Mussel farming and hatchery

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Introduction

The world mussel production (FAO data) during 2010 was 1.81 million tons valued at 1.572 billion US dollars. The world production of Perna viridis during 2011 was 1,21,322 tons valued at 44.95 million US dollars. The total aquaculture production of green mussels in India (2008) was about 17,000 tons. The farming practice of bivalve molluscs is either on bottom or off bottom culture methods. The bottom culture system is also called the broadcast technique. For the off-bottom culture system, this includes the stake or pole method, rack, raft and long-line method. The rack, raft and long-line method are also called the hanging or suspended culture technique. The stake and rack method are mainly used in shallow, intertidal waters while the raft and long-line methods are generally utilized in deeper, open waters. The culture method followed in the different parts of the world is described.

Many culture techniques are used for growing mussels worldwide and the most popular are described below:

1. Bouchot or Intertidal Pole Culture

In France, mussel culture is believed to have started in 1235, when an Irish sailor Patrick Walton survived a shipwreck on the Bay of Aiguillon. He found that the wooden poles and nets that he had kept for trapping birds attracted mussel spat settlement. This became the basis for Bouchot method which is the oldest and the main method utilised in France on the Atlantic and English Channel coasts. This method, well suited to the large intertidal mud flats facilitated the development of the blue mussel (Mytilus edulis) industry in France (Gosling, 2007). The Bouchot method extended to other suitable intertidal areas along the Brittany and Normandy coast. The spats are collected on spat collecting ropes made of coir. These spat bouchots are situated offshore and consists of parallel rows of poles with horizontal coir ropes for collecting seeds. When the seed are a few months old, they are removed from the ropes, placed in mesh tubes and transferred to bouchots for growth.

Mussel seeds are harvested from August – December depending on the size and density of settlement. The seeds are scraped from the poles using a steel blade attached to a metal wire to hold the scrapped off mussel. In this method, ropes with spat attached are wound around large vertical poles (bouchots) in the intertidal zone. The line of poles mainly oak tree trunks 4-7 m long, 12-25 cm diameter at the wider end and about 7cm at the opposite end. The lower 3 meter of the pole is inserted in the seabed. Mesh netting is used to cover the mussels to prevent them being detached and lost. A barrier is placed at the bottom of the pole to prevent predators such as crabs from reaching the mussels. Bouchot are placed perpendicular to the shoreline and consists of 125 poles running for 50-60m and spaced 15-25m from the next line. This method of culture requires large tidal ranges, in order to supply the densely packed mussels with plankton.

Marketable mussels of 4-5cm shell length are harvested when they are 12-18months old. On an average, 25 kg of mussels are harvested from each pole annually. The entire produce is sold domestically. 4000 poles can produce 100 tonnes of mussel per year.

2. Stake culture

In Thailand and Philippines, mussels are grown on bamboo poles (6-8m long) staked at half meter depth and one meter apart or in circle and tied at the top to form a wigwam structure in soft, muddy bottoms. Mussels (Perna viridis) settle on the submerged bamboo stakes. Bamboo poles are often observed to monitor growth as to eliminate predators like starfish and crabs. Bamboo stakes are placed in areas where natural spatfall is expected. Mussels are harvested after a growing period of 6–10 months after stocking or when the animals reach 5–6 cm in length. Each pole yields 8-12 kg of mussel. Harvesting is done by hauling up the bamboo poles and loading them into a raft. Divers are employed to pick out the larger mussels and the small ones left for the next harvest season. This selective harvesting results in two or more yields within the 6–8 months of the farming period. Harvested mussels are cleaned and then placed in baskets and shaken vigorously in seawater until they are clean of barnacles and dirt. Bamboo poles that are worn out are removed while the good ones are cleaned for the next culture season. The stake method is an economical and easy way of growing mussels but has also some shortcomings. The bamboos decay easily and it is at times difficult to match staking operations with spatfall. This culture system also facilitates siltation which makes bays and estuaries too shallow for mussel farming. In Philippines a rope strung in a zigzag fashion or rope web method is used. Each unit consists of two bamboo poles 5 meters apart are driven into the substratum. Two polypropylene rope, 2 meter apart are tied to the bamboo poles.40 m rope of 10-12 mm diameter is used to connect in a zigzag manner. Pegs are inserted at 40 cm intervals (Joseph, 1998).

