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MIGRATION IN PRAWNS WITH SPECIAL REFERENCE TO LIGHT AND WATER CURRENT AS INDUCERS IN *MACROBRACHIUM ROSENBERGII*

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ABSTRACT - Though biology and physiology of prawns have been discussed and considerable interest has been created for the development of prawn aquaculture during the recent years, no effort has been made so far to study the characteristic behaviour of prawns which can be used for the development of a new system of prawn harvesting. In nature, freshwater prawn migrate from river to brackishwater for breeding and the juveniles return back to the river system for growth and development. Prawn move upstream, entering lakes and even paddy fields up to about 200 km from the sea. Construction of barrages across the rivers to check the intrusion of saline water in upstream area and/or to regulate water flow without keeping in mind these considerations have resulted in the drastic reduction in prawn population in several freshwater rivers. Migration of the prawns is induced according to the physiological conditions which is mainly controlled by light and water current. However, hardly any effort has been made to study of the effects of these parameters on migration of prawns which constitute important commercial fisheries throughout the world. Details regarding the migration of penaeid and palaemonid prawns have been discussed in this communication with emphasis on the role of light and water current as inducers of migration in the giant freshwater prawn, *Macrobrachium rosenbergii*.

Key words : Penaeid and palaemonid prawns, life-cycle, migration, *Macrbrachium rosenbergii.*

INTRODUCTION

Freshwater prawns require particular care during harvesting, processing and transport, perhaps more so than marine shrimp. It is essential to avoid poor quality prawns for achieving and sustaining the export potential. In fact, harvesting is a very delicate phase in prawn culture. At present, there are two methods being used for prawn harvesting from aquaculture ponds - (i) the traditional method wherein partial or total harvesting is done using cast net or harvest net and (ii) the electric shocker or electric catcher method wherein electric shock is given to prawns in the soil causing the prawn to leap up and be trapped by the dragnet. However, both of these harvesting methods do have some limitations. The traditional method requires high strength of manpower, takes more time, disturbs the pond bottom and is difficult for efficient adoption in ponds of higher width. On the other hand, high initial investment and higher cost of operation required in frequent replacement of electrodes, difficulty due to frequent recharging of battery and skilled operation required in use of electric shocker limit its use by small and medium level prawn farmers. Moreover, certain factors operating during harvesting may result in loss or damage to the prawns leading to high commercial losses. Therefore, such factors need to be considered before and during the harvesting. Characteristic behaviour of the prawn is one such important factor which is to be given due importance during the harvesting. Prawns are more active at night than in daytime, particularly during night feeding. At night, they tend to swim toward a source of light (Jung and Co, 1988). During pond water exchange, the prawn can be seen swimming towards the pond inlet opposite to water current.

Though biology and physiology of prawns have been discussed and considerable interest has been created for the development of prawn aquaculture during the recent past, no effort has been made so far to study the characteristic behaviour of the prawns which is very important for a better harvesting of the crop and can be used for development of a new system of prawn harvesting (Apud, 1985, Apud *et al*, 1985; Wheaton, 1985; Ghose *et al*, 1994; Sandifer and Hopkins, 1996; Upadhyay *et al*, 2006; Nair *et al*, 2007). Furthermore, in nature, freshwater prawn migrate from river to brackishwater for breeding and the juveniles return back to the river system for growth and development. Prawn move upstream, entering lakes and even paddy fields up to about 200 km from the sea (Waterbase Infoshare, 1995; Upadhyay, 1995). Migration of the prawns is induced according to the physiological condition which is mainly controlled by light and water current (Benfield *et al*, 1990; Ivanov and Stolyarenko, 1992; Covich *et al*, 2003). However, hardly any effort has been made for detailed study of the effect of these parameters on prawn migration. Construction of barrages across the rivers to check the intrusion of saline water in upstream area and/or to regulate water flow without keeping in mind those considerations have resulted in drastic reduction in prawn population in several freshwater rivers (Raman, 1987).

Estuaries and backwaters provide an ideal home for a variety of shellfish organisms. Although clams, oysters, mud crabs and certain species of caridean prawns permanently inhabit this highly dynamic environment, many others utilize the area as their nursery or breeding ground (Young and Carpenter, 1977; Young, 1978; Cole and Long, 1985; Cole *et al*, 1987; Garcia 1988; Sheaves *et al*, 2012)). A number of commercially important penaeid prawns which contribute to the marine fisheries essentially spend their juvenile phase in brackishwater environments while freshwater prawns of Genus *Macrobrachium* migrate to estuaries to facilitate larval development (Fig. 1). All these animals are increasingly exploited by man from the estuarine habitat throughout the year, making them vulnerable to depletion of stock. Prawns and molluscs are the maximum exploited groups**.** Though precise statistics are not available for their fishery, it is estimated that about 26,000 tones of juvenile penaeid prawns, 53,000 tones of clams and 10,000 tones of oysters are exploited annually from estuarine and brackishwater systems in this country (Suseelan and Nair, 1994). Added to the uncontrolled fishing of the natural resources, estuaries and backwaters are subjected to constant changes in their physico-chemical conditions due to various human activities. The widespread reclamation of water areas, construction of barrages and other salt-water exclusion structures, dredging, aquatic pollution *etc* cause ecological damages to the shellfish populations.

Among the two major groups of prawns - penaeids and palaemonids, migration from one environment to another is noticed in many species at different stages of the life-cycle. A certain number of species among the penaeid prawns from the continent frequent the estuaries and coastal lagoons during one stage of the biological cycle (Fig. 2.1). The post-larvae arrive from the sea and enter the lagoons and estuaries to continue their growth until they reach about 10 cm according to the species. At the end of this period, the juveniles swim rapidly back to the open sea where they attain their full adult size and then reproduce. A certain number of field observations on migrations in nature have shown that these are controlled by several external factors, particularly variations in salinity and the currents (Laubier, 1989). Nycthemeral and tidal rhythms have also been suggested to have an impact on behavioural responses of the prawns.

In nature, freshwater prawn migrate from freshwater river to brackishwater areas for breeding and the juveniles return back to the river system for growth**.** The life-cycle of freshwater prawn has four distinct phases - egg, larvae, post-larvae and adult (Fig. 2.2). Depending upon environmental conditions specially temperature, the time spent by each species of *Macrobrachium* in the different phases of life-cycle, its growth rate and maximum size varies. In the natural environment, mating of *Macrobrachium* takes place round the year, although due to environmental reasons, peak mating takes place only during certain periods of the year. A female prawn with matured gonad, copulates just after moulting with a male prawn having a hard shell. During copulation, the male deposits a gelatinous mass (or spermataphore) on the underside of the thorax of the female between her walking legs. The female prawn releases eggs a few hour to a few days after copulation. The number of eggs depends on the size of the female. A fully matured female of 50-100 gm can carry 50,000-100,000 eggs but at first maturity, due to small size of the female, it lays only 5,000-20,000 eggs. As the eggs are extruded from the gonophore, they are fertilized by non-motile sperm retained in the spermatophore. The fertilized eggs are then transferred to a brood chamber on the underside of abdominal region of the female, held in place by a thin membrane and kept aerated by vigorous movement of the abdominal appendages. Eggs are incubated in this way for 21 days and then hatch. In the laboratory, it has been observed that hatching takes place 20 days after copulation. However, it may even take 25-30 days if the temperature remained below 28^{0}C. Ovaries frequently ripen again even while a female is carrying eggs. Immediately after hatching, the female can again release these eggs. In some cases, a female can lay eggs twice a month. The eggs of the prawn are slightly elliptical, the longer axis being 0.6-0.7 mm in length. They are bright orange in colour until two or three days before hatching (New and Singholka, 1985).

