Journal of Aquaculture Research & Development

Soundarapandian et al., J Aquac Res Development 2014, 5:7
DOI: 10.4172/2155-9546.1000280

Research Article Open Access

# Effect of Temperatures on the Embryonic Development, Morphometrics and Survival of Macrobrachium Idella Idella (Hilgendorf, 1898)

**Soundarapandian P*, Dinakaran GK and Varadharajan D**

*Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai–608 502, Tamil Nadu, India*

## Abstract

The development of *M. idella* idella eggs incubated at four different temperatures (26, 30, 33 and 36°C). An increase in major axis length was evident at 26, 30, 33 and 36°C. However at 36°C, size variation increased with developmental stages, indicating abnormalities until 192 h, after which total mortality was observed. A distinct change in morphometric parameters (major half axis, minor half axis, area and perimeter) was demonstrated at higher temperatures, irrespective of the developmental duration of eggs. Length of hatched embryos increased with increasing incubation temperatures. Therefore a rapid rate of increase of major half axis and early hatching was observed at 33°C. The larva hatched first in 33°C (241 hrs) then followed by 30°C (265 hrs) and 26°C (302 hrs). In 36°C (182 h) there was total mortality during embryonic development so there was no hatching.

**Keywords:** *M. idella* Idella; Embryonic development; Temperatures; Effect; Survival

## Introduction

The emission of greenhouse gases and carbon dioxide are expected to increase global mean temperature by 1.5-4.5°C over the next half-century [1]. The impact of such a large temperature will affect the biological functions of freshwater and marine fishes and shellfishes, as most of the species are poikilothermic in nature. Thermal tolerance of aquatic animals is also dependent on acclimation temperature and the duration of acclimation [2]. Over the years, attention has focused on the thermal tolerance of embryos and larvae [3] that are more sensitive to temperature changes than adult fishes [4]. The earlier investigation on Labeo rohita revealed similar results [5]. The embryos of temperate species are more sensitive to extreme temperatures than embryos of tropical species [6]. In general, thermal limits are narrower for early stages and reduced survival of embryos and juveniles. Whereas it was wider for adults [7]. It is also reported that upper lethal temperatures of embryos, larvae [8] and adults [9] of the freshwater Mozambique tilapia (Oreochromis mossambica) varies in the range of 2°C among different life stages. In *M. rosenbergii* and *P. serratus* higher temperature seems to be shortening the incubation period [10]. Hence, the present study was undertaken to assess the effect of low and higher temperatures on the incubation period and embryonic development of edible prawn *M. idella* idella.

## Materials and Methods

### Experimental animals

Gravid or Berried females (80-90 mm) with opaque, greenish, round or oval in shape fertilized eggs in their brood pouch were used for the present experiment.

### Experimental conditions

Twelve newly spawned brooders were stocked; one in each 120L fiber glass tank to assess the effect of incubation temperature on embryonic stages of *M. idella* idella Acclimation was carried out at one degree per day from water temperature (25°C). Since the experiment was carried out during December to January the normal water temperature was found to be 25-26°C.

### Temperature maintenance

The test temperatures (26, 30, 33 and 36°C) were regulated by using automatic thermostat until hatching of the eggs. Sampling of eggs was carried out once the cleavage was completed, since this early development phase was not easily observed and was considered as the initial period (0 h). Eggs were sampled aseptically by gently removing a bunch of eggs from the brood pouch using sterilized forceps and separated with the help of needle and forceps without damaging the eggs. After each sampling, brooders were given a 1-min prophylactic fungus dip treatment in malachite green (5 mg $L^{-1}$) before being returned to incubation tanks.

### Sampling

In four different temperatures the embryonic stages of two brooders were rarely matched. Therefore, embryos were sampled at several intervals (i.e. 0, 24, 48, 72, 96, 120, 144, 168, 192, 216, 240, 264, 288 and 312 h) from each brooder. Organogenesis, developmental changes and physiological processes were recorded under a light microscope. Eggs collected from four sampling points of brood pouch (anterior to posterior) were pooled to minimize sampling error due to position of eggs in brood pouch and assessed the percentage mortality of fully developed embryos (from an aggregate of 12 embryos/brooder) at the onset of hatching. Embryo dimensions (major axis, minor axis, area and perimeter) were measured at 48-h intervals (0, 48, 96, 144, 192h) until total mortality or hatching occurred.