3. On-bottom culture

This method is widely used in Netherlands, Denmark and Germany. The culture is based on the principle of transferring seeds from areas of great abundance where growth is poor to culture plots in lower density to obtain better growth and fattening of the mussel. The culture plots must have a firm substratum and less of drifting sand and silt particles. In Netherlands, the seeds are dredged from Waddenzee. The seeds are laid in intertidal areas to produce mussels with thick shells and strong adductor muscle. In the subtidal areas higher meat yield and thinner shells are produced fit for processing industry. The whole process is highly mechanized from collection of seeds to harvesting and marketing. Waddenzee and Zeeland are the important areas for mussel (M. edulis) farming. In Zeeland, the town of Yerseke is the important mussel trading area. Waddenzee in the northern part of Netherland was used as a source of seed. Since 1950, farming plots were also created here. The seeds which are which are fished from the seed beds during the short well defined period are scattered evenly on the beds allotted by the government to mussel farmers. The seeds are gathered by special mussel boats. About 10 tonnes of mussel seed can be gathered in one hour of dredging operation. The seeds gathered are replanted the same day over the plot measuring 500 x 200 meters. 20 to 35 tonnes of seed are used per hectare for relaying depending upon the size of mussel seed. The mussels are distributed evenly by the farmers if the stocking is found crowded. The starfish problem is managed by salt treatment or removal using starfish nets. The filtering activity of the mussels produces silt which gets deposited under the mussel carpet. This hinders the growth of mussels. Chain harrow are used to level the ground. In the Waddenzee, the mussels are usually kept in the same area but in Zeeland the half grown mussels are relocated to deeper areas where conditions for fattening and growth are better. Waddenzee mussel being slightly larger are suitable for half shell trade and Zeeland mussels are preferred as raw material for canning factories fetching higher price. The mussels are marketable in the Dutch mussel farming areas when they are 2-3 years old. The production by on bottom culture is about 8Kg per m2 of mussel plot or 80 tonnes per hectare. An essential part of the on bottom Dutch mussel farming is the 'rewatering' process. Here before marketing the mussels, they are kept in special lots for 10-14 days for the process of eliminating the weak and damaged mussel.

4. Long line culture

This method is becoming very successful in open sea mussel farming. A rope is stretched horizontally near the water surface and maintained 1-2 m from the surface with buoys. Mussels are grown on vertical ropes known as 'droppers' which hang from the horizontal rope for a length of 4m. Mussel seeds are collected from natural beds and transplanted onto the ropes into a continuous sock-like cotton tube, which is approximately 17.5 cm in width. Small mussels stripped from the collection ropes are inserted. This cotton sock is then wound around the dropper. The mussels grow and attach to the ropes using their byssal threads and the cotton sock slowly disintegrates and falls away. The droppers are placed a minimum of 0.5 m apart and have at least 4 m of free space from the bottom. In deeper waters the gap between the bottom of the line and the sea floor is greater. Anchor ropes extend from each end of the horizontal rope to anchors buried in the mud of the bottom. As the ropes are kept taut, there is no movement around the anchor to disturb the bottom as occurs when boats are anchored. The density at which mussels can be cultured on long lines could be about 300 per meter, but depends on the food availability, which varies from site to site. Mussels grown on longlines can become smothered by naturally settling juvenile mussels and other fouling organisms. For this reason, most farmers prefer to position their farms away from heavy spat settlement areas to avoid layers of spat attaching to larger mussels.

5. Raft Culture

The basic principle of raft culture is similar to long line culture in that the mussels are suspended on droppers but these are suspended from the raft instead of the long lines. The raft itself is anchored to the seabed removing the need for several anchoring systems. Long line culture however, creates less of a visual impact, and the droppers can be spaced farther apart to maximize the use of the available phytoplankton. Raft culture is more suited to areas of dense phytoplankton and to smaller operations, as there is less scope for mechanical harvesting. This method of culture is used in the Galician Bays in Spain, Saldahna Bay in South Africa but has been abandoned by the New Zealand industry in favour of long lines. This method has its origin in Spain in the Galician Bay. Mussel seeds (Mytilus golloprovincialis) settle profusely in the inter-tidal zone in the coastal waters of Galicia. Rias are deep sunken river valleys upto 25 km in length, 2-25 km wide and 40-60m deep. As these rias are protectd by islands at their mouth, these sheltered, nutrient rich rias with 3-4 m of tidal range provide ideal environment for suspended mussel culture. The rafts are constructed using a wooden framework of timber and floats of concrete, steel, styrofoam or fiberglass material. The average size of the raft is 23 × 23 meter which supports 700 ropes. The rafts are anchored along the sides with large concrete moorings. There are over 3000 rafts in the Galician rias. The rafts are spaced at a distance of 80-100m from each other and positioned in groups called parks. These seeds are collected by scrapping the rocks with spade-like steel blades. Seeds can be collected by suspending ropes vertically from the rafts in December and January to catch seeds in February and March. Seeds also settle on the mussel ropes. The length of the mussel ropes varies from 6-9 meters according to the depth of the culture site. Pegs are used at 40 cm intervals to avoid slippage. The average weight of seed per meter of rope is 1.5 to 1.7 kg. About 4600 t of seed per year are needed to maintain the present level of production (Gosling, 2002).