Larvae hatch out during the night. Rapid movement of the female pleopods disperses the newly-hatched larvae which normally swim with their heads down and ‘jump” when they contact a surface. Larvae need brackishwater to survive at this stage. Even if larvae hatch in freshwater, they will not survive if they are not put into brackishwater within two or three days. Larvae in the wild generally eat zooplankton, small insects and larvae of other aquatic invertebrates. Larvae in the hatchery takes minimum 26 days to metamorphose into post-larvae (PL). Post-larvae can tolerate a wide range of salinity but freshwater is their normal habitat. As such, two or three weeks after metamorphosis, the PL move against the current and head towards freshwater canals and rivers. They abandon the planktonic habit at this stage and become omnivorous, feeding on aquatic insects and their larvae, phytoplankton, seeds of cereals, fruit, small molluscs and crustaceans, fish flesh, slaughter house waste and animal remains. They move by crawling and generally swim with their dorsal side uppermost. They can swim rapidly.

Post-larvae begin to migrate upstream from brackishwater into freshwater conditions within one or two weeks after metamorphosis and are soon able to swim against rapidly flowing currents or to crawl over the stones, dead trees and bushes at the shallow edges of river and require high oxygen concentration. The latter also provide substrate for prawn food organisms and shelter. They can climb vertical surfaces and cross land provided there is abundant moisture available. In addition to using the foods available to them as larvae, they now utilize larger pieces of organic material, both of animal and vegetable origin. Their diet includes zooplankton, aquatic animals, small molluscs and crustaceans, algae and organic material - both of vegetable and animal origin. They are also cannibalistic, especially during moulting. Prawns seek food at night and hide during day time. As such, after spending their early life in brackishwater that is connected directly or indirectly with the sea, *M. rosenbergii* migrates upstream, entering freshwater lakes, rivers and paddy fields far from the sea.

Prawns migrate from one environment to another at different stages of their life-cycle which is governed by salinity, water temperature, water current and lunar phase. Migration of prawn is induced according to their physiological condition which is mainly controlled by light and water current. Although a lot has been discussed regarding prawn biology and physiology (Wickins, 1976; Sandifer and Lynn 1980; Berber, 1984; Jinadasa, 1985; Sandifer and Smith, 1985; Rao, 1986; Murthy *et al*, 1987; New, 1990; Singh and Roy, 1994; Diwan and Joseph, 1999; Huberman, 2000; Diwan, 2005), hardly any effort has been made to study in detail the effect of these parameters on prawn migration. It is obvious, therefore, that there is much scope of work on scientific investigation on this area (Wheaton, 1985).

Su and Liao (1987a) investigated the emigration of *Penaeus monodon* from Dapong Bay in southwest Taiwan and reported that the peak emigrations occurred from April-December. Most of the prawns emigrated during 1-2 months after the rainy season. The prawns preferred to emigrate at the new moon or the first quarter moon phases. The size (monthly mean carapace length) of emigrating prawns ranged from 25.0-39.0 mm for the female and 24.6-3.5 mm for the male. New emigrants occurred mainly in March, July, September and November. There was significant difference in fatness between sexes in spring. Another investigation carried out by Su and Liao (1987b) on the emigration of *Penaeus semisulcatus* from Dapong Bay in southwest Taiwan showed that peak emigrations occurred from July-December. The prawns preferred to emigrate at the new moon or full moon phases. Most of the prawns emigrated after the May-June rainy season. The size (monthly mean carapace length) of emigrating prawns ranged from 20.7-33.6 mm for the female and 20.4-29.6 mm for the male. New emigrants occurred in June-August. There was significant difference in fatness between sexes. The fatness in winter was significantly different from that in the other seasons for the female.

Solis-Ibarra *et al* (1993) studied the spatial and temporal variations of post-larval white shrimp, *Penaeus vannamei*, in the coastal zone near Presidio river mouth, Sinaloa, Mexico. Post-larval occurrence generally followed a similar abundance pattern to that described for the neighboring coastal lagoon system. Regarding spatial variation, abundance was greater closer to the shore. Post-larval density was significantly higher near the bottom than at the surface. Post-larval numbers were higher during the rainy season and higher densities recorded at full moon.

Larval and post-larval fishes and crustaceans transported through a tidal channel exhibited vertical and lateral movement in response to tide and light (Hartman *et al,* 1987). Generally, densities were greater on ebb than flood tides. Densities of most sciaenids and flatfishes were greatest near the bottom of the canal on flood tide while clupeids and penaeid shrimps were more dense near the sides of the channel. All species were most dense near the sides of the canal on ebb tide. Lateral and vertical movement in relation to tide is a mechanism whereby estuarine-dependent species migrate to and from coastal nurseries expending minimum energy. Significant diel variation in densities was also observed. Few individuals of any species were captured during daytime. Moreover, densities taken before, during and after sunrise and sunset were inversely related to light. Greatest daytime densities

