ppm (mean 0.045 ppm). This study showed that the level of mercury contamination in the oysters was below the limit of 0.5 ppm (FAO 1983).

Although laboratory studies on the accumulation of certain pesticides in bivalves are available (Mane *et al.,* 1979) it is reported that the pesticides are not a matter of concern for the quality of oysters in India (Gopakumar, 1988).

The pollutants from the oil products, even in small quantities cause problems with taste (Nishihama *et al.,* 1998).

Decontamination of Oysters

In several temperate countries, shell fish safety is achieved through monitoring of the sanitary quality of waters in which it is grown, processing facilities and shell fish meats before delivery to the consumer (Ray and Rao, 1984). To make the shellfish safe for human consumption, broadly 3 methods namely cooking, relaying in clean water and depuration are used (Canzonier, 1988).

Cooking: This is an effective method for oysters which contain labile microbial contaminants. Fortunately in India the oysters are cooked before eating. A relatively higher heat processing time is recommended for canning the bivalves to make them safe from coliforms and faecal streptococci (Gopakumar, 1988).

Relaying in Clean Waters: The practice of relaying shellfish from polluted waters to clean waters is widely practiced in the USA and Europe. The oysters clean themselves from the pollutants. However, this involves additional expenditure. An effective monitoring program of the oyster culture areas and the oysters is essential to assess the level of pollutants in the water and in the shell fish. Monitoring helps to time the harvest either by preponing the harvest before the toxic effects of the algal blooms are fully manifested, or closure of the culture sites until the oysters become safe for consumption.

Recent studies have shown that to some extent depuration of heavy metals is possible by transplanting the bivalves from contaminated to clean sites and keeping them there up to three months before harvest (Chan *et al.,* 1999).

Depuration: Depuration is the process where the live oysters are maintained in filtered seawater, usually in a flow-through system for periods varying from 1-2 days. The oysters clean themselves of the pollutants and also the extraneous particles such as sand grains by pumping the water. It is essential that care is

taken to ensure the optimum survival of the oysters during harvest, transport and depuration process. Weak, injured and animals under stress should be removed before depuration. The harvested oysters should be brought to the depuration plant quickly and during transport and storage, the shell fish should be kept cool and moist. The temperature, dissolved oxygen, salinity and pH of the water should be maintained at levels optimum for the concerned species. Filtration of seawater helps to remove suspended particles. It is desirable that the water is sterilised for use in the depuration plant. It involves (a) Chlorination. It is the cheapest option. (b) Ozonation. It is an effective sterilising process and leaves little residue. However, it is a costly process. (c) UV light sterilization. It is a widely used method of sterilising water for depuration. A great advantage of this process is the low cost and the absence of residual taints and odours from chemical residues (Thrower, 1990).

It is recommended that layers of oysters should not exceed 80 mm height with an overall stocking density of 25 kg per 1000 litres of water. The duration of depuration depends upon the species, their physiological activity, and temperature, oxygen and pH levels of the water (Thrower, 1990). The coliforms, particularly *E. coli* levels in the oysters are to be assessed to evaluate the performance of depuration.

Opinions are divided over whether or not depuration removes pathogenic viruses. Outbreaks of viral infection from depurated shell fish continue to occur (Thrower, 1990). As the oysters are eaten raw in Europe and America, strict sanitary control in farming the oysters, as well as elaborate depuration methods are followed.

At Tuticorin the oysters grown in the CMFRI farm are regularly depurated. Nayar *et al.*,(1983) and Rajapandian *et al.* (1988) have described the depuration of farm grown oysters. Harvested oysters are cleaned externally to remove silt and debris by a strong jet of water. They are placed in trays in one or two layers (Figure 35). Wooden grids hold the trays above the bottom of the depuration tank. A drain valve is provided at the bottom of the tank to facilitate flushing of silt, faeces, pseudofaeces and debris out of the tank. A slow and steady flow of filtered seawater is maintained in the tank for 12 hours. The oysters are flushed with a strong jet of filtered sea water and the operation is repeated for another 12 hours. The oysters are again flushed with a jet of water and are re-laid in chlorinated (3-ppm) seawater for one hour followed by flushing with a strong jet of filtered sea water. Ray and Rao (1984) opined that chlorination is effective at 2-3 ppm levels. Pillai and Selvan (1988) depurated the farm grown and natural bed oysters and mussels for 24 hours in seawater (water changed once after 12 hours) followed by chlorination at 3 ppm for 2 hours. There was significant reduction in the bacterial count. Abraham *et al.* (1998) stated that depuration of grossly contaminated oysters in sand filtered saline water drawn from a borewell and chlorinated at 5 ppm level, followed by

Fig. 35. Depuration of oysters. Oysters spread in trays are held in the depuration tank at Tuticorin
Courtesy : CMFRI, Cochin, Kerala

dechlorination resulted in the reduction of faecal coliforms to the acceptable level.

In recent years, oyster and mussel culture is fast picking up in the country and in view of the public health concerns, it is necessary to formulate and implement measures for monitoring the sediment, quality of the waters in which the shell fish is grown, processing facilities and shell fish meats prior to sale. Quality assurance to the public builds up confidence, expands the market and gives a boost to shell fish aquaculture.

UTILISATION

Raw oysters are widely consumed in Europe and the USA. Details of many traditional oyster products used in China, the Republic of Korea, Hongkong, Malaysia and Thailand were given by Chen (1992). In India, a variety of dishes are made with cooked oyster meat. Nair and Girija (1993) described several oyster products while Jayachandran *et al.* (1988) dealt on some value added products. These include smoked oysters, canned oyster in brine, oil, masala and tomato, pickles, battered and breaded IQF meat, nectar, chowder, soups and dried oyster and minced meat products. The shell is used as spat collector in oyster culture and in the manufacture of Calcium carbide, lime, fertilisers and cement. The shells, broken to suitable size are used as poultry feed.

QUESTIONS

1. Write on various factors to be considered for selecting site for oyster farming.
2. Describe nursery rearing of oyster spat.
3. What is a rack? Write on rack and ren method of oyster culture.
4. What are rafts and long lines? Describe their advantages over other methods of culture.
5. Write short notes on: a) Toxins from algae b) Microbial pollutants c) Depuration d) Stake culture of oysters e) Oyster production by various methods of culture.

CHAPTER 8

Economics of Oyster Culture

STUDIES on the economics of any culture operation or any new technological intervention in the existing farming practices help in decision making and resource allocation. They also help to improve the management practices, leading to increased profitability. The assessment of economic performance of the culture practices includes estimation of annual fixed cost, annual variable cost, annual cost of production, net income and net operating income. The annual fixed cost includes depreciation on establishments like ponds, buildings, water supply systems, major equipment like generators, FRP tank/ boats etc. The annual variable costs comprise the labour wages, staff salaries, contingencies such as cost of chemicals, glasswares, input costs towards seed, nylon ropes, fuel, rafts, stakes, casuarina poles and similar items. The interest on the working capital is calculated for the duration of the culture period. The cost of production is the sum of annual fixed and annual variable costs. The net income is obtained by subtracting the cost of production from the gross revenue.

The Central Marine Fisheries Research Institute has conducted several studies on oyster culture along the Indian coast since 1970's and has set up Research and Development farms in the Tuticorin bay and Ashtamudi Lake. These farms are being used for demonstration, training and technology transfer. Over the years, several aspects of different farming systems have been experimented and standardised, resulting in fairly consistent production rates. Based on the experience gained, the economics of oyster culture (*Crassostrea madrasensis*) by rack and ren method has been worked out. There was no information on economics of hatchery production of seed and on the stake method of oyster culture. The information presented here is based on the costs prevailing at the time of study by the authors. There are no extant laws to lease the public grounds for oyster farming. As a result the lease rentals are not included in the economic analysis by the authors.

A preliminary study on the economics of a 0.25 ha oyster farm with 60 racks was conducted by Nayar *et al.* (1987a). Each rack covered 25 m^2 area, supporting 20 trays with a stock of 4000 oysters. The production from this farm was 2,475 kg of oyster meat and it formed 9 % of the shell-on weight of harvested oysters.

The rack and tray method is highly suitable for the production of cultch-free or single oysters of good shape which command high price in many countries where they are eaten raw, after removing one valve (called half shell oyster). Quayle and Newkirk (1989) stated that tray culture presents many problems, usually costlier than other types of culture, should be attempted as a last resort and may be considered if the purpose is to provide half shell oysters to the market.

In India, oysters are cooked and meat collected from the shells for consumption. As a result the shape of the shell is of little consequence. Nayar *et al.* (1987a) made several assumptions while working out the economics and further studies on rack and tray method were discontinued. During the past two decades, the thrust was on rack and ren method of oyster culture which is cost effective and was adopted by the fishermen. The information given by Nayar *et al.* (1987a) is not dealt here as it has no relevance to the present situation.

ECONOMICS OF RACK AND REN METHOD OF CULTURE

Two studies, one at Tuticorin and the other at Ashtamudi Lake were conducted on the economics of oyster culture by this method. Although the economics of culture operations at these two places as presented below cannot be strictly compared due to the facts such as the duration of culture, source of seed used and the realization of the meat from the oysters, these are given to indicate the economical prospects of this developing culture system.

Rack and Ren Culture at Tuticorin

In the farm at Tuticorin, oyster culture by the rack and ren method was carried in 0.4 ha area with 50 racks (Table 29). From each rack 100 oyster rens were suspended from it. Each ren contained 6 oyster shells with attached hatchery raised spat. The initial weight of the string was 0.5 kg and at the end of one year, on an average it weighed 7.5 kg. The initial investment was Rs 55,000, fixed cost Rs 28,215 and the cost of production of 3.25 tonnes of oyster meat was Rs 82,495. At the end of one year the total revenue was Rs 1,05,000 through sale of 3.25 tonnes of oyster meat for Rs 97,500 and oyster shell for Rs 7,500. The net profit was Rs 22,505 and the production cost of oyster meat was Rs 25.4/ kg. The net income was 27.3 % of the total cost of production. Provision towards the cost of depuration and shucking of the meat was not made by the authors and if included, the production cost would be higher than Rs 25.4/ kg.

Rack and Ren Culture at Ashtamudi

The farm covered 300 m^2 area and in one hectare area, 24 units of 300 m^2 each can be accommodated (Velayudhan *et al.*,1998). A total of 1060 rens, each ren holding 6 oyster shells were suspended from the racks. Natural spat set on

Table 29. Economic evaluation of *C.madrasensis* culture by rack and ren method at Tuticorin [(Rao *et al.* 1992) modified]

Farm area : 0.4 ha — Production : 3.25 tonne meat
Duration of crop : 1 year

	Items		Rs
A.	**Investment**		
	Nursery pond	one	20,000
	FRP dinghy	one	10,000
	Out-board motor 8 H.P.	one	15,000
	Pump set 3.5 H.P.	one	5,000
	Major farm accessories		5,000
	Total		55,000
B.	**Fixed cost**		
	Depreciation on 'A' @ 33.3 %		18,315
	Interest on investment @ 18 % p.a.		9,900
	Total		28,215
C.	**Operational cost**		
	Oyster seed		6,000
	Stakes	50 nos	15,000
	Nylon rope	50 kg	5,000
	Other farm materials, repair etc		3,000
	Labour		10,000
	Harvesting charges		7,000
	Interest on 1-6 @ 18 % p.a.		8,280
	Total		54,280
D.	**Total cost of production**		82,495
E.	**Revenue through sale**		
	3.25 tonne meat @ Rs 30/ kg		97,500
	25 tonne oyster shells Rs 300/ tonne		7,500
	Total		1,05,000
F.	**Total net profit at the end of first year**		22,505
G.	**Unit cost of production**		Rs 25.4/ kg

these rens was used for culture. The duration of the crop was 8 months and 4.25 tonnes shell-on oysters were harvested. The wet meat yield of 425 kg formed 10 % and the heat shucked meat of 340 kg formed 8 % of the weight of shell-on oysters. The data given by Velayudhan *et al.*(1998) was modified by a) considering the cost of nylon rope (Rs 1800) and oyster shells (Rs 636) under operational cost as they are used for one season of 8 months only, b) interest charges were limited to 8 months for items 1 to 6 under 'C' and c) interest not charged for item 7 under 'C' as this activity is carried just before marketing the oysters (Table 30).

The operational cost worked out to Rs 10,967 and the cost of production Rs 16,189 (Table 30). The revenue generated was Rs 21,760, net profit Rs 5,571; the production cost of raw oyster meat was Rs 26.1/ kg and heat

Table 30. Economic evaluation of *C.madrasensis* culture by rack and ren method at Ashtamudi [(Velayudhan *et al.*, 1998) modified]

Farm area: 300 m² Production : shell-on: 4.25 tonnes
Duration of crop : 8 months

Items	Rs
A. Investment	
1. Horizontal poles (6 m) 33 Nos @ Rs 80/ pole	2,640
2. Vertical poles (3 m) 126 Nos @ Rs 40/ pole	5,040
Total	7,680
B. Fixed cost	
1. Depreciation on A at 50 %	3,840
2. Interest @ 18 % on A	1,382
Total	5,222
C. Operational cost	
1. Nylon rope for rens and racks: 15kg @ Rs 120/ kg	1,800
2. Cost of 6,360 shells @ Rs 0.10 for making 1000 strings including cleaning charges	636
3. Fabrication of oyster rens (1060) @ Rs 0.65	689
4. Labour for erecting the rack	300
5. Harvest charges	750
6. Depuration @ Rs 200/ tonne	1,063
7. Heat shucking, including fuel cost @ Rs 15 /kg	5,100
8. Interest @ 18 % on 1 to 6 for 8 months	629
Total	10,967
D. Cost of production	16,189
E. Revenue	
1. Heat shucked meat @ Rs 60/ kg for 340 kg	20,400
2. Value of shell @ Rs 400/ tonne for 3.4 tonne	1,360
Total	21,760
F. Net profit	5,571
G. Unit production cost	
1. Raw meat (425 kg)	26.10/kg
2. Heat shucked meat (340 kg)	47.60/kg

shucked meat Rs 47.6/ kg. The net profit formed 34.4 % of the total cost of production. For the purpose of comparison with the study at Tuticorin, the unit cost of production of raw oyster meat (Table 31, G.1) was also calculated by excluding the heat shucking charges of Rs 5,100. The shucking of raw meat also involves some labour cost, but the oyster farmer attends to this work. In the Ashtamudi area, as is the practice at several other places in Kerala, the oysters are eaten by local people. Velayudhan *et al.*(1998) mentioned that in the local market the cost of 100 shell-on oysters is Rs 25.

A comparison of the net profit on investment in the two studies shows that in the rack and ren method at Tuticorin it was 32.2 % and at Ashtamudi Lake 34.4 %. Thus the profit margin is comparable between the two studies.

ECONOMICS OF RACK AND REN METHOD AS PRACTICED BY FARMERS

Several villagers in Kerala have adopted the rack and ren method of oyster farming (see Chapter 9) and the profit margin will be much higher since the cost of labour accrues to the farmer. The actual expense in the farms at Kayamkulam is given in Table 31. The net profit on investment is 73%. Of the

Table 31. Economics of oyster culture by rack and ren method based on farming as practised by farmers at Kayamkulam Lake, Kerala

Farm area : 25 sq.m
Number of rens = 500
Production = 2.5 mt (200 kg heat shucked meat)
Duration of culture = 8 months

		Rs
A	**Investment**	
1	Horizontal poles (6m)15 nos @ Rs.80/ pole	1,200
2	Vertical poles (3m) 60 nos @ Rs.40 / pole	2,400
	Total	3,600
B	**Fixed cost**	
	Depreciation on A at 50%	1,800
	Interest @ 18% on A	648
	Total	2,448
C	**Operational cost**	
1	Nylon rope 5 kg @ Rs.120	600
2	Cost of 2500 shells @ Rs.0.10	250
3	Fabrication of oyster rens @ Rs. 0.65	325
4	Labour for erecting rack ; 2 persons @Rs.150	300
*5	Harvest charges 2 persons @Rs.150	300
*6	Heat shucking charges for 200 kg @ Rs. 15 /kg	3,000
7	Interest on items 1-4 @ 18% for 8 months	177
	Total	4,952
D	**Cost of production**	
	D= B+C	7400
E	**Revenue**	
1	Heat shucked meat 200 kg@Rs 60 / kg	12,000
2	Value of 2 tonnes oyster shell @ Rs 400	800
	Total	12, 800
F	**Net profit**	
	F=E-D	5, 400
G	**Unit cost of production**	
**1	Raw meat 250 kg	17.6 / kg
2	Heat shucked meat 200 kg	37 / kg

*In operational cost, interest on items C-5 and C-6 were not included as they are incurred at harvest and immediately before marketing

** For calculating the cost of production of raw meat, heat shucking charges of Rs 3000 / under C-6 were excluded

production cost of Rs 7,400 the farmers get Rs 1,500 per member and a farm unit is usually constructed and mangaged by three members who put 500 rens in 25 sq.m area thereby availing a benefit of Rs 4,500. The financial aid of Rs 4,500 /- is offered by the State government as a grant to the farmers, acts as an incentive to attract the first generation farmers to venture into oyster culture. As a result the net profit on investment is very attractive.

As the farmers attend to farm maintanence works such as removal of foulers, borers and predaters during spare time, the labour cost for maintanence is not included. Also the farms are located in creeks, close to the residence of farmers, and there was no labour cost involved for watch and ward.

During the duration of culture (8 months) there was natural spat settlement on culture rens, thereby adding to the initial stock. At harvest the survival varied from 45 to 65% of initial stock.

GENERAL CONSIDERATIONS

The casuarina or bamboo poles used in raft construction are to be frequently replaced due to the damage caused by foulers and borers. Kripa *et al.*(2001) stated that concrete filled 5 cm diameter PVC pipes, used as vertical poles in the rack construction for mussel culture last for 5 years. The cost effectiveness of such innovations in farm materials for oyster culture need to be evaluated.