Thinning out of the mussel ropes are done in 3 to 6 months depending upon the growth. The ropes are removed when the weight attain 10 Kg of mussel per meter. The ropes are hoisted and the mussel transferred to new ropes. About 3.5 Kg of half grown mussels are attached per meter of rope. After 8 to 12 months of growth the mussels attain marketable size of 8-10 cm (Korringa, 1976). Growth of mussels on inshore rafts is less than on rafts in the mouth of the Rias, which demonstrates food constraint at inshore sites (Navarro et al., 1991). Temperature plays an important part on the growth as the mussels in the upper part of water column, above the thermocline (2.5m) were significantly larger than those cultivated in deeper waters (7.5m) (Gosling,2002). Harvesting is done using mussel boats outfitted with power crane and metal baskets to collect the mussel ropes. As the production is about 10 Kg of mussel per meter of rope, a raft having 600 to 1000 ropes of 6-9 meter may produce 30000 to 90000 Kg of mussel per year. After harvesting, the mussels are kept for depuration for 24-48 hours before they are marketed (Korringa, 1976).

6. Rack culture

This is the simplest of the rope method used for green mussel cultivation in India and Philippines. The main purpose of the pole is to support the structure. In between these poles, ropes are suspended either vertically or kept horizontally where the depth is a limitation. The construction is labour intensive but the simplicity in harvesting and accessibility of local materials for farming purposes makes it very adaptable under local conditions. Mussel culture is fast becoming popular in the Malabar area since 1997 following the success achieved by CMFRI in rearing green mussel by rack culture in the backwaters. The simple methods employed for mussel farming was transferred to progressive farmers who took up mussel culture in the backwaters. Soon they found the venture profitable. Demands came from new entrepreneurs for training and mussel farming spread from Kasaragod to Ponnani. Mussel culture in the backwaters of Kerala was first started in Padanna and Cheruvattur Panchayats in Hosdurg Taluk of Kasaragod district. Later it was taken to Elathur in Calicut district and Vallikunnu and Ponnani in Malappuram district. The total production in 2008 was 16,500 tonnes. Some of the constraints are regarding the availability of seed. The seeds required for culture is presently collected from traditional fishing areas and these are often causing conflicts between farmers and mussel fishermen. Hence it is essential that additional spat collectors have to be established along the coast to ensure supply of seeds to the farmers.

The harvesting seasons of cultured mussels is mostly during April – May months and farmers are forced to sell their crop before the onset of monsoon to avoid mass mortality of mussels due to freshwater influx into the backwater system. At present only a few processing plants purchases cultured mussels from the farmers and as a result the local market are flooded with cultured mussels during these months resulting in fall in the prices and thereby affecting the profitability of the operation. Siltation in the backwaters is another problem. This often results in mortality of mussels in the farms. Hence scientific feasibility studies are required to demarcate potential culture sites. Mussel farming is a decade and half old farming practice in India. This is a low investment activity with very good returns. If promoted properly, mussel farming can be used as a tool for women empowerment in the coastal areas and can stimulate a healthy socio-economic development in the area. Better post harvest technologies can develop attractive value added products. Since very good export markets are available for mussels there is further scope of extending the farming practice to suitable areas.

Depuration

Bivalves are filter feeders in their feeding habit. During this process they accumulate all suspended biological materials including harmful microorganisms. Before the product reaches the market, these materials have to be removed from their gut. The process of such purification is called depuration. Hence, depuration is the process of purification of shellfish in which the animals are placed in disinfected recirculating or running seawater and allowed to actively filter feed. The process leads to elimination of bacteria from the bivalve. Disinfections of circulating seawater can be achieved by use of UV radiation, ozone treatment, irradiation etc. Simple depuration can be achieved by starving the bivalves in clean and filtered seawater/ brackish water for a certain period of time. More effective depuration can be achieved by using disinfected water in the depuration process.

