II EDIBLE BIVALVES: MUSSELS AND OYSTERS

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MUSSELS

Edible sea mussels belonging to the genus *Mytilus* are fished in quantities on some parts of the Indian coasts and are commercially important. They are bivalves approximately triangular in shape, with a shell pointed at the anterior end, a firm, horny periostracum, and anchoring byssus threads secreted by byssus glands present in the foot. The mussels attach themselves to rocks or other hard substratum by these threads. The mussel resources are rich on the south-western coast. When occurring in abundance they form thick carpet-like growths on rocks and concrete constructions like piers and wharves. Large beds of *Mytilus* colonise concrete and timber structures in ports and harbours. Two species of mussels are represented along our coasts, the green mussel, *Mytilus viridis* Linnaeus and the brown mussel, *Mytilus* sp. M*ytilus viridis* enjoys a wide distribution, occurring on both the east and west coasts and is fairly abundant at Cochin, Malabar and southern coast of Mysore. On the other hand, the brown mussel has a very restricted distribution extending from South of Quilon to Tirunelveli coast (Jones, 1950; Rao, 1958).

TAXONOMY

Phylum Mollusca
Class Pelecypoda
Order Filibranchia
Sub-Order Mytilacea
Family Mytilidae
Genus *Mytilus*

The family Mytilidae has been included by Thiele (1931) in the order Anisomyaria based on the nature of the adductor muscles, the anterior adductor being very much reduced or more or less completely suppressed in members of the order. Pelseneer (1906) whose classification has been followed in this work has included *Mytilus* under the order Filibranchia comprising bivalves with gills formed of parallel, ventrally directed and reflected filaments with ciliary inter-filamentar junctions. The sub-order Mytilacea including the genus *Mytilus*

comprises of bivalves in which the anterior adductor muscle is smaller than the posterior adductor muscle or even absent, non-vascular junctions connect the gill lamellae, aorta is single and the ramifications of the gonads usually extend into the mantle. In members of the family Mytilidae the shell is anteriorly narrow, inequilateral, the ligament is external, the true hinge is absent and the mantle has one point of union posteriorly separating the exhalent aperture from the rest of the pallial opening. In the genus *Mytilus* the umbo is terminal, the hinge does not have teeth but is denticulated and the ligament is linear (White, 1937).

MYTILUS VIRIDIS Linnaeus

SYNONYMS

Mytilus viridis Linnaeus 1758
Mytilus viridis Linnaeus 1767
Mytilus smaragdinus Chemnitz 1785
Mytilus smaragdinus Reeve 1858
Mytilus smaragdinus Hornell 1917
Mytilus viridis Hornell 1922 b
Mytilus smaragadinus Rai 1932
Mytilus viridis Satyamurthi 1956

COMMON NAMES

Malayalam - *Kallumalkai, Kadukka.*

DESCRIPTION

Shell large, elongate sub-trigonal with its anterior end pointed, arched and beak-like, dorsal margin of shell angularly convex in the middle, posterior margin broadly rounded, ventral margin slightly concave, valves strongly inflated particularly in the anterior part, surface of shell strongly decussately striated, ligament strong and elongated, shell surface covered by a firm, horny, bright green periostracum (Fig. 1 A). The mussel attaches itself to hard substratum by means of tough, thin, flexible byssus threads secreted by byssus glands present in the byssus cavity and the foot.

The body has the visceral mass, with two pairs of gills covered by a pair of mantle lobes which are united dorsally and free ventrally. The gonads extend into the lobes of the mantle. The mantle is cream coloured but during the period of sexual activity it becomes deep reddish orange in colour in females. The foot is much reduced, tongue-shaped and has a groove posteriorly which is used like a sucker to adhere firmly to substratum.

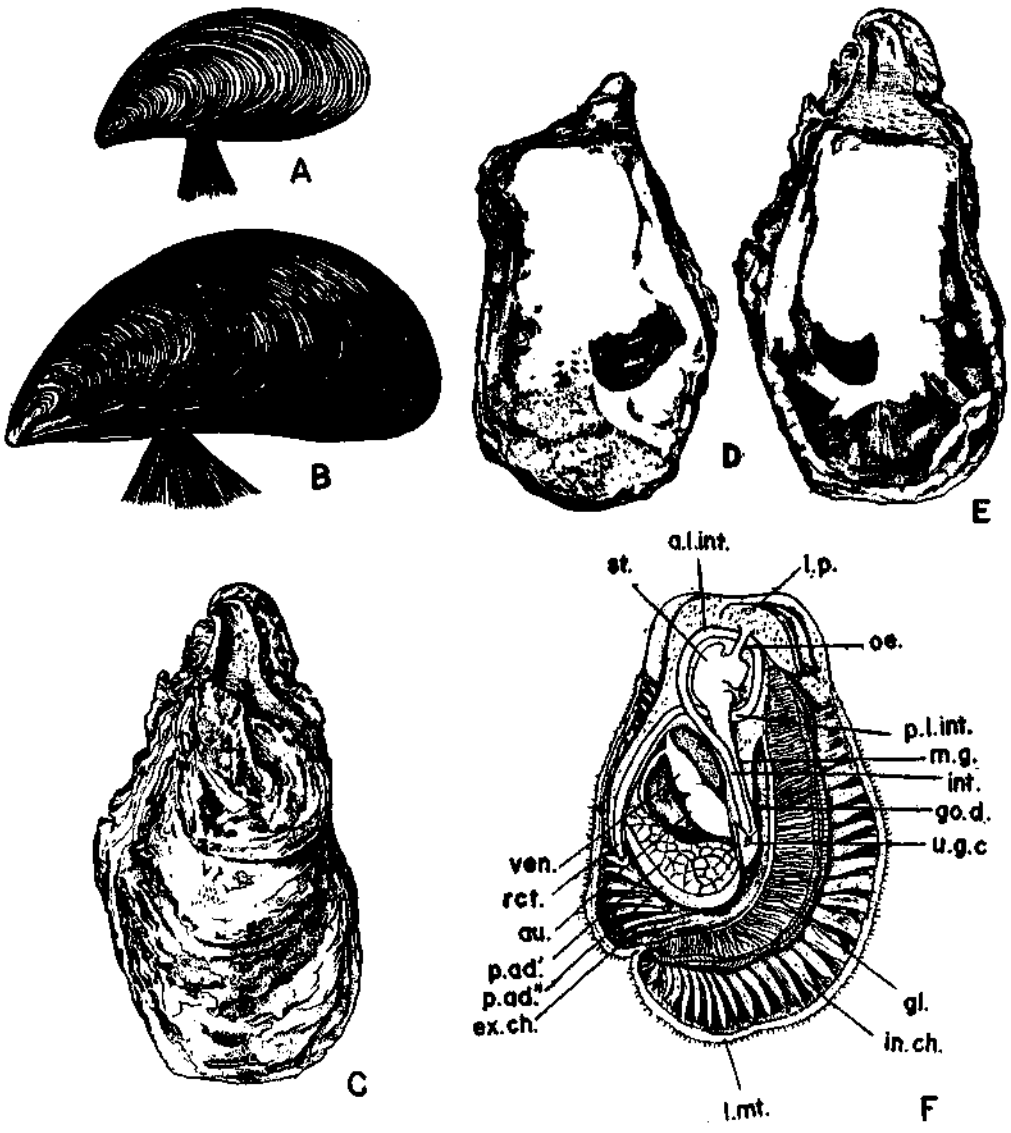

Fig. 1. A. *Mytilus viridis* Linnaeus. B. *Mytilus* sp. C. *Crassostrea madrasensis* (Preston). D and E. Internal view of right and left valves of *C. madrasensis*. F. Anatomy of *C. madrasensis* (Drawing by Mr. K. Virabhadra Rao). a.l.int., anterior loop of intestine; au., auricle; ex.ch., exhalent chamber; gl., gills; go.d., gonoduct; in.ch., inhalent chamber; int., intestine; l.mt., left mantle; l.p., labial palps; m.g., midgut; oe., oesophagus; p.ad'. anterior portion of adductor muscle; p.ad"., posterior portion of adductor muscle; p.l.int., posterior loop of intestine; rct. rectum; st., stomach; u.g.c., urinogenital cleft; ven., ventricle.

Distribution in India

The species occurs all along the east and west coasts of India. On the east coast it occurs generally as stragglers except in harbours. The mussels are abundant at Cochin, Malabar and north of Kerala. On the northern parts of the west coast it is found only in small numbers.

Habitat

In addition to open coasts and harbours the mussels are found in the mouths of estuaries and rivers as they are capable of withstanding wide variations of salinities. The mussels are found from low water mark to a depth of about three metres. They adhere firmly to the hard substratum by means of byssus threads and much effort is required to remove them.

Growth

The growth rate of *Mytilus viridis* is very rapid at Madras. Paul (1942) has recorded that *M. viridis* grows to 14.5 mm, 34.5 mm, 52 mm, 55.5 mm, 77.5 mm, and 103 mm in 30, 84, 164, 167, 241 and 445 days respectively in the Madras Harbour. Growth has been found to be continuous i.e., without interruption in any part of the year. Annual rings or growth checks which occur in bivalves due to cessation or slackening of growth in mussels of temperate seas have not been recorded in this species. Paul (1938) states that *M. viridis* probably attains the maximum size in two or three years. Field (1942) states that availablity of food organisms is the main factor determining the growth of mussels. He says that if food is scarce growth is retarded regardless of other conditions. Paul (1942) observed that growth was poor in mussels inhabiting isolated parts of the Madras Harbour where the inflow and outflow of sea water was restricted.

Reproduction

M. viridis attains maturity very quickly under tropical conditions at Madras. Forty eight day old female mussels 15.5 mm in length and 9.4 mm in breadth have been found to contain ripe eggs (Paul 1942). Spawning has been observed in 93 days old female. The European mussel *Mytilus edulis* becomes sexually mature only when about one year old (White, 1937). Mature individuals of *M. viridis* have been recorded from Madras harbour throughout the year and it has been stated that the species breeds all around the year (Paul, 1938; 1942). However, there is peak breeding activity from March or April to October. By contrast *Mytilus edulis* of British coasts has distinct periodicity spawning taking place twice in a year, between January and March and during July-August (Lebour, 1907. White 1937). Breeding in the tropical species *M. viridis* shows some similarity to that in *Mytilus californianus* off San Francisco with spawning all round the year (Whedon, 1936). But, in the American species peak spawning

begins in October and this is followed by two spawning seasons of smaller intensity in January-February and May-June. Whedon doubts whether changes in water temperature could induce spawning in mussels although they may play a part in the rate of development in early stages.