## Results

### Organogenesis and morphophysiology of eggs

Development of *M. idella* idella eggs incubated at four different

***Corresponding author:** Soundarapandian P, Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Parangipettai –608 502, Tamil Nadu, India, Tel: 04144-243223; E-mail: soundsuma@gmail.com

**Received** August 14, 2014; **Accepted** October 29, 2014; **Published** November 03, 2014

**Citation:** Soundarapandian P, Dinakaran GK, Varadharajan D (2014) Effect of Temperatures on the Embryonic Development, Morphometrics and Survival of Macrobrachium Idella Idella (Hilgendorf, 1898). J Aquac Res Development 5: 280. doi:10.4172/2155-9546.1000280

temperatures is presented in Plate 1. At 0 h, eggs in all the treatments were in similar phase of development (morula stage) and primodial mesodermal and endodermal cells were visible. After 24 h, the blastocyst was visible in all the four-temperature treatments. Embryos were visible after 48 h in all the treatments. However, abnormal embryonic development was evident at 36°C. At 72 h, the primodial compound eye was visible. At 96 h, a considerable increase in the length of the major axis was seen at higher temperatures (30, 33 and 36°C). At 120 h, star shaped and round protoplasmic islands was visible at 33 and 36°C, respectively and heartbeat was discernible at all temperature treatments. The compound eye with a visible optic lobe was visible at higher temperatures (30, 33 and 36°C). At 144 h, star shaped protoplasmic islands appeared at lower temperatures (26 and 30°C). Rudiments of appendages started developing at all acclimation temperatures. At 168 h, paired compound eyes were visible in all treatments. At 192 h, star shaped protoplasmic islands were seen at lower temperatures (26 and 30°C) while at 36°C, protoplasmic islands appeared was degenerated. After 192 h, complete mortality was noticed at 36°C (Plate 1).

At lower temperatures, rudiments of appendages were visible. The primodial digestive canal developed in segments as a dotted line in the posterior region, and appeared to originate from primodial hepatopancreas. The primodial brain was visible at the anterior part of primodial hepatopancreas. The major half axis attained maximum length at the time of hatching. Hatching was initiated by a sudden twitching movement in the posterior region (below the compound eye) by means of the rudimentary antennule. At the time of hatching, telson (or tail) and rudiments of uropod (folded below compound eye) unfolded and the embryonic case was removed from anterior portion by straightening of abdominal segments. Embryos hatched out with a jerky movement and all the anterior appendages in the cephalothoracic region (including walking legs) were started moving vigorously. The larva hatched first in 33°C (241 hrs) then followed by 30°C (292 hrs) and 26°C (340 hrs). In 36°C (192 h) there was total mortality during embryonic development so there was no hatching. Finally, larvae appeared bilaterally symmetrical (zoea 1) (Tables 1-3 and Figure 1). The embryonic development duration decreased with increasing temperatures as indicated by the negative slope in the linear regression equation, y=14.909x + 732.15 and R2=0.9932 (Figure 2).

## Embryonic morphometry

The data on embryonic morphometry of *M. idella* idella exposed to four incubation temperatures (26, 30, 33 and 36°C) are reported in Table 1. An increase in major axis length was evident at 26, 30, 33 and

| S. No. | Incubation temperatures (°C) | Mortality at hatching (%) |
|---|---|---|
| 1 | 26 | 28.75 ± 0.70 |
| 2 | 30 | 25.0 ± 0.77 |
| 3 | 33 | 42.33 ± 0.66 |
| 4 | 36 | 99.00 ± 0.49 |

**Table 1:** Percentage mortality of fully developed embryos at different incubation temperatures (mean of 12 values ± SE).

| S.No. | Incubation temperatures (°C) | Duration of development |
|---|---|---|
| 1 | 26 | 340.00 ± 0.81 |
| 2 | 30 | 292.08 ± 0.79 |
| 3 | 33 | 241.00 ± 0.95 |
| 4 | 36 | 182.07 ± 0.53 |

**Table 2:** Duration of embryonic development with increasing incubation temperatures from morula to eggs hatching (mean of 12 values ± SE).

