GENERAL SUMMARY AND CONCLUSIONS
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The bivalve molluscs in India are exploited for various purposes. The need to popularise these molluscs as food is great. Apart from the edibility value, these molluscs are of multiple use, viz., pearl culture, use of flesh as bait in fishing and shells in preparation of toys, ornaments utility articles, and in lime, paints and cement industries. Considering the immense scope of molluscan fishery and for scientific basis of management decision, the application of research data for the benefit of the fishery has been considered worthwhile. It has been repeatedly stressed by many investigators that the local environment plays an important role in the development of molluscan fishery, and the latter is dependent on the ecological and physiological status of the species under consideration.

The aspects of ecology and physiology of many marine bivalve molluscs from Indian coasts have been worked out by a number of investigators. However, comparatively little data exists on the freshwater species despite their abundant distribution. One of the freshwater species, *Indonaia caeruleus* is widely distributed in both lotic and
lentic environment in Maharashtra State. In Nasik District, Chankapur dam was constructed on the Girna river during the year 1974-75 (latitude 20° 29' and longitude 56° 73'). Along the down stream of this river, there exists a narrow oval pond of about 100 x 30 meters, created due to the southward passage of the river water. Throughout the year there exists lotic environment in the pond and it gets flooded in the peak-monsoon period (July-August). *Indonaiia caeruleus* inhabits in this pond and has been observed to reach a maximum shell length, an average 65 mm, which is comparatively larger than the shell length attained by this species, as revealed from the literature, in different lotic environment in the State. Hence, it was felt necessary to investigate some aspects of its biology. In this view, studies were undertaken from the year 1991 onwards to find out the variations in some ecological parameters and to determine the changes in the metabolic activities like respiration and changes in the digestive tubules, pattern of reproduction and to know whether there exists any endogenous regulation via the central ganglia during the processes of metabolism and reproduction. The study was made on every fortnight, i.e., on no-moon, and full-moon days, which facilitated to understand any lunar periodicity coinciding the above activities.
The analysis of soil content from the habitat of *Indonaia caeruleus*, before and during monsoon season, show high values of total nitrogen, available $P_2O_5$, available $K_2O$, pH and organic carbon in August, while low values of available $P_2O_5$ and electrical conductivity were obtained in June. On the otherhand, total N and pH values are low in March and April. In April available $K_2O$, organic carbon and exchangeable Mg are low but free $CaCO_3$ is high, whereas exchangeable Mg and electrical conductivity are high in March. DTPA extractable Fe is fairly equivalent in April, June and August. The study reveals that the increase or decrease in above parameters are largely associated with the evapo-precipitation reactions and the influx of heavy load of water down the dam, particularly in August. The data on rainfall show commencement of rainy season from no-moon of May and reaches peak in June and July, and the gradually decreases in August and then on no-moon of September. Air temperature on the habitat of the mussels increases from March to June to a maximum, while decreases to a minimum during December to February. The water temperature increases from March to July, decreases in August and increases again in September and October. However, from November it once again decreases till January. During winter months their occurs a broad range in the maximum, to
minimum water temperature than during monsoon and post-monsoon seasons (from June to November). Oxygen content of the water decreases to a minimum two times in a year (June no-moon and October full-moon). Similarly, it increases twice in a year (January full-moon and March no-moon). In general, the pattern, reveals that oxygen content increases from February to March and decreases from May to July. During August and September the oxygen content fluctuates in a narrow range. Highest pH value of water has been recorded in March, while lowest in July, and in the remaining period of the year pH fluctuates in a very narrow range.

The rate of oxygen consumption declines on July no-moon and August no-moon. This period coincides with the peak monsoon season at which time fast flow of the water current is observed over the habitat. This situation results in increasing particle concentrations, creating turbidity, and affects the ventilation rate of these mussels. In winter the rate of oxygen consumption further decreases from December no-moon to February full-moon (minimum values of oxygen consumption are recorded in December and January no-moon period), coinciding with the
low temperatures and declining food availability. This period can be correlated with the dormancy, i.e., mussels enter into a period of zero growth or of a negative growth. During December-January the gonads are almost empty and only in a few individuals gametogenic stage is seen. The rate of oxygen consumption increases from March no-moon onwards till June no-moon, giving maximum values on no-moon days. High temperature, mild flow of water on the habitat and increase in day length in summer are likely to result in the increased ventilation rate. This probably results in the increase in the amount of oxygen to be delivered on to the gills and thereby to increase the filtration rate. Demand for the maximum ingestion rate greatly exceeds the maintenance ratio during this period and provides the energy excess for growth and general body metabolism. This is the end period of spawning and recovery commences in the gonads. From August to November full-moon the rate of oxygen consumption tends to fluctuate in a short range and remains at a moderate level due to the steady current of water. The temperature fluctuations are at a moderate level and the gonads shows various stages of maturity and spawning.
The rate of respiration increases on full-moon days before the period of adductor quiscence and dormancy, i.e., till November and once again increases generally on no-moon, i.e., from March onwards, after the dormancy period. The day length probably plays some role in determining this differential pattern of the rate of respiration, since the minimum value of oxygen consumption is recorded on December no-moon at the time of shortest day length, whereas the maximum value is seen on June no-moon at the time of longest day length and heavy rainfall. As the day length increases the oxygen consumption increases on no-moon days from February to June. Thus, it is likely that lunar cycle also has an impact on the rate of oxygen consumption. Generally, on full-moon days little variations in the oxygen consumption occur, while on no-moon days considerable fluctuations occur in the rate of oxygen consumption.