At present, marketing does not appear to be a matter of much concern in Kerala but needs to be addressed once the production of farm grown oysters goes up beyond the absorbent capacity of local markets. Also connected with marketing is the timing of harvest. It has been proved that a seasonal oyster crop of 6-8 months duration can be raised in the estuaries of Kerala and also at several other places and that the farm stock should be harvested before the monsoon intensifies. If delayed, the oysters spawn resulting in poor and less palatable meat yield. Several oyster products have been developed by the Cochin based Central Institute of Fisheries Technology and Integrated Fisheries Project. It is time for the sea food processing industry to take the lead in utilising the oyster meat in the preparation of diverse and value-added processed products and expand the market base.

QUESTION

1. Give economics of oyster farming by rack and ren method.

CHAPTER 9

Transfer of Technology

RESEARCH and Development, field orientation and trials, and transfer of technology are the main stages in the development and transformation of a biological type project to a full fledged self sustaining commercial project (Lalta and Espeut, 1991). Consequent upon the development of a viable culture technology for oysters, particularly for *C. madrasensis* at the Central Marine Fisheries Research Institute (CMFRI), the Institute initiated need based awareness and transfer of technology programmes to farmers, State Fisheries officials and extension workers at different levels with their active collaboration and participation. The imperative need and importance of this programme was felt not only to attract the entrepreneurs, but also to diversify the culture fisheries of the country to other than fish and shrimp culture. Besides, oyster farming, unlike shrimp culture, does not form a traditional practice in the country and the entrepreneurs are required to be provided information on suitable sites, design and culture base, availability of seed, seeding and rearing the oysters in the system, production potential and economics of culture. Transfer of technology also envisages training of personnel, providing adequate knowledge on different aspects of culture operation and system as a commercial business.

One of the major programmes taken up in this direction, soon after the development of the technology was under the lab to land programme in 1979. Eleven families from two coastal villages in Tuticorin, Sahayapuram and Panimayanagar were selected. All the families belonged to the economically backward segment of the society, living below the poverty line. After selection of fishermen families, an orientation training programme was conducted, wherein various aspects of the techniques of oyster farming were demonstrated and explained to them. The fishermen erected 33 racks and fabricated more than 500 oyster rearing cages. Spat for farming was collected from the natural bed and reared in cages. The fishermen utilized 33% of spare time out of 964 man-days available to them for oyster farming. From the oyster farm, 566 kg of oyster meat was harvested. This demonstration helped to kindle the interest in oyster farming in the Tuticorin area to a great extent (CMFRI, 1979)

TRAINING ON OYSTER CULTURE

Following the lab to land programme, the CMFRI conducted regular long

term (one month duration) and short term training programmes on oyster farming and hatchery techniques in the Institute. The Trainers Training Center (TTC) of CMFRI established in 1983 has also organized training on oyster culture to instructors of extension training centers, teachers, state government officials, entrepreneurs and farmers in different parts of the maritime states. Dissemination of results and exchange of information, on edible bivalve culture including oyster culture were imparted periodically through seminars, workshops and Summer Schools. To popularize the technology further, a pilot project on oyster farming was implemented at the Tuticorin Research Centre of CMFRI in collaboration with the National Agriculture Bank for Rural Development (NABARD) during 1990-91 and in 1993 a location testing programme as a prelude to transfer of this technology to other regions of the coast was organized. Under this programme oyster seed from Tuticorin hatchery were transported to different Centers viz. Cochin, Calicut, Mangalore, Karwar, Madras and Kakinada and feasibility tests were conducted. This paved the way for organizing and implementing a commercial scale oyster culture in Kerala.

DEVELOPMENT OF OYSTER CULTURE IN KERALA

The programme of development of oyster culture in Kerala was initiated in 1993 with location testing at Dharmadam, Chettuva, Munambam, Narakkal, Kunjithai, Ashtamudi Lake and Paravur. Of these centers, Munambam was found to be unsuitable due to heavy fouling ; Kunjithai was only partially suitable and other centers were found to be suitable to start commercial scale culture.

The initial demonstration programmes conducted further at selected centers clearly indicated the significance of three main factors namely, training to farmers and continuous interaction with the target group; support from local governing bodies and funding agencies and market development for the farm produce, for the success of the project. Keeping the requirements of these inputs in view, the collaboration and participation of the Brackishwater Fish Farmers Development Agency (BFFDA) and non-governmental organizations such as Self Help Groups (SHG) formed by women entrepreneurs under the Peoples Development Programme, were involved in the project. For post-harvest and marketing of the cultured oysters, the Integrated Fisheries Project (IFP) of Government of India is also involved. These combined efforts (as indicated in the flow chart from Kripa *et al.*, 2004) greatly helped to the generation of a small scale oyster farming industry in Ashtamudi and Kayamkulam Lake area. At present annually about 750 to 800 tonnes of oysters are produced through farming in Kerala. This has also provided employment opportunities to women in coastal villages.

SOCIAL IMPACT OF OYSTER CULTURE

Oysters are ideal for aquaculture in developing countries like India. Their farming requires relatively low capital investment. The grow out or culture period is 6 to 8 months. In Kerala, oyster farming is a household activity where all the family members are mobilized to participate in different activities such as ren making, farm construction, harvesting, postharvest processing and marketing (Figures 36- 37).

Fig. 36. Oyster farm of women Self Help group at Kayamkulam in Kerala.
Courtesy : CMFRI, Cochin, Kerala

Fig. 37. Harvesting of oysters in Kayamkulam estuary in Kerala
Courtesy : CMFRI, Cochin, Kerala

Though women were involved in all these activities, their participation is more in the ren making (punching and stringing empty shells and suspending) and post harvest processing such as cleaning, shucking and packing. Farm construction and harvesting is usually done by the male members. Marketing in some locations (Kayamkulam Lake) was done exclusively by women while in Ashtamudi Lake the marketing was through Government Department.

A socio-economic survey conducted among the oyster farmers has shown that some farmers of Kayamkulam Lake utilized the money to meet their daily requirements. The regular income to the families is through fishing and the fishers, become unemployed when the trawl ban is implemented during monsoon. For these fishers the money from the sale of 5 to 10 oyster rens per day was the main source of income. Some farmers have utilized the money for meeting the initial expenses connected to schooling of their wards (for purchase of books, uniforms etc.).

Surveys conducted among the oyster farmers of Ashtamudi Lake and Kayamkulam Lake showed that the farmers have no complaints regarding the technology. They have utilized the profit (ranging from Rs 700 to 25,000 depending on the farm size) for various family commitments such as repayment of existing loan taken for house construction, daughter's wedding, children's education etc. In India, the growth of oyster culture activity is picking up. The general constraints in the development of oyster culture in India are given in Table 32.

Table 32. General constraints in the development of oyster farming in India

Constraint	Remarks
Lack of awareness about technology	Partly solved by village level participatory programmes in demonstration farms; wider extension and need based training are needed.
Marketing of farmed oysters	Partly resolved by collaborating with Government Agencies; targeted market survey and product development.
Ownership of farming area/ legal aspects	Appropriate leasing policy and inclusion of oyster farming in State plans needed.
Classification of oyster growing areas according to pollution index	Not resolved. Based on this the oyster trade can be developed.
Availability of finance to farmers	Funding by BFFDA available but timely availability of funds to farmers should be ensured.
Exploring external markets for oysters	Feasibility of single oyster production to be explored; MPEDA's and Indian Embassies help needed.
Reduction in recurring expenditure	More durable PVC pipes fitted with concrete has been found to reduce recurring expenditure.
Infrastructure for depuration	State level action needed.

The important constraints experienced by the oyster farmers in Kerala are:

1) Non availability of finance in time for setting up of spat collectors
2) Poaching
3) Damage to farm structures by fishers who try to catch the fish which aggregate between the rens in the farm.
4) Relatively lower price of oysters, and difficulties in the marketing of farmed oysters
5) Non availability of area for farming in open estuaries, leasing policy, and legal aspects.

Nevertheless, the results of oyster farming demonstrations so far organized and developmental activities initiated in Kerala have greatly helped to motivate and attract the farmers to this field (Fig.38). The center-state-farmer collaborative activies (Fig.39) has turned out to be a role model for other maritime states to plan their bivalve mariculture activity.

Fig. 38. Oyster farmer, Mr.Vincent Mukkadan, the first oyster farmer of the State, also the recipient of best farmer award of Kollam district constituted by the State Government for the year 1998 speaking on the occasion of Oyster Farmers Meet organized jointly by BFFDA and CMFRI in March, 2001. Courtesy: CMFRI, Cochin, Kerala

OYSTER CULTURE AND RURAL DEVELOPMENT

Rural development in a broad sense is the remunerative activities of rural residents by using the resources and opportunities available in their communities and the localities to lead a full creative and healthy life. In the programmes on

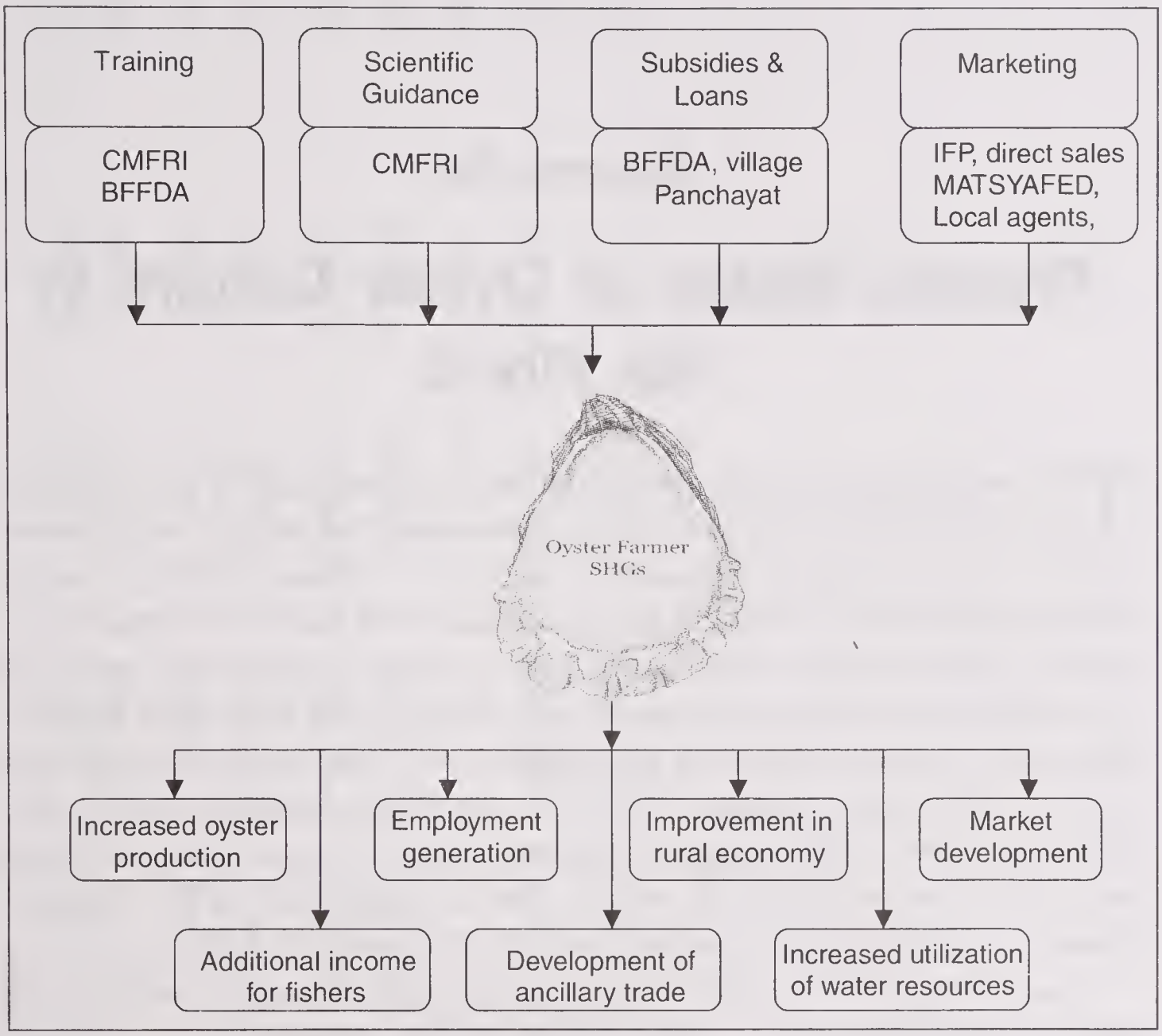

Fig. 39. The center-state collaborative programs in Kerala State
Source: Kripa *et al.* (2004)

oyster culture in Kerala, participation of villagers was given priority. Their involvement in farm construction, ren making and harvesting have greatly induced to develop an urge to own an oyster farm in the villages. Supported by the financial assistance by BFFDA and marketing by Integrated Fisheries Project (IFP) and Aquaculture Development Agency in Kerala (ADAK), the state is poised to double its aquaculture production of oysters in the coming years. The Rural Development Activity (RDA) of this state is in early stage in some areas while in Ashtamudi Lake and Kayamkulam Lake it is in an advanced stage. With the participation of farmers in decision making and ownership, and the involvement of funding and developmental agencies, realisation of the production potential, social benefits in terms of employment and greater income to fish farmers, the prospects and scope of oyster culture industry in the country is undoubtedly enormous.

QUESTIONS

1. Give an account on the technology transfer of oyster culture and the constraints faced by the farmers.

CHAPTER 10

Present Status of Oyster Culture in the World

THE world aquaculture production of molluscs during 2003 was estimated as 1,22,84,758 tonnes and with a production of 44,96,609 metric tonnes oysters were the major contributors with 36.6 % . Clams (37,88,158 metric tonnes) and mussels (15,86,364 mt) contributed 30.8 and 12.9 % repectively. Scallops, others molluscs, gastropods and cephalopods also were farmed and the estimates of production during the period 1999-2003 is given in Table 33. The Pacific oyster, *Crassostrea gigas* ranked first with an annual production of 43,76,802 tonnes forming 97.3 % of the oyster produced during 2003 (Table 34). Chew (2001) suggested the possibility that more than one species are grouped under the Pacific oyster. Next in importance is the American oyster, *C. virginica* with a production of 71,711 tonnes (1.5%).

According to Chew (2001) the five major cultivated oyster species in the order of abundance are *C. gigas* (China leading production), *C. virginica* (predominantly in the east coast of USA), slipper oyster *C. iredalei* (mainly from the Philippines), the European flat oyster, *Ostrea edulis* (European countries) and the Sydney rock oyster, *Saccostrea commercials* (Australia). Other species of importance are *C. plicatula, C. rivularis*, *C. angulata* and *O. chilensis*. As per the FAO (2003 b) statistics the five top oyster producing countries by aquaculture (Table 34) are China (82.1%), Japan (5.8 %), Korean Republic (5.3%), France (2.6 %) and the USA (2.4 %).

CHINA

Molluscs are cultured all along China's 18,000 km coastline and at least 27 bivalve species are farmed. In recent years the decline in shrimp production due to diseases has led to intensified efforts in molluscan culture. Zhong-Qing (1982) dealt with bivalve culture in China while Guo *et al.* (1999) gave an overview of molluscan aquaculture in China. Shilu and Linhua (2002) have rightly called China as a world power for mollusc culture, in spite of the statement of Guo *et al.* (1999) that "Some Chinese scientists and managers believe that the official statistics may overestimate the overall production by 20 to 30 %". The oyster production in China during 2003 was estimated as 3669493 metric tonnes contributing to 82.1% of the global oyster production. Oyster culture began in China more than 2000 years back. The commonly

Table 33. World mollusc production by farming during 1999-03 in tonnes

Group	1999	2000	2001	2002	2003	Average	% in 2003
Clam	27,57,882	26,31,462	31,07,415	34,16,695	37,88,158	3140,322	30.8
Gastropods	2,472	3,270	3,445	2,970	2856	3,002.6	0.1
Oyster	37,22,942	39,98,497	42,07,074	43,37,252	44,96,609	41,52,475	36.6
Mussels	14,46,222	13,70,630	13,85,044	14,95,897	15,86,364	14,56,831	12.9
Scallops	9,52,512	11,56,109	12,19,128	12,28,822	11,78,468	11,47,008	9.6
Cephalopods	33	28	16	14	10	20.2	0.0
Miscellaneous Marine Molluscs	12,58,626	15,98,913	13,61,717	13,89,586	12,32,293	13,68,227	10.0
Total Mollusc	1,01,40,689	1,07,58,909	1,12,83,839	1,18,71,236	1,22,84,758		100.0

Source : FAO, 2003 b

Table 34. World Oyster production and top five oyster producing countries during 1999-03 in metric tonnes (FAO, 2003 b). Figures are in metric tonnes

Species	1999	2000	2001	2002	2003
Pacific cupped oyster	36,02,605	39,10,231	41,07,596	42,34,533	43,76,802
American cupped oyster	57,522	42,662	45,058	54,154	71,711
Cupped oysters nei	34,430	17,636	21,172	22,447	21,700
Slipper cupped oyster	14,804	14,222	19,042	12,570	14,500
European flat oyster	6,242	6,039	6,387	7,109	5,226
Sydney cupped oyster	5,024	4,961	4,912	4,605	4,928
Mangrove cupped oyster	1,870	1,632	1,483	1,300	1,313
Chilean flat oyster	291	200	229	235	211
Flat oysters nei	115	98	187	172	102
Gasar cupped oyster	.	95	88	81	75
Cortez oyster	.	685	593	21	21
Olympia flat oyster	21	20	310	21	17
Hooded oyster	4	2	3	4	3
Indian backwater oyster	14	14	14	0	0
TOTAL	3,722,942	3,998,497	4,207,074	4,337,252	4,496,609
MAJOR OYSTER PRODUCING COUNTRIES					
	1999	2000	2001	2002	2003
China, Hong Kong SAR	29,88,915	32,92,332	34,91,582	36,26,650	36,69,493
Japan	2,05,345	2,21,252	2,31,495	2,21,376	2,60,644
Korea, Republic of	1,77,259	1,77,079	1,74,117	1,82,229	2,38,326
France	1,39,000	1,35,500	1,09,040	1,15,284	1,17,000
United States of America	87,432	76,953	95,403	93,820	1,08,723

cultivated species are *C. plicatula*, *C. rivularis* and *C. gigas*. Among them *C. plicatula* is most important followed by *C. rivularis*.