Spat

Spatfall takes place throughout the year in the Madras harbour with maximum density in the peak breeding period March-October (Paul, *loc. cit.*). Information is not available on the early growth of spat.

Food

The food and feeding habits of *Mytilus viridis* have not been studied in any detail. Field (1922) recorded as many as twenty nine species of diatoms and nine species of Protozoa in the stomachs of *M. edulis* but found that organic detritus formed half of the total amount of contents in the stomachs. It is considered that the detritus and smaller planktonic organisms are fed upon by the mussels and the rest is rejected as pseudofaeces.

Chemical composition

There is no information on the chemical composition of Indian mussels. Mussels are rich in protein and glycogen. In *M. edulis* of Great Britain protein forms 54.83%, glycogen 14.51%, lipid 8.06%, and salts 12.15% dry wt. (Daniel, 1923) and the glycogen level falls to a low level (5.95%) after spawning. Giese (1969) has recently investigated the organic constituents of the different parts of the body of *M. edulis* of Pacific coast of United States of America. The data reveal that the mantle and gonads of the mussels are richer than other body components in lipid (12.4 % dry wt.) while the foot has a high carbohydrate content (19.3 %). The seasonal changes in the chemical composition of the mussels should be studied to determine when the meats are in fit condition for consumption.

Fishery

The mussels are fished at Cochin, Malabar, Karwar, Ratnagiri, Bombay and Madras for eating. There is a good fishery for the green mussels from Varkalay near Quilon to the southern Mysore coast (Jones, 1968), the bivalves caught being found on the surface of rocks and man-made structures like piers and wharves. In Tellicherry there is an active fishery, 30 dug-out canoes being employed daily. On the south-western coast mussels are fished by dislodging hem with an iron chisel mounted on a wooden handle. Fishing is done between

9-10 a.m. and 2 p.m. Each boat in Tellichery lands 25-50 kg of mussels which are worth Rs. 6-12. They are sold in fresh condition in the markets at Re. 1 to Rs. 2. per hundred. Mussels are sold in markets at Calicut, Beypore, Cannanore Tellicherry and Mahe (Rao, 1958). At Bombay, Ratnagiri and Karwar the mussels are very much relished but they are rare there. At these centres mussels are fished only in fair sea seasons at low tide (Rai, 1932). Hornell (1922b) has stated that good quantities of green mussels occur in Sonapur backwaters but at present the mussels are sparse in the area and in Pulicat Lake. On the east coast the limited green mussel resources that exist are not fished intensively. No closed season is observed anywhere on the Indian coasts.

Mussel Culture

Mussel culture is not practised in India. There is good scope for culturing the green mussel in the numerous estuaries and backwaters of the country. Mussel culture is done on a large scale in western countries like Holland, France, Spain and England. There are two methods of mussel culture, the French or 'Buchot' method and the British method. The French method is stated (Field, 1908) to have been evolved as early as 1035 by an Irishman named Walton who was the sole survivor of a shipwreck in the Bay of Aiguillon. In this method V-shaped wooden enclosures the 'buchots' with the apex pointing out to the sea protecting the growing mussels from the vagaries of winds, waves and ice, are set up. A buchot consists of rows of stakes placed 60 cm apart and interlaced with a meshwork of flexible willow or chestnut branches 30-45 cm long and 5 cm in diameter. The stakes are trunks of trees, 3.6-4.5 metres in height and 15-30 cm. in diameter and driven into the ground to half their length. There are separate buchots for collecting spat and for fattening mussels. The buchots extend from high tide mark to deep water far away from the shore. Mussel spat settle on the buchots and grow and when about 5 months old they are transferred to buchots nearer shore where they are fastened in clusters with old netting. As the mussels attain larger and larger sizes, they are progressivly transferred some at a time to buchots nearer shore. When the mussels are 4-5 cm in size at the end of about one year they are kept on the stakes near the high tide level where they remain in good condition in spite of exposure twice a day. From there the mussels are taken whenever required for marketing. In the British method of culture which is comparatively very simple, young mussels are gathered from natural beds and transferred to estuaries or sheltered bays or backwaters where they are exposed part of the day at low tide and there is a good flow of water. The average yield from an acre of a mussel farm is estimated to be more than 100 tons. As the growth rate of the Indian mussels is very rapid and as they attain sexual maturity very quickly, in about three months time, culture of this species will be profitable if done with care on scientific lines.

MYTILUS SP.

This species is known as the brown mussel due to the predominant brown colour of the periostracum lining the shell. Its specific identity has not yet been established. This species grows to a length of about 11·8 cm. (4·6 inches) and is stouter than the green mussel.

COMMON NAMES

Malayalam — *Chippi, Muthuva, Muthu chippi*
Tamil — *Kallika, Kadal ka*

DESCRIPTION

Shell large, elongate sub-trigonal in shape with anterior end angular and pointed, dorsal margin angular, convex in the middle, posterior margin broadly rounded, ventral margin slightly concave, valves strongly inflated, especially in the anterior part, surface covered by a firm, horny, brown periostracum. The mussel attaches itself to substratum by well-developed byssus threads (Fig. 1 B).

DISTRIBUTION IN INDIA

From south of Quilon to Kanyakumari on west coast and along Tirunelveli coast.

HABITAT

Like the green mussel the brown mussel also is a sedentary bivalve living attached to rocks, piers and wharves. It has been recorded upto a depth of 6 metres. Complete submergence, clear water, availability of food and light, and presence of little suspended impurities are stated by Jones (1950) to be ideal conditions for this mussel. Mussels exposed to waves carrying sand or mud constantly get chocked up and die.

REPRODUCTION

Jones (*loc. cit.*) states that the breeding season of the mussel appears to be extended. The monsoon period June to August is the peak breeding period. In this period many rocks in the littoral region that are exposed in summer are submerged under the sea which becomes rough and moves shoreward in the rainy months. Clusters of young spat settle on the rocks over large areas. There is a second breeding peak in October and November but this is small in intensity as compared to the earlier one.

PESTS

Crabs of *Pinnotheres* sp. have been recorded inside brown mussels by Jones (1950). The crabs must be harmful to the well-being of the mussels by competing

for planktonic food organisms. The percentage of incidence of crabs in the mussels and whether the presence of the crabs affects the quality of the meat of the mussels should be studied. Algae and animals like hydroids, polyzoans, annelids and barnacles live attached to the surface of the shell of the mussels and are harmful to the mussels by weakening the shell, by polluting the water and by competing for food materials. The parasitic copepod *Mytilicola* occurs in mussels in Europe and America and causes significant damage (Quayle, 1969).

FISHERY

There are important fishing centres between Kovalam near Trivandrum and Kanyakumari. The centres between Kovalam and Vizhinjam and those between Colachel and Muttom are the most important ones (Jones, 1968). Between Poovar and Kovalam mussel fishing is done by *pulayas* also known as *cherumas*. The mussel fishery extends from September to May or early June on south Travancore and Tirunelveli coasts. In September as the sea is calmer than in the preceding period carpet-like growths of *Mytilus* beds on rocks in the littoral region are exposed. Fishermen, women, children and old people gather the mussels from the rocks with hands, sometimes using a chisel mounted on a wooden handle. The regular fishing season begins in mid-November and continues till May. By the middle of November most of the mussels in the shoreward rocks having been fished, fishermen dive to submerged rocks in the subtidal zone and gather mussels present on them by dislodging with a chisel called 'uli'. The uli is a blunt edged knife 7.5 cm in width fixed on a softwood handle 45 cm. long and 3.8 cm. diameter. The mussels collected are put in a coir bag 45 cm. in length and 30 cm. in width. After diving as long as he can and collecting mussels the fisherman comes up and goes down after resting for sometime. Fishing is done between 9 or 10 a.m. and 2 p.m. To reach the seaward rocks the fishermen go in catamarans. A fisherman earns Rs. 4 to Rs. 8 per day when fishing is good. Marketing of the mussels is done by women who are usually of the fishermen's families. The mussels are sold in villages within a radius of three to eight kilometres from landing centres.

World production of mussels of the genus *Mytilus* has increased from 164,000 tonnes in 1958 to 320,000 tonnes in 1969 (F. A. O, 1970 a). Holland, the largest mussel producing country harvested 105,900 tonnes in 1969, which is about 33% of the world mussel production. The other important mussel producing countries are Spain (93,700 tonnes), France (28,200 tonnes), Chile 17,500 tonnes), Denmark (16,300 tonnes), Italy (15,000 tonnes). Statistics are not available about the mussel catches in India. Jones (1950) has mentioned that thousands of maunds of the brown mussel are fished every year. At the present time the mussel beds are not as rich as in former times (Jones, 1968). The total mussel production of India may be some hundreds of tonnes per year.

UTILIZATION OF MUSSELS

In India the value of mussels as nutritious food is not realized to a large extent. Mussels are usually consumed after cooking in the form of a curry. People of poorer classes boil the mussels with pieces of roots of tapioca or cassova with a little quantity of water and when they are cooked, drain and eat them. Some people eat raw mussels but this is very rare. Pearls ranging in size from a tiny pin-head to that of a pepper-corn are secreted by mussels but there is no demand for them. Empty shells of mussels are heaped and sold to lime kiln owners who manufacture lime. The shells of the brown mussel are powdered and utilized as manure in gardens and cocoanut farms.

Sea mussels are very much relished in western countries. Mussels are stated to be easily digestible and are recommended for people suffering from weak digestion (Field, 1908). Mussels are used in various ways in the West. In European countries and United States of America crushed *Mytilus edulis* is employed as bait and thrown overboard in mackerel fishing. The mud in the vicinity of mussel beds is rich in organic materials and used as manure for growing carrots and onions in Great Britain. The shells are carved and polished and ornamental articles made (White, 1937).