| Parameter | Duration of embryonic development | Acclimation temperatures (°C) | | | |
|---|---|---|---|---|---|
| | (h) | 26 | 30 | 33 | 36 |
| Major half axis (µm) | 0 | 260.15 ± 3.54 | 270.3 ± 3.33 | 275.71 ± 2.63 | 275.06 ± 3.21 |
| | 48 | 273.26 ± 2.96 | 276.65 ± 2.64 | 279.17 ± 1.36 | 281.61 ± 2.36 |
| | 96 | 279.18 ± 3.08 | 285.95 ± 1.86 | 291.11 ± 3.23 | 289.23 ± 2.15 |
| | 144 | 287.23 ± 2.67 | 290.60 ± 4.38 | 298.20 ± 2.21 | 303.10 ± 3.25 |
| | 192 | 293.12 ± 3.56 | 303.72 ± 3.25 | 308.16 ± 2.06 | 311.69 ± 7.31 |
| | **Mean ± SE** | 278.58 ± 5.72 | 285.44 ± 5.77 | 290.47 ± 5.99 | 292.13 ± 6.75 |
| Minor half axis (µm) | 0 | 224.61 ± 3.18 | 233.07 ± 4.37 | 234.06 ± 1.62 | 235.16 ± 3.02 |
| | 48 | 227.15 ± 2.96 | 233.5 ± 2.38 | 235.61 ± 1.68 | 232.22 ± 2.12 |
| | 96 | 231.38 ± 2.24 | 235.61 ± 2.52 | 237.56 ± 3.18 | 234.81 ± 4.16 |
| | 144 | 234.77 ± 2.52 | 236.04 ± 1.86 | 238.11 ± 2.20 | 239.16 ± 3.69 |
| | 192 | 236.03 ± 2.37 | 237.30 ± 2.45 | 238.65 ± 1.85 | 240.56 ± 3.28 |
| | **Mean ± SE** | 230.79 ± 2.17 | 235.10 ± 0.79 | 236.80 ± 0.85 | 236.38 ± 1.52 |
| Area (x10$^5$) (µm$^2$) | 0 | 1.83 ± 0.38 | 1.98 ± 0.28 | 2.03 ± 0.23 | 2.03 ± 0.36 |
| | 48 | 1.95 ± 0.56 | 2.03 ± 0.18 | 2.07 ± 0.32 | 2.05 ± 0.26 |
| | 96 | 2.03 ± 0.28 | 2.12 ± 0.42 | 2.18 ± 0.19 | 2.13 ± 0.19 |
| | 144 | 2.12 ± 0.26 | 2.16 ± 0.33 | 2.23 ± 0.16 | 2.28 ± 0.42 |
| | 192 | 2.17 ± 0.41 | 2.26 ± 0.27 | 2.31 ± 0.40 | 2.35 ± 0.32 |
| | Mean ± SE | 2.02 ± 0.07 | 2.11 ± 0.06 | 2.16 ± 0.06 | 2.17 ± 0.08 |
| Perimeter (µm) | 0 | 1522.16 ± 24.36 | 1580.60 ± 32.21 | 1600.68 ± 30.12 | 1602.09 ± 26.62 |
| | 48 | 1571.32 ± 32.41 | 1601.86 ± 28.06 | 1616.41 ± 22.02 | 1613.44 ± 17.24 |
| | 96 | 1603.19 ± 30.21 | 1637.73 ± 31.68 | 1660.04 ± 19.83 | 1645.47 ± 42.33 |
| | 144 | 1639.06 ± 28.25 | 1653.67 ± 22.63 | 1684.04 ± 34.22 | 1702.71 ± 36.23 |
| | 192 | 1661.53 ± 22.32 | 1698.82 ± 33.72 | 1717.01 ± 28.43 | 1734.07 ± 23.54 |
| | Mean ± SE | 1599.45 ± 22.5 | 1634.54 ± 18.8 | 1655.64 ± 19.5 | 1659.56 ± 24.6 |

**Table 3:** Effect of incubation temperatures (26, 30, 33, 36°C) on morphological changes during the embryonic development of *M. idella idella* eggs until hatching.

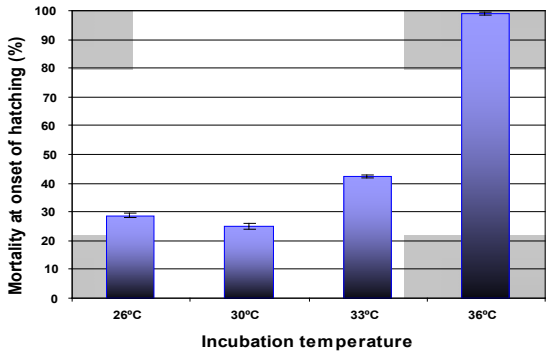


**Figure 1:** Percentage mortality of fully developed embryos at the onset of hatching.

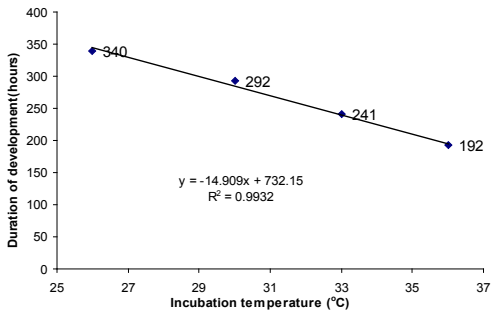


**Figure 2:** Duration of embryonic development with increasing incubation temperatures (morula to hatching). Data labels against each incubation temperature indicate the actual duration of development (mean of 12 values).