Depuration process

a. The basic principle for controlled purification or depuration of bivalve involves providing clean and purified seawater in tanks, whereby the bivalve filter and pump such water for a period of 24 hours or more if required.

b. Ideally a depuration plant should be located near the least polluted source of water in the vicinity of bivalve farms. Also the physical characteristics (salinity, temperature, dissolved oxygen etc.) of the seawater used in the depuration plant should not be radically different from that of the bivalve farming areas. Care should be taken such that the level of dissolved oxygen should not be allowed to drop below 2 mg/l.

c. Two concrete seawater storage tanks of the dimension 20 x 8 x 8 m (total capacity 160 tonnes) should be constructed at a level above that of the depuration tank to facilitate gravity flow into the depuration tank (see figure). The water to be used will be first pumped into a rapid sand filter (preferably 2, arranged serially) to remove all suspended material.

d. The choices for disinfection of seawater are chlorination, ozonation and UV light irradiation. The latter two are expensive, and hence chlorination (@ 3 ppm) is the method chosen for this project. After chlorinating for 12 h, the water will be dechlorinated using vigorous aeration and / or neutralization with Sodium thiosulphate for 12 h.

e. Most depuration plants use flow through, once through or fill and draw principles. It is proposed here to use the batch process (fill and draw), wherein seawater is drawn from the supply treated with predetermined amount of disinfectant to reduce bacterial levels, stored for a time, then pumped to the tank containing bivalves. The process will be repeated once to ensure complete depuration (see flow chart).

f. Each depuration unit will consist of one concrete tanks of the size 15 x 4 x 1 m with a gradient of 3% to hold bivalves (see figure). Bivalves will be placed in perforated plastic trays of standard size. The trays in a single tier will be raised from the tank bottom with the help of PVC pipe runners. The tank will have drain plugs at the lower end to facilitate cleaning and flushing.

Run duration and Capacity

a. The duration of the run will be 24 h, in two cycles with one complete flushing for both mussels and oysters (see flow chart). The unit will have the capacity to hold 1.0 tonnes of mussels and 0.62 tonnes of oysters per run. The water requirement per run will be 144 m3.

Hatchery techniques for green mussel

Mussel farming in India is totally dependent on the wild collection of spat settled on inter- tidal and subtidal rocky patches along the coast. The hatchery produced spats are likely to become important in the future with the scaling-up of commercial mussel farming activities along the coast.

1. Site selection criteria (Sreenivasan, 1998)

Sites adjacent to good quality seawater source is a primary requirement for the setting up of a hatchery. Seawater should be free from pollution, suspended organic and inorganic particles. Water intake near effluent discharge points of industries, sewage treatment plants and river mouths are to be avoided. Salinity range of seawater between 30-35 psu is considered as optimum for year-round spat production. Sourcing of seawater from open coastal areas allows uninterrupted supply of fully saline water with minimum seasonal variations. Sites accessible by road, near mussel farming sites have added advantages. Information on the physico-chemical parameters of the proposed site need to be collected prior to deciding on the adequacy of a site for a hatchery. Remedial measures to improve inadequate quality seawater can be extremely costly and may adversely affect the profitability of a venture.

2. Hatchery facilities

The design and layout of hatchery varies from site to site, geographic location, level of sophistication, availability of capital and target of production. Hatcheries may or may not include a nursery component. There are two basic parts to a bivalve hatchery, the sea water system and the physical building. An ideal hatchery for producing about five million spat per annum requires not less than 20x10m of built-up area. The hatchery building should be designed and constructed in such a way as to get maximum light and air inside the hatchery. Floors should be of concrete and have sufficient drains. It is much better to have fibreglass tanks so they can be easily moved or changed if needed. All surfaces should be painted with a good quality epoxy resin. Before constructing a hatchery, government regulations controlling discharge of effluents should be reviewed and if they exist they must be followed. Large floor drains sunk into the floors of wet areas are essential and should be located conveniently throughout the hatchery. Periodically large volumes of water must be discharged, e.g. when emptying tanks, and the drains must be able to handle such discharges.