Crassostrea plicatula

Zhong-Qing (1982) estimated the production of this species at 83.3 % while Guo *et al.* (1999) stated that it forms 50-60 % of the Chinese oyster production. It is a smaller species compared to the other two and is thin-shelled. It grows rapidly in the first year, after which shell growth is very poor. Traditionally it is cultured on stone pilings, vertical strips (over 1 m tall), and bamboo or wooden stakes. Only natural spat are used for culture and they are available throughout the year with peaks in May and September. The traditional methods of culture are the stake method with bamboo stakes and the stone bridge method. In recent times raft and long line cultures became popular with farmers since they give higher production and amenable to culture in the open coastal waters. In some areas stake and stone bridge methods were abandoned due to low production. Seed collected in May are harvested within a year, usually from December onwards, touching peak harvest in February, coinciding

with the Chinese New Year. The seed collected in September are harvested after 14-17 months when they reach the market size of 6-7 cm.

The stake method is suitable for soft bottom. Bamboo or other wooden stakes of 1.2 m long and 1.5 cm diameter are planted in the middle tidal flats before the spat fall peaks, at the rate of 1.5-1.8 x 10^5 stakes/ ha for spat collection. The average yield is 60 t/ ha but sometimes it may touch 110 t/ ha.

Zhong-Qing (1982) mentioned about the stone-bridge method used in sandy mud bottom. Bridges made of stone bars (80 cm x 20 cm x 8 cm diameter) are used to collect spat on midtidal flats during May/ June. During 7-12 months grow out, the bridges are moved to places to ensure abundant food supplies. In one hectare 15,000 stone bars are laid and the average yield is 30 tonnes/ ha. Sometimes the yield may touch 80 tonnes/ ha.

Crassostrea rivularis

This species lives in estuaries of low salinity along most of the Chinese coast. In Chinese it is called *Jinjiang*, which means 'close to river'. Low salinities are favoured by the spat for settlement. The farmers recognise two forms of this oyster; the one with white meat is preferred for its flavour and higher value than the red meat oyster. The culture methods are similar to those used for *C. plicatula.* Gravel, oyster shells and cement plates are used for spat collection. Peak spatfall occurs in June-August when salinity is at its minimum and temperature at its maximum for the year. Since early 1960's scientists have successfully developed spatfall forecast based on larval abundance and hydrography and help the farmers about the suitable time to lay spat collectors. The culture site is generally divided into rectangular plots and the spat collectors are lined up in rows. In a hectare, 3.0 to 3.8 x 10^4 cement bars of size 40-80 cm x 6 cm x 4 cm diameter or 1.0 to 1.4 x 10^5 cement plates of 17-24 cm x 14-19 cm size are positioned. After 3-4 years of culture *C. rivularis* is harvested. Before harvest, the oysters are removed to fertile grounds for a few months for fattening (Zhong-Qing, 1982).

In a farm at Guang, concrete stakes, 50 cm long and 6 x 6 cm at cross section are used both for spat collection and grow out. A dozen oysters/ stake is considered as optimum. About 30,000 stakes are planted in a hectare and the production is 5.448 tonnes of oyster meat (Guo *et al.,* 1999). *C. rivularis* is also cultured on shell strings hanging from rafts or long lines. Unlike *C. plicatula,* this species grows rapidly for 3 years and harvested after 2-3 years, at a size of 10-15 cm.

Zhong-Qing (1982) indicated that a raft measuring 84 m^2 area gives the same yield in 2 years which 677 m^2 area used for bottom culture gives in 4 years.

Crassostrea gigas

This species naturally occurs along the Chinese coast and also there were introductions from Japan. It accounts for 10-20 % of oyster production in China. The culture depends exclusively on hatchery raised seed (Guo *et al.,* 1999) and in the hatchery it is carried in 10-100 m^3 concrete tanks. Vitamin supplements and antibiotics are often used. Spat collection in the hatchery is on strings of scallop or oyster shells. Density of 20-30 spat/ shell is considered suitable but often spat set is 2-3 times higher. In such cases farmers may break the spat attached shell into 2 pieces. Each shell costs US $ 0.01-0.02. These are inserted into nylon ropes and suspended from long lines. At a few places bottom culture is also practiced.

C. gigas grows rapidly and reaches 8-10 cm in the first growing season. The seed are produced in hatchery in spring so that the oysters have a full season to grow. Oysters may be harvested within the first year of grow out. However, oysters grown in intertidal areas require 2-2.5 years to reach marketable size.

Triploid oysters are used for cultivation in Shandong and Liaoning Provinces because of faster growth and higher survival against "summer mortality", a syndrome linked to reproduction (Perdue *et al.,* 1981).

In China, raw oysters are rarely consumed. A variety of dishes are made from cooked oysters and some are dried for storage.

Perspectives: Marine molluscs are among the best loved seafood in China. The rapid development of mariculture of molluscs resulted in the deterioration of the culture environment and in many areas the carrying capacity may have exceeded. The rafts and long lines cover most of the area of the bays. Red tides became more frequent. Further development depends upon technological advances towards ecofriendly culture (Guo et al., 1999).

JAPAN

Japan produced 260644 tonnes of oysters in 2003 and occupied second position by contributing 5.8% of the global oyster production. Aquaculture in Japan which included oyster culture was dealt by Bardach *et al.* (1972), Imai (1977) and Kafuku and Ikenoue (1983) while Korringa (1976a) gave an account on *C. gigas* culture in the Hiroshima bay in Japan. In 1670, Kovayashi of Hiroshima placed bamboo poles with twigs and nets in the seawater, collected spat and attempted to culture them. This marked the beginning of oyster culture in Japan (Imai, 1977). The "hanging culture" was developed in late 1920s and since 1950s oyster culture advanced rapidly by adopting the raft and long line culture systems.

C. gigas is the most important oyster species farmed in Japan. It is mostly cultured in two regions : a) along the Pacific coast in the Tohoku region with the Miyagi Prefecture as its center, and b) the Seto Inland sea with Hiroshima Prefecture as its centre. *C. gigas* grows to a maximum size of 35 cm in shell

height and the harvest size is 8 cm onwards. It spawns in summer, and in the southern Japan it spawns several times while in the north it spawns once in a year or at times once in 2 years. *C. gigas* culture is practiced by using the natural spat.

Seed Collection

Collection of natural spat is limited to a few places such as the Sendai bay of the Miyagi Prefecture and the Hiroshima coast in the Seto Inland sea. The former area is most productive for seed collection. The reasons for the high seed availability in the Sendai bay include large spawning stock of oysters, temperature rise to optimum level in summer, healthy growth of larvae, favourable physico-chemical factors contributing towards the retention of the larvae in the bay, leading to heavy spatfall (Imai, 1977).

In the Miyagi Prefecture area the seed oyster industry is concentrated in Honshu. As water temperature reaches 20^0 C in late spring or early summer, spatfall occurs from May to August with two or more peaks. The August peak is preferred since fouling intensity is low and survival high when compared to the spat collected late in spring. The biologists forecast the setting time, enabling the farmers to suspend the spat collectors. Scallop or oyster shell strings are suspended from bamboo racks. In Japanese language the shell strings are called 'rens' (Imai, 1977). The ren is folded at the centre and the two ends are hung from the rack forming a double collector string. A 1.8 m collecting ren holds 70-80 oyster shells or 100 scallop shells without spacers. The scallop shell rens are used for cultivation in Japan while oyster shell rens are meant for export to the USA and Canada where they are better suited for bottom culture.

In the Inland sea of the Hiroshima coast, spat collection is similar to that followed at the Miyagi Prefecture except that 2.5 cm spacers made of bamboo, or plastic are inserted between the shell collectors.

Imai (1977) has given the spat settlement on various shell cultches used in Japan. The number of *C. gigas* spat per oyster shell are 20-30, scallop shell 30-60, clam shell 30-50, and abalone shell 30. According to Kafuku and Ikenoue (1983) on an average, 25 oyster seed are attached to 10 cm height shell collector. Settlement of 200 spat/ shell is considered as good and about 50-60 survive to the seed oyster size of 1-1.5 cm in about a month's time (Bardach *et al.,* 1972). At this stage the rens are removed, the shells are restrung on thicker wires with bamboo or plastic spacers, 20 cm apart for grow out culture.

Hardening of Seed

Imai (1977) called hardening of oyster seed as 'floor-rearing'. The seed are hardened in intertidal areas, both for domestic and export purposes. The areas selected for hardening are characterised by weak tidal currents and low food

availability. Attached *C. gigas* seed of 5-10 mm size, held on rens are moved to hardening racks in September. The rens are laid horizontally along the tops of the racks. The rens are so positioned that the seed are exposed to air for 4-5 hr during each tidal cycle. The seed hardening is continued through winter till about February. Hardening results in slower growth, and exposure to sun and wind thickens the shell margins. They develop resistance to stress. After hardening they are separated from rens, cleaned of silt, drills etc. and are packed for export. The hardened seed have better survival and also grow rapidly when transferred to subtidal grow out facility.

Transport of Hardened Seed

In Japan the technique for hardening the seed of *C. gigas* was developed essentially to meet the rigors of 10 days shipment to the USA and Canada. They are transported in cases, each case holding about 10,000 shells with attached spat. The cases are covered by straw mats to prevent drying during transportation. The straw mats are sprayed with seawater two or three times daily during the voyage to North America. Beginning in 1920 *C. gigas* seed were exported to the USA till 1970's (except for a break during the second world war). Annually about one billion *C. gigas* seed (half of Japan's seed production) used to be exported to the USA (Bardach *et al.*,1972).

Bottom Culture

This is the oldest method and the bottom should be firm. Towards this end, stones, bamboo and empty shells are covered on the substrate. In some places the culture beds are rectangular 30 to 60 m in length and 4 to 6 m in width, arranged at intervals of 6 to 10 m. In Ariakekai, *C. rivularis* is cultured by this method. The seed are grown for 1.5 to 2 years with little management practice. Production is said to be 1.5 kg meat/ m^2 (Imai, 1977).

Rack Culture

C. gigas culture is carried in shallow waters of 2-4 m depth at low tide. Rows of bamboo poles are driven vertically in the substratum and are connected by horizontal poles. Cross poles are laid on the latter and tied. About 6-10 shells are strung, 20 cm apart on 1.5 m long string and 20 such strings are hung for every 3.3 m^2 area of the rack. The strings are harvested during the following spring. Production in the Hiroshima bay is 0.48 kg meat/ m^2 raft. Continuous rack culture in the same grounds in Malsushima bay resulted in decreased yield and it is attributed to biodeposition of the oysters (Imai, 1977).

Raft Culture

Bamboo or ceder wood poles are used in raft construction. Bulk of oyster production by farming in Japan is by this method (Kafuku and Ikenoue,1983). On a raft of 4.5 x 9.0 m about 200 strings are hung. The shells are strung at

10-15 cm interval on rope or galvanised wire of 3 to 6 m length depending on the water depth, and are hung 40-50 cm apart, from the raft. Spat density of 20/ shell is considered as desirable for optimum growth. Seeded rens are hung from the rafts in spring following the year of seeding. From October to next April *C. gigas* attains about 10 cm size and harvested (Imai, 1977).

The Inland sea of Hiroshima is well protected and sheltered permitting the use of rafts in waters upto 10 m depth. Here rens with *C. gigas* seed are suspended during July-August and by the end of December the individual oysters weigh 30-60 g. Harvesting begins in December and continues throughout spring, thus the growing season from spat collection to harvest is 6-8 months. Between 3-10 % of these oysters are grown for the second year to produce 10-20 cm oysters specially for half shell market. These oysters are grown in special book-type hanging cages from rafts. It is stated that the use of hardened seed gives better growth in oysters cultured for two years. In a typical raft culture operation in Inland sea, production per ren is 6 kg oyster meat in 6-8 months (Bardach *et al.,* 1972).

In the northern regions of Japan due to colder winter, *C. gigas* are harvested after 18 months.

The rafts, in various regions of Japan vary in size from 38.8 to 164 m^2. The number of strings vary from 1.89 to 6.02 / m^2 of raft, the number of shell collectors on rens 284 to 750/ m^2 of raft and oyster production 3.5 to 14.83 kg meat/ m^2 of raft area (Imai, 1977).

In some regions the spat of *C. gigas* are collected from the same grow out sites and in other cases the seed are brought from other areas for planting. In the same culture site, the growth of oysters on rens suspended from inner rafts is slower when compared to those held on the racks at the periphery. This is attributed to lower quantity of food available to the oysters on inner rafts. A 7-month study conducted on the effect of seed density on the growth of raft cultured *C. gigas* in Onagawa bay showed that fastest growth of 7.15 g meat weight was obtained at 10 seed/ shell collector against 4.16 g meat weight observed at 60 seed/ shell collector (see Imai, 1977).

Long Line Culture

Long line culture is the second major contributor of cultured oysters in Japan. Introduction of this method enabled to extend the area of oyster culture to 30 m depth. Synthetic ropes and plastic buoys are used (Kafuku and Ikenoue, 1983). This method of culture is practiced at the mouths of bays or in open coastal waters and is popular in Iwati and Miyagi Prefectures. Compared to rafts, long lines are advantageous due to lower initial expenses and maintenance costs, and greater capacity to withstand strong winds, waves and currents. The seeded rens are hung in spring, and harvesting begins in October of the same year. The production of *C. gigas* on long lines is comparable to that of the raft method of culture. A long line of 60 m length holding 300 rens (each ren 7 m

long) yields 1.2 tonnes of *C. gigas* meat in 18 months. In one hectare 44 long lines of the above size can be located and the estimated production is 53 tonnes oyster meat. Long lines moored in deeper waters are used for suspending 10-15 m long rens (Bardach *et al.,* 1972). Growth of *C. gigas* on long lines located far away from the shore is not satisfactory (see Imai, 1977).

Comparison of *C.gigas* Production by Different Methods

A study conducted by Tamura (see Imai, 1977) in the Hiroshima Prefecture on the production rate of *C. gigas* by different culture methods showed that raft culture gives the highest yield of 15.74 kg meat/ m^2, rack 0.48 kg meat/ m^2 and bamboo pole 0.19 kg meat/ m^2.

Problems in Oyster Culture

Imai (1977) and Kafuku and Ikenoue (1983) listed the following problems faced by the oyster industry in Japan.

1. Oyster culture sites are facing pollution problems due to the discharge of industrial wastes. 2. Culture sites are concentrated in limited regions and continuous use of these areas resulted in loss of quality of oysters. Low dissolved oxygen levels in these sites are attributed to accumulation of organic matter and insufficient flow of sea water, leading to elevated levels of Hydrogen peroxide which is toxic to oysters. 3. Fall in water salinity due to heavy rains causes oyster mortalities. 4. Red tides deplete dissolved oxygen levels and cause oyster mortalities. 5. Oyster drills such as *Thais clavigera*, *T. beronni* and *Ocenebra japanica* prey upon oysters and sometimes cause heavy mortality of the farmed stock. 6. Fouling by barnacles, mussels and bryozoans results in competition for food and space. Heavy barnacle settlement on the cultch at the time of oyster spat collection results in low seed production.

Newkirk (1991) stated that the oyster production areas like the Hiroshima Prefecture may be at their limit of carrying capacity and negative effects of the high intensity culture and pollution are now limiting the growth.

FRANCE

During 2003 France produced 117,000 tonnes of oysters by aquaculture comprising 2000 tonnes of flat oyster, *Ostrea edulis* and 115,000 tonnes of *Crassostrea gigas* . Pillay (1990) mentioned that the Portuguese oyster *C. angulata* is considered by some to be the same or derived from *C. gigas*. Oysters are grown mostly on the bottom since regularly shaped oysters are produced by this method, to cater to the needs of half shell oyster trade. The gourmets choice in France is for the half shell of flat oyster, *Ostrea edulis*. Not many water bodies are suitable for the culture of this species. The Portuguese oyster *Crassostrea angulata* is also cultured traditionally on the bottom. Natural spat are used for culture. Bardach *et al.* (1972), Korringa (1976 a, 1976 b) and Pillay (1990) dealt on oyster culture in France.

Ostrea edulis

The most important seed collection area is the north coast of Brittany. The Gulf of Morbihan is famous for seed collection. Compared to *C. angulata*, this species is less hardy and thrives best below low water mark and in higher salinities (> 25 ppt). Culture period is long due to slower growth and gives low yield.

Natural spat collection: In the Gulf of Morbihan the season for spat collection is from June-September when the water temperature is 20^0 C or more. Biologists monitor the abundance of oyster larvae in the plankton collections and provide information on spat setting time to the farmers. They also monitor the barnacle larval abundance to determine the best time for oyster spat collection.

Semi-cylindrical ceramic tiles of 13 cm length and 10-12 cm diameter coated with lime are used for natural spat collection. A stack of three to six pairs of tiles is tied together for easy handling; the stacks are placed on wooden platforms, 15-30 cm above the ground. The tiles are left in the position throughout the summer and fall to receive several successive spatfalls. Spat set of 30-50/ tile is considered as satisfactory. Natural seed collection is generally a family operation. Every year some 30 million tile collectors are laid, producing one billion seed (Bardach *et al.,* 1972). During winter the thumbnail sized seed are scrapped from tiles for planting on the bottom in grow out areas, known as 'parks' in southern Brittany. The movement of sand due to the tides may bury the oyster seed and at low tide the sand is manually removed. The major concern to the oyster seed industry is the low winter temperatures, resulting in seed mortality.

Bottom Culture in Parks: The parks in the northern Brittany vary in size from a few to several hectares and are protected from sand and sediment incursions by the construction of earthen and brush dykes, 30-70 cm high (Bardach *et al.,* 1972). Sand or fine gravel is spread, after the bottom is levelled, to maintain its firmness. The shallower areas of the park used for rearing spat to young oysters are protected by net fencing (Pillay, 1990). The young oysters are held in the parks for 1-1.5 years, collected and transferred to deeper beds in 3-10 m of water. Here they are grown for 2 years, collected by dredging and transplanted back in the intertidal parks for fattening. Planting the oysters in deeper waters results in better growth and also the culture site is expanded. The total duration of *O. edulis* bottom culture is about 4.5 years. Production rate of *O. edulis* is 1.7 tonnes/ ha/ year (Bardach *et al.,* 1972).