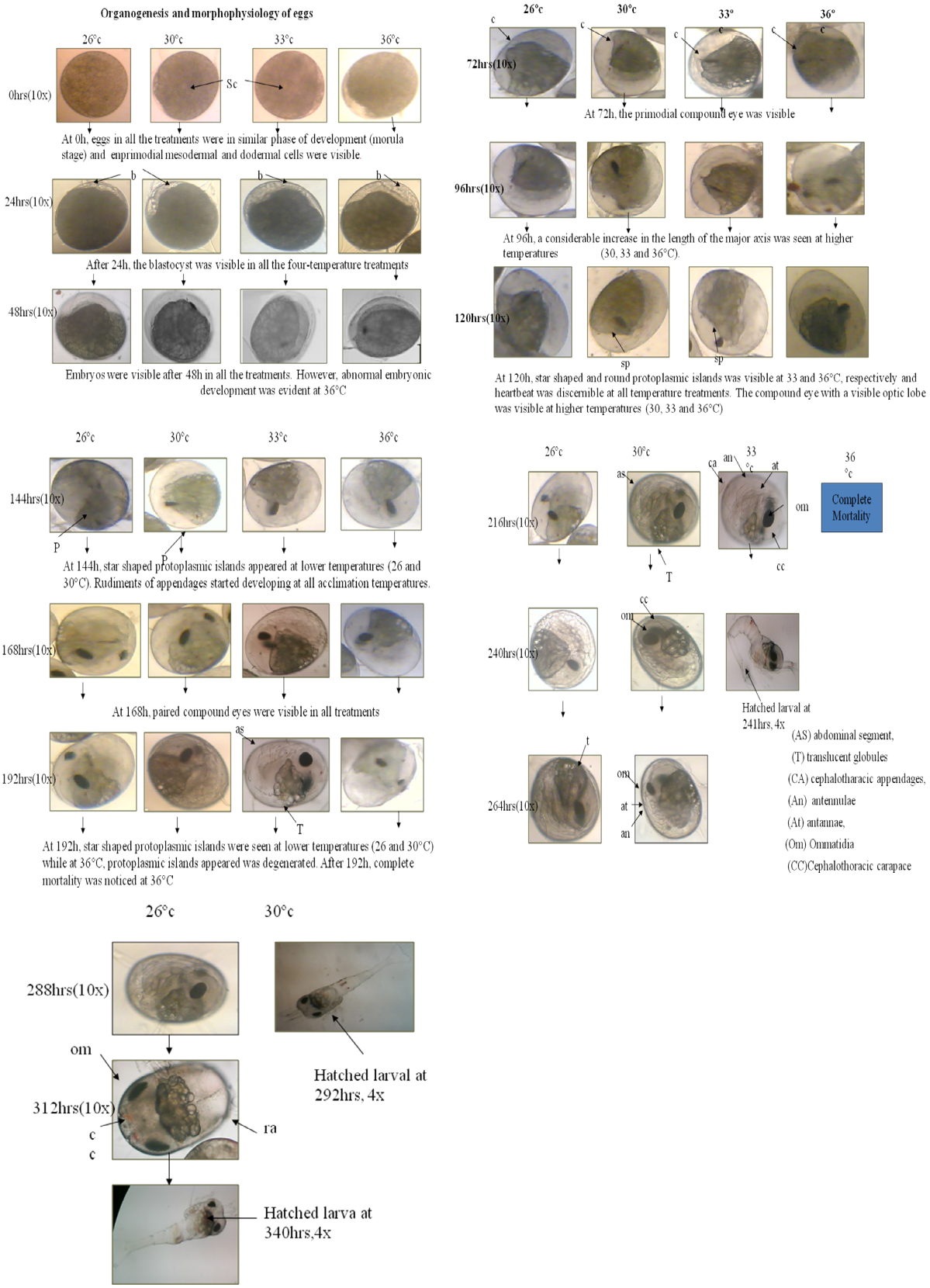


**Plate 1:** Development of *M. idella idella* eggs incubation at four different temperatures. sc-superfical cleavage, b-blastocyst, c-compound eye, p-protoplasmic island, sp-starshaped protoplasmic island, ra-rudimentary alimentary canal, an-antennule, at-antannae, om-Ommatidia, cc-Cephalothoracic carapace, ca-ephalotharacic appendages, as-abdominal segment.

36°C. However at 36°C, size variation increased with developmental stages, indicating abnormalities until 192 h, after which total mortality was observed. A distinct change in morphometric parameters (major half axis, minor half axis, area and perimeter) was demonstrated at higher temperatures, irrespective of the developmental duration of eggs. Length of hatched embryos increased with increasing incubation temperatures.

Therefore a rapid rate of increase of major half axis and early hatching was observed at 33°C (Plate 1).