OYSTERS

Some of the bivalve molluscs belonging to different families are popularly known as 'hammer oysters' (Family Isognomonidae), 'pearl oysters' (Family Pteridae), edible oysters (Family Ostreidae), 'window-pane oysters, (Family Anomiidae) and 'finger oysters' (Family Solenidae). However, whenever the name oyster is used without any prefix it means only the edible oyster. In some countries like the United States of America, Canada, United Kingdom, Japan, Korea, China (Taiwan) and Philippines large quantities of oysters are fished from natural beds and also cultured. In these countries edible oysters are considered as a delicacy. The edible oysters with which the following account deals are highly nutritious containing good quantities of glycogen, lipids, protein, Vitamins especially A, B and D and several essential minerals (Quayle 1969; Gunter and McKee, 1960). In India substantial oyster resources exist which remain unutilized but for some harvesting to meet the requirements of a small section of population for food and conversion of the oyster shells into lime. Different aspects of the biology of oysters have been studied in various parts of the world and there are thousands of scientific papers on the subject (*vide* Korringa, 1952; Yonge, 1960; Loosanoff and Davis, 1963; Galtsoff, 1964). The keen interest evinced in the study of oysters is due to their commercial importance.

As many as eleven species of oysters have been stated to occur on the Indian coasts (Awati and Rai, 1931). The occurrence of some of these species

has to be confirmed by a detailed study of material as we know little of their taxonomic characters from the known records. Four species of oysters *Crassostrea madrasensis* (Preston), *C. cucullata* (Born), *C. gryphoides* (Schlotheim) and *C. discoidea* (Gould) occur in appreciable quantities at different places on the coasts of India and are commercially important while the others are found sporadically and are of scientific interest only.

TAXONOMY

Phylum Mollusca
Class Pelecypoda
Order Eulamellibranchia
Sub-Order Ostracea
Family Ostreidae
Genus *Crassostrea*

Thiele (1931) has included the family Ostreidae under the Order Anisomyria based on the nature of the adductor muscles, the anterior adductor muscle being reduced or totally suppressed in members of the Order. Pelseneer (1906) whose classification is usually followed includes the family Ostreidae in the Order Eulamellibranchia which consists of bivalves with gills composed of branchial filaments united at regular intervals by vascular junctions. Members of the sub-order Ostracea (Series according to Thiele) are monomyarian or with a very small anterior adductor muscle, the mantle is open, the foot is reduced in size, the gills are folded and the shell is inequivalve. The family Ostreidae is characterized by very much reduced foot which does not have byssus gland, the gills are fused to the mantle, and the shell is fixed to the substratum by the left valve which is larger than the right one.

Originally about a hundred species of recent oysters and 500 species of fossil oysters were described based on variations in shape, size, colour and texture of the adult shell and some of the points of difference are of little taxonomic significance (Korringa, 1952). The shape of the shell of adult oysters varies greatly under the influence of factors like nature of substratum, salinity, current velocity, exposure etc. and it has been found that it is unreasonable to erect numerous species based on these differences. Ranson (1948, 1950) distinguished oyster genera mainly on the basis of the structure of the larval shell and divided recent oysters into three genera, *Pycnodonta, Gryphaea* (synonymous with *Crassostrea*) and *Ostrea*. In *Pycnodonta* the larval shell has equal valves, there are five teeth on the provinculum and the interior ligament is present immediately following the provinculum and the adult is oviparous, the rectum traverses through the ventricle, promyal chamber is present and chalky deposits are of lamellated type. In *Ostrea* the larval shell consists of unequal valves with two teeth on each side of the provinculum, the anterior pair may be reduced, the interior ligament is placed in

the provinculum, the adult is larviparous, rectum does not pass through the ventricle, promyal chamber absent and chalky deposits of shell are lamellated.

As pointed out by Hemming the fossil species *Gryphaea arcuata* Lamarck is the type species of the genus *Gryphaea* (Korringa, 1952). Children's selection of *Gryphaea angulata* as type species of the genus *Gryphaea* is not tenable as at the time, in 1801, when the generic name *Gryphaea* was published by Lamarck, *Gryphaea angulata* was just only a name and cannot be considered as an originally included species. According to the international rules of nomenclature the generic name *Gryphaea* could be used only for fossil species and the generic name *Crassostrea* (Sacco, 1897) is the first valid name for oysters of the type *angulata, virginica, gigas, madrasensis, cucullata* etc. The distinguishing features of the genus *Crassostrea* are: the shell is very irregular in shape, attached to the substratum by the lower left valve, the hinge is toothless, with linear margin, the ligament is partly external and laminated upon a trigonal area in each valve, there is only one adductor muscle viz., the posterior adductor muscle, the adult is oviparous, rectum does not pass through ventricle, promyal chamber present and chalky deposits are lamellated.

CRASSOSTREA MADRASENSIS (Preston)

SYNONYMS

Ostrea cucullata Hornell 1910
Ostrea virginica Annandale and Kemp 1916
Ostrea virginiana Hornell 1922b
Ostrea virginiana var. *madrasensis* Moses 1928
Ostrea arakanensis Winckworth 1931
Ostrea madrasensis Preston 1916
Ostrea madrasensis Awati and Rai 1931
Ostrea madrasensis Gravely 1941
Ostrea madrasensis Paul 1942
Ostrea madrasensis Rao 1951
Ostrea (Crassostrea) madrasensis Rao 1956
Ostrea madrasensis Satyamurthi 1956
Crassostrea madrasensis Rao 1958

COMMON NAMES

Tamil — *Ali, Kalungu, Patti.*
Malayalam — *Muringa, Muru.*

DESCRIPTION

Shell straight, shape irregular, covered by numerous foliaceous laminae, left valve deep, right one slightly concave, hinge narrow and elongated, adductor

scar sub-central, reniform and dark purple in colour, inner surface of valves white, glosssy and smooth, purplish black colouration on the inner margin of the valves (Figs. 1 C and D).

BODY

A brief account of the description of the soft parts of *C. madrasensis* has been given by Moses (1928). The right and the left mantle lobes of the oyster enclose a large mantle cavity which is divisible into a lower inhalent chamber (Fig. 1 E, in. ch.) and an upper exhalent chamber (ex. ch.). In the inhalent chamber are two pairs of gills one each on the right and left sides extending forwards upto the two labial palps (l. p.) between which the mouth is present. In about the middle of the body is the adductor which runs across the two valves of the shell. It consists of a large anterior translucent portion (p. ad'.) formed of striated muscle fibres, which brings about rapid contraction that can close the shell quickly and a narrow posterior portion (p. ad''.) composed of smooth muscle fibres, which functions as a catch muscle to fix the valves in a particular position either partially or fully open. In front of the posterior adductor is the pericardium enclosing the heart with two auricles (au.) and a ventricle (v.). The digestive system consists of a narrow oesophagus leading from the mouth, a spacious stomach (st.) closely pressed against the ramifications of the digestive gland of either side, a slightly twisted midgut with a style sac in the oral process, a long intestine (int.) partly within the oral process and partly encircling the stomach and a rectum opening into the exhalent chamber by the anus located on the dorsal side of the adductor muscle. Much branched vesicles with connective passages at the junction of the mantle with the body constitute the kidneys. The gonads of the oyster are creamy white, highly branched, tubular follicles lying below the body epithelium around the visceral organs (Rao, 1956). The follicles of the two sides almost fuse at the hinge region and are absent below the oesophagus and around the pericardium. The gonoducts of the two sides open into two separate urino-genital clefts near the adductor muscle. In fully ripe females the ramifications of the follicle tubules are clearly discernible and this is not the case in ripe males. In partly spawned oysters of both sexes the upper portion of the gonad is flabby and there is accumulation of watery fluid, while lower below there are ripe germ cells within the follicles. The amount of watery fluid in the gonads depends on the extent of spawning. Generally the fully spent female oyster presents a more flabby appearance than a fully spawned male.

DISTRIBUTION IN INDIA

Sonapur, deltas of Godavari and Krishna, Gokulapalli, Pulicat, Ennur, Madras, Cuddalore, Athankarai and Kanchanagudi near Mandapam, Kerala coast and Port Blair (Andaman Islands).

HABITAT

C. madrasensis is essentially a brackish water oyster. It occurs as thick beds in estuaries, backwaters, ports and harbours and only sporadically on the open coasts. The oysters are found from the intertidal zone to a depth of about 4 metres. They colonise not only rocky or concrete surfaces but also hard muddy bottom where they thrive well. The general shape of the oysters varies in relation to the substratum. Those settling on flat rocky surfaces are round, those growing on soft mud are long and narrow, and those growing on uneven surfaces have shapes which conform to that of the substratum. Oysters growing in the upper parts of estuaries possess heavier meats and more massive shells as compared to those along the coast or at the mouth of estuaries. Overcrowding results in highly irregular form (Rao and Nayar, 1956).

MATURATION OF GONADS

The adult oysters of Madras harbour are in a partially spawned condition all round the year (Paul, 1942; Rao, 1951) under marine conditions. The oysters of Adyar backwaters exhibit seasonal changes in gonadal activity (Rao *loc. cit.*). The gonads were full or partially spent in March — April 1948, spent in May and in recovering stage in the period June — September. The gonads contained ripe gametes in September and October and were in full or partially spawned condition in the period November — January. There was recovery of the gonadal follicles in January and February but no rapid proliferation. In contrast to the ripe gonadal condition of oysters in March and April 1948 there was cytolysis and dissolution of eggs in March — April 1949 and only males were ripe. It has been suggested that the difference may be due to variations in salinity of the habitat water. The salinity of Adyar backwaters was 20 — 28‰ in March — April 1948 and much higher, 32 — 37·9‰ in March — May 1949.

In *C. madrasensis* of Ennur backwaters gametogenetic activity takes place twice in a year, once in March and again in September (Rao, 1956). Gametogenesis beginning about March is of very short duration while that beginning in September extends till December. A small or large percentage of oysters belonging to both sexes are mature throughout the year in the Ennur backwaters. In *C. madrasensis* of Athankarai estuary near Mandapam also gametogenetic activity was observed to take place twice in a year, in August–September and in March (Satyanarayana Rao - unpublished). The salinity of the estuary is very high 46–53‰ in August due to evaporation. In Athankarai estuary ripe oysters belonging to both sexes occured in most of the months in the year in high percentages (Table I). This appears to be due to the estuary remaining connected with the sea throughout the year.