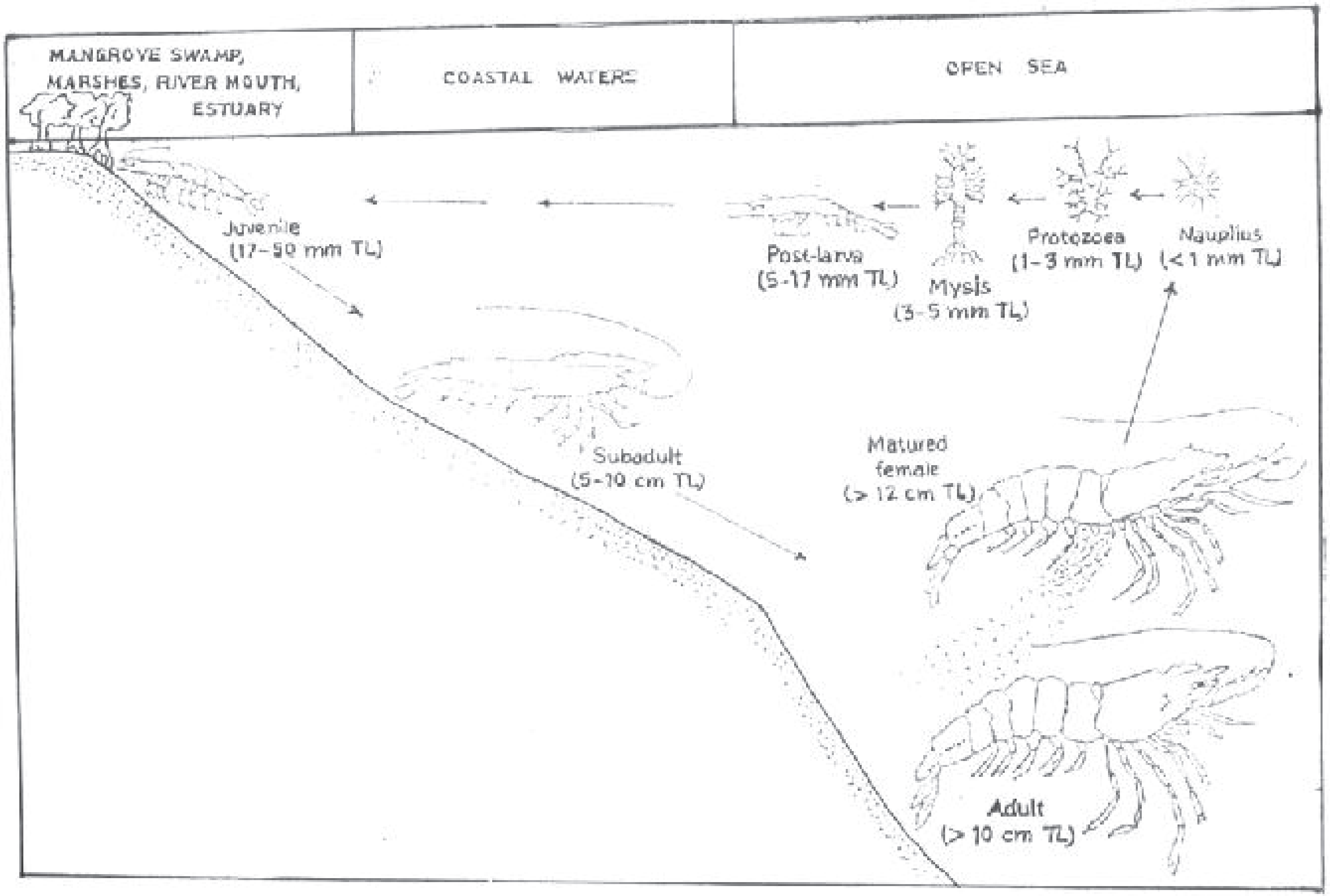

Fig. 2.1 : The life history of penaeid prawns.

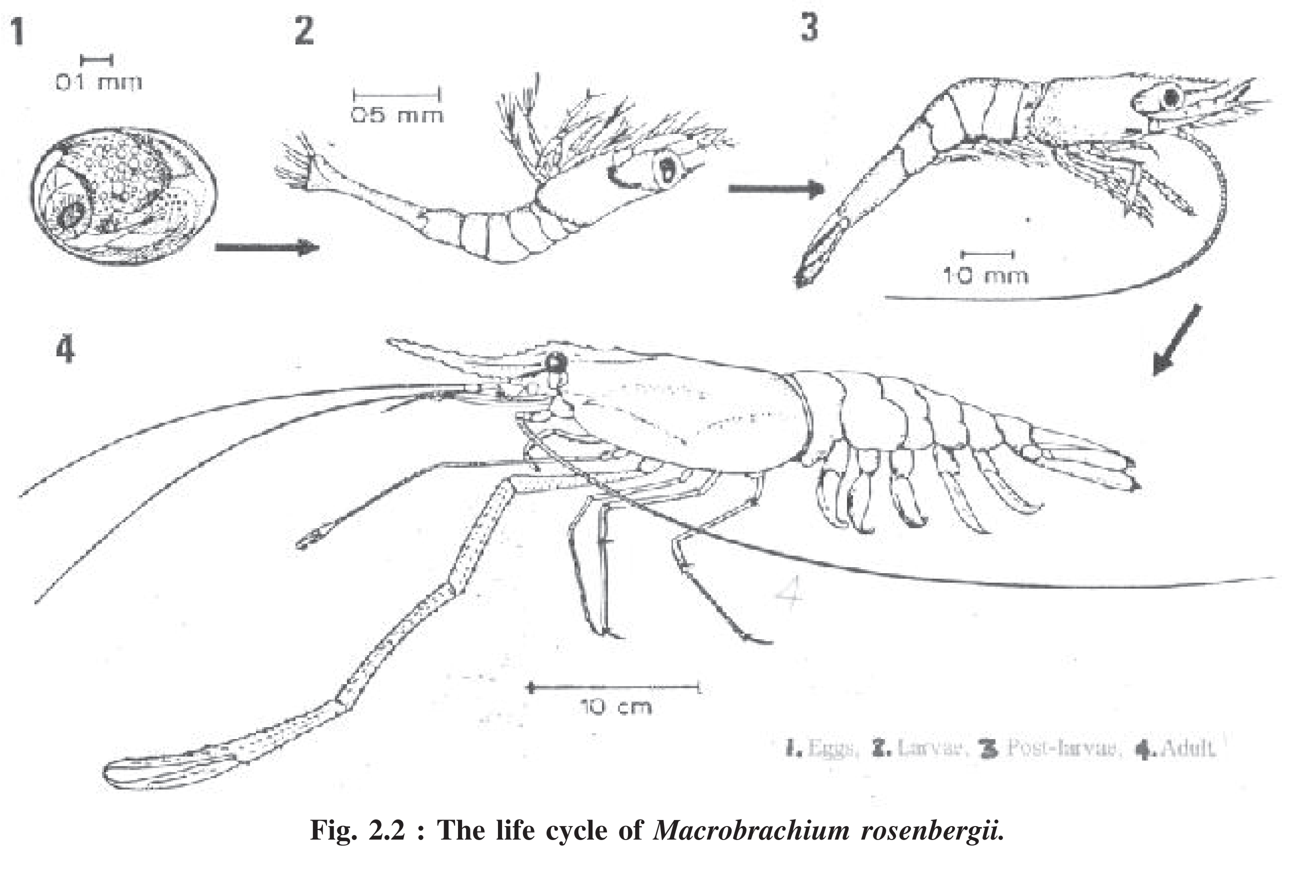

Fig. 2.2 : The life cycle of *Macrobrachium rosenbergii.*

Fig. 1 : *Macrobrachium rosembergii* used in the experiments. Males with large chelate legs.

were near the bottom where light intensity was lowest. Densities at night were generally greatest near the surface.

Matthews *et al* (1991) examined the interaction between endogenous rhythms, light and salinity changes on post-larval brown shrimp, *Penaeus aztecus*, activity levels under laboratory conditions in order to understand estuarine recruitment and retention. Post-larvae have strong circadian and occasional circatidal activity rhythms. The post-larvae respond to salinity increases and light level decreases by increasing swimming activity. The post-larvae decrease swimming activity in response to decreases in salinity and increases in light. These changes in activity have been reported to occur only during dark/ nocturnal conditions. Temporally selective activity in the presence of different environmental signals attests to the plasticity of a post-larvae response to environmental signals and provides a mechanism for estuarine immigration. The presence of a response hierarchy to environmental signals may also help account for the ability of post-larval penaeids to immigrate into estuaries with different hydroperiods and salinity regimes.

Le-Reste (1987) investigated the influence of salinity and current upon the size of the shrimps, *Penaeus notialis* in Casamance Estuary, situated in southern Senegal which supports an important shrimp fishery exploiting the shrimp migrating towards the sea. The size of the shrimps varies not only at different points along the estuary for a given period of time but also varies with season and year. Studies by Staples (1979) and Staples and Vance (1986) on emigration of juvenile banana prawns, *Penaeus merguiensis* from a mangrove estuary and recruitment to offshore areas in the wet-dry tropic of Gulf of Carpentria, clearly demonstrated the importance of rainfall to the emigration processes of this penaeid prawn. Most emigration has been reported to occur during the wet