## Discussion

Prior knowledge on the effects of temperature on cultured aquatic organisms, especially during embryogenesis, is a prerequisite for successful hatchery operation and seed production. Embryonic development is a complex process in which cellular differentiation and proliferation occurs simultaneously but at different rates [11]. Both organogenesis and somatic growth are controlled by enzymatic activities. Embryonic development of ectotherms mainly depends on the differential expression of certain genes and temperature [12] and the rates of their biological functions are critically dependent on environmental temperature. The effect of temperature on developmental rate is direct and development is faster at higher temperatures. However, this increase of developmental rate of embryos at higher temperatures occurs only within tolerable thermal limits [13]. In the present study, organogenesis and physiological responses of *M. idella* idella eggs incubated at different temperatures indicates that higher temperatures increase the rate of embryonic development. Dark brownish structures appearing on the surface of embryos during the development phase of *M. idella* idella are known as protoplasmic islands. Morphology of protoplasmic islands of embryos was specific at different incubation temperatures. Embryos with round, oval or star shaped protoplasmic islands demonstrated normal development until hatching. But at 36°C the protoplasmic island were not clearly visible. Immediately after appearance of degenerated protoplasmic islands, complete mortality was recorded at 36°C. Further isolation and structural analysis of these protoplasmic islands may indicate a functional significance during early development of *M. idella M. idella* idella. It is evident that heat shock proteins are induced at early developmental phases in response to various physiological stimuli (growth factors, cell differentiation, and hormonal stimulation) and under the influence of temperature [14]. In *M. rosenbergii* also at 36°C complete mortality of embryos was reported once the protoplasmic island was degenerated [15].

Morphometric measurements indicated that an early increase in the length of the major axis of embryos at higher temperatures. Finally, length at hatching was increased with increasing temperatures and the larval major axis was highest at 33°C. However, complete mortality was observed at 36°C after 10 days, which indicates that incubation at 36°C is an upper temperature threshold for *M. idella* idella embryos. Earlier reports on duration of hatching in Macrobrachium spp at different temperatures indicates that eggs hatch out in 25 days at 26°C, 20 days at 28-28.5°C and in 17 days at 32°C [16]. In the present study, in *M. idella* idella hatching took first at 33°C (241 hrs) than followed by 30°C (292 hrs) and 26°C (340 hrs). Even though hatching took first at 33°C the survival rate was low when compared with 30 and 26°C. In *M. rosenbergii* the survival was more at 33°C than in 29 and 25°C [15]. In most crustaceans the incubation period is highly dependent on the temperature [17,18]. Incubation periods of Moreton Bay (Australia) population of S. serrata are usually in early spring, at water temperatures of 18-20°C [17]. Water temperatures in estuaries and coastal waters along the north coast of South Africa range between 17-22°C in winter and 23-30°C in summer [19]. Temperature directly influences the developmental rate and development is faster at increasing temperatures. However, this increase of developmental rate of embryos with increase in temperatures occurs only within the acceptable thermal limits [7,13]. In general, thermal limits are narrower for early stages and reduced survival of embryos and juveniles but wider for the adults [7]. Acclimation temperature or thermal history may also affect the temperature tolerance of embryos. In crayfish, time needed for egg development varies with temperature, suggesting the possibility of extending or reducing the incubation period [20]. In crustacean eggs, metabolic rate increases with temperature [21], which affects growth [22], survival [23], and yolk absorption rates [24]. However, high temperature could cause high mortality or serious deformities during egg incubation [25]. Studies on fish [26,27], crustaceans [23,25] and molluscs [28] have shown that there are different approaches to studying the effects of temperature on development. One of the criteria is to measure changes in lipid, protein, and carbohydrate biochemical contents during egg development, which reflect utilization rate [29].