Weight specific oxygen consumption increases on no-moon days of March, May and June at the time of decrease in the body weights. With the increase in the body weights on full-moon days of March, May and June, and also on July no-moon days the weight specific oxygen consumption decreases. The results further reveal that the rate of
oxygen consumption correlates with the weight of the animal only from March to July, the period of increasing temperature, day length and mild flow of water on the habitat. It is likely that during this period, the ventilation rate comparatively remains constant and the amount of oxygen consumed by the mussels tends to be weight specific. Latter on, from mid-monsoon to winter the ventilation rate and the amount of oxygen consumed by the mussels do not show any weight dependency, which is possibly due to marked variations in the rainfall (i.e., at the close of monsoon), varying amount of food availability, fluctuations in temperature, and due to growth, maturation and release of the gametes.

The cytological appearance of the digestive diverticula is found to be more or less constant in any one animal and does not differ in different mussels in a given fortnight. The digestive tubules are in phases like (1) holding, (2) absorption, (3) fragmentation spherules, and (4) re-organization. The digestive tubules consist of two cell types, the basiphilic cells in groups lay in the crypts of the tubules and can be seperated from larger groups of the digestive cells. The number of groups of the basiphil cells are minimum 3. The amoebocytes are
generally scattered in the interlobular connective tissue in abundance but their number decreases in winter. The small clusters of cells form a new tubule from the nests of young cells which eventually leave the old tubule, leaving one or two young cells in the old tubule to repopulate the empty old tubule. The size of lumen is large in holding phase than the absorption and the fragmentation spherules phases. In re-organization phase, the height of digestive cells and the diameter of tubules both comparatively decrease. In general, the height of the digestive cells increases in absorption phase than in the fragmentation spherules phase and that the height of the cells further increases in monsoon, irrespective of the absorption or fragmentation spherules phases.

Changes in the tubules correspond to the feeding and digestive sequence predominating in different fortnights of summer, monsoon, post-monsoon and winter seasons. Prior to the arrival of the food in the lumen, the tubules are in the holding phase. The digestive cells at this time have low appearance. With the arrival of food, the tubules begin a phase of absorption and the digestive cells increase in height and get filled with food particles which appear as inclusions. During active absorption phase the crypt cells possess flagellae, possibly to circulate the fluid and suspended material arriving in the diverticula from the stomach. This phase becomes dominant on July.
no-moon, October full-moon, March full-moon and April no-moon. The dark stained inclusions in the digestive cells appear during the holding and absorption phases. Many vacuoles appear during absorption phase on January full-moon and May no-moon, which probably reveal low food uptake from the surrounding medium. Due to the intracellular digestion, the digestive cells undergo a process of breakdown in which the apices of the cells are pinched off abundantly to form fragmentation spherules. This phase is markedly seen on June full-moon, August no-moon and full-moon, September full-moon and May full-moon, revealing that the digestive cells have almost completed the process of breakdown. The fragmentation spherules are not seen during holding, absorption or reorganization phase. The fragmentation spherules phase is succeeded by a phase of the re-organization during which the digestive cells resume their low profile. This phase is predominated on November full-moon, i.e., the beginning of winter season.

Following the first rain-fall in May, the period of longer day length, the phases of absorption and fragmentation spherules predominate till the end of the monsoon. Complete closure of monsoon results to the dominant holding phase of tubules on October no-moon, followed by a longer period of the absorption phase during
October full-moon and November no-moon. This shows that during monsoon greater food availability with speedy current of water over the habitat results in intake of many particles by the mussels. Subsequent to the low food availability and steady water current in post-monsoon, the holding phase is followed by absorption phase. No fragmentation spherules phase is seen from post-monsoon onwards. With the start of winter, i.e., on November full-moon, the re-organization of the tubules takes place. There is a short absorption phase on December full-moon but a longer period is seen on January full-moon and February no-moon. This period is coincided with a comparatively short day length and lower water temperature. With the beginning of longer bright sunny days, resulting in the rise in temperature and the oxygen content of the water, i.e., from March no-moon, increase in the demand of uptake of food by the mussels results in the absorption phase. This phase continues to occur till April no-moon. The occurrence a longer period of the absorption phase is probably because of declining food availability in the surrounding water. The continued existence of the unfavourable environment on April full-moon results in the holding phase. Return of this holding phase prepares the mussels to begin another cycle of events to commence the phases of absorption and digestion.
The results show that more food is taken up and utilized by the mussels from June no-moon, i.e., beginning of the monsoon till November no-moon, i.e., the end of the post-monsoon period. After this period variations in physico-chemical parameters and the decreased food availability in the surrounding water result in low food intake. From postmonsoon to summer, i.e., from October no-moon to May full-moon, the phase of absorption is longer, whereas that of breakdown, i.e., fragmentation spherules is short.