Fattening and Greening in Claires: The word 'fattening' is misleading since the process involves primarily the deposition of glycogen. In France oysters are fattened after they reach the market size. By this process the oyster meat increases in size and weight and the colour changes to creamy white with good flavour. Fattening requires calm, shallow, relatively warm and preferably

brackish water, rich in plankton. Artificial shallow ponds of 0.1 to 0.2 ha in size are constructed on marsh land adjacent to sea. These ponds are known as claires and are connected by a system of gates and channels. The claires are prepared in summer by draining the water and exposing them to the sun for several weeks. They are fertilised and filled with water up to 25 cm depth; water is exchanged twice a month during spring tides. The oysters of about 40 g shell-on weight are stocked in the claires at 4/ m^2 in late summer and fall, and in six months the weight is nearly doubled (Bardach *et al.,* 1972). They are highly priced and much sought in the French market. The blue-green diatom *Navicula astrearia* occurs naturally in some claires and gives green colour to oyster meat. This so called greening further increases the value of the flat oyster in the market.

Rack Culture: A common method of *O. edulis* and *C. angulata* culture on the Atlantic coast is the rack method (Pillay, 1990). The natural spat are held in synthetic bags of 1 m long and 0.5 m wide and these are fastened by rubber bands to wooden or metal racks, 0.5 m above the ground. Each bag contains 5 kg of 1.5-2 year old *O. edulis* and a density of 6,000-7,000 bags/ ha is considered as satisfactory for growth.

Hanging Culture: In recent years this method has become very popular on the Mediterranean coast of France. Ropes laden with oysters are suspended in protected areas from metal or wooden frames, ensuring that the oysters are always submerged. Seed oysters are stuck on synthetic ropes or specially made wooden poles by using quick setting cement. On a 2 m long rope/ pole about 75 or 80 oysters are stuck (Pillay, 1990). Foulers are manually removed. For harvest the ropes are brought to the shore and the oysters are detached. The yield is high at 5 kg per rope/ pole but the shell is often fragile and tends to open after harvesting.

Predators and Diseases: The spat are preyed upon by the crabs (*Carcinidas* sp). Major predator of oysters is the starfish *Asterias* sp. and it is controlled either by manual removal or by the application of quick lime on the oyster bed. Large scale mortalities of *O. edulis* occurred in France from 1968 for a decade. The protistan parasites *Marteilia refringens* and *Bonamia ostreae* were implicated. The only means of control appears to be to avoid planting oyster seed during July and August when *M. refringens* infections occur (Pillay, 1990).

Crassostrea angulata

The seed of this species are also collected on lime coated ceramic tiles which are placed closer to the shore as they can withstand longer exposure to sun. The tiles are increasingly replaced by wire mesh bags containing oyster shells. The shell bags are placed on wooden racks or platforms, 25 to 30 cm above ground. Generally the seed are left in the collection sites for two years. The spat collected on oyster shells in bags are grown till harvest with little care.

Sometimes 2 year-old seed oysters are thinned and transferred to new bags. The oyster seed attached to oyster shells are also sown on the bottom. *C. angulata* is basically cultured in intertidal areas within the estuaries (Bardach *et al.*, 1972). Those seed grown on soft sediments may be smothered by mud and are periodically turned and brought to the surface by rakes.

Fattening and greening of *C. angulata* is becoming popular. This type of culture takes 4-6 months and the oysters are stocked at 12/ m^2 in claires. Production is 7.5 t/ ha/ year (Bardach *et al.*, 1972).

Prospects

The European flat oyster *O. edulis* is highly esteemed in France and its cultivation is mainly targeted towards the half shell market. Compared to *C. angulata*, this species thrives well at higher salinities, growth is slower and production rate low. There is growing interest in the culture of *C. gigas* particularly after the heavy mortality of *C. angulata* in 1970's.

Some farmers use synthetic spat collectors, in place of ceramic tiles. The close set perforations on the surface allow the lime coating to adhere; the surface area is enhanced by 25 % over the conventional ceramic tile and the attached spat are removed with ease by twisting the synthetic collector. There are machines to punch the shells for ren making, to scrap the oyster seed from the tiles and to grade the harvested oysters for market. Gathering the oysters from the ground is also mechanised (Korringa, 1976 a, 1976 b).

A noteworthy feature of the bottom culture of oysters in France is the care taken by farmers to maintain the park bottom in good condition. Towards this end, every year up to 1000 m^3 of crushed stone per hectare is spread on the ground (Korringa, 1976 b).

PHILIPPINES

In 2003, the production of slipper oyster, *Crassostrea iredalei*, by aquaculture was 14,510 tonnes. Bivalve culture in the Philippines was dealt by Young and Serna (1982) and Joseph (1998) described the mussel and oyster culture in the tropics which included the Philippines. Bivalve farming began in the Philippines in early 1900. Oyster farms ranging in size from 100 m^2 to 2 ha account for 60 % of the production. *C. iredalei* is the most favoured species for culture and is marketed at 6-9 cm in length while to a lesser extent, *C. malabonensis*, a smaller species is marketed at 4-5 cm size (Young and Serna, 1982). Several types of oyster culture are practiced.

Bottom Culture

This is also called as broadcasting method. Spat collectors such as oyster shells, stones, rocks, boulders, tin cans and a variety of scrap are laid on firm bottom, as spat collectors where natural setting occurs. In areas devoid of natural oyster populations, collectors with attached spat are brought and

scattered on the bed. Subtidal areas are also used for oyster culture. The oysters are harvested after 8-10 months culture. When grown on stones or boulders, the oysters are usually harvested at low tide by detatching them, leaving behind the cultch. This method is not popular, in spite of low investment, and the disadvantages include: it is substrate specific requiring firm bottom, production rate low, high oyster mortalities due to siltation and predation, and harvest is difficult particularly if stones are used as spat collectors (Young and Serna, 1982; Joseph, 1998).

Stake Method

This method is widely followed and the species grown are *C. iredalei*, *C. malabonensis* and *C. cucullata* (Angell, 1986). Bamboo stakes of 5-9 cm diameter are driven into the bottom in rows and are positioned 50 cm apart, during April-July spawning. The stake is used as the substrate for spat settlement. Some farmers tie horizontal bamboo pieces to the stakes or attach empty oyster shells on the stakes to increase the surface area for spat collection. There are several variations in the stake method. The lattice method of culture is popular in the Philippines and Ablan (1955) described this method in detail. The lattices are constructed with bamboo poles of 5-9 cm diameter, held in the form of inverted 'V' and tied together with galvanised wire. Lattice rows are erected 5 m apart at < 1 m depth at low tide. All the three oyster species mentioned above are grown by this method (Angell, 1986). This method of culture is considered as intermediate between stake and rack culture (Angell, 1986). For harvest the bamboo stakes are usually lifted from the water, the oysters removed on the shore or in a boat, and the stakes discarded. If the stakes are strong to last for another season, the oysters are scrapped or pulled off by divers and brought to the shore for separation of clusters. When compared to bottom culture, stake method has the advantage of low oyster mortality, faster growth and higher production rate. The disadvantages are many such as; predators such as crabs and starfish can crawl on the stakes and attack the oysters; harvesting the oysters from the stakes is difficult; and bamboo collects fewer spat per unit area than do oyster shell (Young and Serna, 1982). A 0.5 ha stake culture farm can hold 35,500 stakes producing about 8,600 l of shucked oyster meat (Blanco, 1956).

Hanging Method

In this method empty oyster or coconut shells are used as collectors. They are hung on synthetic twine or heavy monofilament nylon line and are held 10 cm apart by bamboo spacers; otherwise knots are made in the twine. In some places, for spat collection, the shells are strung without spacers and then restrung with spacers for grow out culture. There are several methods of hanging culture. **(a)** Strings of oyster or coconut shells spaced about 25 cm apart on polyethylene rope are hung from a bamboo platform. **(b)** The cultch

consists of a long line of threaded oyster shells held apart by 10-12 cm long tubes. Four parallel lines, approximately 20 m long and 20 cm apart are strung between two bamboo posts. This is a fixed long line directly holding the cultch. Oysters grow fast by this long line method as they are not crowded. **(c)** Oyster shells are held in bamboo tray (1.5 x 1.0 m) with 15 cm sides. These trays are kept on horizontal supports fixed in near still waters. The oyster seed are left to grow to market size in the tray. For harvest the oyster trays are brought to the shore where the oysters are separated. The duration of the culture is 6-8 months. The advantages of the hanging method over other methods are: faster growth, higher production, lower mortality from silt and predators, independent of the nature of substratum, and harvesting is easy. High cost of the materials is the disadvantage (Young and Serna, 1982).

For market, most of the oysters are transported in the shell. For long distance markets shucked meat, packed in polyethylene bags, is transported. Oysters are rarely processed into various products. As per a study conducted on the economics of various methods of oyster culture in the Philippines by Librero *et al.* (1976) the earnings on sales per hectare by bottom culture are 10 %, stake method 36 %, lattice method 50 % and hanging culture 73 %.

Problems

The Becoor bay near Manila, where the first oyster farms were established, became the leading centre for oyster and mussel production between 1935 and 1950, followed by a decline after 1960, due to microbial and industrial pollution (Young and Serna, 1982). The growth and decline of shellfish farming in the Becoor bay is now part of history. Newkirk (1991) stated that the problems affecting oyster culture in the Philippines are deforestation resulting in increased runoff and siltation, pesticide and sewage pollution, loss of mangroves and occurrence of red tides.

THAILAND

The production of oysters by aquaculture in Thailand during 2003 was 16 000 tonnes. Saraya (1982) described bivalve culture; Joseph (1989,1998) dealt with oyster and mussel culture and Pripanapong and Youngvanichset (2000) wrote on oyster culture in Thailand. Oyster culture was first attempted in Chantaburi Province in 1942 and spread to other areas. Its development during the period 1942-1980 was slow for want of investment incentives. In Thailand, oysters rank first among the farmed molluscs and three oyster species namely *Crassostrea belcheri* (some consider it as *C. lugubris*), *C. iredalei* and *Saccostrea cucullata* are cultured. In 1995 the total area under culture was 1419 ha and *C. belcheri* was farmed in 51 % of the area (Pripanapong and Youngvanichset, 2000). Oyster culture practices include the traditional method of placing rocks on hard or sand-mud bottoms to semi-traditional method of installing bamboo or other stakes on the sea bed. Tray hanging culture is a

recent development but not popular due to high cost of investment (Tiensongrasmee, 2000). The most commonly used oyster culture methods are on cement pipe, bamboo stick, cement pole, besides tray culture, and hanging culture (Pripanapong and Youngvanichset, 2000). Average annual production rate of oysters in Thailand was estimated by Young and Serna (1982) at 19 t/ ha/ year (culture method not specified).

Bottom Culture

This is a traditional method and large stones or rocks are placed on hard sandy or sandy-mud bottom. Rocks are piled up in group of 5-10 and these are placed in rows, 10 cm apart. The spat set on these materials are harvested after 1-1.5 years.

Cement Pipe Culture

Cement pipe of 40-50 cm in diameter is cut into 20-45 cm in length, and inserted on to bamboo pole which stacks on the bottom. Each set of pipes is 65 cm apart in column and 1.5-1.6 m in row. Both spat collection and grow out are carried on the cement pipe. This method is commonly practiced in Surat Thani and after 18 months the oysters are harvested. The pipes are kept in the sea bed for about 8 months and *C. lugubris* attains > 7 cm shell height (Bromanonda, 1978). This species attains 11 cm shell height in one year. Average production rate of *C. lugubris* is 45 oysters per pipe or 75,000 oysters/ 0.16 ha (Bromanonda, 1978). The production of oysters at Surat Thani area was estimated at 39,400 numbers/ ha/ year by Joseph (1989).

Bamboo Stick Culture

Dried bamboo sticks of 1-1.5 m in length are stacked 40-50 cm above the bottom, 15-20 cm apart from each other in a row. The rows are set 2-3 m apart. The bamboo stick is used both for spat collection and grow out culture. In Surat Thani, this method of oyster culture is practiced. High mortality may occur due to collapse of the bamboo sticks.

Cement Pole Culture

Cement pole of 12-15 cm in diameter and 30-35 cm in length with a hole on side is inserted on the bamboo or wooden pole. These cement poles are spaced on the bamboo at 20 cm apart in a row and the distance between the rows is 2.5-3.0 m.

Tray Culture

Commonly used trays made of hard wood measure 80 x 100 x 15 cm in length, width and height. They are suspended from a raft. These trays are also used by farmers for holding the harvested oysters before they are marketed. Now used motor cycle tyres as trays became popular among the farmers. The tyre

is divided into two rings with nylon net and lined with rope. Sets of tyres are hung 1 m apart under a raft. The grow out culture is 6-8 months. Used motor cycle tyres have > 10 years life for tray culture, are cost effective and yield oysters of good shape for market. Tyres are widely used as trays in the west coast.

Hanging Culture

Oyster spat numbering two, taken from a collector are attached together, with cement on the rope. The ropes are suspended either from racks or rafts.

Hanging culture of ropes with spat cemented, from raft or long line is most suitable for the west coast, while cement pole and tyre-tray hanging from raft is found to be well-suited for the east coast.

Remarks

It is of interest to know that apart from split bamboo poles, specially made cement tubes are used for spat collection in Thailand (Joseph, 1989). The natural seed set on spat collectors are carefully removed and refixed on nylon ropes and cement blocks in a linear fashion. Although labour intensive, this practice helps to seed the grow out substrate at appropriate density to optimise production. It assumes significance because it is common knowledge that in some sites the spat fall may be scarce while in others it may be intense and in such situations the above practice has the potential to play a decisive role in better utilization of the seed resources. The utilization of the used motor cycle tyres as substitute for costly, specially made trays is yet another innovation in the oyster culture practiced in Thailand.

Large oysters, especially *C. belcheri* are popular and valued high in the domestic market. Oysters are mostly sold in the domestic market either fresh or preserved.

The major constraints for the expansion of oyster culture in Thailand are inadequate seed supply, shortage of suitable culture areas and lack of quality control (Newkirk, 1991). Tookwinas *et al.* (1990) described the problems for oyster culture in Bang Prong Bay in Chonburi Province of Thailand where oysters suffered mass mortalities during 1989. The mortalities are attributed to deterioration in the water quality due to high stocking densities and also the oyster farms covered 80 % of the bay.

QUESTIONS

1. Describe oyster culture in China or Japan.
2. Write on the importance of oysters in the world aquaculture.

Chapter 11

Recent Developments in Oyster Culture

DURING the past two decades several developments have taken place in oyster culture, specially in the hatchery production of seed. In the nutrition front, systems have been developed to produce live microalgae at high densities by adding appropriate dose of carbon dioxide in the culture media, dried heterotrophically grown replacement diets in lieu of live microalgae and microencapsulated diets as supplement to the normal diet. Success has been achieved in the cryopreservation of sperms and D- larvae, remote setting of larvae and use of chemicals to enhance spat settlement. For rearing the oyster spat, flowthrough systems in the hatcheries and several types of forced upwelling practices for the nursery rearing of the spat are in vogue. Use of the concept probiotics is an emerging science in the larval rearing to improve the health of the larvae. Oyster genetics including selection, hybridization, polyploidy and biotechnology are the frontier areas of science where significant contributions have come towards increasing the productivity in the grow out systems. The use of oysters along with seaweeds as biofilters in purifying the shrimp farm effluents has received considerable attention. Narasimham (1998) gave some of the developments in the hatchery production of bivalve seed.

Broodstock Development and Spawning Induction

Broodstock development in the hatcheries involves considerable expenditure. It is of interest to note that encouraging results have been obtained by conditioning the oyster broodstock in waters of high phytoplankton production such as shrimp farms. Spent *Crassostrea iredalei* introduced into shrimp farm showed rapid gonad development and 60 % of the oysters became fully ripe within 30 days (Wong, 1994). In Thailand, Nugranad (1991) observed that fish or shrimp earthern ponds, characterised by the presence of phytoplankton blooms do provide excellent facilities for conditioning the oyster broodstock.

The techniques of conditioning of bivalve broodstocks in the hatchery were reviewed by Utting and Millican (1997). The authors stated that " the objectives of bivalve broodstock conditioning are to maximize fecundity of parent animals, while maintaining egg quality and larval viability". Gonad maturation depends upon food availability, diet quality and water temperature

during conditioning. Based on the review they made the following observations. Live microalgae as food give better results than 100 % spray-dried algae. It is desirable to use two or three algal species rather than a single species. The best diets are those high in PUFAs. A suitable ration for bivalve broodstocks is 6 % of the dry meat weight in dry weight of algae per day for most species reared at 20-22 °C. At lower temperatures 3 % may be sufficient. The role of dietary protein during broodstock conditioning needs detailed studies. In spite of several decades of hatchery production of bivalve seed the techniques available for broodstock conditioning are still far from ideal (Utting and Millican ,1997).

Apart from thermal shock, the most commonly used stimulant for spawning induction is the addition of gametes stripped from another oyster. Some commercial hatcheries remove the ripe gonad portion from the male and female oysters and place it in a blender with 1 mm filtered seawater. The tissue is blended for 5-10 seconds. The liquid tissue is passed through 73 µm screen with eggs collected on a 44 µm screen. Then the eggs are washed in filtered seawater. Eggs obtained by stripping usually produce fewer larvae than a natural spawn since immature eggs are included. This method is commonly used in *C.gigas* hatcheries (Castagna *et al.,* 1996).

Serotonin induces spawning particularly in males. Serotonin concentration of 2.0 mM is obtained by dissolving 7.7 mg in 10 ml of 1 mm filtered seawater. Approximately 0.4 ml of the 2.0 mM solution is injected into the adductor muscle of the oyster. In about 15 minutes after the injection, ripe oysters spawn (Gibbons and Castagna, 1984).