In temperate waters there is a close relation between gonadal activity of oysters and water temperature (Loosanoff, 1942). Gametogenesis takes place in

spring, spawning in summer and the oysters enter resting phase in winter when the water temperature falls to extremely low levels. Loosanoff and Davis (1952) induced gametogenetic activity in hibernating *O. (C.) virginica* in winter by rearing them at higher than natural temperatures in laboratory and spawning took place at 15° C. The minimum temperature at which spawning takes place differs in the northern and southern populations of the American oyster. This is considered to be due to the populations belonging to different physiological races (Loosanoff and Davis *loc. cit.*). In Ennur backwaters water temperature has been found to vary between 25.7° C and 33° C during the year and Rao (1956) states that there has been no evidence to show that gametogenetic activity is inhibited by the lower levels of the temperature range.

TABLE I

Percentages of ripe male and female *Crassostrea madrasensis* of Athankarai Estuary in the period August 1969–December 1970 with data on temperature and salinity of the Estuary.

Months	Ripe males expressed as percentage of total males	Ripe females expressed as percentage of total females	Water Temperature °C	Salinity ‰
August, 1969	41.6	88.8	30.5	45.8
September	17.5	50.0	30.3	51.83
October	54.5	100.0	28.3	13.13
November	0.0	94.7	28.8	30.40
December	...	...	...	...
January, 1970	100.0	100.0	28.8	7.93
February	100.0	100.0	27.8	19.79
March	69.5	80.0	27.8	25.00
April	84.2	100.0	32.2	14.37
May	71.4	100.0	28.8	31.87
June	52.6	4.5	30.5	32.97
July	50.0	0.0	27.5	42.21
August	22.2	57.1	29.0	39.19
September	76.9	83.3	30.0	38.79
October	84.2	100.0	29.6	33.67
November	72.7	91.6	26.1	17.99
December	100.0	87.5	26.8	19.06
Average	62.3	79.8	28.8	29.00

HERMAPHRODITISM

Hermaphroditism has been recorded to occur in *C. madrasensis* by Rao (1953, 1956). Hermaphrodites occurred in all the seasons. In the pre-monsoon and monsoon months oysters changing from male to female sex occur and in the post-monsoon and summer months oysters changing from female to males sex have been noted. In *C. madrasensis* of Athankarai estuary harmaphrodites showed a regular periodicity in occurrence oysters changing from male to female sex having been observed in the pre-monsoon and post-monsoon months and individuals changing from female to male sex in post-monsoon and summer months (Satyanarayana Rao – unpublished).

The type of hermaphroditism noted in the Indian species *C. madrasensis* is similar to that in the American oyster *C. virginica* and the Pacific oyster *C. gigas* and is what is termed ambisexuality or monoecism with alternative sexuality (Coe, 1943) i. e., the adults function as separate sexes in any one spawning season and sex change occurs in between two consecutive spawning seasons. On the other hand in the larviparous oysters *Ostrea edulis* (Orton 1927a, 1927b, 1933), *O. lurida* (Coe 1932a, 1934) and *O. equestris* (Gutsell, 1926) exhibit what is known as "ambisexuality or monoecism with rhythmical consecutive sexuality". In these species oysters which are males or females in the early part of the spawning season undergo sex-change in the course of the season, the ratio of the extent of the male and female germ cells differing at different periods of the breeding season. In these species, the oysters complete three sexual phases in the course of the first year and one or two phases in the succeeding years. Some males do not undergo sex change for a prolonged period. These are called "true males" (Coe, 1932b; 1934; 1943; Gutsell, 1926).

The causal factors responsible for sex change in oysters are not quite clear. The primary gonad of oysters contains undifferentiated gonia that could develop into male or female germ cells. Usually the initial sexual phase is male (termed protandry). However, in a few the first sexual phase may be female. At the conclusion of the spawning season or much before that as in larviparous oysters the reproductive follicles shrink and are in a quiscent phase. At this stage the gonads have potentiality of developing either into male or female sex. Coe (1936) observed that oyster populations living under comparatively more favourable conditions have a greater percentage of females than males. Excision of gills has been found to be accompanied by dominance of males in *C. gigas* (Amemiya, 1935). Occurrence of the commensal crab *Pinnotheres* in *C. cucullata* (Awati and Rai, 1931) and overcrowding of oysters are some of the other conditions with which dominance of males has been correlated.

Orton (1927b) suggested that carbohydrate metabolism is predominant in males while in the females it is protein metabolism which is dominant and sex

change is due to rhythmical changes in metabolism of the oysters. Biochemical studies by Egami (1951) in *C. gigas* lend support to Orton's hypothesis.

SEX RATIO

In summer season when the gonads of oysters are fairly full the males are dominant (59.6%) in Ennur backwaters (Rao, 1956), females forming only 38.6%. In the pre-monsoon months the proportion of females is greater (55.7%) than that of males (41.7%). In the monsoon period in the course of which spawning takes place (in November and December) females continue to be the dominant sex. In the post-monsoon period as the gonadal follicles are resorbed the males preponderated over the females. Sexually indeterminate oysters occur almost throughout the year and are maximum (about 10.7%) in the pre-monsoon and post-monsoon periods at the conclusion of two periods of gonadal activity. Hermaphrodite oysters have also been recorded throughout the year in backwaters in small percentages (0.9 to 8.5%).

SPAWNING

Hornell (1910a) recorded peak sexual activity in *C. madrasensis* of the east coast rivers and backwaters between October-November and considered that a fall in the salinity and not arise in water temperature is the main stimulating factor. In 1922 he stated that there is a secondary peak in spawning in oysters in March-April with stray spawning in between and opined that not only a rise in temperature but also a fall in salinity induces spawning (Hornell, 1922b). Sunder Raj (1930) mentioned that a salinity range of 8.42‰–29.99‰ with a specific gravity 1.007–1.020 favours breeding and early development but this is a very wide range. Panikkar and Aiyar (1939) observed motile sperms in male oysters of Adayar river in November, 1934 and October and November, 1935. Paul (1942) recorded that the oysters of Madras harbour breed throughout the year with maximum activity between April and October.

Rao (1951) observed a main spawning period in *C. madrasensis* of Adyar backwaters between October and December and usually a second season existed in March-April. In the first spawning season the salinity of the backwaters was 22–25‰ and temperature 24–25° C. In the second season the salinity was 20–25‰ and temperature 29°–33° C. Rao (*loc. cit.*) found that oysters of Adyar backwaters exhibited natural spawning in the laboratory as well as in the field in the breeding period but failed to spawn in the field in the non-reproductive period when kept in different grades of salinity. Unlike oysters of the Adyar backwaters the oysters of the Madras harbour were in a partially spawned condition throughout the year as noted by Paul (1942). Maturation of gonads and production of ripe gametes in April 1953 and 1954 in oysters of Ennur backwaters was not followed by spawning while maturation in October in these two years was followed by successful spawning.

Early Development

The early development of the oyster has been partially studied by Moses (1928) and Devanesan and Chacko (1955). The fully ripe egg is spherical and ranges between 0·051 mm and 0·085 mm in diameter. One polar body extruded within twenty minutes after fertilization and two indentations and later a third indentation appeared and the egg became divided into a three-celled structure. One of the three cells divided several times rapidly and the resulting cells which were small were situated on the undivided two cells. About an hour after the first segmentation the two cells underwent division and by this time the cap of cells at the top descended and enclosed them resulting in the formation of blastula. The blastula is spherical at first and later becomes elongated and flattened at the top and bottom and develops a depression at the bottom. The two ends of the elongated and flattened blastula are brought nearer as to enclose a hollow depression and the gastrula is formed which develops shell gland, a prototroch and a circlet of cilia anteriorly and becomes the veliger. The shell gland invagination becomes everted and the walls of the invagination spread laterally over the body of the larva and the middle portion of the body becomes flattened.

Occurrence of larvae in plankton

Oyster larvae have been observed in the Adyar backwaters between the middle of March and the first week of May (Rao, 1951). There was a progressive decrease in the abundance of larvae during the period. The salinity varied between 20·32‰ and 28·59‰ and the average temperature was 32·8° C. As the average water temperature reached 33·2° C in April heavy mortality was observed. Larvae again appeared in the backwaters from 26th November to third week of January with peak numbers in the end of this period. The average salinity was 29·01‰ and temperature 24·2 — 25·2° C in this period. The larvae appear to require slightly higher salinities for setting than those (22 — 26‰) at which spawning takes place.

Under marine conditions of the Madras harbour larvae of *C. madrasensis* occur in plankton in all the months with maxima in the periods May — July and November — January corresponding to times of high temperature and low salinity respectively (Rao *loc. cit.*).

Spatfall

From field observations and experiments conducted in the laboratory to find out the effect of different grades of salinity prepared with sea water and estuarine water on the spatfall Rao (*loc. cit.*) found that in the Adyar backwaters conditions were favourable for spatfall only when the backwaters were in communication with the sea and the salinity increased to 28—30‰. Chidambaram

and Dinamani as cited by Devanesan and Chacko (1955) also have recorded that there was no spatfall in Ennur backwaters between 26th January 1948 and 17th November 1949 during which period the sand bar at the mouth of the backwaters remained closed and there has been spatfall between 18th November 1949 and 18th June 1950 when the backwaters were connected with the sea. The information collected clearly shows that some factor present in sea water as yet unascertained facilitates spawning and spatfall in *Crassostrea madrasensis*. Rao (*loc. cit.*) states that the periodical inflow and outflow of tidal and flood water with the tidal amplitude and the circulation of water that is maintained constantly when the backwaters and estuary are in communication with the sea may influence spawning and spat setting. The pH of the backwaters as well as coastal waters of Madras fluctuates over a very small range of 8·3 — 8·6 (Rao *loc. cit.*) and this could be considered to play no role in the success or failure of spatfall.