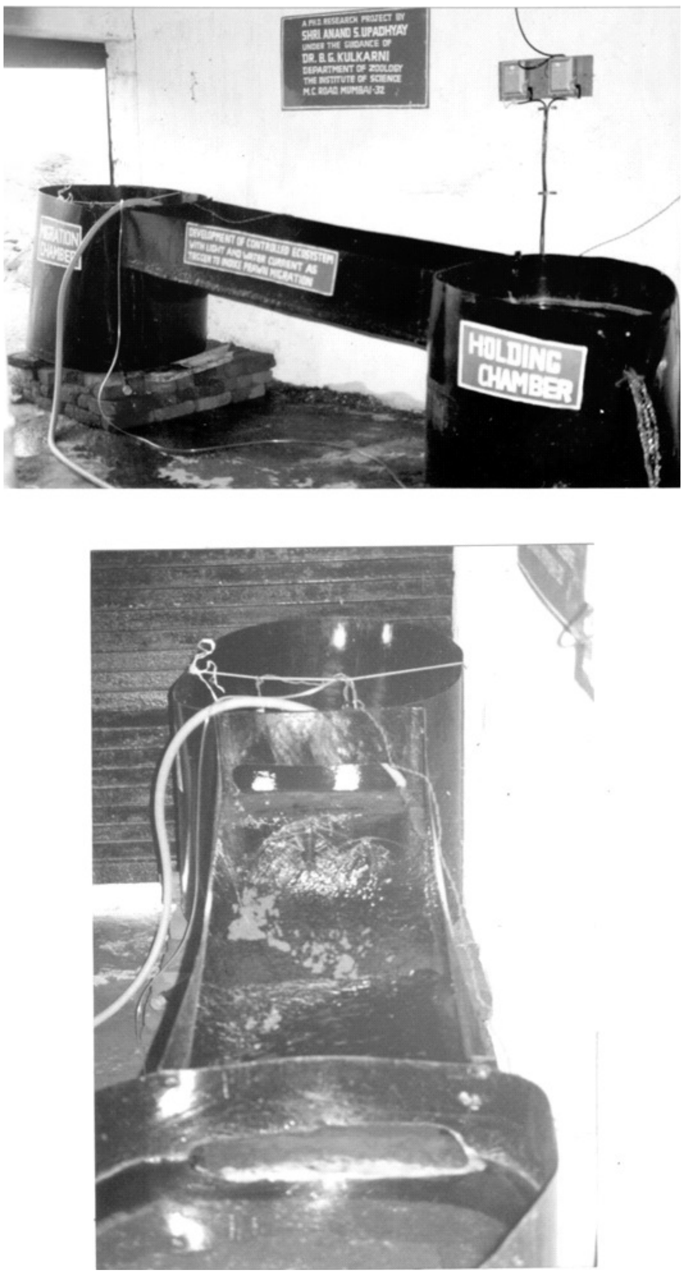

Fig. 3: Experimental set-up for study of prawn migratory behavior.

summer months (December-March) when 80% of annual precipitation occurred. By investigating the distribution and migrations of the prawn, *Palaemon longirostris* in Mira River estuary (Southwest Portugal), Cartaxana (1994) reported that estuarine distribution of prawns appeared to follow the salinity displacement, the animals being found at river stations during summer and autumn when saline encroachment up the estuary was greater. During winter and spring when freshwater input from the river was greatest, the prawns migrated downstream to brackish areas. Ovigerous females were collected only from estuarine areas during January-August, suggesting that reproduction does not take place in freshwater habitats. Higher percentage of females than males were generally observed. Females, particularly ovigerous ones, were larger than males.

Investigation on the annual variations of the shrimp, *Penaeus notialis* production in Casamance Estuary (Senegal) by Le-Reste (1983) suggested that yearly variations of catches could be related to the estuary salinity. When salinity is high, shrimps migrate seaward at a large size and that results in large catches in the estuary. But when the salinity is low, shrimps migrate early. After a good correlation between salinity and rainfall was observed, a significant correlation between catches and rainfall was pointed out. Another study carried out by Le-Reste (1986) in Casamance Estuary indicated that shrimp catches depend to a large extent on the seaward migration size. This size depends on current velocity and salinity. Decrease in current velocity results in increasing size. Size is maximum when salinity is approximately equals 30 ppt and decreasing as salinity is rising or dwindling from this value. Kuderski *et al* (1982) have suggested that the shrimp distribution at Broa Inlet is related to the current direction of the bottom water layer. A trend in shrimp migration toward higher salinity waters was shown. Henderson and Holmes (1987) studied the population biology of the common shrimp, *Crangon crangon* in Severn Estuary and Bristol Channel and observed regular seasonal migrations of the common shrimp in order to avoid low salinity and to reproduce. Growth and emigration of *Penaeus indicus* in St. Lucia Estuary, southern Africa has been studied by Benfield *et al* (1990). Shrimp emigration has been reported from the estuary between the sizes of 18-25 mm (CL). The onset of emigration appeared to be related to the declining water temperature.

Phototactic behaviour of adults of the Sudanese fairy shrimp, *Streptocephalus proboscideus* was studied under laboratory conditions (Luc *et al,* 1995). Males were less negatively phototactic than females. This was also evident when colour filters were used. Females only became little less negatively phototactic under yellow light whereas males showed a strong positively phototactic response. The response to the positioning of a yellow filter was stronger than to the use of a red or blue filter for both the sexes. The laboratory findings were compared with casual field observations on *Streptocephalus torvicornis* that indicated differential vertical distribution between the sexes and a nocturnal vertical migration. Migratory behaviour with ascent starting at dusk was also predicted for *S. proboscideus*. It is reported that this behaviour may reduce common stress factors in desert pools such as photodamage, visual predation pressure and high surface temperatures.

A study was undertaken by Glaister (1978) on the impact of river discharge on distribution and production of the school prawn, *Metapenaeus macleayi* in the Clarence River Region, northern New South Wales. Relationships between river discharge and production (catch) of this species were examined as part of an ecological study of this species in Clarence River region. Schooling behaviour of juvenile *M. macleayi* exhibited a lunar periodicity and mean daily abundance peaked five days after full moon. This was followed seven days later by a peak in mean daily abundance of emigrating juvenile *M. macleayi*. Fluctuations in the magnitude of the oceanic component of the total annual catch were found to determine the difference between high and low production seasons. During the period examined, there was a direct relationship between Clarence River discharge and the oceanic component of total production of *M. macleayi* for various time periods. Enhancement of the seasonal emigration of *M. macleayi* from the three estuaries in November due to increased river discharges has been reported and it was suggested that modification of discharges by restriction of freshwater flow could adversely affect production. After studying the tidal behaviour of post-larval penaeid prawns in a Southeast African estuary, Forbes and Benfield (1986) suggested that their movement into the water column is triggered by pressure changes and this is modified by light, salinity, and the nature of the substratum.

Attraction of post-larval brown prawn, *Penaeus aztecus* and white shrimp *P. setiferus* to estuarine water from Galveston Bay, Texas was measured by Benfield and Aldrich (1992) in a laminar-flow choice chamber. In replicate experiments conducted during their normal recruitment periods, both the species selected the estuarine water with significantly higher frequencies than the synthetic seawater (control). Experiments conducted through the end of the brown shrimp recruitment period indicated that estuarine water lost its attractiveness by late-autumn/early-winter suggesting a biogenic source of attractant. Post-larvae displayed a nonsignificant tendency to turn upstream in the estuarine water and downstream in the control, behaviour which is speculated to assist them in orienting towards nursery habitats.

Vance (1992) studied the activity patterns of *Penaeus merguiensis*, *P. esculentus* and *Metapenaeus endeavouri* in response to simulated tidal and day-night cycles in the laboratory. When these cycles were imposed separately, each species was more active at night and near the times of high tide. However, when the tidal and day-night cycles were imposed together, the relative strengths of the responses to the two factors differed among the species. *M. endeavouri* was strongly influenced by the day-night cycle, virtually no activity occurred during the day but peaks of activity at night occurred near high tide. *P. merguiensis* and *P. esculentus* displayed some activity during the day with peaks around and just after high tide. However, for these two species, the peaks of activity near high tide at night were found to be higher than the peaks during the day. All species were reported to be more active at night and in the natural habitat of the prawns.