Experiments with Liocarcinus depurator showed that a three-fold decrease in development time could occur in successive batches of eggs incubated during the early spring to mid-summer breeding season in one locality [30]. In *L. holsatus* and Necora puber hatching success was greater at low temperature-low salinity and high temperature-high salinity combinations. However, *L. holsatus* was relatively more tolerant to the lower range while *N. puber* was more tolerant to the higher range [31]. The better survival of *L. holsatus* eggs and larvae at lower temperatures than that of *N. puber* may reflect field situation; *L. holsatus* produces eggs and larvae earlier and at colder temperatures than does *N. puber* [30,32] noted that within a related group of species there was a direct relationship between egg size and incubation period. In the present study the eggs of the same species (*M. idella* idella) responded differently when exposed to same environmental conditions [33] studied the effect of temperature on egg extrusion rate in *C. quadricarinatus*. They found that egg production was more frequent when mature females were maintained in water over 28°C compared to 25°C and lower. In general the survival and incubation time decreased with increased temperature [34]. As expected, higher temperature caused faster development because it had a direct effect on physiological and biochemical processes [35]. This is a reflection of higher metabolic rate [20] and a decrease in the duration of embryonic or larval development, commonly documented for crustaceans [23]. This effect was previously observed in *C. quadricarinatus* by [34,36] reported approximately 28 days for egg incubation until hatching at 28°C, which is very similar to the present work. The difference in water temperature from 22 to 31°C resulted in 50% shorter development time from egg extrusion to juvenile stage in the work. However, shorter development time in response to higher water temperature is compromised with abnormal development and lower survival [37] found most hatchling crayfish reared at extremely high temperatures had deformed limbs and failed to moult normally. In the present study, deformities and abnormal sizes were not considered, although some deformed hatchlings were observed at 33°C that subsequently died. Crustaceans are highly sensitive to environmental changes during ontogeny, and are therefore at higher risk to reach lethal temperature during this period [24,38] report that the consumption rate of total lipid and protein in Artemia gradually increases as temperature increases. The higher lipid depletion rate at higher temperature occurs because lipids are the main source of energy during ontogeny of aquatic

organisms [39,40]. Growth and differentiation processes demand large amounts of energy and all metabolic processes are intensified when the temperature is higher [25]. It was also observed that lipid consumption per day intensified at hatching, which could be related to a higher energy production need during this process [41]. For proteins, the consumption rate during embryogenesis might increase as temperature rises [42]. At high temperatures, tissue synthesis is inefficient due to the high cell proliferation rate, and more protein is used as fuel [39]. In the present study, embryonic development was assessed after acclimating the brooders (carrying newly released eggs in the brood chamber) at the rate of 1°C per day to test the temperatures and maintained until hatching, as described by [43]. A negative slope in the linear regression of development time to hatching, indicates a strong inverse relation with incubation temperature.

Our study indicates a direct linear relationship between development rates of *M. idella* idella embryos with incubation temperature. Hence, a direct relation between organogenesis and morphological measurements and development was established. A rapid increase in major axis length observed at 30 and 33°C with a concomitant rate of development and earlier hatching. But when compared to 30°C with 33°C the survival rate is very low. Increase in larval length was observed at higher incubation temperatures indicate that such larvae may develop into dominant prawns. Therefore, incubation temperature may prove vital in producing healthy, high quality prawn seeds for successful prawn farming, by taking advantage of "leap frog pattern" of enhanced growth and overall production. However, this hypothesis needs to be investigated by rearing freshwater prawns from embryos until adult stages at higher temperatures.

In the present study the optimal temperature for incubating *M. idella* idella eggs is recorded at 30°C considering the rate of development and hatching percentage. Total mortality was found at 36°C. High temperatures are related to poor cementing and attachment of eggs [31]. In the case of *M. rosenbergii*, the development and hatching percentage were maximum at 33°C than in 29°C and 99% mortality was recorded at 36°C [15]. Poor hatching percentage and formation of malformed embryos in later stages at 36°C suggest that this rearing temperature is well above the tolerance limit for development of L. rohita eggs or may be due to the lack of adequate enzymes involved in hatching [44]. This may be due to adaptive response of *M. idella* idella embryos evolved over the years due to global warming and climatic changes. The complete mortality percentage and gross morphological abnormalities at 36°C suggest that the thermal limit for embryonic development of *M. idella* idella is below 36°C. However, some of the embryos reared at 33°C reached relatively advanced developmental stages in a short time, inspite of low survival rate and gross abnormalities.

From the point of fertilization until hatching, low temperatures retard and high temperatures accelerate embryonic development [45,46]. According to [26] 29-33°C is acceptable for *M. rosenbergii* embryonic development, which is higher than earlier reports of 29-31°C [47]. According to [5] the optimal temperature for incubating *L. rohita* eggs is recorded at 31°C considering the rate of development and hatching percentage, which is higher than earlier reports of *L. rohita* [48]. But in the present experiment, *M. idella* idella at 26-30°C were found to be optimum temperature than other experimental temperature. Overall results suggest that 30°C is the ideal temperature for egg incubation of *M. idella* idella for faster embryonic development, better hatching percentage and least time duration for attaining given ontogenic stages. In *L. rohita* at 26 and 31°C suggests that these temperature ranges are most suitable for incubation but 31°C is the ideal temperature for egg incubation. A rise in the optimum temperature for embryonic development over the years may be due to continuous warming in the test region along with a gain of adaptive capability and induced thermal tolerance over the years. This hypothesis needs to be tested at the genetic level. These results may be a prelude to effectively utilize the benefits of temperature on better hatching rate and reduced hatchery man-days and ultimately the cost of production in *M. idella* idella hatcheries. However, hatchery seed production of *M. idella* idella is recommended between 26 and 30°C. This study reveals that *M. idella* idella embryos can accommodate climatic changes due to global warming up to 33°C, without hampering the reproduction and embryonic development.