In the entire process of feeding and digestion there are further differences with respect to the day length. In post-monsoon, winter and summer the day length inequality, i.e., full-moon and no-moon inequality, results in the phase of absorption being relatively longer between the full-moon and no-moon period of October full-moon, November no-moon, January full-moon, February no-moon, March no-moon and April no-moon, though subsequent phases of intracellular digestion, assimilation, breakdown and holding are occurring on approximately in a similar length. No-moon days tends only to affect the holding phase i.e., just before and after the re-organization phase has occurred on November full-moon. Increased phase of
holding, thus must result in the succeeding period of winter dormancy for lesser utilization of digestive enzymes and a lesser body of cell tissue to breakdown and reform. The food availability decreases at this time from the surrounding water.

The sexes are separate and adult mature gonads are white in males and cream in colour in females. The outer demibranch creates an ovisacs which acts as an accessory reproductive organ. The study carried out on the samples collected on every no-moon and full-moon days reveals that the annual reproductive cycle is divided into 6 stages: (1) recovery, (2) gametogenesis, (3) active gametogenesis, (4) mature, (5) partially shed, and (6) many shed. Males undergo gonad recovery earlier than females. The recovery stage is extended in females than in males. This recovery stage begins from April full-moon in males and extends till June full-moon, while in females it occurs from May no-moon to July no-moon. The gametogenic activity is commenced in many mussels firstly in males and then in females. Active gametogenic stage of gonads predominants in July and August and for the second time from January to March. Majority of the males and females mature on August full-moon, September no-moon, October full-moon and again on March full-moon.
Many mature gametes are mostly released from September full-moon to November full-moon and also on April. Mature condition of the gametes is not reached in many mussels in December, January and February.

From March no-moon in both males and females the gametogenic activity completely stops and no more gametes are matured from April onwards. In males follicles never show complete release of sperms. A few relict sperms in every follicle are retained. However, in females a few follicles release all the mature oocytes but others are being retained which undergo lysis. As the gametogenic cycle progresses in both the sexes and is being repeated, the lipid globules and nutritive cells begins to diminish in quantity, and the follicles enlarge in size. With the onset of partial spawning the follicle wall becomes papery and gonads become transluscent, filled with much liquid.

The gametogenic activity commences from the arrival of a first few rains and decreasing temperature. This environment enhances the feeding activity and thereby maturation of the gametes. With the close of monsoon, the spawning activity is enhanced, simultaneously new gametes are being formed and are matured in the gonads but as the food availability in the environment decreases and the
temperature decreases to the minimum in December and January not many gametes are developed to mature stage. However, with the increasing temperature and the metabolic activities gonads mature in March and the spawning is extended till April.

In all the three, cerebral, visceral and pedal ganglia the neurosecretory cells are present. In cerebral and visceral ganglia neurosecretory cells are located on dorsal and lateral periphery, while in pedal ganglia these are located on the dorsal periphery and midline of the fusion of the two lobes of the ganglia. The neurosecretory cells are of Type I and Type II. Type I cells are pyriform in shape and are unipolar or bipolar, whereas Type II are oval or round. Type II cells are many in number than Type I in all the central ganglia. The neurosecretory activity of Type I neurosecretory cells show 4 stages in cerebral ganglia and 3 stages in visceral and pedal ganglia are distinguished. The Type II neurosecretory cells do not show such distinct stages. In all the ganglia the neurosecretory cell of Type I do not reveal any one stage of the neurosecretory cycle at any one fortnight and complete release of the neurosecretory products is never seen. Frequently axonal transport of neurosecretory material is
distinctly seen. Hence, maximum number of the cells in any one of the stages are considered in the study to show any relation with the changing environment or with the changing reproductive stages.

In cerebral ganglia the neurosecretory cycle of Type I cells show correlation with gametogenesis, maturation and spawning. In the visceral and pedal some stages relate with spawning, while others with seasonal changes in the environment and the activity of the mussels. The maximum number of the stage II of the neurosecretion cycle in Type I cells from cerebral ganglia and the stage I of Type I cells from visceral and pedal ganglia correlate with monsoon, while the stage III of visceral ganglia correlate with increasing temperature and increased metabolic activities of the mussels, probably due to the stress effect imposed on visceral ganglia. The stage II of pedal ganglia is correlate with the peak spawning activity and pedal movement and stage III correlate with summer drastic environmental condition.

It can be inferred that the distribution and biology of the freshwater bivalve molluscs, in general, is influenced by the local ecological factors like temperature, pH, oxygen content, rainfall, soil contents,
drought conditions, presence of suitable micro-organisms, water flow system, fishes as host for glochidia, etc. Such parameters require special attention while elaborating the impact of exogenous factors upon the ecophysiology of freshwater bivalve species, particularly in the view of feeding and digestion, and reproduction. Amongst the endogenous factors wide occurrence of Ach, 5-HT and catecholamines in the nervous system, and neurohormones of the neurosecretory cells from the central ganglia require special attention. Since these two endogenous factors have a considerable influence on the physiological activity of the bivalve shell-fishes.