Abundance and seasonal migrations of the penaeid shrimp, *Metapenaeus affinis* within Iraqi waters has been studied by Salman *et al* (1990). Migration of *M. affinis* from the Arabian Gulf to nursery grounds in the inland waters of Iraq has been reported to extends from May/June-January/February. Spawning at sea appears to occur immediately after emigration. Gonad development was not observed. The distribution and migration of the prawn, *Penaeus orientalis* population and the variation of the central fishing ground in seven area bay along the coast of the central Yellow Sea has been studied by Liu and Gao (1990). Every year in the middle of June and beginning of July, the newly released young prawns has been reported to inhabit mainly the shallow estuary of the bay and gradually disperse to the surrounding vicinity for feeding.

The use of smoothed splines to assess the distribution of humpy shrimps (*Pandalus goniurus*) in Anadyr Gulf in June-early July and in late July 1975 made it possible to compute migration speeds of commercial aggregations (Ivanov and Stolyarenko, 1992). The speed was found to decrease from 3.2 km/day to 1.4 km/day as the aggregations moved northeastward from the area off Cape Navarin. Sheridan *et al* (1987) investigated movements of brown shrimp, *Penaeus aztecus* and pink shrimp, *P. duorarum* relative to the US-Mexico border in the western Gulf of Mexico. Shrimp were collected by trawl, marked with polyethylene streamer tags and released during March-November at sites between Galveston, Texas and Tampico, Tamaulipas, Mexico. Tagged brown shrimp moved up to 620 km from release sites and remained free up to 430 days. Tagged pink shrimp moved a maximum 428 km and were free up to 446 days.

The stomach contents of deepwater prawns can indicate where prawns have been feeding since mid-water and bottom habitats each have characteristic sets of species . Recent research suggests that the diets of some North West Slope prawns, which are trawled by demersal gear, indicate that prawns not only migrate into midwater at night but also feed there (Rainer, 1994). Emmerson (1987) investigated tidal migration and feeding of the shrimp, *Palaemon pacificus* in Tippers Creek, Swartkops river estuary, Cape Province. They were found to invade the Zostera and adjacent *Spartina maritima* beds with the flood tides, then retreat back to the creek channel on the ebb tides. Significantly higher *P. pacificus* numbers were recorded throughout the transect during the day than during the night. The gut fullness index exhibited two peaks (day and night) and both were coincidental with the high tides. The composition of food items in the guts changed with time.

Juveniles of most of the cultivable penaeid prawns of the southwest coast of India are caught in large quantities from shallow brackishwater area, before they migrate to the sea for maturation and breeding. Fluctuations in the catches of juvenile prawns from the Cochin backwater with reference to rainfall, tidal flow and lunar periodicity have been observed (Anon, 1982). A detailed study has been made by Appuchand and Manisseri (1993) on emigration of juveniles of cultivable penaeid prawns in relation to depth, tide and some biological factors such as species composition, abundance, size, sex *etc*. The seasonal fishery for *Penaeus indicus* along the southwest and southeast coasts of India was studied by Manisseri (1988). Occurrence of *P. indicus* population in sequence along the fishing centres of the southwest and southeast coasts suggests probable migration of the prawn from the former to the latter coast during the fishing season. This confirms the presently believed migratory behaviour of the species. Another investigation conducted by Nandakumar (1988) on the banana prawn, *Penaeus merguiensis* fishery along the North Kanara coast during 1981-84 indicated sporadicity of occurrence and schooling behaviour of the species. Patterns of occurrence at different fishery centres suggest the species to have migrated in shoals from south to north along the coast. Kathirvel *et al* (1985) reported an unusual bumper catch of white prawn, *Penaeus indicus* from Kovalam Bay

Table 1: Light intensity of 15 watt bulb in various colours.

Colour of the bulb	Light intensity (Lux)	
	At the beginning of the migration ladder (measured at 220 cm from the light source)	At the end of the migration ladder (measured at 37 cm from the light source)
Ordinary	4	120
Milky	4	95
Yellow	2	60
Green	1	39
Red	1	32
Blue	1	28

Table 2 : Light intensity of 60 watt bulb in various colours.

Colour of the bulb	Light intensity (Lux)	
	At the beginning of the migration ladder (measured at 220 cm from the light source)	At the end of the migration ladder (measured at 37 cm from the light source)
Ordinary	816	54
Milky	45	690
Yellow	26	382
Green	10	122
Red	11	157
Blue	13	144

near Madras in December 1984. These unusually large catches were believed to be due to a southward migration of the species during to the prevailing southerly wind and current.

Rao and Gopalakrishnavya (1976) studied penaeid prawn catches from Pulicat Lake in relation to ingress of post-larvae and lake hydrography The post-larvae of *P. indicus* immigrate into the lake mostly during August-October and March-April and those of *P. monodon* during July-November and March-April. The post-larvae of *P. semisulcatus* immigrate during August-October and March-May/June. These larval peaks determine the magnitude of the subsequent prawn production in the lake. Natarajan (1991) recorded the day-night variations in the locomotor activity of *Penaeus indicus* and *P. monodon* grown in the culture pond adjacent to the Vellar Estuary, Porto Novo coast, south India in the laboratory using a simple acktograph recording system. Under natural photoperiodic regimes, these penaeids showed peak activity during darkness around 3-4 hrs after sunset. This nocturnal activity was persistent and free-run in constant darkness and was uninfluenced by 16-28^{0}C ambient temperatures suggesting an endogenous timer. Light appeared to be an efficient synchronizer of the rhythm. Temperature also entrained the rhythm if offered for substantially longer periods than the light stimuli.

James (1987) studied the diurnal variations in abundance of penaeid prawn post-larvae at Ennore Estuary near Madras. During 1983-1984, collections of penaeid prawn post-larvae were made by Renfro net at night and day near the bar mouth of Ennore estuary, during the 4 phases of the moon. The number of post-larvae was more during the night on 91% of the observed days in the first quarter, 81% of the days on new moon, 75% of the days in the last quarter and only 60% of the days on full moon. Number of post-larvae collected was usually more in the mornings of full moon rather than at nights. It was noticed that the day collections were generally richer during October and November in all the phases of the moon.

Berber (1984) has presented a summary comprising the main aspects of the biology, ecology and fishery of the species of Genus *Macrobrachium* inhabiting Atlantic and Pacific coasts of Mexico. Information on distribution, common names, food habits, habitat, sex ratios, sexual maturity, spawning, fecundity, larval stages, reproduction time period, growth, parasites and illnesses, predators, physical and chemical parameters influencing on their life-cycle and migrations have also been collected. Furthermore, fishery aspects of *M. acanthurus*, *M. tenellum*, *M. americanum* and *M. carcinus* also analyzed.The estuarine phase in the life-cycle of

Macrobrachium petersi has also been studied. A combined field and laboratory study was undertaken to investigate the eco-physiology of adult, juvenile, post-larvae and larvae of the species in relation to temperature and salinity distribution in Keikamma Estuary (Read, 1983). It has been observed that adults migrate to the estuary under flood conditions and upstream in response to elevated salinity.

Entry of freshwater prawns like *Macrobrachium lar fabricius, Macrobrachium australe* and other invertebrate in freshwater of Opunohu River catchment in Moorea, French Polynesia as juveniles and their migration upstream has been reported by Resh *et al* (1992). Their larval offspring has been observed to return to the ocean for growth and development. Mean size of *M. lar* has been found to be generally larger in upstream than downstream reaches. Martinez-Palacios *et al* (1985) reported a high migratory response of newly metamorphosed post-larval of *Macrobrachium* spp. in mixed larval rearing tanks during the dark period with a water flow range of approximately 1 lpm. In the northern Bolgoda Lake, Sri Lanka, Jinadasa (1985) observed that *M. rosenbergii* migrates into that lake from the nearby freshwater streams, twice during the year. The fishery for *M. rosenbergii* in the lake has been reported to coincides with its two spawning migrations.