High Density Microalgae Production by Adding Carbon Dioxide in Culture Media

The batch culture practice of raising live microalgae for use as food to the oyster larvae under axenic conditions usually gives a density of 1.0 – 1.5 million cells/ml. Addition of carbon dioxide gas enhances the microalgae growth. Carbon dioxide is supplied from compressed gas cylinders, and very little is needed (about 0.5%) in the air supplied to the algal culture. The carbon dioxide is passed through a flowmeter, taking care that the quantity used will keep the pH of the culture between 7.8 and 8.0. The pH is monitored though a pH meter. Both the air and the carbon dioxide are filtered through an in-line filter unit of 0.3-0.5 µm before they enter the microalgae culture media (Laing, 1991). By releasing the carbon dioxide gas into the culture media, algae cell concentrations go upto 6.0 million cells/ml (Wong, 1994).

In the commercial hatcheries in the USA carbon dioxide gas is passed into aerated algae culture containers for 15 seconds, about every 30 minutes at psi above ambient pressure to maintain the pH in 7.5 to 8.0 range. This is done in the hatcheries with a system of electric timer and solenoid valve connected to

a CO_2 tank and by manually plurging for a few minutes twice a day (Castagna *et al.,* 1996).

Preserved and Dried Algae as Replacement Diets

Live microalgae are the natural food for bivalves and considerable work has been done to utilize dried and preserved algae as a partial substitute to live microalgae. Centrifugation of algae into a paste form and stored in refrigerator greatly facilitates its use in the hatcheries. The shelf-life of *Thalassiosira pseudonana* concentrate (paste) is more than one year and it is possible to utilize excess and offseason algal production in paste form (Donaldson, 1991).

In recent years large scale outdoor pond production of a few algae such as *Spirulina* and *Dunaliella salina* has resulted in the bulk availability of spray-dried powder of these algae in the market. Spray dried extract of *D.salina* improved the growth of rock oyster larvae when it was supplemented with live algae (Numaguchi and Nell, 1991).

Techniques have been developed for the large scale production of marine microalgae under heterotrophic growth conditions, i.e. utilizing organic carbon instead of light as a source of energy. The growth of bivalve larvae and juveniles fed with dried *Tetraselmis suecica* is comparable to that obtained for live, light grown (photoautotrophic) *T.suecica*. The performance of dried algae was generally inferior to that of controls fed on live algae. Heterotrophic mass production of algae has been realised for very few species and most of the species that are known to be of high nutritional value for bivalves such as *Chaetoceros, Isochrysis, Skeletonema, Thalassiosira* and *Monochrysis* are not capable of growing in the dark (Gladue, 1991).

Artificial Diets

The production of live microalgae as food for bivalves in the hatchery accounts for about 30 % cost of the total seed production (Coutteau and Sorgeloos, 1993). In this context several attempts have been made to develop suitable non-algal artificial diets not only to reduce the cost of seed production but also to find out alternate artificial diet for larval rearing. Langdon and Newell (1996) have dealt on artificial diets for oysters. The studies by Dunathan *et al.,* (1969) and Turgeon and Haven (1978) showed that it is possible to increase the tissue weight and glycogen content of *C.virginica* by adding carbohydrate supplements. Urban and Langdon (1984) conducted growth studies on *C.virginica* by providing algae supplemented with various non-algal foods. They observed that upto 50 % of an algal ration could be substituted with a mixture of yeast, rice, starch and kaolin without a significant reduction in oyster growth. These powder diets are nutritionally incomplete, caused water quality problems and subsequently promoted bacterial proliferation in culture systems (Coutteau and Sorgeloos, 1993).

Microencapsulated Diets

Some progress was made in the development of microencapsulated diets. Laing (1987) used cross-linked, protein-walled commercially prepared capsules known as 'Frippak' as diet in growth experiments with juvenile *C.gigas.* He reported that upto 60 % of an algal ration could be substituted with the encapsulated diet without significant reduction in growth when compared with the growth of oysters fed on a full algal ration.

Lipid walled encapsulated diets were also tried on oysters. Langdon (1982) reported improved growth of juvenile *C.virginica* fed on algae with supplements of lipid-walled capsules containing water soluble vitamins compared with that of oysters fed algae alone. Chu *et al.* (1987) also used lipid-walled capsules containing protein, dextrose and vitamin B to *C.virginica* larvae. They stated that in some experiments, capsule-fed larvae grew to settlement and metamorphosis, while no larval settlement was observed in other experiments (also capsule fed). These authors speculated that the observed variation in the performance of capsule-fed larvae was due to differences in the bacterial population present in larval cultures.

Langdon and Bolton (1984) noted that the growth of *C.virginica* larvae fed on a microencapsulated artificial diet was reduced by 50 % when antibiotics were added to the culture medium. They suggested that bacteria are important in the nutrition of oysters fed on microencapsulated diets.

Feeding microcapsules high in (n-3) HUFA as a supplement to live algae can improve the growth of oyster seed fed with algae that are deficient in these essential fatty acids (Langdon and Waldock, 1981). In India, Kandasamy and Muthiah (1988) used microencapsulated diets as a supplement to live *Isochrysis galbana* to the D-larvae of *Crassostrea madrasensis*. Mean diameter of the capsule was 3 mm and contained oyster oil or clam oil or fish oil extracts. The larvae are given the feed at 10,000 or 20,000 capsules as supplement to *I.galbana* per day. Spat setting was higher in the larvae fed with oyster oil extract than the control where *I.galbana* diet alone was given. Better linear growth and greater weight increase was observed among the oyster spat fed with oyster oil and fish oil extracts in capsules, compared to the control where *I.galbana* diet alone was given.

The main problems in the use of microencapsulate diets are associated with selection of suitable capsule type, setting, clumping and bacterial degradation of the particles, leaching of nutrients and low digestibility of the capsule wall (Chu *et al.,* 1987; Langdon, 1989). The use of microencapsulated diets for bivalves at present mostly remain in the research laboratories due to high cost and difficulty in producing capsules of small size on a large scale (Coutteau and Sorgeloos, 1993).

Yeast

Studies have been conducted on the use of yeast cells as food for bivalves due to their high protein content, small particle size and good stability in the water

column. Further they can be mass produced at low cost. However, poor total nutritional value of yeast deter it to be used as an exclusive diet in the hatchery. Urban and Langdon (1984) obtained greatly improved growth in *C.virginica* by supplementing 50 % with the dried yeast *Candida utilis*, rice starch and kaolin, instead of yeast alone.

Manipulated Yeasts

Techniques towards improving the digestibility and the nutritional composition of yeast-based diets resulted in manipulated yeast product with good potential as a substitute for unicellular algae. A preliminary experiment, performed with *Tapes philippinarum* at a Spanish commercial hatchery, revealed that 80 % replacement of the algal control diet by the yeast product yielded a daily growth rate of upto 93 % of that obtained in the algae-fed controls over a 4-week culture period (Coutteau and Sorgeloos, 1993). The above authors demonstrated in *C.gigas* seed that replacing 80 % of the algal diet with manipulated yeast product gave an average daily growth rate of 70-80 % of that obtained in the algal control treatments during a three week study. These studies showed that the use of manipulated yeast diets as partial replacement to live microalgae diet gave a slower growth rate when compared with the controls. The authors stated that instead of dried yeast, use of manipulated yeast diet with improved digestibility and nutritional value has considerable potential as a low cost partial substitute for live algae in bivalve seed production.

Conclusion

In conclusion, it is observed that the main thrust of the nutritional and food technology research in oyster culture is on the development of more efficient and less expensive feeds for the seed production in the hatcheries. This is being tackled either through high density microalgal production, their preservation and storage or artificial diets of appropriate particle size containing balanced nutrient content. The results of the above mentioned experimental studies indicate that the live algae could be partially replaced by dried or preserved algal paste (Coutteau and Sorgeloos, 1993) and the artificial diets are used only in a few commercial hatcheries at present. According to Coutteau and Sorgeloos (1993) live algae could only be partially replaced by dried *T. suecica* (upto 25-50%) or preserved algal paste upto 75%.

Cryopreservation of Sperms and D-larvae

Freezing and preserving (cryopreservation) of gametes and embryos are used in selective breeding and artificial propagation. This technique is already used in fish farming (Rogan, 1994). Techniques have been developed to cryopreserve the sperm and D-larvae of bivalves but not the unfertilized eggs. In a preliminary study Renard (1991) showed that normal *C.gigas* larvae can be obtained from frozen-thawed embryos in the presence of methanol and sucrose.

Chao *et al.,* (1997) cryopreserved the late embryos and early larvae of *C.gigas* and the clam *Meretrix lusoria.* Survival rates ranging from 62.3 to 75.1 % were obtained in oysters by using a stepwise freezing protocol. Four hour old larvae/embryos at 28°C were equilibrated in 2 M dimethyl sulfoxide (DMSO) +0.06 M trehalose plus seawater for 10 minutes at 27°C and were then cooled to 0°C followed by cooling to -12°C at the rate of 1°C/minute and held at this temperature for 10-15 minutes allowing equilibration after seeding. Further cooling to -35°C is achieved at the rate of -2°C/minute, allowed for 10-20 minutes equilibration before quenching in liquid nitrogen. After thawing in a water bath at 28°C they were placed in seawater to remove DMSO. The swimming embryos exhibited rotary movements following thawing. For *M.lusoria* embryos/larvae with the cryoprotectants 2 M DMSO + 0.06 M glucose, survival rates ranged from 73.3 to 84.2 % by using the above protocol.

Some success has been achieved with D-larvae of *C.gigas* and the clam *Tapes philippinarum.* Larvae frozen to -196°C at 24 hours from fertilization have been thawed and reared. In the case of *T.philippinarum* the trial was continued to 10 days beyond metamorphosis (Utting, 1993). Cryopreservation is expensive and it may be some time before it is routinely used in the bivalve hatcheries (Burnell, 1994).

Use of Chemicals to Enhance Spat Settlement

A critical phase in the life history of the oyster is settlement and metamorphosis as spat. Successful settlement and subsequent survival results in increased spat production. When ready to set, the pediveliger larvae exhibit "swim-crawl" behaviour and become "behaviourally competent" to respond to simulation for settlement (Coon *et al.,* 1990). They crawl on the surface exploring its suitability, and unattractive surfaces do not sufficiently stimulate the larvae to settle and undergo metamorphosis. They resume swimming, further exploring the settling surfaces. The larvae are known to postpone metamorphosis for several weeks if conditions are not favourable (Loosanoff and Davis, 1963). Coon *et al.* (1990) found that cultured larvae of *C.gigas* could remain competent while delaying metamorphosis for at least 30 days.

In the oyster hatcheries, 10-30 % of larvae are reported to set as spat (Wong, 1994). The settlement rate can be increased between 70 and 90 % by exposure to appropriate concentration of neuroactive compounds such as epinephrine, nor-epinephrine, L-Dopa and GABA (Coon *et al.,* 1985, 1986; Wong, 1994). Addition of epinephrine and nor-epinephrine at concentrations of 10^{4}-10^{5} M induces oyster larvae to settle and metamorphose (without settlement surface) as cultchless spat (Coon *et al.* (1986). Haws and DiMichele (1993) described a modified procedure for the use of epinephrine which consistently induced metamorphosis in 90 % of *C.gigas* and *C.virginica.* Epinephrine is first dissolved in a solution of 0.005 N Hydrochloric acid made

with distilled water and then added to seawater (10^4 M) as described by Coon *et al.,* (1986). Ascorbic acid (10^2 M) is added to prevent oxidation of the epinephrine and the pH of the epinephrine-seawater solution is adjusted to 8.0 with NaOH. The oyster larvae are treated in this solution for 4 hours in the dark. After treatment they are collected in a sieve and returned to the rearing containers. Maximum response to metamorphosis was similar for both the oyster species (93-96.8 %) and the time at which this occurred varied between 24-108 hours for different cultures. The mortality rate between epinephrine treated larvae and control was similar and the final survival rate was highly variable between cultures (30.9-84.9 %). The mechanism by which epinephrine acts to induce metamorphosis is not known and no short term detrimental effects of epinephrine was observed (Haws and DiMichele, 1993).

It is held by oyster biologists that a surface film is developed on the cultch when held in the seawater and this film enhances the settlement of oyster larvae. Weiner *et al.* (1985) studied a bacterium first isolated from *C.virginica* hatchery tanks. The bacterium, *Shewanella colwelliana* when attached to a surface such as an oyster shell produces L-3, 4-dihydroxy phenyl alanine (L-Dopa), other melanin precursors and melanin which enhances settlement of *C.virginica* (Weiner *et al.,* 1985, 1989). Similar observation was made on the larval settlement of *C.gigas* and *O.edulis* (Fitt *et al.,* 1990; Tritar *et al.,* 1992).

REMOTE SETTING

The development of hatchery technology for oyster seed production paved the way for the expansion of oyster culture into new cultivable areas where no natural stocks were available or natural spatfall was poor. Initially the set larvae (spat) on cultch were transported from hatchery to culture site. But this procedure necessitated large consignment space which significantly raised the transportation costs. Further the maintenance of larvae till the spat stage suitable for transportation, increased the production cost in the hatchery. Remote setting is a solution to this problem.

Remote setting is the method by which eyed or pediveliger larvae are transported without water, in moist condition to distant places where they are set on the cultch material. The use of this technique has revolutionized oyster culture on the west coast of the USA where seed production is no longer a problem (Chew, 1991). Significant results were obtained by Henderson (1982) in larval transport and distant setting of C*rassostrea gigas* and Gibbons (1988) in *C.virginica.*

Prior to shipment the eyed or pediveliger larvae in the rearing tank are collected on a 280 µm screen, wrapped in nylon cloth and moist paper covers, to prevent dehydration. Between 7-10 million larvae are packed in a gauze cloth bag of the size of a baseball, placed in a small cooler and kept moist with ice packs for transport up to 7 days. The temperature is maintained at 2-5^{0}C

during transport (Chew, 1991) . On reaching destination, the larvae are released in setting tanks containing seawater at 20-25^{0}C. Aeration is provided to promote even dispersal of larvae and the tanks are usually covered during setting. Different types of cultch materials for attached spat and oyster or clam shell chips of 5-6 mm size for single spat are introduced into the setting tank. Larval density of 150 nos/shell cultch was recommended by Jones and Jones (1988) to get 10-20 spat/shell. The larvae are fed with live microalgae or stored algal paste. After setting is complete the cultch is transferred to the nursery.

In India, Unnikrishnan *et al.* (2001) studied the remote setting of *Crassostrea madrasensis* larvae produced in the Shellfish Hatchery of CMFRI, Tuticorin. The pediveliger larvae were transported to Cochin in moist condition at 27 ± 1^{0}C and 32 ± 1^{0}C temperatures. The transportation time from Tuticorin to Cochin was 18 hrs. In the larvae transported under the above two temperature regimes, the survival rate was 100% after 24 hrs rearing in the settlement tanks. The settlement rate was 61-68%. The survival of the post-set spat after 25 days of rearing was 66.2 to 73.4% in 30 ppt salinity and 71.3% to 87.5% in 15 ppt salinity. Higher settlement rate and post-set survival was reported in larvae transported at the lower temperature of 27 ± 1^{0}C than at the atmospheric temperature of 32 ± 1^{0}C (Unnikrishnan *et al.,* 2001).

In temperate countries the oyster larvae in moist condition are transported at about 5^{0}C temperature but in India larval transport at 27 ± 1^{0}C (that is 5^{0}C below atmospheric temperature) was found to be effective. From Malaysia, Wong (1994) reported that the eyed larvae of *C.belcheri* kept at 5^{0}C performed worse than the controls and at 15^{0}C the performance of the eyed larvae, held up to 72 hrs was either equal or better than the control.

In the USA, farmers usually get 20-30% of the larvae of *C.gigas* setting as spat (Henderson, 1982; Roland *et al.,* 1989); in some cases as high as 80% spat set on cultch material has been reported (Chew, 1991). For the same species, Holliday *et al.* (1991) have reported 68% spat set, after cold storage of larvae at 11^{0}C for 98 hrs and 77-85% spat set for *Saccostrea commercialis.* The results obtained in India with regard to setting rate of larvae compare favourable with the above results but the duration of the transport of larvae was only 18 hrs and there is need for further studies to standardise the techniques of remote setting for long distance transport involving 2-3 days journey. Roland *et al.* (1989) observed that the proportion of larval setting was affected by water circulation rate, temperature, salinity, cultch type and feeding rate.

The technique involved in remote setting is simple and has tremendous potential, particularly for the cultivation of triploid oysters for which the seed is raised in the hatcheries. The advantages in the farming of triploid oysters are given later in this chapter.

NURSERY REARING OF SPAT

Oyster larvae settle as spat between 300-400 µm size and nursery rearing is necessary to ensure good survival of the spat until they are large enough to withstand some competition and smothering effects of silt (Matthiessen, 1989). Nursery rearing is carried until the spat grow to 20-25 mm size.

Many hatcheries have nursery facilities and the cultched seed are usually grown in raceways through which filtered seawater is circulated. The single spat, immediately after settlement are reared in upwelling systems. They may be land-based or located in an estuary. The former consists of flow-through troughs or 'upwellers' (Bayes, 1981). Upweller systems consist of containers provided with a screen as bottom (silos) containing oyster spat. The silos are held inside a large container in such a manner that seawater enters through the screen at the bottom, flows upward through the oyster spat producing a semi-fluidised bed of spat, and discharged usually through a side exit pipe (Bayes, 1981; Spencer *et al.,* 1986). The passage of plankton rich seawater through the oyster seed assemblage allows them to be held in large numbers and at the same time permits rapid growth, and discourages fouling and clumping of spat (Castagna *et al.,* 1996). Several silos are arranged in each upwelling unit. Seawater filtered through a 45 µm mesh is used so that naturally occurring algae are available as food and flow rate of 20-50 ml/minute/gram spat is recommended (Utting and Spencer, 1991). There are different types of upwellers and some are vertical pipes or cylinders of 15-20 cm diameter and individually plumbed so that water can flow from the bottom to outside on the top with oyster seed loosely packed within the water column.

Utting and Spencer (1991) described an upwelling recirculation nursery system for spat. It consists of 10 tubes loaded with 60 gram spat biomass/tube. Seawater flow rate is 20-30 ml/minute/gram live weight, i.e. 1.5-1.8 l/minute/tube. The air lift system raises about 18 l/minute to the header tank. Optimum recommended daily food supply for 600 g biomass (10 tubes × 60 g) is equal to 171 l of *Tetraselmis* equivalents at 1 million cells/ml (equal to 3 feeds of 57 l/day). This works out to 34 g/day of spray-dried algae. The water is changed three times per week.