a. Seawater supply system consists of an intake point, a draw well, sedimentation tank, filter bed, a water sump, overhead tank and delivery lines. Seawater pumped directly from the ocean is first passed through sand filters that filter out most particulate material. A well maintained sand filter will remove the major portion of detritus and organisms from the water that may interfere with bivalve larvae. It also eliminates many of the fouling organisms that could settle and grow in pipes in the hatchery. A series of two or more such filters are generally installed and they are regularly back-flushed to avoid clogging of the filter media. Other types of filters may be used depending on personal preference and cost considerations. The filter bed normally consists of river sand at the top, charcoal, pebbles and granite stones at the bottom. The seawater passed through the filter bed is further purified by passing through 15μm 10μm and 5μm cartridge filters and sterilised in UV chamber prior to use in the hatchery tanks. After filtration, all or part of the seawater is pumped to a storage tank that may be made of either concrete or fibreglass. The daily water requirement of the seawater is around 10,000 l. Capacity of the storage tank is around 20,000 l and that of the overhead tank is 10,000 l. Necessary electric pumps are to be provided for pumping the seawater at various points. Stand-by motors and generator are also required to meet any contingencies.

b. Aeration: Air circulation to the tanks is being carried out by using air compressors which can be either of piston or rotary vane type. The air is passed through a series of filters to remove oil and moisture and supplied to the hatchery through PVC pipes. Air can be drawn at the required places from these pipes running the entire length of the hatchery at a height of 3 m through the nozzles. The air is supplied to the culture tanks through diffuser stones. Electrical air blowers are also used which can supply oil free air.

c. Algal culture facility: The success of a bivalve hatchery depends on the production of algae. Large quantities of high quality algae must be available when needed. It is a most important part of any hatchery and considerable thought should be given to providing a sufficient and efficient working area for this purpose. Since algae are used in all phases of production, the facility should be located centrally and conveniently. A small room is required to maintain stock cultures of algae. Flagellates measuring less than 10 μm are the main food of bivalve larvae while mixed algal culture are used for feeding the spat and seed. The important species used in the bivalve culture system are Isochrysis galbana and Chaetoceros calitrans. Walne's medium is used for the maintenance of stock culture as well as for mass culture. Normal room temperature is not ideal for the maintenance and culture of flagellates. Hence air conditioned rooms are used which have 23-25° C during daytime. One of the most important factors determining the successful culture of the microalgae is the type and quantum of illumination. Too much of light will cause the culture to decline earlier.

d. Stock culture: Haufkin flasks with Walne's medium are inoculated with the microalgae. The flasks are placed under tube lights (800 lux). When their maximum exponential phase is reached, light intensity is reduced to 400 lux to enable further growth. Normally the flagellates will enter the stationary phase of growth after 12-15 days. In this phase, the culture can be kept for a period of 2 months without aeration.

e. Mass culture: Using the inoculum from the stock culture room, the flagellates are grown in large scale in 20 l glass carboys or in 100 l perspex tanks. Fully grown stock culture is used as inoculums for the mass culture.

f. Broodstock holding and spawning area: Space is required to hold and condition broodstock. The amount of space needed depends in part on the number of species being held and whether some or most of the conditioning will be undertaken in the open environment rather than in the hatchery. Space is required for spawning trays but this can be part of the larval rearing area.

g. Larval culture area: Another major part of the hatchery is occupied by the larval rearing facility and dimensions of this area depend on the scale of production. The space is occupied with tanks, the number needed depending on production levels and the techniques used to rear larvae. Larval rearing tanks are generally made of fibreglass (1000 l) and should be thoroughly leached prior to use.

3. Seed production technology

a. Collection of broodstock: Broodstocks required for induced spawning are selected keeping in view of the area, growth, condition factor size and age of the standing population. They are collected from population where they are known to occur in healthy condition. The prevailing environmental conditions of the area has to be taken into consideration, since based on these factors only manipulation of temperature regime is effected –for conditioning the broodstock for maturation and induced spawning.

b. Conditioning of bloodstock: The selected broodstock are cleaned thoroughly and placed on a synthetic twine knit PVC frame in FRP tanks. Filtered seawater is filled in the tank and well aerated. Mixed phytoplankton cultured in outdoor tanks using sterilised seawater, are added twice a day. The broodstocks are conditioned about 5°C below the ambient temperature. Periodical examination of the gonads is made to assess the maturity of the gametes. On observing suitable maturity, the brood stocks are transferred to spawning tanks.

