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Effects of Temperature and Salinity on Incubation Time, Hatching Success, and Larvae Survival of the Giant Tiger Prawn *Penaeus monodon* under Experimental Conditions

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Abstract

Prawns are commercially one of the most important marine resources. However, in their early developmental stages, they face challenges related to physico-chemical and environmental changes. This study aimed at investigating the effects of temperature and salinity on egg incubation time, hatching success, larval and postlarval survival of the giant tiger prawn, *Penaeus monodon* (Fabricius 1798) obtained from the coastal waters of Tanzania. The adult females *P. monodon* collected off Rufiji delta were left to acclimatize and spawn at 28.5 ± 0.5 °C and 32 ppt in the hatchery. Spawned eggs were incubated at experimental temperatures of 27 °C, 31 °C and 35 °C with three subgroups of salinities of 30 ppt, 35 ppt and 40 ppt. The incubation time was longest (15.2 hours) at 27 °C and 30 ppt, and shortest (10.7 hours) at 35 °C and 40 ppt. Hatching success was highest (85.2%) at 31 °C temperature and 30 ppt salinity, and lowest (69.45%) at 35 °C and 40 ppt. Larval and postlarval survival was suitable at 27–31 °C and 30–35 ppt. These findings suggest that optimum rearing temperature and salinity for *P. monodon* range 27–31 °C and 30–35 ppt, respectively. Changes in temperature and salinity above the optimum range may jeopardize the hatching and subsequent survival of *P. monodon* especially at their early developmental stages which are more sensitive to environmental changes.

Keywords: *Penaeus monodon*, Temperature, Salinity, Incubation time, Hatching success, Survival rate.

Introduction

Prawns are one of the most important marine resources in the world, 60% of which are traded internationally (FAO 2009). Most of the commercial prawns belong to the family Penaeidae, with the giant tiger prawn, *Penaeus monodon*, being among the dominant prawn species caught from the wild in the coastal waters of Tanzania and the most marketable prawn species in the world (Teikwa and Mgaya 2003, Mosha and Gallardo 2013). In Tanzania, prawn fishery has developed into a profitable industry and is operated by both artisanal fishers and commercial trawlers (Silas 2011, United Republic of Tanzania 2016). In 2007, the government of Tanzania introduced a moratorium on commercial prawn trawlers due to decreased catch rates because of overexploitation leaving the fishery to small scale fishers (United Republic of Tanzania 2016). Besides being collected from the wild,

prawns can be farmed to not only boost economies, but also alleviate fishing pressures on the wild stocks.

During their early developmental stages, prawns are particularly delicate and vulnerable to environmental variability that may result from climate change (Ahmed 2013), with salinity and temperature being the two most important environmental factors affecting hatching success, hatching time, larval and postlarval survival rate, growth, and development (Aktas and Çavdar 2012, Mohanty et al. 2016). Temperature influences spawning activity, incubation time, offshore larvae survival, growth, and settlement of postlarvae inshore (Silas 2011). Salinity plays critical roles on egg, embryo, larval and postlarval development during the life cycle as it affects hatching, growth, survival, and distribution of many aquatic organisms (Anger 2003). Since prawns are not able to withstand major changes in temperature and salinity during their larval development (Anger 2003), increased temperature and salinity may have detrimental effects on their growth and survival, consequently affecting the prawn fishing and farming industry.

Penaeus monodon is so far, the only prawn species reared in aquaculture farms in Tanzania. Available information on the effects of water temperature and salinity on larval penaeid prawns is limited to other species such as *Penaeus merguiensis* and shows that salinity has a greater effect on survival than temperature (Zacharia and Kakati 2004). Increased mortalities at relatively high temperatures (above 32 °C) (Aktas and Cavdar 2012), and reduced survival rates at temperatures above 32.6 °C and salinity below 30 ppt and above 35 ppt have been reported for *Metapenaeus dalli* (Crisp et al. 2017). As well, during incubation time, reduced hatching success at increased salinity (above 35 ppt) was observed for the brown shrimp *Metapenaeus monoceros* (Aktas and Çavdar 2012).