Apart from shore based upwellers, systems are also designed for operation on rafts or floats to be deployed in bays or estuaries (Bayes, 1981; Baldwin *et al.,* 1995).

In the nursery rearing of spat, these upwelling systems ensure control over the predators and foulers resulting in greater survival of the spat. The present system followed in India wherein the oyster spat are reared in synthetic mesh bags, suspended from racks in the Tuticorin bay is cost effective with reasonably good survival (Figure 27).

PROBIOTICS

The word Probiotic is used as promoter of life and is opposite of the word antibiotic. For livestock and poultry, a number of commercial preparations are available to promote colonization of desirable bacteria in the gut. In aquaculture the use of probiotics is relatively recent and commercial use is mostly confined to shrimp farming.

Several definitions of probiotic are available. Fuller (1989) defined it as "a live microbial feed supplement, which beneficially affects the animal by improving its intestinal microflora" while Havenaar and Huis int Veld (1992) called it as "a mono or mixed culture of live micro-organisms when consumed by an animal or man, affect beneficially by improving the properties of the indigenous microflora of the gut". Tannock's (1997) version of probiotics is "live microbial cells administered as dietary supplements with the aim of improving health". A more recent version of the definition of probiotics is "microbial cells that are administered in such a way as to enter the gastrointestinal tract and to be kept alive, with the aim of improving health" (Gatesoupe, 1999). The probiotics are expected to perform the following functions: a) antagonism to pathogens, b) gut colonization with possible adhesion to intestinal mucus and c) increased resistance of the host to the pathogens (Gatesoupe, 1999).

Douillet and Langdon (1994) found that addition of the bacteria (strain CA2) as a food supplement to xenic larval cultures of *Crassostrea gigas* consistently enhanced the growth of larvae during different seasons of the year. Addition of CA2 bacteria at 10^5 cells/ml to cultures of algae *Isochrysis galbana* (ISO), *I. aff. galbana* (T-ISO) or *Pseudoisochrysis paradoxa* (VA-12) fed to *C.gigas* larvae increased larval growth, the proportion of larvae that set to produce spat, and the subsequent size of the spat. These authors suggested that addition of CA2 bacteria may provide essential nutrients not present in the algal diets or improve their digestion by supplying digestive enzymes to the larvae. They have recommended supplemental feeding of bivalve larvae with CA2 bacteria in the hatcheries to enhance production and stressed the need for further research in this area.

Gibson *et al.* (1998) stated that, the probiotics in part inhibit the pathogens by producing substances and these inhibitory agents are called bactereocin-like inhibitory substances (BLIS). These authors assessed the ability of BLIS producing *Aeromonas luedia* (strain A 199) to act as a probiotic on *C.gigas* larvae. When A 199 strain alone was added, the viability of the larvae was not significantly different from the controls. On the other hand, when only *Vibrio tubiashii* was added there was heavy larval mortality between day 3 and 5. Addition of *V.tubiashii* followed by the introduction of A 199 showed a significant difference between the viability of the larvae when compared with the larvae in the control and the larvae inoculated with only probiotic A 199 strain.

Riquelme *et al.* (1996) found significant improvement in the survival of scallop larvae after preliminary treatment with *Alteromonas haloplanktis* for one hour followed by challenge with *Vibrio anguillarum*. According to Gatesoupe (1999), these authors assumed that the probiotic strain produced inhibitory substances that blocked bacterial growth in the larval rearing medium, including growth of the probiotic itself (autoinhibition).

Reviewing the use of probiotics in aquaculture, Gatesoupe (1999) has drawn the following conclusions. The application of probiotics is successful in terrestrial animals; it is promising in aquaculture and needs considerable research input. Some bacterial strains may increase the survival of bivalve larvae when they are introduced into the rearing medium (Riquelme *et al.*, 1997), probably as food supplement (Douillet and Langdon, 1994). In many studies the fate of the probiotic in the rearing medium and in the gastrointestinal tract is not answered. Immunological and molecular probes are useful tools to trace the probiotic cells.

GENETICS

Considerable research has been carried out on the application of genetics for the improvements in the production of bivalves, particularly on oysters. Newkirk (1980) gave a review of genetics and potential for selective breeding of bivalves. Since then there were a large number of studies and recently Gaffney (1996), Longwell and Stiles (1996) and Newkirk (1996) dealt on oyster genetics while Sheridan (1997) gave an excellent review on genetic improvement of oyster production.

Quantitative Genetics

Genetic Parameter Estimates: Newkirk (1996) stated that the relative importance of the genetic variance is often expressed as a ratio of the genetic variance to the total phenotypic variance (which is composed of the genetic and environmental components). This ratio is called the heritability.

In *Crassostrea gigas*, Lannan (1980) obtained full-sib variance component heritability estimates of 0.31 ± 0.06 for larval survival and 0.09 ± 0.08 for setting success, and at 18 months of age, 0.33 ± 0.19 for total weight, 0.32 ± 0.30 for shell weight, 0.37 ± 0.20 for wet meat weight and 0.46 ± 0.22 for the wet meat to total weight ratio. In the same species Hedgecock *et al.* (1991) estimated the half-sib variance component heritability for wet meat weight at commercial harvest size to be approximately 0.20. They stated that non-additive genetic variations could be important for this trait, and a sex effect resulted in female oysters being around 10 % heavier than male oysters.

In *C.virginica*, Newkirk *et al.* (1977) reported full and half-sib variance component heritability estimates of 0.09 to 0.51 at 6 days of age and of 0.50 to 0.60 at 16 days of age for growth rate.

In *Ostrea edulis*, Toro and Newkirk (1990) obtained offspring/ mid-parent regression heritability estimates of 0.14 ± 0.12 and 0.24 ± 0.20 for live weight and 0.11 ± 0.04 and 0.19 ± 0.07 for shell weight after one and two growing seasons respectively (i.e. at 6 and 18 months of age). Offspring-parent regression estimates of genetic, phenotypic and environmental correlations between the above two traits were 0.96, 0.85 and 0.84 respectively after one growing season and 0.99, 0.74 and 0.67 respectively after two growing seasons. These authors found the genetic and phenotypic correlations between the first and second growing seasons for the same trait as 0.72 and 0.48 respectively for live weight and 0.75 and 0.70 respectively for shell weight. The authors have subjected the oyster population to one generation of divergent selection for live weight after one growing season.

After reviewing the heritability estimates in oysters, Sheridan (1997) stated that they indicate selection in oyster populations for increased growth rate and increased disease resistance should be successful. He cautioned that they should be taken as a very rough guide as to the possible selection response, and these heritability estimates have high standard errors.

Selection: Selection is the process wherein the individuals that have superior performance are bred, resulting in a genetic change in the stock. Selection saves certain genotypes and removes others. The information needed for selection include a) the heritability of the traits concerned, b) the correlation (both phenotypic and genotypic) between traits and c) the relative economic value of various traits if more than one trait is considered (Newkirk, 1996). The important traits focused in the oyster breeding programmes by researchers are growth, survival and resistance to disease. Newkirk (1988) highlighted the importance of sampling widely prior to commencing a breeding programme. Most of the studies on oyster selection were made on growth rate and live weight and a few studies were conducted on selection for resistance to disease.

The results of a study on selection for increased live weight for one generation of *C.virginica* were reported by Haley and Newkirk (1982). The parents studied were 2,3 and 4 years old oysters and a control population. The offspring of 3 and 4 year old oysters were significantly heavier at 27 months of age than the control line progeny, indicating that selection should be effective in improving the growth rate. Paynter and Dimichele (1990) compared the linear growth rate of *C.virginica* between the native population and a line originally derived from this population and selected for improved growth rate for 18 generations by an oyster farmer. The selected oysters had a higher growth rate of 28 % in the first and 24 % in the second growing seasons when compared to the native oysters.

Haskin and Ford (1988) and H.H. Haskin (pers comm. to Sheridan, 1997) selected *C.virginica* for resistance to MSX parasite, *Haplosporidium nelsonii* and found that selected strains have survival rates upto 10 times when compared

to the control lines. This selection study was conducted for five generations. It is suggested that inbreeding had no detrimental effect on survival of the selected strain. In a study, *C.virginica* derived from the Delaware Bay-selected oysters and maintained at a commercial hatchery on Long Island were compared to an MSX susceptible stock from Long Island in growth trials in Massachusetts (Matthiessen *et al.*, 1990). The authors found that Delaware oysters grew faster than the Long Island oysters and the resistance to MSX was confirmed.

From a study by Haley and Newkirk (1982) on the European oyster *Ostrea edulis*, after one generation for selection for four lines of oysters, the estimated heritabilities for increased live weight at about two years of age were 0.39, 0.47. 0.47 and 0.72. Newkirk and Haley (1983) in their study on the live weight of the same oyster species in the second generation realized heritability of 0.16, 0.17, 0.20 and 0.22 (Sheridan, 1997).

Hershberger *et al.* (1984) have shown that in *C.gigas* selection has improved resistance to summer mortality. After three generations of selection, cumulative mortality was around 20 % while in the control 62 % mortality was observed. In oyster culture carried in the temperate waters, these results are significant as summer mortalities are a matter of concern.

In *Saccostrea commercialis*, Nell *et al.* (1996) found that after one generation of selection for increased live weight, two of the four selection lines were significantly heavier ($P< 0.05$) than two control lines.

Inbreeding, Heterosis and Heterozygosity: Following Sheridan (1997) this section on inbreeding is considered together with heterosis and heterozygosity since there were very few studies on deliberate inbreeding in oysters and also the oyster inbreeding studies examined the effect of inbreeding by comparing the performance of the inbred lines with their crosses. Inbreeding is the crossing of individuals of close relationship. It reduces genetic variation, increases homozygosity and as a result deleterious recessive genes find expression, leading to decreased fitness of oyster (Newkirk, 1996). This is known as inbreeding depression.

Out of six studies conducted on the American and Pacific oysters on the effects of inbreeding, in one study (Lannan, 1980) only the inbred stock was found to be superior to outbred stock (Sheridan, 1997). Lannan (1980) subjected *C.gigas* to two generations of full-sib matings and stated that on an average, the inbred larvae had higher survival (0.165 %) than the outbred larvae (0.100 %) and this difference was highly significant. In the remaining five reports, inbreeding did not improve the performance of the desired traits in the oysters and in comparison, the performance of the outbred lines was generally better (see Sheridan,1997).

Oysters have, extremely high progeny numbers (upto 25 million larvae per mating as reported by Holliday, 1992) and could be expected to maintain a higher level of heterozygosity than that predicted from the effective population

size. Sheridan (1997) wrote "This expectation is due to these large progeny numbers containing all possible gene combinations (even for tightly linked genes) thus providing natural selection with considerable scope to favour the (perhaps small proportion of) individuals fortunate not to be homozygous for deleterious recessive genes". Comparison of heterozygosity levels estimated from parent numbers and from protein electrophoresis by Smith *et al.* (1986) for the Pacific oyster, Dillon and Manzi (1987) for the hard clam *Mercenaria mercenaria* and by Vrijenhoek *et al.* (1990) for the American oyster, showed this to be the situation. Sheridan (1997) considered this as a possible reason why outbred lines were not always superior to inbred lines.

Positive correlation between heterozygosity and the growth rate and/ or live weight were reported by several authors. Singh and Zouros (1981) found such a relationship for seven electrophoretically detectable loci in one year old American oyster. Four of the loci studied had three alleles. Out of fifteen heterozygotes, fourteen showed overdominance for growth rate. Foltz *et al.* (1983) reanalysed the data of the above authors and found that heterozygosity at these levels accounted for 4 % of growth variability and there was no evidence of epistasis. A study was conducted by Hu *et al.* (1993) on the effect of a polymorphic enzyme on survival and shell size at about three months after metamorphosis in one of Haskin and Ford's (1988) American oyster disease resistant selection lines. The results indicated that juvenile oysters, heterozygous for this locus possessed a significantly ($P < 0.05$) greater survival and tended to be larger than the corresponding homozygotes.

Zouros and Mallet (1989) reviewed the experimental evidence for the presence of a positive association between growth rate and heterozygosity in marine molluscs. They stated that populations with a heterozygote deficiency are also likely to show a positive association between the growth rate and heterozygosity. The review of the experimental evidence by these authors indicated that a heterozygote deficiency in marine bivalves tended to decline (and in some cases disappear) as the population aged. They have noted that none of the genetic explanations were consistent with the experimental evidence reviewed by them and they tended to favour the associative overdominance hypothesis (AOH) which does not involve overdominant gene action. Associated overdominance is attributed to linkage disequilibria between genes affecting the trait apparently influenced by overdominant gene action (i.e. growth rate) and deleterious recessive genes entering the population by mutation (Sheridan, 1997). Hu *et al.* (1993) also favoured the AOH as the most likely reason for their results. The AOH is consistent with the experimental data from both plants and other animals and suggests that true overdominance is not an important property of the genes (Falconer, 1981). Sheridan (1997) stated "A positive association between heterozygosity and growth rate in conjunction with a heterozygosity deficiency that declines as a population

ages could be due to the faster growing individuals having a poorer fitness during the larval stage and a better post-setting fitness." A positive association between heterozygosity and both growth rate and survival is also a common consequence of crossbreeding (Sheridan, 1981).

The strategies adopted for improving cross bred performance are: inbreeding and retaining the better nicking lines, reciprocal recurrent selection and within line selection, whilst also retaining the better nicking lines (Fairfull, 1990). For improved cross bred performance, Bell (1982) and Wei and Van der Steen (1991) recommended a combination of within line and reciprocal recurrent selection. Sheridan (1997) wrote ".....the improving performance, of the crossbred population over successive generations of within line selection is a combination of the improving performance of the parent lines and the increasing heterosis in the cross between them". Mallet and Haley (1984) reported substantial reciprocal mating effects for heterosis (or hybrid vigour); this highlights the importance of examining the performance of both reciprocal matings for all crosses before determining the male and female parent lines to be used in producing the crossbred market oyster.

Environmental Variability and Oyster Growth Rate: In tray-grown oysters it is well known that the growth rate is sensitive to apparently small environmental differences due to their location within the tray (Sheridan *et al.* 1996). An oyster production system specially developed to minimize (if not eliminate) any competition between neighbouring oysters for evaluating the performance in genetic studies was developed by Sheridan *et al.* (1996). In oyster genetics, consideration should also be given to the possible impact of the genotype by environmental interactions on oyster productivity.

Conclusion: Reviewing the work on oyster genetics, Sheridan (1997) wrote "Thus the application of the genetic improvement techniques so successfully, applied to other livestock species should also be successful in producing more productive oyster stocks."

In oyster breeding programme, within line selection of oysters with traits which are economical, important and amenable to selection, are to be taken. The selection method for each trait will depend upon its heritability and the cost of rearing the pedigreed families. The performance of pure strains and their reciprocal crosses should be assessed. Also selection lines should be evaluated under standardized environmental conditions at a stocking density that preclude competition between neighbouring oysters. With a view to take advantage of hybrid vigour, the oyster should be a cross between different selection lines (Sheridan, 1997).

Chromosomal Engineering

Fifteen species of *Crossostrea*, six species of *Ostrea* and three species of *Saccostrea* studied by various authors have a haploid number of 10 chromosomes (see Longwell and Stiles, 1996). In the Pacific oyster the

diploid complement (2 n) of chromosomes is 20, in triploids 30 and in tetraploids 40. Exact multiples of haploid set of chromosomes are known as euploids eg: diploid, triploid. Any deviation from the euploid number is classified as aneuploid. For example oysters with 2 n+1 chromosomes (total 21) or 2 n-1 (total 19) are called aneuploids. There is no evidence of sex chromosome pair in oysters (Longwell and Stiles, 1996). Bivalves are particularly amenable to various forms of chromosomal manipulations. Diploid females usually spawn tetraploid eggs (four sets of chromosomes per cell, 4 n) which after interaction with haploid (1 n) sperm, undergo sequential reductions in maternal chromosome number (4n to 2n and 2 n to 1n) through release of the first (2 n) and second (1 n) polar bodies (Ward *et al.* 2000).

Triploidy and Tetraploidy: Triploid oysters were first produced in the early 1980's (Stanley *et al.*,1981). Triploid oysters have several advantages over diploids and *Crassostrea gigas* production by aquaculture using triploids approximately accounts for one third to one half from the Washington State alone (Chew, 1994).

Triploidy induction: Allen (1987) and Beaumont and Fairbrother (1991) reviewed the methods used by workers to induce triploidy in bivalves; they are produced by inhibiting the extrusion of second polar body immediately after fertilization. To achieve this, treatments with chemicals, pressure, temperature and electric impulses are applied. Also mating of diploids with tetraploids results in triploids.

Scarpa *et al.* (1994) used 6 methods, some of them combinations, to induce triploidy in the mussel, *Mytilus galloprovincialis*. The agents used are cytochalasin B (CB at 1 mg /l), heat (HT:30°C), Calcium chloride (CA:0.1M), combined exposure to CA 0.1M and heat 30°C (CAHT), Caffeine (CF:15mM) and combined exposure to 15mM Caffeine and heat 30°C (CFHT). They were applied 20 minutes after sperm addition so as to suppress polar body II formation, and left for 15 minutes. Calcium treatment was least efficient (4.7-7.5%) in inducing triploidy. The other 5 agents on an average induced 86% (CB), 81% (HT&CFHT), 73% CAHT and 71%(CF) triploids. The proportion of D-larvae of 48 hr was reduced in all the treatments, being least reduced by CB and most reduced in CAHT. The authors concluded that CB is the most effective among the methods used and heat treatment is the second alternative.

Cadoret (1992) used a microslide electrofusion chamber to test different field strengths, durations and number of electrical pulses on the viability of 2-cell oyster and mussel embryos. Then by applying the most promising parameters to fertilized eggs in a larger chamber, triploid production went up to 55% and 36% and tetraploids up to 20% and 26% for oysters and mussels respectively.