c. Induced spawning: Thermal manipulation by raising the water temperature few degrees above the ambient temperature is found to be effective to induce spawning in most of the bivalves. Chemicals such as Tris, hydrogen peroxide and sodium hydroxide were also found to induce spawning.

d. Larval rearing and spat production: Soon after spawning, the adult mussels are removed from the spawning tank. The water in the tank is kept without disturbance for the fertilization to take place. After fertilization, the seawater in the spawning tank containing the fertilized eggs is diluted several times and the eggs were allowed to develop. After 24 hours, the D-shaped larvae are transferred to 1000 l FRP tanks at the rate of 2 larvae/ml of seawater. Feeding with microalgal food is initiated from the first day after spawning. Quantity of algal cells supplied is dependent on the number of larvae and is also increased gradually with growth of the larvae. Water change is undertaken once in two days. Mild aeration is also resorted. Utmost hygienic conditions are maintained in the hatchery with proper cleaning of the containers, sieves, tubes and aeration stones. Since larval growth is influenced by larval density, food supply, water quality, water temperature and other factors, regular monitoring is done on the water quality and conditions of the larvae. Records are maintained on initial larval density, growth and number of spat settled.

e. Nursery rearing: Spat settled in the hatchery tanks were transferred to the nursery either in open sea or in enclosed bay systems for further growth. After attaining suitable size for transplantation, they are transferred to the farms.

4. Developmental stage of mussel seed (Laxmilatha, et al., 2011)

a. Eggs released by the females are brick red in colour, spherical in shape and measure 45–50μm in diameter. Fertilization is complete within 20 min of spawning and the first and second polar bodies are observed 20 min after fertilization.

b. The 8-celled stage is observed after 40 min.

c. Larvae with apical tuft of cilia and long flagellum is attained 6–8 h after fertilization

d. ‘D’-hinge veliger by 20–22 h. The ‘D’-hinge shells of the veliger (Prodissoconch I) are transparent with conspicuous granules. The velum is well developed, with a velar hood covered with small cilia that aid in fast clockwise circular movements of the larvae. The internal organs are heavily granulated. The straight hinge larvae measure 70–90 μm in the anteroposterior axis and 60–70 μm in the dorsoventral axis. The larvae are very active, spinning and swimming around rapidly.

e. Umbo stage: The straight hinge stage, transform to umbo stage on day 7. This stage is characterized by yellow digestive caecae, concentric ridges and lack of radial striae, typical of Prodissoconch II. The larvae, range from 90 to 260 μm in the anteroposterior axis and from 70 to 240 μm in the dorsoventral axis. The larvae which were clam shaped with both valves equal become more globular and develop mantle folds.

f. Eye spot stage is characterized by the presence of a black rounded spot below the food mass. The eye spot and the rudimentary foot became distinctly visible by days 13–14 and the larvae measure 220–370 μm in the anteroposterior axis and 200–330 μm in the dorsoventral axis. The eye spot became deeply pigmented and ctenidial ridges develop in the larvae.

g. Pediveliger stage The development of the functional foot indicated the pediveliger stage by the 16–19th day. The larvae measure 280–400 μm in the anteroposterior axis and 360–380 μm in the dorsoventral axis. Larvae at this stage are capable of swimming with the velar cilia as well as crawling with the foot. The velar crown is reduced in size and the larvae transform from the free swimming pelagic larvae to the creeping, crawling benthic stage ready to attach to the substratum. Gill filaments were clearly visible. The radial ridges were also distinct and green coloration was noticed along the margins of the shells.

h. Plantigrade stage: The pediveliger, at the end of the crawling stage settle on the substratum and become plantigrade and begin its sessile life. Spat settlement could be observed from the 21st day onwards. The larva measure 400–490 μm in the anteroposterior axis and 380–480 μm in the dorsoventral axis. The velum disappears, labial palps appear and additional gill filaments appear. The concentric growth lines, foot, heart, posterior adductor muscle, mantle edge, visceral mass, intestine and chromatophore pigments are distinctly seen.

i. Spat: The plantigrade transform into young spat by developing the characteristic adult shell. The shell by now assumes the typical oblong shape like the adult mussel. The hinge line, the anterior and posterior auricles and the byssal notch typical of the adult mussel are formed. The spat attached to the bottom substratum by secreting the byssus threads. Spatfall or settlement began on the 21st day and continued up to 35th day. The spat measure $510 \times 390 \mu$m on 21st day and 910×460 μm on 28th day.

For further reading

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