GROWTH

Hornell's data (1910a) on spat of oysters of Ennur shows that the spat grow to a size of 27 mm in 1¾ months. Paul (1942) has recorded that oyster spat grow to 0·8 mm, 4·4 mm, 6·3 mm, 6·5 mm, and 12 mm in length (height) in 3, 10, 13, 16 and 19 days respectively in Madras harbour. Rao and Nayar (1956) observed that in the first week oyster spat showed, when reared in laboratory growth rate similar to that observed by Paul (*loc. cit.*) but later it was poor and spat attained a height of 10·3 mm in 61 days. Rao and Nayar recorded that in the third week of November spat ranged between 2 mm and 7·5 mm in height with an average value of 4·5 mm in the Adyar estuary (Table II). In December when the spat was one month and three weeks old a maximum size of 35 mm and an average size of 18 mm were recorded. In January 2¼ month old spat had a maximum height of 45 mm and an average height of 26 mm. February samples were almost similar to those in January. In March the five month old oysters reached a maximum size of 54 mm and an average size of 30·4 mm and six month old oysters a maximum size of 61 mm and an average size of 36·8 mm. There was very little increase in the maximum height of the spat between May and September but the average height showed an increase during this period. In October when the sand bar at the mouth of estuary opened the oysters put forth fresh shoots and by the end of the month a maximum height of 84 mm and an average height of 50·6 mm were recorded. One year and 4 months old oysters showed a maximum height of 109 mm and an average height of 63·7 mm. The growth rate of the tropical oyster *C. madrasensis* is much faster than that in *Ostrea edulis* of Thames Estuary, which ranges between 5 and 35 mm with an average of 19·6 mm at the end of one year (Orton 1926, 1937). The rate of growth of *C. madrasensis* is about the same as that in *C. virginica* determined by Ingle (1950) and Menzel (1951). *C. virginica* grows to a height of 50 mm in 2 months, 75 mm in 4 or 5 months and 100 mm in 9 months after setting.

TABLE II

The maximum, minimum and mean height and modal values of the populations of oyster spat in samples from the Adyar Estuary during 1953-1955 (after Rao and Nayar, 1956)

Date	Min. Height (mm)	Max. Height (mm)	Mean Height (mm)	Modal Height (mm)
November 1953				
23rd	2·0	7·5	4·5	4·5
30th	1·5	8·5	4·1	4·5
December 1953				
7th	3·1	12·5	7·8	7·5
14th	2·0	25·0	9·3	7·5
21st	6·0	24·2	13·9	10·5
28th	10·0	35·0	18·0	13·5
January 1954				
6th	10·0	32·0	19·6	
27th	8·0	37·0	20·9	22·5
29th	15·0	45·0	26·6	
February 1954				
1st	13·0	28·0	21·8	
15th	17·0	38·0	25·7	22·5
26th	15·0	40·0	26·3	
March 1954				
1st	17·0	50·0	28·8	
8th	20·0	36·0	27·1	28·5
22nd	21·0	48·0	33·4	
29th	27·0	54·0	34·2	
April 1954				
5th	17·0	42·0	29·4	
12th	23·0	57 0	39·2	40·5
19th	18·0	55·0	40·4	
26th	28·0	61·0	39·2	
May 1954				
3rd	22·0	52·0	30·5	
10th	27·0	50·0	38·4	43·5
17th	22·0	56·0	42·7	
25th	30·0	53·0	37·4	
June 1954	24	57·0	36·2	40·5
July 1954	26	61·0	45·4	40·5
August 1954	26	65·0	48·4	49·5
September 1954	27	65·0	46·4	52·5
October 1954	27	84·0	50·6	55·5
November 1954				
1953 Yr. Cl. 15th	25	96·0	55·5	52·5
1954 Yr. Cl. 15th	1·5	6·0	4·2	4·5
1954 Yr. Cl. 22nd	1·5	10·0	5·2	4·5
1954 Yr. Cl. 29th	1·5	22·5	7·6	7·5
December 1954				
1953 Yr. Cl.	31·5	102·0	57·9	52·5
1954 Yr. Cl. 7th	2·5	25·2	12·1	13·5
1954 Yr. Cl. 13th	1·5	33·0	9·6	10·5
1954 Yr. Cl. 20th	4·0	32·0	13·2	10·5
1954 Yr. Cl. 27th	2·5	30·0	14·6	19·5
January 1955				
1953 Yr. Cl.	23·0	107·0	60·5	61·5
1954 Yr. Cl. 3rd	7·0	32·0	15·2	
1954 Yr. Cl. 10th	4·0	31·0	15·1	
1954 Yr. Cl. 17th	8·0	30·0	16·1	13·5
1954 Yr. Cl. 24th	6·0	32·0	16·4	
1954 Yr. Cl. 31st	2·0	33·0	13·8	
February 1955				
1953 Yr. Cl.	32·0	109·0	63·7	No def. Mode
1954 Yr. Cl. 7th	0·5	29·0	12·4	
1954 Yr. Cl. 14th	3·5	41·0	23·1	
1954 Yr. Cl. 21st	8·0	31·0	21·3	22·5
1954 Yr. Cl. 28th	10·0	49·0	24·4	

Distinct zonation has been seen on the shells of oysters collected during or after the opening of the bar in Adyar estuary (Rao and Nayar *loc. cit.*); there is a whitish zone of earlier formation followed by recently formed darkish one. The two zones are separated by an interruption line or ring. The interruption lines are annual and are formed during the period of unfavourable growth when the bar is closed every year.

The growth rate of the oysters is rapid between October and March, moderate during the period April and June and very poor between July and September. Growth is favoured when the estuary is in communication with the sea and it is markedly slackened when the bar is closed. An abundant supply of food organisms is believed to be responsible for the fast growth of the oyster when the bar is open. Fluctuations in pH are not marked in the Adyar estuary and there is no relationship between them and growth of the oyster.

About 23% of the oysters of Adyar estuary reach marketable size, 70 mm and above when 16 months old. A majority of the oysters attain marketable size only in the third year of their life.

Food

Moses (1928) has stated that diatoms are the main food of the oysters. He has mentioned that half the amount of the contents in stomachs of the oysters consists of unrecognizable plant detritus and the diatoms *Biddulphia, Rhizosolenia, Chaetoceros, Coscinodiscus, Pleurosigma* and *Navicula-Ceratium*, Foraminifers, Peridinians, *Dinophysis*, sponge spicules, setae of polychaete larvae and Daphnids have been observed in the stomachs of oysters.

The diatoms *Coscinodiscus excentricus, Rhizosolenia cylindrus, Chaetoceros indicus, Bacillaria paradoxa, Biddulphia sinensis, Nitzschia seriata, Pleurosigma angulatum* and *Guinardia flaccida* were recorded in the stomachs of oysters of Ennur by Jacob and Nelliyander as reported by Devanesan and Chacko (1955) and it was assumed that the oysters feed on the diatoms. *Nitzschia, Pleurosigma* and *Navicula* were noticed in large numbers in the months of December, January and February. Our present knowledge about the diet of oysters is imperfect and the subject requires intensive study.

Parasites, Pests and Predators

The Polychaete *Polydora ciliata* and *Polydora armata* (identified by G. P. K. Achari) have been recorded on the oysters of Athankarai estuary. *P. ciliata* which is more common causes severe damage to the shells by making extensive tubular burrows. The oysters attacked by the worms are weak and the meats of the oysters are very poor in quality and watery which could be attributed to the

oysters utilizing more than usual energy for secretion of shell. Korringa (1952) states that by bathing oysters parasitized by *Polydora* for 16 hours in fresh water or for 3 hours in ½% solution in sea water of the ammonium salt of dinitro-ortho-cresol the worms could be killed and the oysters soon exhibit better growth.

Deposition of silt and mud causes mortality of oysters. The algae *Polysiphonia* sp., *Enteromorpha* sp. and Myxophyceae occur as epi-flora of oysters. *Polysiphonia* forms a thick layer on the oysters in the upper portion of Athankarai estuary. Mussels of the genus *Modiolus* are found in large numbers on oysters at Pulicat, Ennur and Athankarai. The barnacle *Balanus amphitrite* is moderately common on oysters at Athankarai. The drill *Thais rudolphi* has been seen boring into young oysters near the mouth of the Athankarai estuary on a few occasions.

The crabs *Scylla serrata* and *Thalamita crenata* feed on the oysters and are predators. Fortunately the well-known enemies of oysters such as starfishes and limpets are rare on oyster beds of Indian coasts.

Quality of meat and percentage edibility

The percentage edibility (weight of meat of oyster expressed as a percentage of total weight of the oyster) has been reported by Venkataraman and Chari (1951) to be low in July and fairly high in October with corresponding variations in fat content. The low levels in July have been attributed to growth of the oysters and maturation of gonads and increase in October to intensive feeding prior to spawning. Rao (1956) found two periods in the year when the meat weights and percentage edibility were high, May – June and September–October and a fall was noticed in the values in periods succeeding them following spawning. The average percentage edibility of oysters of Athankarai estuary was observed to be high in the months January-February, April and November-December (Table III).

Chemical composition

Venkataraman and Chari (*loc. cit.*) have studied the seasonal quantitative changes in water, fat, protein, glycogen, ash, phosphorus, calcium, iron, and copper contents of oysters of Ennur (Table IV). The oysters were found to accumulate fat during the period August-November and a maximum of 2.71% wet wt. was recorded in November. The fat content decreased to 1.5% in January after spawning. The protein content varied between 5.72% and 13.31% and glycogen between 0.44% and 5.85%. The data did not reveal well defined changes in glycogen content in relation to gonadal condition in contrast to the findings of Okazaki and Kobayashi (1928) and Masumoto *et al.* (1934) in Japanese oysters. The water content of oysters ranged between 76.67% and 85.04% and showed an inverse relation to fat content. Kasinathan (1964) observed that the saponification value of male oysters is higher than that of

females and the iodine number of fat of the females is higher than that of males.

TABLE III

Average meat weight and percentage edibility of *Crassostrea madrasensis* of Athankarai Estuary in successive months in the period August, 1969-December, 1970.