Desrosiers *et al.* (1993) induced triploidy in the Pacific oyster *C.gigas* , scallop *Placopecten magellanicus* and mussel *M.edulis* by using the chemical

6-dimethylaminopurine (6-DMAP). The highest percentage of triploids produced in the oysters was 90%, in scallops 95%, but larger exposure interfered with cleavage and resulted in abnormalities, particularly in the mussel. Triploid larvae of the three bivalves showed higher mortality rates than the control diploids. Gerard *et al.* (1994a) treated *C.gigas* with 6-DMAP and also Cytochalasin B (CB). Survival to D-stage was inversely related to 6-DMAP concentration and the percentage of triploids was shown to be 6-DMAP dose dependent. The optimum treatment was found to be 450 µ mol /l of 6-DMAP beginning 15 minutes after fertilisation over a 10 minute period yielded a mean of 85% triploidy production; the mean survival to D-larval stage was 64%. Treatment with 1mg / l of CB, 20 minutes after fertilisation over a 15 minute period yielded a mean production of 95% triploids and the mean survival to D-larvae was only 36%. According to Gerard *et al.* (1994 a) the advantages of 6-DMAP over CB are : a) 6-DMAP is not carcinogenic, b) it is cheaper, c) water soluble and easy to use and d) gives higher production of D-larvae.

Nell *et al.* (1994) induced triploidy in S*accostrea commercialis* by CB treatment and obtained 84% success rate. Hand and Nell (1999) succeeded in inducing triploidy in 88% of *S.commercialis* by CB treatment. Treatment with CB or with 6-DMAP is commonly followed in commercial hatcheries by inhibiting the extrusion of second polar body (Eudeline *et al.,* 2000). Guo *et al.* (1996) listed the following as disadvantages of the CB method: a) Induction of triploidy is not 100% effective and the success rate is about 80% in commercial hatcheries. Success rate < 80% is a problem for hatchery management resulting in waste of effort. b) CB is toxic and the health and safety of hatchery personal is a matter of concern and c) The blocking of polar body 2 may result in lower survival and slower growth in the triploids.

Guo *et al.* (1996) suggested that the above disadvantages can be avoided if triploids are produced by mating tetraploids with diploids. Guo and Allen (1994 b) produced viable tetraploid *C.gigas* and reared them to sexual maturity for the first time in a mollusc. They blocked the polar body 1 in eggs from triploid, fertilised with normal haploid sperm. Tetraploid *C. gigas* matured at one year of age with close to normal sex ratio and fecundity. Gamets produced by the tetraploids are fully functional in terms of fertilization, meiosis and chromosome segregation. Guo *et al.* (1996) noticed that the sperm from the tetraploids were less motile than normal sperm of the diploids but possessed high fertilization rates in many replicates. Out of 710 *C.gigas* sampled by the mating of tetraploid and diploid oysters, all were triploids except one (0.1%) which happened to be a tetraploid. The authors stated that it may be due to spontaneous failure of releasing polar body 2 in a normal egg fertilised by a diploid sperm. In a concurrent study with the above, Guo *et al.* (1996) obtained 46% triploids by CB treatment in *C.gigas*. Guo *et al.* (1996) concluded

that " triploid production by mating tetraploids and diploids is as simple as producing normal diploids, and no artificial treatment is required". The mated triploids were found to be as viable as normal diploids; they appeared to show polyploid gigantism, an advantage in aquaculture.

In India, triploid oysters (C.*madrasensis*) have been successfully produced using physical and chemical stimulants, (CMFRI, 2001) by arresting the release of second polar body. Exposure of oyster embryos to 6- DMAP at concentration 100 mM for a period of 8 minutes commencing from 15 minutes post-fertilization was found to be optimum for triploidy induction. For Cytochalasin B, the optimum dosage was 0.05 mg/l concentration for one minute. Application of cold shock at 5 °C for 10 minutes, and heat shock at 37°C for 5 minutes were also found to be optimum for producing triploid oysters. Karyological examination has revealed 30 chromosomes in triploids as against 20 in the diploid controls. Highest triploid induction of 63% was obtained in 100 mM treatment with 6 - DMAP for 10 minutes. The triploid spat of *C. madrasensis* registered a growth rate of 5.53 mm / month (for 6 - DMAP treated), 5.8 mm (for cold induced) and 5.5 mm for the control.

Methods to detect triploidy: Three methods are in vogue to determine polyploidy in bivalves namely chromosome counting technique, flow cytometry and microfluorometry. Apart from these Gerard *et al.* (1994 b) used a method known as 'Image analysis' while Child and Watkins (1994) developed a simple method based on the measurement of cell nucleus diameter to detect triploids.

Chromosome counting technique: The number of triploids produced is usually estimated at the embryo stage by counting chromosomes. This technique when applied to later stages requires the use of cytotoxic chemical, Colchicine; it is also slow and tedious.

Flow cytometry: This was described by Chaiton and Allen (1985). It is used to estimate the number of triploid cell nuclei obtained from gill tissue and haemolymph (Allen 1983) and larvae (Downing, 1989). This equipment is very expensive and is not widely available (Child and Watkins, 1994).

Microfluorometry : The essential equipment used in this method is also expensive. Komaru *et al.* (1988) determined triploidy in scallop C*hlamys nobilis* by DNA microflurometry with DAPI staining.

Image analysis : This method is routinely used in medical check-ups to determine the ploidy level of cancerous cells. Gerard *et al.* (1994 b) applied this method to detect triploidy in *C.gigas, O.edulis* and the clam *Ruditapes philippinarum.* They concluded that image analysis technique appears to be a very efficient method for ploidy determination in bivalves. This technique is cheaper than flow cytometry but expensive when compared to microfluorometry (Gerard *et al.,* 1994 b).

Measurement of nucleus diameter: This method assumes that the nucleus of a triploid bivalve is approximately spherical and 1.5 times greater in volume when compared with diploid nucleus due to additional DNA content. A sample of gill tissue or haemolymph cell nuclei are stained and measured. In the Manila clam, Child and Watkins (1994) found the ratio of diploid DNA content to triploid DNA content as 1:1.51 which is close to the theoretical value of 1:1.5.

Advantages of triploids: Nell *et al.* (1994) have reported that triploid *S.commercialis* were on average 41% heavier in whole weight than diploids after 2.5 years of growth. The triploid oysters also maintained higher dry meat weight and higher condition index values than their diploid siblings at all sites during the final 10 months growth to market size. The same authors summarized the growth performance (% whole weight increase) of triploid *C.gigas, C. virginica* and *S. commercialis* over diploids recorded by various authors. The triplods were 23 to 71% heavier than diploids between 5 to 31 months growth. Triploid *C.gigas* had growth advantage of about 23% over diploid controls in 2-3 year olds. Also the former maintained meat condition while diploids, due to spawning were not marketable for several months (Ward *et al.,* 2000). Hand and Nell (1999) stated that in two years, *S.commercialis* triploids of smaller size grade grew 35.6% faster in whole weight and the larger grade 56.6% faster when compared to diploids of corresponding grades in initial size. Growth advantage of triploid *C.gigas* was most obvious at 8 months post-fertilisation and 2 months before sexual maturity. At this time triploid oysters were 35 - 51% larger than normal diploids (Guo *et al.,* 1996). In the polyploid gigantism in molluscs there is no cell number compensation so that larger cells in the polyploids will generally result in larger body size (Guo and Allen, 1994 b). Thus the main advantages of triploid oysters over diploids are summarised below:

- The gonad is not well developed resulting in relatively steady condition index which enables year round marketing (Allen, 1988).
- Reduced gonad development results in higher growth rate and more meat yield, although only under favorable conditions (Davis, 1989).
- Due to low fecundity, triploids have also been used for population control and biological containment of non - native species (Guo and Allen, 1994 a).

Aneuploidy: Cytogenetic abnormalities such as aneuploidy are known to be common in bivalves and aneuploidy has also been observed in triploid and tetraploid oysters (see Leitao *et al.,* 2001). This phenomenon which usually originates from non - disjunction of chromosomes during mitosis or meiosis is mostly lethal in higher animals like mammals or results in growth retardation. But it is less deleterious in lower animals and plants. A negative correlation between somatic aneuploidy and growth rate has been reported in the offspring

of cultivated *C.gigas* (Thiriot - Quievreux *et al.* 1988, 1992) and in natural populations of the same species (Zouros *et al.,* 1996). In 13 diploid populations of *C.gigas* studied by Leitao *et al* (2001) between 1988 to 1999, slow-growing oysters always showed higher levels of aneuploidy than the fast growing oysters in all the cultivated and natural populations. Such growth retardation of aneuploids was not observed in triploid and tetraploid *C.gigas* (Guo and Allen, 1994 b; Wang *et al.,* 1999).

Wang *et al.* (1999) observed that triploids produced by mating tetraploids and diploids produced 20% more aneuploids than the triploids produced by blocking the second polar body of the fertilized eggs of diploid *C.gigas* (2.2%). The authors suggested that the Pacific oyster can tolerate aneuploidy by 5-10% of the genome, i.e. 2 n ± 1, 3 n ± 3 and 4 n ± 2 where n=10. Wang *et al.* (1999) concluded that with or without aneuploids the diploid and tetraploid cross oysters (triploids) grow faster than the triploids produced by chemical treatment.

The reasons for the relationship between growth and aneuploidy are not yet known but a genetic basis (Zouros *et al.,* 1996), environmental factors such as pollution (Dixon, 1982) and viral diseases (Maroun *et al.,* 1986) were suggested.

Biotechnological Approaches

Modern aquaculture is growing through a rapid growth phase stimulated by the recent develoments in biotechnology and its application. New technologies, which permit the identification and manufacture of natural products such as hormones that find application in hatcheries, are being developed. Other techniques include the introduction of foreign genetic material into oysters to produce transgenic animals. Newkirk (1996) outlined some of the techniques that may find application in oyster genetics to increase production. These include cloning of genes to produce hormones that can be used in the hatchery to increase seed production, DNA fingerprinting instead of electrophoretic analysis to study population genetics and production of transgenic oysters. Researches using these biotechnological tools towards increasing the production of the oyster are still in the nascent stage of development.

Interspecies Hybridization

Some studies were conducted to hybridize the species of *Crassostrea* and often it resulted in failure of fertilization, meiosis or in abnormal development.

Normal fertilization, meiosis and cleavage were reported in the crosses of *C. virginica* with *C. rhizophorae* and also in the crosses of the former with *C.gigas* (Menzel, 1973; Stiles, 1978; Scarpa and Allen, 1992). Similar results were obtained in cross fertilization of *C.gigas* with *C.angulata*, a possible synonym or subspecies of the latter (Menzel, 1973; Carriker and Gaffney, 1996). In many cases of interspecies hybridization, despite normal cleavage

the hybrids failed to metamorphose (Longwell and Stiles, 1996). Gaffney and Allen (1993) reviewed hybridization among *Crassostrea* species.

Recently Soletchnik *et al.* (2002) have reported on the hybrids of *C.gigas* and *C. angulata*. After the hatchery and nursery phases the hybrids were successfully reared for two years and a clear maternal effect was observed for growth and reproductive characteristics of the hybrids. While Gaffney and Allen (1993) stated that *C.gigas* and *C.angulata* are indistinguishable in terms of protein polymorphism, karyotype and larval morphology , Heral and Deslous - Paoli (1991) reported them as two distinct species on the basis of physiological reproductive characterstics.

OYSTERS AS BIOFILTERS IN AQUACULTURE

During the past decade shrimp farming has grown phenomenally in coastal areas in the country. However, in recent years, the outbreak of diseases in the cultured shrimps and the loss of stock is a serious set back. Added to this is the concern expressed by the environmentalists about the pollution effects due to the discharge of shrimp pond waste water into the coastal waters causing eutrophication and increased turbidity.

In the shrimp and fish farms the unused artificial food, faecal matter, and dead/decaying organic matter results in the production of ammonia. By nitrification, ammonia is converted into nitrites and nitrates which result in plankton blooms within the pond and also in the waste water released from the pond. The oxygen demand in the pond rises since nitrification is an aerobic process and also the plankton blooms need oxygen. The waste water from the culture ponds contains high load of suspended particulate matter composed of detritus, bacteria and phytoplankton; it is also rich in dissolved nutrients.

Several studies were conducted to develop a system of biological filtration of the shrimps / fish pond waste water by the use of bivalves to reduce the load of suspended particulate matter, followed by seaweeds to bring down the concentration of dissolved nutrients so that the health of the environment and farmed shrimp / fish can be improved. One may call it as an 'Integrated farming system' which is largely sustainable and also brings additional economic benefits by way of production of bivalves and seaweeds (Appukuttan and Kripa, 2001). The use of oysters as biofilters is dealt in this section.

Oysters and Shrimp Culture

A study was conducted by Jakob *et al.* (1993) in Hawaii, USA to assess the potential of growing the American oyster *Crassostrea virginica* using marine shrimp culture pond water in onshore flow through tanks. Cultchless oyster seed of 0.04 g mean weight, numbering 5000, were stocked in trays held in 310 l flow through system (tank T1) , receiving water at 40 l/minute. In another 310 l tank (T2) with 80 l/minute water flow rate, about 2000 oyster seed of 0.05 g mean weight were stocked. The seawater was drawn into the

tanks from the shrimp pond in which semi-intensive culture of *Penaeus vannamei* was carried at a stocking density of 15 - 20 nos/m^2. After 268 days the oysters in T1 tank have attained 68 g mean weight and in T2 tank the mean weight recorded was 78 g. The marketable size of 58 g was attained in 198 days in T1 and 183 days in T2 tank. Based on this study the authors concluded that "...undiluted, semi- intensive marine shrimp pond water provides all the requirements for the very rapid growth of the American oyster *Crassostrea virginica* ...".

From Australia, Jones and Preston (1999) conducted a study of 2 hrs duration in water drawn from an intensive commercial shrimp farm stocked with *Penaeus japonicus* (35 nos/m^2). The shrimp pond water was filled in 34 l tanks, stocked with 8, 16 and 24 oysters (*Saccostrea commercialis*) of average 55 g weight. During the two hour study period the water remained static in the tanks. Filtration of the shrimp pond effluent water by the high density oysters (24 nos / tank) reduced the total suspended solids to 49%, bacterial numbers to 58%, total nitrogen to 80% and total phosphorous to 67% of the initial values. The combined effects of settlement and oyster filtration reduced the concentration of chlorophyll *a* to 8% of the initial effluent value. Except for the bacterial numbers, there was reduction in all the parameters mentioned above in the two remaining oyster tanks holding 8 and 16 oysters when compared to the control. The authors suggested that 12 % of the shrimp pond area may be set aside for oyster filtration and based on 20% water exchange per day, a 1 -ha pond would need 1,20,000 oysters (at the same stocking density used in the high density treatment in this study).

In a laboratory scale study from Australia Jones *et al.* (2001) evaluated the effectiveness of a three-stage shrimp pond effluent treatment system. In the first stage the pond water was collected and allowed to settle for 24 hrs. Part of this water was transferred to tanks holding oysters *S. commercialis* and maintained for 24 hrs, followed by transfer of this water to tanks stocked with macroalgae *Gracilaria edulis* for another 24 hrs. The results on the overall improvement in the water quality after 72 hrs (end of stage 3 of the experiment), expressed as final percentage of initial concentration were as follows: Total suspended solids 12% , total N 28% , total P 14% , NH_4 76%, NO_3 30%, dissolved P 35%, bacteria 30% and chlorophyll *a* 0.7%. The authors stated that previous attempts to improve effluent water quality using filterfeeding bivalves and macroalgae to reduce nutrients have been hampered by high concentration of clay particles typically found in untreated pond effluent. These particles inhibit feeding in bivalves and reduce photosynthesis in macroalgae. They stressed the need for sedimentation of the pond effluent before it is subjected to biofilteration. Jones *et al.* (2001) suggested combined culture of oyster and seaweed in the same tank. However, the growth requirements of each species have to be optimized. Otherwise, more biomass

may be decaying than that produced, lowering water quality (Jones *et al.*, 2001).

A study was conducted by Wanninayake *et al.* (1998) in Sri Lanka on the use of *Crassostrea madrasensis* in reducing the suspended solids and chlorophyll concentration in the effluent water of a semi-intensive shrimp culture system. Two size groups of oysters, 20-30 cm and 50-60 cm were used (the sizes given seem to be typographical error and should read as mm instead of cm). Larger oyster group was more efficient in reducing the suspended solids and chlorophyll concentration than the smaller group. The efficiency of the former group was better in 20 ppt than in 30 ppt salinity of the effluent water. The authors concluded that *C.madrasensis* can be effectively used to treat the shrimp pond effluent water to reduce the levels of suspended solids and chlorophyll concentration.

Hu - jiachai *et al.* (1995) in a study on shrimp and oyster mixed culture in shrimp pond, reported that the shrimp yield increased by 30%, and oyster meat yield increased by 20.3% resulting in high economic benefits.

Oysters and Finfish Culture

Jones and Iwama (1991) conducted a study in the ploYculture of the oyster *C. gigas* with chinook salmon *Oncorhynchus tshawytscha*. Oysters of 1-year age were reared for 5 months in suspended lentern net cages (A) inside salmon net cages, (B) within the salmon farm but outside the salmon net cages, and (C) the controls in a commercial oyster farm, 4-6 km away from salmon farm. The growth of oysters were significantly higher in (A) and (B) than in the control (C). The greatest difference in growth, by a factor of 3, occurred between A and C. Also the growth of oysters in B was significantly lower than those in A. The condition index values of oysters showed the same pattern as the growth, between the 3 stations in September and October. The concentration of chlorophyll *a* and *b,* and particulate organic matter at stations A and B were significantly higher than at station C. The contribution made by the salmon farm to the available food in the water may be an important factor in enhancing the growth of oysters in and around the salmon farm. Introduced pelleted feed and faecal wastes from the salmon farm into the water, in addition to the available energy contributed by detritus and bacteria are obvious sources of energy. This study by Jones and Iwama (1991) provided evidence for the culture of *C.gigas* along side a commercial salmon farm and the authors stated "The elevated feed levels that appear to be closely associated with the intensive rearing of the Pacific salmon can improve both growth and condition index of suspended oysters".