Available information on *Penaueus monodon* postlarvae indicates reduced survival rates at temperatures above 31 °C (Chaitanawisuti et al. 2013). Information on the optimal salinity and temperature for egg incubation time, hatching success and survival rate of larvae and postlarvae of the giant tiger prawn *P. monodon* in the coastal waters of Tanzania is inadequate. Such information is fundamental for enhancement of its production, especially considering the dwindling catch rates as well as rapid changing global climate. Furthermore, understanding the effects of temperature and salinity on the incubation and larval culture of the giant tiger prawn is important as it could enable the establishment of the tolerable conditions for optimal production of this commercially important penaeid.

The purpose of the present study was to determine the incubation time, hatching success, larvae and postlarvae survival of *P. monodon* at the combination of three different temperature levels (27 °C, 31 °C and 35 °C) and three salinity levels (30, 35 and 40 ppt).

Materials and Methods

Broodstock collection and acclimatization

The gravid female giant tiger prawn *P. monodon* measuring 70 g to 100 g were collected in April 2018 from the coast of Tanzania (off Rufiji Delta) using a beach seine net measuring 10 m long and a stretched mesh size of 3.5 cm square mesh cover. Collected *P. monodon* individuals were packed in polythene bags (⅓ filled with seawater of 32–34 ppt, and ⅔ aerated) at ambient temperature and transported to Alpha Krust hatchery located at Kilindoni village at the immediate coast of Mafia Island. Acclimation of *P. monodon* was done at 28.5 °C ± 0.5 and 32 ppt in 50 litres tank capacity for 6 hours with continuous aeration using electricity-driven air blowers. *P. monodon* species is prone to white spot diseases caused by bacteria and white spot syndrome baculovirus or other viruses. To ensure the quality of the broodstock, polymerase chain reaction (PCR) test for white spot diseases was performed in the hatchery laboratory before being stocked into either a maturation tank, spawning tank, or experimental vessels. Healthy individuals were then transferred to rectangular concrete-built maturation tank of 8,000 litres capacity with 1.5 m depth to

allow *P. monodon* to adapt to the new environment. Continuous aeration in the maturation tank was provided directly through the plastic aeration tubes from the base to ensure equal air distribution throughout the tank. To reduce the accumulation of ammonia, about 30% of the water from the maturation tank was flown out daily and replaced. In the maturation tank, the broodstock was fed with chopped scallops, clams, polychaetes, and cattle liver. Scallops, clams, polychaetes, and cattle liver were soaked in water temperature between 50 °C and 60 °C for at least 2 hours to get rid of viral infections as they do not survive at high temperatures (Millard et al. 2021).

Egg development observations

Female *P. monodon* were checked for developing eggs in the ovaries by illuminating on the underside of the stomach using waterproof hand red light torch. The appearance of green-yellow colour in the stomach marked stage IV egg development in the ovaries. *P. monodon* gravid females with stage IV eggs were transferred to 500 litres capacity fiberglass spawning tank with a stocking density of one female/tank. Spawning usually occurred during the night and was checked at two hours interval after adult female *P. monodon* has been placed in the spawning tank. The waterproof red-light torch was also used to check for spawning. About 500,000 eggs were spawned per individual female prawn. Eggs were counted by taking five 10 ml sample from a sample volume of 200 ml in a beaker using a pipette and counted by observation under a microscope in a depression slide. Total number of eggs were calculated by using the following formula:

$$\text{Total number of eggs} = \frac{\text{Number of eggs from sample x Total volume of water}}{\text{Sample volume (ml)}}$$

The spawned females were immediately removed from the spawning tank by using a scoop net to avoid cannibalism. Floating eggs were collected from spawning tank using 1 µm mesh size sieve within one hour as done by Zacharia and Kakati (2004). The eggs were sampled and checked for infections using polymerase chain reaction (PCR) in the hatchery laboratory. Eggs were subsequently transferred to experimental hatching aquaria and reared until postlarval stage. Feeding of the hatched nauplii larvae started when they metamorphosed to the sixth (last) naupliar stage and fed with algae *Chaetocerus* sp. cultured in the hatchery. Subsequent stages after nauplii were fed with freshly hatched *Artemia* sp.