Months	Average meat weight of oysters (gm)	Average percentage edibility of oysters
August, 1969	6·12	4·60
September	5·67	4·95
October	7·10	5·31
November	7·74	5·49
December	...	...
January, 1970	10·82	7·13
February	8·33	6·55
March	7·33	4·92
April	8·86	6·86
May	8·10	5·31
June	8·73	4·97
July	6·46	3·10
August	8·57	4·40
September	9·03	4·30
October	8·01	4·42
November	10·27	5·95
December	8·93	5·01

FISHERY

The oysters are fished at Pulicat, Ennur, Madras, Kanchanagudi (near Mandapam) and on Kerala coast. The oysters are gathered by separating them from the rocky substratum or dead oysters to which they adhere, using stones in the vicinity or a hammer. The oysters are fished by men and women of fishermen community. The oysters from Pulicat, Ennur and Cochin are supplied mostly to a few modern hotels in Madras and Cochin. The general public do not know of the nutritious nature of oysters and only some persons who frequent western style hotels and very poor people usually fisherfolk eat oysters. On the south-west coast oysters are fished usually for the massive shells which are

TABLE IV

Seasonal changes in chemical composition of *Crassostrea madrasensis* of Ennur backwaters (after Venkataraman and Chari, 1951)

Months	Edibility %	Water %	Protein %	Fat %	Ash %	Glycogen %	P_2O_5 %	CaO %	Iron mg %	Copper mg %
October, 1949	...	85·04	6·93	2·22	1·29	...	0·307	0·315	5·32	...
November	10·67	77·49	8·07	2·71	2·02	...	0·364	0·555	...	2·14
December	8·22	81·19	13·31	1·79	2·00	1·12	0·388	0·170	11·70	2·56
January, 1950	8·36	82·71	10·13	1.54	1·80	0·46	0·389	0·261	13.00	3·27
February	9·23	82·87	11·07	1·95	1·01	0·44	0·419	0·121	12·92	3·12
March	9·22	80·11	10·81	1·74	1·50	1·62	0·385	0·377	10·21	2·79
April	5·93	79·23	10·80	1·90	2·06	1·52	0·440	...	2·53	7·69
May	8·92	79·54	8·18	1·69	1·48	...	0·305	0·076	8·72	3·17
June	5·48	79·77	10·62	1·69	1·61	2·77	0·331	0·154	11·63	3·95
July	6·99	76·67	9·88	1·49	1·75	5·63	0·328	0·060	12.21	2·96
August	10·92	78·57	10·30	2·40	1·51	3·02	0·472	0·088	6·83	2·78
September	10·37	78·63	9·65	2·23	1·11	3·12	0·229	0·072	10·85	1·45

used to strengthen banks of backwaters. Oysters have been removed indiscriminately from natural beds at Pulicat, Ennur, Tellicherry, Beypore and Vembanad in the past but still there are large beds which should be protected by the government by prohibiting capture of young oysters, fixing a closed season and regulating the extent of fishing.

Oyster Culture

It is necessary to practise oyster culture as continuous fishing of oysters from natural beds will lead to destruction of stocks. As pointed out by Hornell (1910b) after visiting the famous Arcachon oyster farm near Bordeaux in southern France, oyster culture could be done on the east coast adopting the methods employed in Arcachon with such modifications as local conditions and economy make necessary. To mention briefly, in Arcachon the oyster spat are collected on tiles lined by a mixture of lime and sand in the season when spatfall takes place, the spat are removed from the tiles after a period of growth in January and then reared in cases kept in protected backwaters known as "oyster parks." Great care is taken of the growing oysters with periodical cleaning and removal of epiflora, epifauna, slime and mud that are injurious to the well-being and healthy growth of the oysters; predators like crabs and fishes are prevented from entering the parks by construction of a palisade of poles around the parks. Predators which may enter through crevices in between poles of the palisade are caught. In Japan the oysters *Crassostrea gigas* and *C. rivularis* are cultured on a large scale. Spat are collected on bamboo poles, tree branches, tiles, shells or stones, the young oysters are removed after some months and grown in bunches attached to wire or ropes hanging from a large number of racks, rafts or long lines the latter two being held in position using floats and anchors. There is also an important industry of seed oyster production in Japan. For producing seed oysters the spat are collected as in the case of culture of adult oysters, allowed to grow till some time when ropes holding clusters of young oysters are placed on high grids where they are exposed for several hours daily at ebb tides. The strongest oysters only survive this treatment which lasts till several months. Those that survive develop a gasket like seal which enables them to retain some sea water during periods of exposure and these seed oysters are shipped to other places in Japan for culture. The seed oysters are largely exported across the Pacific to America (Cahn, 1950).

Crassostrea gryphoides (Schlotheim)

Synonyms

Ostrea gryphoides Newton and Smith 1912
Ostrea gryphoides Awati and Rai 1931
Crassostrea gryphoides Durve and Bal 1961

This species shows resemblance to *C. madrasensis* and is distinguished from the latter in the shell being broad, roundish and more bulky; there is a prominent central groove with elevations in the sides on the hinge of the left valve, the adductor muscle scar is oblong and pearly white and the entire inner surface of valves is white and glossy.

DESCRIPTION

Shell oblong, narrow in the anterior margin and broader in the posterior margin, laminated, lower valve very thick, especially in the anterior region below the ligamental area, ligamental area drawn out to a considerable distance, broad and has a deep groove in the middle; it generally curves to the left and in some to the right, transverse and longitudinal striations in groove area; upper valve thin, flat and opercular; no denticles on the margin; interior of valves white and glossy; muscle scar more or less heart-shaped and pearly white (Fig. 2 A).

DISTRIBUTION IN INDIA AND PAKISTAN

From Cutch to Karwar coast and on Cuttack coast. The species is represented also in Karachi harbour and Sind coast (Pakistan).

HABITAT

This species occurs in estuaries and backwaters. It is found in the low tide zone. Sometimes it occurs at depths of 5 to 7 metres. The species is represented in almost every estuary and backwater of the Maharashtra coast.

MATURATION OF GONADS

In *C. gryphoides* of Kelwa near Bombay gametogenetic activity commences in late April or May (Durve, 1965). In the beginning of June the oysters show active gametogenesis and rapid growth of follicles. Spermatids and spermatozoa are found in large numbers in males and mature ova in females. Towards the end of June almost all oysters are mature but stray numbers of oysters in resting phases are also present. Spawning takes place in the monsoon period between July and September. In the post-monsoon period October to mid-November the gonads are in indeterminate phase with the follicles shrunken and containing phagocytic cells. In the winter (November to February) the gonadal follicles

Fig. 2. A. *Crassostrea gryphoides* (Schotheim). B. *Crassostrea cucullata* (Born). C and D Internal view of right and left valves of *C. cucullata*. E. Anatomy of *C. cucullata* (after Awati and Bal, 1931). ad., adductor muscle; an., anus; c. aff. v., common afferent vessel; ex. ch., exhalent chamber; g.. gonad; g. d., gonidial ductules; gl., gills; go. d., gonidial duct; labial palps; mt., mantle; r. d., renal duct; u. g. g., urinogenital groove; v.m., visceral mass. F. *Crassostrea discoidea* (Gould).

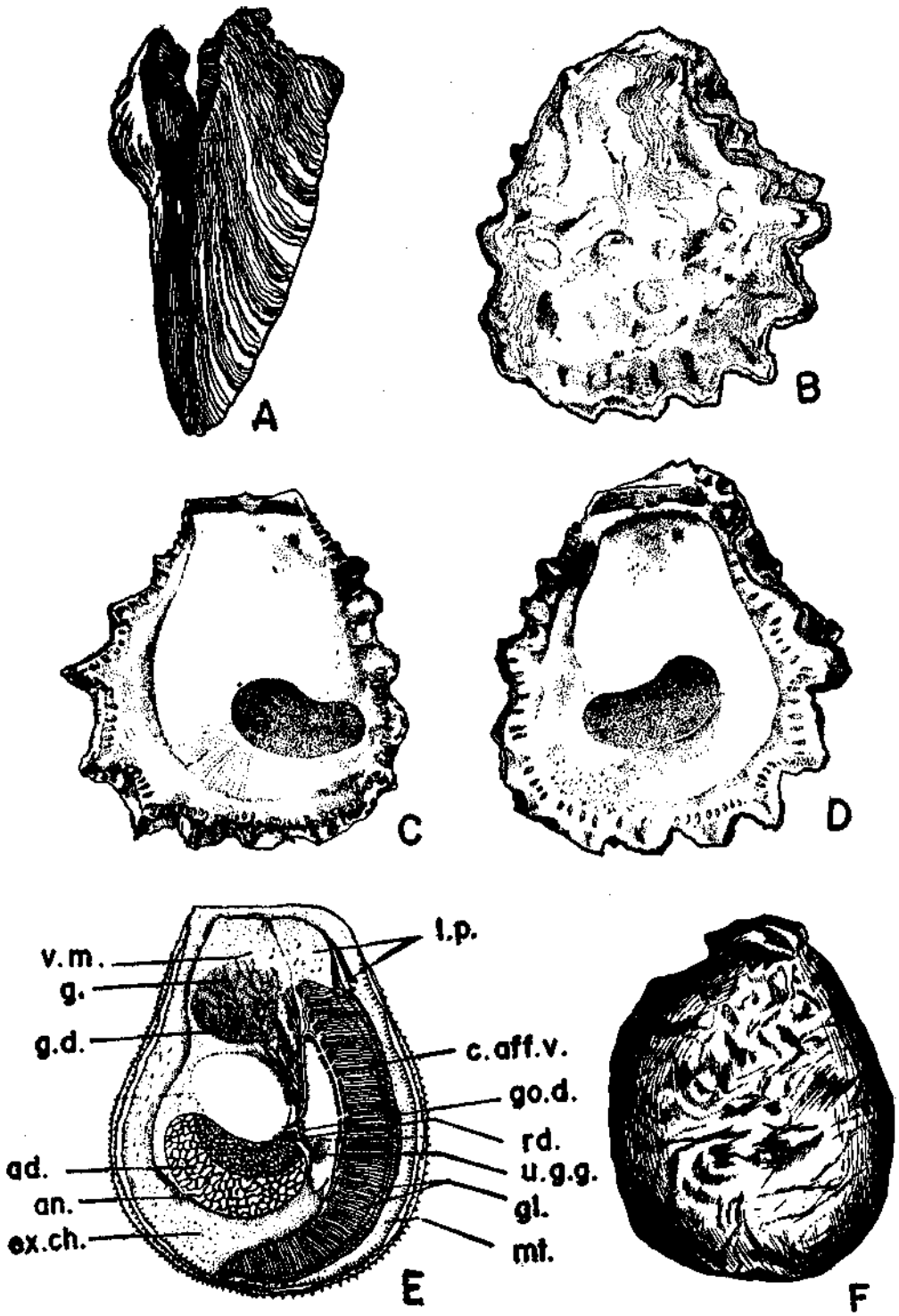

Fig. 2

are in the resting phase and sexes cannot be distinguished. The gonads are in this condition till April.