## Acknowledgment

Authors are grateful to the Director of the Centre and the authorities of Annamalai University for providing with facilities. They extend their thanks to Prof. L. Kannan, for critically going through the manuscript and offering comments. The Umino Pet Palace, Chennai is acknowledged for the supply of fishes. We also thankfully acknowledge the valuable comments obtained from three anonymous reviewers, which greatly improved the manuscript.

## References

1. Hounghton RA, Woodwell GM (1989) Global climatic change. Sci American 260: 36-44.
2. Chatterjee N, Pal AK, Manush SM, Das T, Mukherjee SC (2004) Thermal tolerance and metabolic status of Labeo rohita and Cyprinus carpio early fingerlings acclimated to three different temperatures. J Ther Biol 29: 265-270.
3. Houde ED (1989) Comparative growth, mortality, and energetics of marine fish larvae: temperature and implied latitudinal effects. Fish Bull US 87: 471-495.
4. Brett JR (1969) Temperature and fishes. Chesapeake Science 10: 275-276.
5. Das T, Pal AK, Chakraborty SK, Manush SM, Dalvi RS, et al. (2006) Thermal dependence of embryonic development and hatching ratein Labeo rohita, Hamilton, 1822. Aquacult 255: 536-541.
6. Buddington RK, Hazel JR, Poroshov SI, Vaneehenhaam J (1993) Ontogeny of the capacity for homeoviscous adaptation in white sturgeon (Acipenser transmontanus). J Exp Zool 256: 18-28.
7. Cossins AR, Bowler K (1987) Temperature Biology of Animals. Chapman and Hall, London.
8. Subasinghe RP, Sommerville C (1992) Effects of temperature on hatchability, development and growth of eggs and yolk-sac fry of Orechromis mossambicus (Peters) under artificial incubation. Aqua Fisher Manag 23: 31-90.
9. Allanson BR, Noble RG (1964) The tolerance of Tilapia mossambica (Peters) to high temperature. Trans Amer Fish Soc 93: 323-332.
10. Manush SM, Pal AK, Chatterjee N, Das T, Mukherjee SC (2004) Thermal tolerance and oxygen consumption of Macrobrachium rosenbergii acclimated to three temperatures. J Ther Biol 29: 15-19.
11. Hall BK (1922) Evolutionary Developmental Biology. Chapman and Hall, London.
12. Ojanguren AF, Brana F (2003) Thermal dependence of embryonic growth and development in brown trout. J Fish Biol 62: 580-590.
13. Atkinson D (1996) Ectotherm life-history responses to developmental temperature.
14. Gething M, Sambrook J (1992) Protein folding in the cell. Nat 355: 35-45.
15. Manush SM, Pal AK, Das T, Mukherjee SC (2006) The influence of temperatures ranging from 25 to 36ºC on developmental rates, morphometrics and survival of freshwater prawn (Macrobrachium rosenbergii) embryos. Aquacult 256: 529-536.
16. Ogasawara YF (1984) Ecology of prawns and shrimp.
17. Haesman MP, Fielder DE (1983) Laboratory spawning and mass rearing of the mangrove crab Scylla serrata (Forskal), from first zoea to first crab stage. Aquacult 34: 303-316.
18. Hines AH (1986) Larval pattern in the life histories of Brachyuran crabs

(Crustacea, Decapoda, Brachyura). Bull Mar Sci 39: 444-466.