Migration of freshwater shrimp to upstream from riverine pools biota in a Puerto Rican Montane stream resulting from a major hurricane has been reported by Covich *et al* (1991). Cartaxana (1992) observed migration of the prawn, *Palaemon longirostris* downstream in Mira River and estuary when seasonal rain begins. Furthermore, larval released activity has been reported to be concentrated in brackishwaters during winter and early spring. Prawns collected in brackishwater have been found to be bigger than those found in freshwater areas and almost 100% of females were ovigerous. Kwon *et al* (1977) has investigated the effects of chlorinity upon growth of earlier larvae and post-larva of the giant freshwater prawn, *M. rosenbergii* and established that zoea larvae required different chlorinities to grow according to each stage. Post-larvae are able to live better in freshwater than zoea larvae which only survive for 15 hrs. However, post-larvae can only live for one day in sea water while zoea larvae can live for six days. It has been suggested that radish pigments on the body surface may be directly proportional to chlorinity during the period of zoea rearing. Further, it has been suggested that in nature this species probably migrates from upstream to near the estuary of the river for spawning and growth.

Basic conditions of fishways for freshwater amphidromous shrimps, two atyids *Caridina japonica* and *Paratya compressa* and a palaemonid, *Macrobrachium japonicum* which migrate to upstream habitats by walking at night, has been studied using an experimental apparatus comprised of ten distinct flooring materials. The effective fishway conditions has been defined to be three-dimensional mesh structure (0.5 mm mesh size) *e.g.* cellular concrete, in the flooring less than or equal to 50 ^{0} at the inclination and less than or equal to 65 cm/sec at the surface current velocity in the fishway (Hamano *et al*, 1995).

Water-control structures are used in the coastal zone to enhance species-specific habitat, mainly for waterflow and in attempts to control saltwater intrusion and soil erosion. These structures invariably affect the movement of marine transient organisms. Rogers *et al* (1992) used traps and trawls to evaluate the effects on nekton of a low-elevation weir, a fixed-crest weir and a slotted weir. Species richness and emigration of most species decreased as water control increased. Average weight *per* emigrating brown shrimp, *Penaeus aztecus* increased with water control, although total biomass decreased. Immigration and emigration of brown shrimp were delayed by water control and this effect was increased in ponds having greater water control. The number of emigrating brown shrimp was reported to be 3.4 times greater (1.8 times greater for biomass) from a pond controlled by a slotted weir than from one controlled by a fixed-crest weir. Knudsen *et al* (1989) investigated the effects of water control weirs on growth, emigration and mortality of brown shrimp, *Penaeus aztecus.* Juvenile brown shrimp were captured, marked and released in two shallow water marsh ponds. One pond had a weir at its only exit. All surviving marked brown shrimp were recaptured as they emigrated from each pond. Total biomass of brown shrimp emigrating from the unweired pond was more than double the biomass from the weired pond.

The observation of a large-scale upstream migration of a population of *M. australiense* at Glebe Weir on the Dawson river, south-east Queensland has been reported by Lee and Fielder (1979). Concentrations of migrating prawns were first observed on the vertical buttress wall of the weir at 16.45 hrs and within 30 minutes, dense aggregations were observed on the wall. Each prawn took 60-90 minutes to climb the weir and disperse. It has been postulated that on migration after completing their life-cycle within the freshwater system, they acquire a positive rheotactic response to prevent themselves being washed into the sea.

A number of palaemonid prawns occur in the

Godavari estuarine system but very few of them like *Macrobrachium rosenbergii*, *M. malcolmsonii*, *Palaemon tenuipes* and *Palaemon styliferus* are of commercial importance. The fishing grounds of all the prawns are confined to the lower saline zone of the estuary. The fishing season for them coincides with their breeding migration to this area, both from the sea and the upper freshwater stretches of the river. However, declining trend in prawn production with fall in flood discharges due to the construction of major river projects has been reported by Subrahmanyam (1990). Man-made hurdles like regulators, anicuts and dams on the rivers cause hardship to these prawns in accomplishing their normal course of life. *M. malcolmsonii* is found to surmount these obstacles with great adaptability whereas in the other species, depletion of the stock has occurred at many places (Raman, 1987).

General biology of giant freshwater prawn, *Macrobrachium rosenbergii* with relevance to culture of the species has also been described and aspects such as species identity, food habits, growth, habits, sexuality, maturity, breeding migrations, fecundity, induced maturation and incubation have been examined (Rao, 1986, 1991; Pandey and Kumar, 2006a, b, 2007; Pillai *et al*, 2010). Murthy *et al* (1987) has studied the reproductive biology of the freshwater prawn, *Macrobrachium equidens* at Netravathi-Gurpur estuaries and observed that species appeared to migrate from the freshwater zone of the river to the estuary for breeding. Furthermore, it has been observed that exposure to an estuarine environment is obligatory for the first moult of the non-feeding zoea of the riverine prawn, *Macrobrachium* (Pandian, 1987). Hence the riverine migration is critical for successful completion of its life-cycle. Several species of *Macrobrachium* have been reported to become totally freshwater habitants, producing fewer eggs and restricted larval life. Other species inhabit brackishwater and undergo less risk. In a few other species, adults migrate to the estuary and spawn a large number of eggs. Their duration of non-feeding first zoeal stage is brief. In the other species, the first zoea stage lasts longer and undertakes passive migration. Annual reproductive cycles of both sexes of the freshwater prawn, *Macrobrachium birmanicum choprai* in the Ganga river has been studied by Singh and Roy (1994) and distinct histological changes in the gonads of both sexes during the reproductive cycle was observed. While the male did not exhibit a distinct breeding peak, the female recorded a distinct reproductive peak in July/August. The animals did not appear in the catches from late October-February probably owing to their migration into deeper zones of the rivers.

Light and water current as inducers of migration in *Macrobrachium rosenbergii*

Since there exists much scope of work for scientific investigation in the area of prawn migration, an attempt has been made to evolve a model at laboratory scale to study the migration in the giant freshwater prawn using light intensity and water current as triggers. The potential applications of this work lies - (i) in the development of a system for harvesting of the prawn crop by a new method based on light intensity and water current, (ii) in planning and design of barrages across the freshwater rivers in estuarine/coastal areas with least affect on prawn migration to upstream river side and (iii) in evolving a new system for collection of the prawn brooders/berried female from the natural sources. Apart from being a fundamental research, this investigation will be having applied values for further development of prawn aquaculture. The present work was designed with the objectives to - develop an experimental model on controlled ecosystem to study prawn migration, to study the inducement of migration in prawn using various intensities of light and water current and to evolve the optimum parameters of the light intensity and water current as induces for migration of *M. rosenbergii*.

Macrobrachium rosenbergii (de Man) were collected from rivers in Bilimora (Gujarat) and Bhiwandi (Maharashtra) as well as from the aquaculture farms in Nellore (Andhra Pradesh). After collection, prawns were temporarily kept in 250 liter capacity tanks made of high density polyethylene (HDPE) with aeration from battery operated aerators. Maximum 20 prawns were kept in each tank. They were then acclimatized to 23^0C by gradually reducing water temperature using ice and chilled water. Thereafter, the prawns were transported to the experimental site at Koturde village, Mahad, district Raigad (Maharashtra) in oxygen inflated polyethylene bags. Each plyethylene bag was filled in with five liter of freshwater of same temperature as of tank water. Thereafter, depending upon body weight (biomass) and transportation duration, 4-6 prawns were shifted into each bag. Polyethylene bag was inflated with oxygen gas and tied tightly using rubber bands to avoid leakage of gas as well as water during transportation. This inflated bag containing prawns was kept inside a card board box. Thermo-coal sheets of 8 mm thickness were placed at all sides between bag and box wall for thermal insulation to avoid rising of water temperature during transportation. 2-4 small polyethylene bags packed with ice cubes of size 250 gm each were placed between the thermo-coal sheet and oxygen inflated polyethylene bag at its corners. This was done in order to maintain lower temperature during transportation. Then card board box was packed using cello tape and prawns were transported to experimental site. The size of female prawns used were in the range of 25-125 g while that of male was above 250 g.