Sex Ratio

Alternate predominance of males and females has been recorded between April and June in Kelwa waters (Durve, *loc. cit.*). Females form the dominant sex till August when there is a marked fall in salinity and temperature. Males are dominant in September and October when there is a rise in the salinity. The variations in the sex ratio do not show any correlation with salinity and temperature.

Spawning

Spawning takes place in Kelwa waters between July and September (Durve, *loc. cit.*). As observed in *C. madrasensis* of the east coast by Hornell (1910a) and Rao (1956) it is stated that a fall in salinity following monsoon rains is the main stimulant to spawning in *C. gryphoides* also. An optimum range of salinity 13·15 – 28‰ favours spawning. Spawning continues till the end of July and early August when very low salinities (3·42 – 6·98‰) prevail. Males exhibit closer correlation with lower salinity than females in regard to spawning activity. Spawning was over in females earlier than males which continued to spawn in October and early part of November when there was a well-defined rise in salinity.

Water temperature varied between 19·4° C in February and 33·4° C in May, 31° C in July and 27·4° C in September and was 31·8° C in October. Durve (*loc. cit.*) considers that the above changes in water temperature do not have any role in spawning activity.

Growth

Spatfall begins in Kelwa backwaters in July and extends till September (Durve and Bal, 1962). The average height of spat at the end of July, August and Septemper, 1957 were 2·5 mm, 4·2 mm and 7·8 mm with a monthly increase of 2·5, 1·7 and 3·6 mm respectively. The rate of growth during the above three months is slow compared to that in the succeeding period October-February, 1958. In the months March, April and May growth rate was retarded being 1·0, 1·0 and 1·5 mm respectively. Between June and August there is no increase either in the modal or mean values of the height of spat.

The rate of growth of spat of *C. gryphoides* is slower as compared to that in *C. madrasensis*. The spat of the former species exhibit a maximum growth of 37·2 mm and an average growth of 21·3 mm in height in six months. The corresponding figures for *C. madrasensis* are 60 mm and 40 mm respectively. At the end of one year *C. gryphoides* attains a maximum size of 47·9 mm and an average size

of 33·8 mm compared to sizes of 84 mm and 51 mm recorded by Rao and Nayar (1956) in *C. madrasensis*. Durve (1962) states that a large percentage of adult *C. gryphoides* put on fresh marginal shoots during the period September to March and considers that during this period growth is vigorous. After March the shell shoots begin to become dark and opaque. *C. gryphoides* grows to a height of 15 to 17 cm. On the Sind coast the species attains a large size of 30 to 38 cm.

Durve (*loc. cit.*) opines that water temperature in Kelwa which varies between 25·7 and 33·4° C (Durve and Bal, 1960) may not influence growth in *C. gryphoides*. He finds correlation between salinity values and intensity of growth. Rate of growth is rapid in the post-monsoon period and winter, October to February when the salinity is moderate, it is retarded in the period of constant high salinity (March – May) and there is almost no growth in the period July – August. Durve's observations are similar to those of Rao and Nayar (1956) stating that very high salinity conditions bring about a retardation in growth rate of *C. madrasensis* and also constantly low salinities bring about a marked decline in growth under tropical conditions.

Food

Diatoms belonging to as many as twenty genera and detritus have been recorded in the stomachs of oysters of Bombay coast (Durve, 1964b) and have been considered to be food of the oysters. *Coscinodiscus, Thalassiosira, Biddulphia, Cocconeis, Achnanthes, Diploneis* and *Synedra* were the dominant diatoms found in the stomachs. Detritus was present in the stomachs throughout the year. Diatoms were absent in stomachs between June and August when detritus also was low. Feeding activity as determined by stomach contents increased from October immediately after spawning and was as its peak from December to February. Protozoa and metazoa were not recorded except for a nauplius and some pieces of bodies of crustaceans.

Quality of meat and percentage edibility

C. gryphoides of Kelwa are fatty and cream-coloured from late October or November to June and the quality is low in the spawning period, July to September due to discharge of reproductive products (Durve, 1964a). The percentage edibility and condition index of *C. gryphoides* showed similar pattern of seasonal changes corresponding to gonadal condition of oysters. The values for the two measures are high in the period January to June and show a steep fall in July – September during the spawning period. From October as the oysters begin to recover after breeding season both the percentage edibility and index of condition rise and are high from December till July. Durve states that the fall in percentage edibility of females in the spawning season is much more rapid than in males.

Durve (*loc. cit.*) calculated the coefficient of correlation between depth of oyster and index of condition and observed that differences in depth did not affect the index of condition but the latter was found to vary with the height of the oyster. The meat volume bears a relationship to cavity volume but this is said to vary in different months.

Chemical composition

The seasonal changes in the content of water, fat, protein, glycogen, calcium and phosphorus and calorific values of the oysters have been studied by Durve and Bal (1961). The water content was found to increase during the spawning season and it has been attributed to change in the physiological state, the nutritional conditions and salinity. Water content of the oysters shows a reciprocal relationship to the content of fat, glycogen and protein. The maturing and mature oysters accumulate fat, glycogen and protein and the percentages fall in the spawning season in July–September. There is re-accumulation of the organic constitutuents from October. The fat content of the oysters varied between 0·48 and 3·20% wet wt., glycogen content between 0·69 and 7·01% and protein content between 2·79% and 9·89%. The calcium and phosphorus values are higher in the spawning period when there is a fall in the weight of the meat and organic constituents. The calorific value of the oysters is high throughout the year with the exception of the period July – October when there is a fall due to loss of fat, glycogen and protein.

Parasites

Pinnotheres sp. has been observed to infest *C. gryphoides* (Durve, 1965) but the incidence of the parasitic crab is very low. Only five out of several hundreds of oysters examined were parasitized by the crab. The oysters infested were male, female or sexually indeterminate and none of them were hermaphrodite. So it has not been possible to find out if the presence of the crab causes sex change as suggested in *C. cucullata* by Awati and Rai (1931). The parasitized oysters are of poor quality and this is attributed to interference with the normal food supply of the oysters.

Fishery

This species is fished from large natural beds that exist in backwaters, creeks and similar habitats from north Kanara to Kutch. An axe like instrument called 'koodal' is used to remove the oysters (Rai, 1932). The important fishing centres for this species are Malad, Boisar, Satpati creeks, Palghar, Sanjam Kalve, Dahisar and Navapur on Bombay coast and Alibag, Ratnagiri, Jaytapur, Malwan, Vengurla, Goa, Karwar, Gangawali Tadri and Honavar south of Bombay. Thousands of oysters of this species and *C. cucullata* are collected and sold to hotels, clubs and private individuals in Bombay and other places.

Young oysters are dislodged from natural beds near Bombay and planted on hard ground by a few fishermen. The oysters are allowed to grow upto marketable size and then sold. The species is suitable for culturing.

CRASSOSTREA CUCULLATA (Born)

SYNONYMS

Ostrea forskalii Chemnitz 1785
Ostrea cucullata Born 1890
Ostrea cucullata Hornell 1922 b
Ostrea cucullata Awati and Rai 1931
Ostrea forskalii Gravely 1941
Ostrea forskalii Satyamurthi 1956
Crassostrea cucullata Rao 1958

The Australian oyster *Ostrea (Crassostrea) commercialis* is considered as a synonym of *O. (C.) cucullata* but Iredale and Roughley (1933) hold the view that it is a distinct species. The salient characteristics of the Australian oyster are the left valve is rather deep, the right valve is nearly flat, both valves radially crumpled (plaited), colouration is bluish externally, whitish internally, hinge is of moderate size and hinge line short.

DESCRIPTION

Shell more or less trigonal, sometimes oblong, extremely hard and plaited, plaits more or less angular, generally small, lower valve thick, overlapping at margin, hooded under the margin, hinge elongated frequently produced at the apex; upper valve flat or slightly convex in the middle, plaited towards the margin, greater portion of the margins of both upper and lower valves denticulated; muscle scar oblong and striated (Figs. 2 B, C and D).

The morphology of this species has been studied by Awati and Rai (1931). The general structure of the body (Fig. 2 E) is similar to that of *C. madrasensis*.

DISTRIBUTION IN INDIA

All along the east and west coasts of India.

HABITAT

The oysters occur firmly attached to sandstone, granite boulders or coralstones in the intertidal region in brackish waters and mouths of estuaries. They are also found on the rocks of open coasts. This species is primarily an inhabitant of the midlittoral zone where it occurs in large numbers but the oysters are found in the supralittoral fringe also due to the availability of suitable substratum. They are

very hardy animals since they survive in spite of the very high temperatures to which they are subjected to in the day-time on the rocks on which they live.

Reproduction

We do not have precise information about the period at which gametogenesis takes place in this species during the course of the year. From the settlement of spat on cultch kept on Bombay coast Awati and Rai (1931) concluded that the species spawns almost throughout the year with the exception of the monsoon period, middle of June to the end of September. Spawning commences in October when the density of seawater is 1·021. Spawning activity is not intensive in the winter due to low salinity of the sea water. The main spawning season is from March to June and there is a slack spawning season from October to February when spatfall is restricted and irregular. A striking feature about reproduction in this species is that it does not breed during the monsoon period when the other species *C. gryphoides* and *C. madrasensis* spawn. Awati and Rai *(loc. cit.)* have suggested that salinity and temperature may be influenceing spawning in this species. The higher levels of salinity and temperature appear to favour spawning and spatfall in this oyster.

In the Australian oyster *O. (C.) commercialis* also spawning occurs in several months of the year (Roughley, 1933). The oysters rapidly mature during the spring season and there is spawning in December and January. Spawning has also been observed again in summer months. In addition spatfall was recorded in November also.