19. Robertson WD, Kruger A (1994) Size at maturity, mating and spawning in the portunid crab, Scylla serrata (Forskal) in Natal, South Africa. Est Coast Shelf Sci 39: 185-200.
20. Reynolds J (2002) Growth and reproduction.
21. Naylor K, Taylor E, Bennett D (1999) Oxygen uptake of developing eggs of Cancer pagurus (Crustacea: Decapoda: Cancridae) and consequent behavior of ovigerous females. J Mar Biol Ass 79: 305-315.
22. Jones DA (1994) Effect of temperature on growth and survival of the tropical freshwater crayfish Cherax quadricarinatus (Von Martens) Decapoda: Parastacidae.
23. Paula J, Mendes R, Paci S, Mc Laughin P, Gheradi F, et al. (2001) Combined effects of temperature and salinity on the larval development of the estuarine mud prawn Upogebia africana (Crustacea, Thalassinidae). Hydrobiol 449: 141-148.
24. Evjemo O, Danielsen T, Olsen Y (2001) Losses of lipid, protein and n-3 fatty acids in enriched Artemia franciscana starved at different temperatures. Aquacult 193: 65-80.
25. Kumlu M, Eroldogan O, Aktas M (2000) Effects of temperature and salinity on larval growth, survival and development of Penaeus semisulcatus. Aquacult 188: 167-173.
26. Ojanguren A, Reyes-Gavilan F, Rodrıguez R (1999) Effects of temperature on growth and efficiency of yolk utilization in eggs and pre-feeding larval stages of Atlantic salmon. Aquacult Int 7: 81-87.
27. Keckeis H, Kamler E, Bauer-Nemeschkal E, Schneeweiss K (2001) Survival, development and food energy partitioning of nase larvae and early juveniles at different temperatures. J Fish Biol 59: 45-61.
28. Gilroy A, Edwards S (1998) Optimum temperature for growth of Australian abalone Haliotis rubra (Leach) and greenlip abalone, Haliotis laevigata (Leach). Aquacult Int 29: 481-485.
29. Lemos D, Phan V (2001) Energy partitioning into growth, respiration, excretion and exuvia during larval development of the shrimp Farfantepenaeus paulensis. Aquacult 199: 131-143.
30. Wear RG (1974) Incubation in British decapod crustacea, and the effects of temperature on the rate and success of embryonic development. J Mar Biol Assoc 54: 745-762.
31. Choy SC (1986) Ecological studies on Liocarcinus puber (L.) and L. holsatus (Fabricius) (Crustacea, Brachyura, Portunidae) around the Gower Peninsula, South Wales.
32. Choy SC (1988) Reproductive biology of Liocarcinus puber and L. holsatus (Decapoda, Brachyura, Portunidae) from the Gower Peninsula, South Wales. Mar Ecol 9: 227-241.
33. Yeh H, Rouse D (1995) Effects of water temperature, density, and sex ratio on the spawning rate of red claw crayfish Cherax quadricarinatus (Von Martens). J World Aquacult Soc 26: 160-164.
34. Zhao Y, Meng F, Chen L, GU Z, Xu G, et al. (2000) Effects of different gradient temperatures on embryonic development of the Cherax quadricarinatus (Crustacea, Decapoda). J Lake Sci 12: 59-62.
35. Brown C, Terwilliger N (1999) Developmental changes in oxygen uptake in Cancer magister (Dana) in response to changes in salinity and temperature. J Exp Mar Biol Ecol 241: 179-192.
36. Yeh H, Rouse D (1994) Indoor spawning and egg development of the red claw crayfish Cherax quadricarinatus. J World Aquacult Soc 25: 297-301.
37. Rhodes C (1981) Artificial incubation of the eggs of the crayfish Austropotamobius pallipes. Aquacult 25: 129-150.
38. Agard J (1999) A four dimensional response surface analysis of the ontogeny of physiological adaptation to salinity and temperature in larvae of the palaemonid shrimp Macrobrachium rosenbergii (de Man). J Exp Mar Biol Ecol 236: 209-233.
39. Anderson DT (1982) Embryology. Acadamic Press, New York.
40. Holland DL (1978) Lipid reserves and energy metabolism in the larvae of benthic marine invertebrates.
41. Heras H, Gonzales-Baro M, Pollero R (2000) Lipid and fatty acid composition and energy partitioning during the embryo development in the shrimp Macrobrachium borellii. Lipids 35: 645-651.
42. Conceicao L, Ozorio R, Suurd E, Verreth J (1998) Amino acid profile and amino acid utilization in larval African catfish Clarias gariepinus, effects of ontogeny and temperature. Fish Physiol Biochem 19: 43-57.
43. Beitinger TL, Bennett WA, McCauley RW (2000) Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environ Biol Fishes 58: 237-275.
44. Reddy PK, Lam TJ (1991) Effect of thyroid hormones on hatching in the tilapia, Oreochromis mossambicus. Gene Compar Endocri 81: 484-491.
45. Hart PR, Purser GJ (1995) Effects of salinity and temperature on eggs and larvae of the greenback flounder. Aquacult 136: 221-230.
46. Hamel P, Mangan P, East P, Lapointe M, Laurendeau P (1997) Comparison of different models to predict the in situ embryonic development rate of fish with special reference to white sucker (Catostomus commersoni). Canadian J Fish Aquat Sci 54: 190-197.
47. Sebastian CD (1996) A manual on seed production and farming of giant freshwater prawn, Macrobrachium rosenbegii. The Marine products Export Development Authority, (Ministry of Commerce, Govt of India), Pananmpilly Avenue, Cochin.
48. Ponnuraj M, Murugesan AG, Sukumaran N (2002) Effect of temperature on incubation time, fertilization rate and survival of the spawn of Rohu, Labeo rohita.