Shpigel *et al.* (1993) conducted a study in Israel on an integrated farming system involving the gilthead seabream *Sparus aurata* and the oyster *C.gigas*. The fish were reared in 3 PVC lined ponds, each with 100 m^2 water spread area and provided with a daily water exchange of 30 - 50 %. Each pond was

stocked with 500 - 770 kg of fish and fed pelleted diet. Oysters of 4-5 months age (4.8 ± 1.4 g) were cultured for 60 days at a density of 50 g/l in plastic mesh trays held in 600 l cylindrical tanks. In the oyster culture unit A, water from a single fish pond was recirculated through this tank. Unit B received effluents from all the three fish ponds after they have passed through a sedimentation pond. Oysters in unit C received effluents from all the fish ponds prior to discharge into the sedimentation pond. The water temperature, salinity, pH , ammonia and particulate organic matter values were comparable between the 3 oyster culture units. However, the growth rate of oysters in unit B at 1.56% / day was significantly faster than those in unit C at 1.24% / day, and the oysters in unit C grew significantly faster than those in unit A (0.32% /day). The condition index (CI) value of oysters in B at 12.34 was significantly higher than the value of 9.14 obtained in unit A and the CI value in C at 11.21 showed no significant difference between the CI values of oysters in A and B units. The authors suggested that the main reasons for the better performance of the oysters provided with water from the sedimentation pond (unit B) are due to higher algal diversity, additional nutritious food consisting of attached benthic diatoms and stable algal concentration.

Remarks

Several studies were conducted using other bivalves such as mussels and clams as biofilters in treating the fish/shrimp pond effluents. The results obtained are comparable to those reported for oysters (see Appukuttan and Kripa, 2001). From India no work seems to have been done using oysters. One report pertains to the integrated culture of the green mussel *Perna viridis* and the shrimp *Penaeus monodon* carried at Mithapur in Gujarat State (Subramanyam and Gopalakrishnan, 2000). In a 0.5 ha shrimp pond having 1m depth, *P. monodon* seed were stocked at 6 nos/m^2 and pelleted shrimp feed (34-37% protein) was given. After 150 days of culture, shrimp production was 330 kg (average weight 15.9 g). For mussel culture, 6 racks (authors called them as rafts but from their figure 2 they are racks) covering 36 m^2 area were constructed in the shrimp pond. Mussel seed of 21.2 mm average length were transported from Karwar and the seeded ropes were tied horizontally to the racks. After 150 days of culture the mussels attained 68.5 mm average length and the production was 306 kg . The growth of the mussels compared favourably with the results obtained on growth in seafarming by various authors from India (CMFRI, 1980). Shrimp growth was slow and the authors attributed this to lower winter temperatures of 21.1 to 24.7°C for the major part of the duration of culture. While this study indicated the feasibility of shrimp and mussel culture, information on the role of mussels in the biofilteration of suspended matter is lacking. The available information indicates that oysters can be successfully used to reduce the concentration of phytoplankton, bacteria and detritus in the shrimp/fish farm effluent. Instead of direct introduction of

oysters into shrimp/fish ponds, it is desirable that oysters are introduced into a separate pond to which the effluent water from shrimp/fish pond is drawn, after sedimentation. This procedure reduces the concentration of suspended clay particles, which inhibit filteration by the oysters, resulting in reduced growth. Further, if the oysters are grown directly in the shrimp/fish pond the biodeposition (faeces and pseudofaeces) by the oysters adds to the effluent load in the shrimp/fish pond. Jones *et al.* (2001) advocated combined culture of oysters and seaweeds in the same tank. An important aspect to be considered in these integrated systems of culture is the optimum requirements of various environmental parameters for the survival and growth of oysters and seaweeds. The concept of integrated farming systems involving shrimp/fish with bivalves and seaweeds towards developing sustainable coastal aquaculture has been successfully tested by several laboratory and field studies. However, commercialization of integrated farming involving oysters is yet to take off.

In recent years there is growing environmental concern about the adverse impact of the effluents of shrimp farm wastewater, which is discharged in to coastal waters. Oysters can be successfully used as biofilters to reduce the concentration of phytoplankton, bacteria and detritus of shrimp farm effuluent water, thus improving the health of the environment. It is emphasized that there is urgency to undertake researches on this aspect in the country.

QUESTIONS

1. What is remote setting? Describe its advantages.
2. Write on triploidy, its induction and advantages in oyster culture.
3. Write an account on oysters as biofilters in aquaculture.
4. Write short notes on: a) Microencapsulated diets b) Cryopreservation of sperms and D-larvae c) Use of chemicals to enhance spat settlement d) Probiotics e) Heterosis f) Aneuploidy

CHAPTER 12

Strategies for Development of Oyster Culture

IN India, oyster culture is in an early stage of development. Since 1996, small-scale oyster culture has been taken up by villagers in the estuaries of Kerala state and the current annual production is between 750-800 tonnes. Women are participating in oyster culture activities such as preparation of rens, post-harvert handling and marketing. The Central Marine Fisheries Research Institute (CMFRI) after having developed oyster culture technology, is organizing awareness campaigns, setting demonstration farms in various places, and is providing technology support on a continuous basis for the benefit of the farmers. Realising the potential of oyster culture for employment and income generation in the coastal rural areas, Financial Institutions and Development Agencies are providing finance to oyster farmers. As a result, oyster culture is spreading fast into new areas with the active participation of a generation of first time farmers. Based on the information documented on oyster resources and culture in the country in the preceding Chapters, the gaps in the knowledge, future research needs, constraints faced by farmers and the steps to be taken for the development of oyster resources and culture on a sustainable basis in the Indian context are dealt in this Chapter.

OYSTER RESOURCES

The taxonomy of the oysters occurring in India needs detailed studies. Among the commercially important oysters *Crassostrea madrasensis* is by far the most important. A few surveys conducted over a period of time in several water bodies in the states of Andhra Pradesh, Tamil Nadu and Kerala gave valuable information about the species composition, distribution, population density, biomass, and size composition of oysters. From other states, the information available is scanty and there is need to assess the magnitude of oyster resources in these states. At present there is no system of monitoring the production of oysters. It is necessary to regularly monitor the production, and to study the various population parameters of the exploited stocks, at least at the major production centres so that appropriate management measures can be taken.

BIOLOGY

The biology of *C.madrasensis* has been studied in considerable detail from several parts of the country. However, an important aspect such as descriptions of distinctive characters of oyster larvae for identification from plankton is not studied in this species. Also, except for the reports on the occurrence of the protozoan parasite *Perkinsus marinus* and trematode parasites, no detailed studies on oyster parasites and diseases are made. Oysters are susceptible for infections by viruses, bacteria, trematodes, and cestodes etc., which cause oyster mortalities. With oyster culture expanding, information is called for on the parasites and diseases of oysters and the prevention and control measures.

Both *C.gryphoides* and *Saccostrea cucullata* are smaller species with slower growth rate when compared to *C.madrasensis*. Very few biological studies were conducted on the former two species.

NATURAL SEED

In India, at present farmers use natural seed for culture. In the global scenario also, more than 90% of the seed is sourced from the natural spatfall. In oyster biology it is well known that while many areas may be suitable for grow out culture, spat fall in sufficient quantities for commercial operations occurs only in a few places. For example in Japan, Sendai Bay is known to be most productive for spat collection. Although several studies have been made in India on the seed resources from different areas, it is necessary to generate comprehensive data base about the season and seed availability for commercial operations. The Ashtamudi Lake has proved to be a very good site for seed collection. There is intense spat settlement in this area for about three months, forcing the farmers to scrap the spat that settled later, along with foulers so as to ensure better oyster growth. As oyster culture grows it is worth while for the farmers of Ashtamudi Lake area to lay additional spat collectors and sell the seed to culturists in other areas.

In Thailand, natural seed is scrapped from the cultch and cemented on ropes at suitable distance for grow out culture. Although labour intensive this method ensures optimum utilisation of the seed and may be tried at the Ashtamudi Lake where excessive spat set is wasted.

HATCHERY SEED

The methods followed in India for broodstock conditioning, induced spawning and larvae / spat rearing have given consistent results. It was reported from Thailand that fish or shrimp ponds with high phytoplankton production provide excellent facilities for oyster broodstock conditioning. It is desirable to assess the suitability of such facilities for broodstock development.

A major problem faced by the hatcheries throughout the world is to maintain synchronization of the production of live microalgae in sufficient

quantities, depending upon the food requirements of the broodstock , larvae and spat held in the hatchery. Microalgae, dried as powder or in paste form are successfully used in many hatcheries as a partial substitute to live microalgae. Similarly it is reported that addition of Carbon dioxide gas enhances the microalgae growth, resulting in up to 6.0 million cells / ml against 1.0 - 1.5 million cells by the conventional method. These aspects call for detailed studies in order to develop appropriate technology to meet these requirements in the hatcheries.

Considerable research input is also required on aspects such as artificial diets (microencapsulated diets, yeasts and manipulated yeasts), cryopreservation of embryos and larvae, and probiotics before they are considered for commercial use.

Remote setting of oyster larvae has great potential once hatchery seed are used for commercial operations. The study conducted in the country involving 18 hours transport gave highly encouraging results and there is need to develop techniques for long duration transport covering 2-3 days.

The neuroactive compounds such as epinephrine, nor-epinephrine, L - DOPA and GABA induce oyster larvae to settle and metamorphose (without settlement surface) as cultchless spat and up to 90% success was reported which is more than double generally obtained in the hatcheries. At present cultchless spat are not used in oyster culture in India. Nevertheless, in the long term perspective it is desirable to generate information on this aspect.

NURSERY REARING OF SEED

Spat from commercial hatcheries are reared in nurseries till they reach 20-25 mm size. For this purpose several designs of upwelling systems have been developed which are either land-based or positioned on rafts or floats in bays and estuaries. These 'upwellers' are usually attached to the hatcheries and provide greater control over seed rearing, resulting in higher survival. There is no immediate commercial application of the upwelling systems in the country since natural seed are presently used but as a part of hatchery technology upgradation, it is desirable to undertake researches on the upwelling systems.

GENETICS

Considerable progress was made in oyster genetics in the USA towards improving their performance in aquaculture. Although not fully put to commercial use, genetic parameter estimates, selection, inbreeding, heterosis and heterozygosity have generated valuable information in enhancing the growth rate, survival and disease resistance in *C. gigas* and *C. virginica*. It is suggested that in India investigations on oyster genetics on the above aspects should be initiated. The most significant achievement in oyster genetics is the production of triploids which have several advantages over diploids

such as steady condition index enabling year round marketability, higher growth rate resulting in increased meat yield, and in population control. Triploids are widely used in the commercial culture of *C.gigas* along the Pacific coast of USA where hatchery seed form the basis of farming operation. The oyster farmers in Kerala have no option except to harvest the oysters before the peak spawning period so as to avoid losses due to poor condition of the oyster meat due to spawning. Triploid oysters greatly mitigate this problem and a staggered harvest can be planned depending upon market demand, provided the various environmental parameters of the culture site are within the tolerable range of the oysters.

GROW OUT CULTURE

There are several aspects of grow out culture which include species and site selection, farming technology, monitoring the health of the culture site and the farmed stock and information on the carrying capacity of the grow out site. Sound database on the above aspects helps to take appropriate management measures towards developing oyster farming as a sustainable activity in the country.

Oyster Species Selection

Among the commercially important oysters in India, *C.madrasensis* is by far the most important species. It has wider distribution, euryhaline and thrives well in backwaters and estuaries, amenable to culture, grows fast reaching market size in 6-8 months grow out culture and is widely marketed. As a consequence, this species is the basis of commercial aquaculture production of oysters from the country.

C.gryphoides has restricted distribution along the west coast, thrives well in estuaries and is a smaller species with slower growth rate. *Saccostrea cucullata* is widely distributed, occurring at the mouth of the estuaries and prefers marine environment; it is also a smaller species with slower growth rate (Chapters 2&3). Both these species seem to have limited potential as aquaculture candidates.

Culture Sites

Several studies were conducted in the four southern states, and certain sites suitable for *C. madrasensis* culture have been identified (Chapter 7). Nevertheless there is need to identify more water bodies from these four states and also from other maritime states from where there is no information available at present. For this purpose, location testing programs may be undertaken, using the wild and hatchery raised seed.

There are no extant laws to make available sites suitable for oyster culture to farmers on lease basis. For this purpose necessary laws should be enacted,

taking into consideration other activities such as traditional fishing, recreation, navigation and tourism.

Culture Methods

The rack and ren method of oyster culture has proved to be highly suitable in the estuaries. The technology of rack and tray culture method has also been developed. There are other methods of oyster culture practiced in many countries and their suitability under Indian conditions needs to be studied.

In France, on-bottom oyster culture is extensively practiced. It was reported that cultchless and attached spat of *C.madrasensis*, set on oyster shells planted on the bottom in the Kormapallam canal and Karapad creek at Tuticorin attained 75 mm average length in one year. Both production rate and input cost by this culture method are known to be low, and more importantly, it is substrate specific, requiring hard bottom. In suitable areas this method of culture may be given a trial.

Much of the oyster production from Japan comes from raft and longline culture and the farms are set up in waters upto 30 m depth from the shore. In India no studies were conducted in open waters using rafts and longlines for oyster culture but open sea raft culture of mussels brought to light the difficulties in maintaining the rafts in position due to rough sea conditions. Further, *C.madrasensis* is an estuarine species and the prospects of developing raft / longline culture of this species in open coastal waters appear to be bleak.

Public Health

The oysters are known to accumulate pollutants such as pathogenic bacteria and viruses, toxins produced by algae, and heavy metals, pesticides and hydrocarbons. Consumption of these oysters by humans causes several diseases and at times proves fatal. In temperate countries standards for the safe levels of various pollutants are fixed and the culture sites and the farmed stock are regularly monitored. If the level of pollutants is high, harvesting of the shell-fish is closed. There is urgent need to regularly monitor the sediment and the quality of water of the culture sites and the farmed oysters for pollutants. Currently this is one of the weakest links in oyster culture and has a significant bearing in building public confidence for the expansion of the market. Also depuration facilities should be developed at suitable areas so as to ensure the quality of the oyster meat.

Carrying Capacity and Biodeposition

It has long been recognized that large aggregations of shell-fish may have a significant impact on nutrient and energy recycling in shallow marine ecosystems (Dame *et al.,* 1980). Carrying capacity denotes the ability of the ecosystem to support shell-fish production without affecting the growth rates;

uncontrolled increase in the stocking density eventually results in reduced growth rate and degradation of the environment. In China, Japan and Thailand there are reports of oyster culture being carried at high stocking density, exceeding the carrying capacity of the water bodies (chapter 10). It is time to undertake studies in the country on the carrying capacity of the culture sites before the damage is done.

Biodeposition of oysters is another aspect to be considered. Seasonal cropping pattern followed by Kerala farmers is expected to have reduced detrimental effects of biodeposition when compared to year round farming in the same site for several years.

Integrated Farming

In several countries efforts are on to develop integrated farming systems using shrimp / fish pond effluent water for the production of bivalves and seaweeds. The bivalves are used to reduce the load of suspended particulate matter and the seaweeds to bring down the concentration of dissolved nutrients so that the adverse impact on the environment due to the release of pond effluents is controlled. Apart from their use in land-based farms, introduction of oysters into salmon cages in seafarming gave encouraging results. The development of integrated farming systems using oysters as one of the components is an important area of research that needs priority attention.

ECONOMICS

The available data on the economics of oyster culture is largely based on the operation of experimental / demonstration farms of CMFRI and is indicative of the profitability (Chapter 8). There is need to work out the economics based on commercial operations, taking into consideration the input costs, production and market value of the produce which change from time to time.

SOCIAL CONSIDERATIONS

It is increasingly realised in recent times that the availability of mere technology is not adequate for the sustained development of a sector. It is necessary; rather it has become imperative that various agencies, more importantly the different communities interested in the sector are comprehensively involved from the beginning in the formulation, planning, development and implementation of the programme. As the oyster culture is essentially carried out in the ecosensitive coastal areas, vibrant community participation would thus ensure not only developing an integrated perspective on the management of coastal resources but also a healthy and all round development of the sector.

TECHNOLOGY TRANSFER

The oyster culture technology was developed in the country in 1970's and it took about two decades before the commercial farms were set up. As a result

of sustained efforts by the scientists working at the CMFRI, oyster culture is spreading fast in Kerala (Chapter 9). The continuous interaction of the scientists with farmers and linking them with organizations such as the Brackishwater Fish Farmers Development Agency, which is providing finance, augurs well for the growth of oyster culture. Apart from expanding oyster culture in Kerala estuaries, there is wide scope to transfer the farming technology to the end users in other maritime states.

Unlike shrimps, oysters are not traditionally cultured in India. Lack of awareness about the prospects and economic benefits of oyster culture and non - availability of trained personnel with adequate knowledge in the culture system greatly hamper the wider propagation of oyster culture at present. It is therefore, essential to organise and implement need-based training programmes to meet the personnel requirement of the sector. The Trainers Training Centre of the CMFRI is actively working on these lines.

MARKET

Some coastal communities in states such as Kerala, Karnataka, Goa and Maharashtra and also people in a few metropolitan cities conventionally eat oysters. In the rest of the country, particularly in the interior parts, oyster consumption is practically non-existent. Against this domestic scenario, oysters are among the luxury seafoods in temperate countries such as Canada, USA and in Europe. The lack of demand is a matter of concern. There is need to widen the market base, particularly into the interior areas, with vigorous extension drive by popularizing the oyster products and creating awareness about the nutritional value. As a result of the efforts at the Central Institute of Fisheries Technology and the Integrated Fisheries Project (IFP) several oyster products have been developed. The IFP has ventured into marketing the oyster products and the reports indicate considerable demand for canned oysters in the north eastern states and metropolitan cities. As per the figures released by the Marine Products Development Authority, about 700 tonnes of oyster shell powder valued at Rs.21 lakhs was exported from the country in 1999 and oyster meat does not figure in the seafood exports.

Quality assurance is a prime factor for market promotion. To achieve this adequate care has to be taken beginning with the grow out culture till the product reaches the consumer. In essence the single most import factor that calls for immediate attention is the development of market for oyster and oyster products.

QUESTIONS

1. Describe the important gaps in knowledge and the thrust areas for R&D towards developing sustainable oyster farming in the country.

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ISBN : 81-7164-070-2