Sex change

Awati and Rai (1931) have recorded that a great majority of the oysters parasitized by the crab *Pinnotheres* sp. are either males or hermaphrodites and the numbers of females is very small. From this the authors have inferred that the crab usually of female sex which lies attached to the gills in the inhalent chamber may be responsible for sex change in the oyster by reducing the food supply of the oyster or by inducing a change in the metabolism.

Hermaphroditism

Hermaphrodites have been stated (Awati and Rai *loc. cit.*) to occur chiefly in the monsoon season and at other times hermaphrodites have been rare. Hermaphroditism has been attributed to deficient food supply and unhealthy condition in the monsoon period.

Sex ratio

Out of 794 oysters examined by Awati and Rai *(loc. cit.)*, 41·7% were found to be males, 56·4% females and 2·9% hermaphrodites. Information is not available about the proportion of the sexes in different months of the year.

As already mentioned the crab *Pinnotheres* has been found to infest the rock oyster. The majority of the oysters which are infested are males (82%) and the incidence of the crab is very low in the case of female and hermaphrodite oysters (10% and 6% respectively). *Pinnotheres* infesting the oysters have been found to belong to female sex. Sea-weeds, hydroids, barnacles and other sessile forms grow on the shells and either make shell weak or clog the paths of water currents.

Fertilization

Artificial fertilization has been successfully accomplished in the rock oyster by Awati and Rai (1931) who have also studied early development. Fertilization was effected in a mixture of 3 parts of sea water and one part fresh water. When spermatozoa and ripe eggs are put in the water spermatozoa cluster around eggs and finally one spermatozoan fertilizes the egg.

Development

The first polar body is budded off 35–40 minutes after mixing sperms and eggs and the second polar body after another five minutes. First segmentation division takes place after another five or ten minutes resulting in a micromere and a bigger macromere. The micromere divides repeatedly and forms an outer layer enclosing a macromere. After sometime the macromere also divides and the resulting cells constitute the lining of the embryonic gut. The micromeres become ciliated and surround the macromeres except at the point where the blastopore is situated. Gastrulation takes place through epiboly as well as invagination. The larva assumes a disc-like flattened form. Then a depression appears on the surface, which grows deeper progressively and this becomes the digestive cavity. The larva becomes almost spherical and swims rapidly by means of cilia. Later, the larva develops a pre-oral circlet of long cilia at the pre-stomial region. The larva is trochophore larva. The mouth of the larva lying below the pre-oral circlet of cilia leads into the oesophagus which is followed by the stomach, a short gut and rectum which opens through the anus. The larva swims very swiftly near the surface of water.

Quality of oyster meat

The meat of *C. cucullata* of Bombay coast is in the best condition between April and June (Awati and Rai, 1931).

Fishery

The fishermen collect the oysters using a hand-dredge consisting of a net attached to a triangular frame made of bamboo with a handle, a spade, a pick-axe and a knife with large blades. The oysters are sold either as they are or after

shucking. The shucked meats are put in sea water until they are sold in the markets. This species has a delicate flavour and is esteemed (Rai, 1932). Thousands of oysters are fished and supplied to hotels and clubs in Bombay and mofussil towns.

This species also is not cultured in India but for collection of young oysters by some fishermen of Bombay coast who grow them on hard ground in the lower part of the intertical zone and sell them when they attain a size of about 85 mm in height.

CRASSOSTREA DISCOIDEA (Gould)

SYNONYMS

Ostrea discoidea Awati and Rai 1931
Crassostrea discoidea Rao 1958

DESCRIPTION

Shell large, flat, rounded, foliaceous with conspicuous lines of growth, lower valve sligtly concave, ligamental area small, upper valve of the same size and shape as the lower and slightly convex, inner surface of valves clear and nacreous, no denticulations present, muscle scar oblong and cloudy white or smoky white in colour (Fig. 2 F).

DISTRIBUTION IN INDIAN REGION

North Kanara to Kutch. The species is represented at Dwarka, Bombay (Mahim), Ratnagiri and Jaytapur. It is also found in Karachi and Sind creeks (Rai, 1932)

This species occurs attached to rocks in deep waters of the littoral zone. The oysters grow to a size of about 15 cm in height and are fairly abundant at Dwarka, Bombay and Jaytapore. We do not have information on the biology of this species.

CRASSOSTREA CRISTA-GALLI (Linnaeus)

SYNONYMS

Mytilus crista-galli Linnaeus 1758
Ostrea cristagalli Lamarck 1819
Ostrea (Lopha) cristagalli Standen and Leicester 1906
Ostrea cristagalli Hornell 1922b
Ostrea crista-galli Prashad 1932
Ostrea cristagalli Satyamurthi 1956

DESCRIPTION

Shell broadly rounded or subquadrate in shape, margins of valves thrown into very deep, sharp angular plaits, the teeth-like processes of the two valves interlocking with each other. Outer surface of folds have diverging close set granulated striae. Colour of shell varies from brownish to violet. Internal surface of valves greyish white.

DISTRIBUTION IN INDIA

Tanjore coast, Palk Bay, Gulf of Mannar, Okha.

This species is known as cock's comb oyster due to its shape that resembles cock's comb. Generally solitary specimens are found cemented to stones or coral stones in small numbers. In Pishotra in Okha district oyster beds of this species exist but they are not commercially important as the oysters are of small size and have irregular growth.

CRASSOSTREA(?) FOLIUM (Gemlin)

SYNONYMS

Ostrea folium Chemnitz 1781
Ostrea folium Gmelin 1791
Ostrea folium Reeve 1873
Ostrea folium Satyamurthi 1956
Ostrea folium Kundu 1965

DESCRIPTION

Shell broadly ovate in outline, left valve deeply concavely excavated along the middle to fit surface of attachment. The right valve is raised into a characteristic broadly rounded tube-like, longitudinal rib along the middle corresponding to the excavation of the left valve. On either side of this medial, rib-like elevation the shell is thrown into numerous rounded folds which diverge away from the middle line. The surface is more or less smooth except for a few thin, overlapping laminae towards the margin. The shell is of a pale brownish purple colour.

DISTRIBUTION IN INDIAN REGION

This species is a rare one found in stray numbers in Pamban and Gulf of Kutch. Sometimes it occurs attached to twigs on the coast.

From the collections made in the Indian region Awati and Rai (1931) have described four more species of oysters viz., *Ostrea cornucopia* Chemnitz, *Ostrea glomerata* Gould, *Ostrea belcheri* Sowerby and *Ostrea quercina* Sowerby. They

mention that yet another three species *O. crenulifera* Sowerby (synonymous with *O. plicata* Chemnitz), *O. bicolor* Hanley and *O. lacerata* Hanley have been reported in Memoirs and Proceedings of Manchester Literary and Philosophical Society, Vol. 7, 4th Series. The descriptions of the four species of oysters given by Awati and Rai (*loc. cit.*) are given below. It is doubtful whether they are referable to the genus *Crassostrea*.

CRASSOSTREA(?) CORNUCOPIA (Chemnitz)

Shell more or less oblong, solid, with lines of growth, transverse striations well-marked, longitudinal fine striations present, plaited, plaits deep and rounded; lower valve larger than the upper with a tendency to grow upwards, with a deep cavity, the latter extending under the hinge margin; ligamental area highly developed, drawn out to a very considerable distance, tapering, with a distinct groove; upper valve flat, opercular in form; no denticulations present; muscle scar more or less oblong.

This species is said to have a superficial resemblance to *O. (C.) cucullata.*

DISTRIBUTION IN INDIA

It is generally found among clusters of *C. cucullata.* The species has been recorded from rocks around Marmagoa.

CRASSOSTREA(?) GLOMERATA (Gould)

Shell irregular, small, seldom exceeding two inches in length; lower valve extensively applied to rocks, with a deep cavity extending under the hinge line, growing upwards, plaited, plaits radially arranged and deep; margins of the lower valve with characteristic spout-like processes; upper valve small and flat; no denticulations; muscle scar generally dark purple.

Reeve (1878) states that it is difficult to distinguish this species from *cucullata* if indeed they be not identical.

DISTRIBUTION IN INDIAN REGION

Found on rocks around Karachi.

CRASSOSTREA(?) BELCHERI (Sowerby)

DESCRIPTION

"Shell very large, compressed, spatulate, rather thick, elognated, foliaceous, with large purplish green scales, lower valve flat; upper convex; hinge broad, ventral margin expanded." -Reeve (1878); after Awati and Rai (*loc. cit.*).

CRASSOSTREA (?) QUERCINA (Sowerby)

Shell small, with undulations, dirty purple in colour, with lines of growth; lower valve flat, thin; upper valve same as the lower but slightly concave; inner surface polished, with big patches of green colour; margins purple or brown; small denticles on the margin near the hinge area; muscle scar circular, large and conspicuous, centrally placed, of a green colour.

DISTRIBUTION IN INDIAN REGION

Found attached to shells of other oysters near about Karachi.

UTILIZATION

Oysters are utilized only to a limited extent in India. In our country the oysters are cooked in ghee or vegetable oil after mixing salt and condiments. Only in some places on the west coast people know about the nutritious shellfish and eat them. But for this, only poor people usually fishermen consume them. The massive shells of the oysters are collected in large quantities and sold to lime kiln owners who convert them into lime which is a valuable commercial product being used for whitewashing. In western countries where the oysters are greatly relished, oysters are eaten raw and in a variety of forms like oyster stew, smoked oysters, oyster meat canned in salad oil, oyster meat boiled in wine, breaded oysters etc.

OYSTER PRODUCTION

Statistics are not available about the quantity of oysters harvested in India. The total quantity may be small. Oysters have always been an important food resource for the world population (Shaw, 1969). The total world production of oysters was 639,000 tonnes in 1958 (F.A.O., 1969a) and there had been an increase in the annual production in recent years. The average annual production in the period 1964–69 was 793,000 tonnes and production in 1969 was 760,000 tonnes. The world's leading oyster producer is United States of America (production 355,400 tonnes in 1968) followed by Japan (245,500 tonnes), France (39,500 tonnes), Korea (33,200 tonnes), Mexico (42,400 tonnes) and China (Taiwan) (11,700 tonnes). Other important oyster harvesting countries are Australia (7,500 tonnes), Canada (5,500 tonnes) and United Kingdom (200 tonnes). There is a good potential for increasing oyster production of India by culturing the different species that abound our coasts.