Natural water of Koturde Dam at Mahad in district Raigad (Maharashtra) was used without any treatment or modification in its physico-chemical properties. Dissolved oxygen (DO) concentration of the water used during investigation varied between 5-6 mg/l, pH being 6.9. Temperature of water used for prawn migration during night varied between 23.5 and 27.5^{0}C. Daytime temperature of water was measured to be 27.5 - 32^{0}C. Feed used for feeding prawn during the course of investigation was squids and cuttle fish collected from the nearby sea coast at Shrivardhan. Required quantity of fresh feed was collected on fortnightly basis and kept in deep freezer for feeding as per schedule. Prawns were fed @ 2-4% of their body weight (twice daily) during morning (9.00 hrs) and evening (16.00 hrs).

Experimental setup: The present study was carried out with main objective of developing a controlled model of ecosystem with light and water current as trigger to induce migration of prawn. For this purpose, a laboratory model of the ecosystem was developed. The experimental set up consisted of - (i) Holding Chamber,(ii) Migration Chamber and (iii) Migration Ladder (Fig. 3).

While holding chamber of the laboratory model represented freshwater body at downstream side of a river, migration chamber represented for freshwater area in upstream side. Since in actual field condition, the bed slope of water body is usually not more than 1:10, the migration ladder, connecting holding as well as migration chamber together were given the same slope. The shape of holding chamber and migration chamber was selected as circular because of easy operation and low maintenance cost. The holding chamber and migration chamber were made of FRP made circular tanks, 90 cm in diameter and 85 cm in height. Holding chamber was provided with a natural bottom of sandy clay - soil. Migration chamber bottom was in FRP itself. Capacity of each of these tanks was 100 liters. Migration ladder was made in U shape using a FRP sheet of size 1.85 x 120 cm. Bottom width of migration ladder was 60 cm, height of each of the two side walls being 30 cm. The entire setup was fabricated in FRP sheet of thickness 1.3 mm using isothelic resin with a provision for placement of migration chamber at different heights with respect to holding chamber for providing migration ladder a desired slope. Migration ladder was joined together with holding chamber and migration chamber at the top, allowing free flow of water and prawn migration across the desired gradient. The water was pumped to the ecosystem using 1 hp centrifugal pumps. The water flow was regulated by polypropylene ball valves mounted at the discharge end of the pump.

Illumination arrangement: In order to provide suitable illumination of various intensities, 15 and 60-watt bulbs in various colour were used in the specially made provision over the water level in the migration chamber, illuminating the migration ladder up to its furthest point**.**

Measurement of water flow rate: The experiments were conducted at various arbitrarily chosen value of water current as mentioned below. The water current was measured using Pilot tube which is a standard device for measurement of the water velocity.

Flow rate/water current	Low	Medium	High
Flow rate (cum/hr)	1.50	3.00	6.00
Water current (m/sec)	0.50	0.75	1.50

Measurement of light intensity : The light intensity was measured using lux meter at two different points in the experimental setup - (i) at the beginning of migration ladder (37 cm from the light source) and (ii) at the end of migration ladder.

The light intensity of 60-watt bulbs in different colour was adjusted to full, medium and low levels using a voltage regulator. The data on light intensities of 15 - and 60 - watts bulbs in different colour measured at above two points in the controlled model of the eco-system developed for the purpose are presented in the Tables 1 & 2.

Experimental Procedure: The water current was created inside migration ladder due to gravity flow, continuously flowing through it at a uniform flow rate from migration chamber towards over flow level drainage outlet in holding chamber. Freshwater from the dam was directly pumped into the migration chamber. The overflow of water from the migration chamber under gravity through migration ladder to the holding chamber resulted in creation of water current. The water flow inside the migration ladder and subsequently the water current was adjusted to various levels by regulating the discharge of pump, pumping the dam water. The water current in the migration ladder was maintained at a constant rate throughout a particular study by continuous pumping of the dam water into the migration chamber, the excess water being drained out through the overflow outlet in holding chamber. The various flow rates used for study were 1.35, 3 and 6 cu-m/hr.

The migration ladder was kept illuminated throughout a particular study by two bulbs of either 15- or 60-watt capacity each. 15-watt bulbs were used while investigating the prawn migration at low light intensity at a particular value of water current. During investigation on high light intensity, 60-watt bulbs were used. Bulbs used during the study were in various colours *e.g*. red, green, blue, yellow, milky as well as ordinary for their different intensity in same wattage capacity. While studying the migration in dark condition, the bulbs were kept off. The entire set up was kept inside a closed room in order to maintain a particular light condition and to avoid outside disturbances.

The study was conducted by observing the migration at regular interval in a batch of *M. rosenbergii* against the water current to migration chamber under various combination of water current and light intensity. The various combination of water current and light intensity used during study were - (i) low water current (0.50 m/sec) and low light intensity (15 - watt bulbs), (ii) low water current (0.50 m/sec) and high light intensity (60 - watt bulbs), (iii) moderate water current (0.75 m/sec) and high light intensity (60 - watt bulbs), (iv) high water current (1.50 m/sec) and high light intensity (60 - watt bulbs), (v) low water current (0.50 m/sec) in dark condition, (vi) moderate water current (0.75 m/sec) in dark condition and (vii) high water current (0.50 m/sec) in dark condition.

In each batch, 10 prawns were taken after daily evening feeding at 16.00 hrs. With water supply to migration chamber and light illuminating the migration ladder on, these prawns were kept in holding chamber at 18.00 hrs. The squid cut to small pieces were added to holding and migration chamber @ of 1% of body weight in each and the experiment started. Next day at 08.00 hrs, prawns migrated to migration chamber as well as those of holding chamber were taken out and kept in a separate tank and fed with squid @ 2% of their body weight at 09.00 hrs and 16.00 hrs. The dead prawns (if any) and the shell of moulted prawns were removed from the set up. The same batch of prawns was used for the seven experiments using different colours (*e.g.* red, green, blue, yellow, milky, ordinary and dark condition) of the bulbs of either 15 - or 60 - watts but for the same value of water current. Thereafter, those prawns were released to culture tanks. The entire experiment was repeated for 3-5 times using new batches of prawn. The light was kept off while studying the migration in during dark condition.

During the course of investigation, observing migration of prawns at regular interval under different light intensities and water current conditions were carried out. The numbers of prawn migrated from holding chamber to migration chamber over the period of 2, 4, 6, 8, 12 and 14 hrs were recorded. Observation on prawn migration was made by counting the number of prawns in migration chamber without any disturbance. An ordinary two-cell torch was used to count the number of migrated prawn into migration chamber. The experiment was repeated for minimum three batches at a particular light intensity and water current. During experiments, it was observed that before commencement of migration, 4-6 prawns gathered in the holding chamber at the entrance of the migration ladder against the water current. Then an individual or some time two prawns started migration towards migration chamber. After their migration to migration chamber, others followed the pursuit either individually or together with another prawns.

Data on migration of prawns show that at low water current of 0.50 m/sec and low light intensity of two numbers of 15 - watt bulb of various colours, percentage of prawn migrated to migration chamber at the end of 14 hrs exceeded 50%. The intensity of light emitted from 15- watt bulbs used during investigation has been found to be 28-120 lux (Table 1) measured at 37 cm from the light source. Average of prawn migrated to migration chamber at the end of 14 hrs at low water current and low light intensity of red colour (32 lux), green colour (28 lux), blue colour (39 lux), yellow colour (60 lux), milky colour (95 lux) and ordinary (120 lux) were observed to be 60%, 50%, 50%, 54%, 52% and 56%, respectively. At low water current of 0.50 m/sec, average percentage of prawn migrated under dark condition was observed to be 54%. No migration was observed to have taken place up to 20.00 hrs. However, few migrations were observed before mid- night. Significant enhancement in migration of prawns was noticed after 001 hrs with peak towards dawn. Moreover, few migrations were also noticed between 06.00 hrs up to 08.00 hrs.

Data on migration of prawns show that for the same value of water current (0.50 m/sec) but with increase in light intensity using two number of 60 - watt bulbs, percentage of prawn migrated to migration chamber at the end of 14 hrs differed to earlier observed readings at low light intensity. Average of prawn migrated to migration chamber at the end of 14 hrs at low water current and high light intensity of red colour (157 lux), green colour (122) lux, blue colour (144 lux), yellow colour (382 lux), milky colour (690 lux) and ordinary (816 lux), all measured at 37 cm from the light source, were observed to be 57%, 47%, 50%, 33%, 27% and 20%, respectively. No migration was observed to have taken place up to 22.00 hrs. Few migrations were observed before mid-night. Enhancement in the migration of prawns was noticed towards dawn.

Difference in migration of prawns under low light intensity of 15 - watt bulbs of red, green and blue colours to that of under 60 - watt bulbs of the same colour has been observed to be less significant. However, considerable difference has been observed in migration under yellow, milky and ordinary bulbs of 15 - watt to that of less than 60 - watt. This was probably due to wide difference in the light intensity of bulbs of these colours in 15 - and 60 - watt (Table 1, 2).

Data on prawn migration at a moderate water current of 0.75 m/sec and high light intensity of two numbers of 60 - watt bulbs in different colours show that with moderate enhancement in water current migration was further reduced. Average of prawn migrated to migration chamber at the end of 14 hrs at moderate water current and high light intensity of red colour (157 lux), green colour (122) lux, blue colour (144 lux), yellow colur (382 lux), milky colour (690 lux) and ordinary (816 lux), all measured at 37 cm from the light source, were observed to be 47%, 37%, 40%, 27%, 23% and 17%, respectively. Moreover, at this value of water current, average percentage of prawn migrated under dark condition also got affected and only 33% migration was observed. No migration was observed to have taken place up to 20.00 hrs, however, few migrations were observed before mid-night. Enhancement in the migration of prawns was noticed towards dawn. migration continued up to 08.00 hrs. When the water current was increased to 1.5 m/sec, no migration did take place either under light or in dark condition. Moreover, no migration was observed during the day period after 09.00 hrs.

It is evident from present investigation that at low water current, no significant difference has been noticed in the numbers of prawn migrated under and with low light intensity of up to 120 lux emitted from two numbers of 15-watt bulbs in various colours. However, significance influence of colour of 60-watt bulbs, emitting light of higher intensity, was seen on migration of prawns at low and moderate water current. Migration was observed to be higher under light emitted from two numbers of 60-watt bulbs in red, blue and green bulbs than yellow, milky and ordinary. Under light emitted from 60-watt bulbs, maximum migration was observed using a red colour bulb. However, it was seen to be minimum under ordinary bulbs of same capacity, probably due to difference in the intensity of light emitted from this colour bulb to that of red colour.

The characteristics in number of prawn migration showed that in the controlled model of ecosystem with migration ladder placed at a slope of 1 in 10 *i.e.* 5.71^0 maximum migration of prawn did take place when the flow rate was 1.35 cu-m/ hr, water current being 0.50 m/sec with low light intensity up to 120 lux measured at 37 cm from the light source. When the bed slope of the migration ladder was increased from 1:10 to 1:4 (*i.e.* from 5.71^0 to 15.68^0) the migration of prawn completely stopped probably due to increased water current. Change in the migratory behaviour of the prawns indicated that the migration was greatly influenced by the light intensity and water current.

This study demonstrates that at low water current of 0.50 m/sec and under low light of 15-watt bulbs, the colour of bulb does not have much significance role to be played. However, at a comparatively higher velocity of 0.75-m/sec, migration is significantly influenced with colours of the bulbs emitting light of higher intensity. Therefore, it is established that light intensity and water current do affect prawn migration significantly. During investigation, it has been observed that when feed was added only to holding chamber and migration chamber was kept without any feed, prawn migrated to migration chamber returned back to holding chamber between 4-8 a.m. Moreover, once shifted to experimental setup from the culture tank, the body colour of prawns changed from white-brown and became black, probably due to black colour of the experimental setup. After migration from holding chamber, it was observed that few prawns moulted in the migration chamber. Once shifted from migration chamber after completion of the batch to culture tank and kept with male prawns, most of the remaining prawns also moulted and became berried.

CONCLUSIONS

(i) Light intensity and the water current influences the migration of *M. rosenbergii.* Enhancement in light intensity and water current beyond certain limit has adverse impact on migration of the prawn. However, it is water current which more significantly influences the prawn migration. During the present investigation, prawn migration was found to be maximum at low light intensity below 160 lux and at low water current of 0.50 m/sec.

(ii) At low light intensity of a 15-watt bulb, migration of the freshwater prawn was mainly affected by water current and significant migration has been observed even in dark condition.

(iii) At high illumination of a 60-watt bulb in low water current condition, migration of *M. rosenbergii* was observed to be more with red, blue and green bulbs than that of yellow, ordinary and milky. This was probably due to less intensity of the light of the red (157 lux), green (122 lux) and blue (144 lux) bulbs to that of ordinary (816), milky (690 lux) and yellow (382 lux) for the same rating (wattage).

(iv) Percentage of *M. rosenbergii* migrated up to 02.00 hrs in the night under the illumination of 15 - watt bulb of lower intensity has been observed to be more to that of under the illumination of 60 - watt bulb of higher intensity. Bright light appears to have adverse effect on migration.

(v) At high water current of 1.50 m/sec, no migration of prawn was observed. As such, high water current appears to be detrimental to migration of *M. rosenbergii*.

(vi) No migration of prawn was observed during the day period between 09.00-18.00 hrs. Furthermore, only few prawns were observed to have migrated before the midnight. The investigation suggests that high migration starts after midnight in *M. rosenbergii* which is extended up to the dawn.

(vii) It was observed that *M. rosenbergii* always migrated from the sides of the migration ladder and not from the middle of the ladder. During migration, the prawns were seen walking against the water current from the sides of migration ladder.

(viii) Migration was faster in small to medium sizes of *M. rosenbergii* in the range of 40-100 g while it was less in bigger prawns. In large-sized prawns, migration in males was observed to be very less probably due to old age and bad health (necrosis in legs).

(ix) The level difference between the bottom of the holding chamber and the migration ladder was found to have considerable effect on the percentage of *M. rosenbergii* migrated to migration chamber. Migration was found to be more when the bottom of the holding chamber was given a gentle slope from the lowest level of migration ladder towards the outlet in the holding chamber. With increase in this level difference in the bottom of holding chamber to the migration ladder, the migration was reduced.

(x) Noise/vibrations in surroundings due to operation of machinery such as DG set and air - blower adversely affected the migration of the freshwater giant prawn.

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