Temperature-salinity experiment

The average temperature and salinity in the Rufiji Delta where the broodstock (spawners) were collected are 28.2–31.2 °C and 2–32 ppt, respectively (Minu et al. 2020). The experiments were conducted at three different temperature groups of 27 °C, 31 °C and 35 °C. Each group had three subgroups of different salinities; 30 ppt, 35 ppt and 40 ppt, following the procedures by Chaitanawisuti et al. (2013), with some modifications. Chaitanawisuti et al. (2013) used a 3 x 4 factorial design with three temperatures 29 °C, 33 °C and 35 °C and salinities of 25 ppt, 30 ppt, 33 ppt and 35 ppt to determine *P. monodon* postlarvae survival. The temperature and salinity ranges for the present study were selected based on the reported climatic variability that exists along the coastal areas of Tanzania and climate prediction models (World Bank Group 2016). The effect of temperature and salinity on hatching success, survival of individual larval stages, postlarval stages and cumulative survival from nauplii to postlarval of *P. monodon* was determined in the laboratory using a 3 × 3 two-factor factorials experimental design. A total of nine 10 litres capacity glass aquaria, were used, with a stocking density of 140 eggs per litre. The required salinity was obtained by either diluting the filtered seawater or addition of the sea salt to filtered seawater to keep the variation within ± 0.5 ppt, and was checked

after every 12 hours. A temperature control unit comprising of submersible heaters 200 W regulated by a thermostat was used to maintain the experimental temperature. Control experiment was maintained at 28.5 °C ± 0.5 and 32 ppt, which are the average ranges from the marine part of the delta. Each combination of temperature-salinity was conducted with three replications per treatment from different broodstock (spawners) obtained from the same locality. Replication was necessary to consider variability in experimental results and ensure validity of the data. The experiment aquaria were continuously aerated to ensure constant and equal air distribution. The experimental aquaria were covered by aluminium foil to reduce evaporation and possible changes in the salinity due to evaporation.

Egg incubation time, hatching success and survival rate

The stages of development from the embryo were monitored individually and cumulatively. Time taken for the eggs to hatch was recorded as incubation time. Immediately hatched nauplii larvae were maintained in the set experimental conditions. Hatching success was determined after 24 hours using the following formula:

$$\text{Percentage hatching success} = \frac{\text{No. of nauplii larve from sample (n) x 100}}{\text{Total number of stocked eggs (N)}}$$

Larval development stages (nauplii, protozoea, mysis and postlarval) were assessed by observing under a compound microscope and were identified according to Motoh (1985) and Ronquillo et al. (2006). Larvae survival was determined when 50% of the larvae metamorphosed to the subsequent larval stage using the following formula:

$$\text{Percentage survival} = \frac{\text{Mean No. of larvae survived at the end of larval stage(n) x 100}}{\text{Total number of stocked larvae (N)}}$$

The cumulative survival was determined at the termination of the experiments when postlarvae stage five (PL_5) was reached. The larvae that settled at the bottom of the aquaria and those that did not respond to the mechanical stimulation by the needle were considered as dead. Unhatched eggs, dead larvae and other debris were removed from the experimental aquaria by siphoning.

Data analysis

The results of hatching success, incubation time, individual stage survival and cumulative survival were tested for normality using Shapiro Wilk test. Percentage data were arcsine transformed before statistical analyses and converted into percentages for reporting. Two-way ANOVA and Tukey's pairwise comparison test were used to compare the mean values of the individual treatments. Results were considered significant at $p < 0.05$ (Zar 2010). The results were presented as Mean ± Standard Error of Mean (SEM). Statistical analysis was carried out using Statistical Program for the Social Sciences (SPSS) version 20.

Results

Incubation time

Overall, the results show that incubation time decreased with increasing salinity and temperature (Figure 1). Eggs incubated at high temperatures of 31 °C and 35 °C had shorter mean incubation time of 10.7 and 11.5 hours, respectively, than those incubated at lower temperature of 27 °C which had an incubation time of 12.5 hours, and the difference was significant ($p < 0.05$). Similarly, eggs incubated at high salinities of 40 ppt and 35 ppt had shorter incubation time of 10.7 and 12.3 hours, respectively, than those incubated at lowest salinity of 30 ppt (12.9 hours) regardless of temperatures (Figure 1). The difference in incubation time among salinities was significant ($p < 0.05$). The longest mean incubation time of 15.2 hours was recorded at 30 ppt and 27 °C followed by 14.5 hours recorded at 31 °C and 30 ppt.

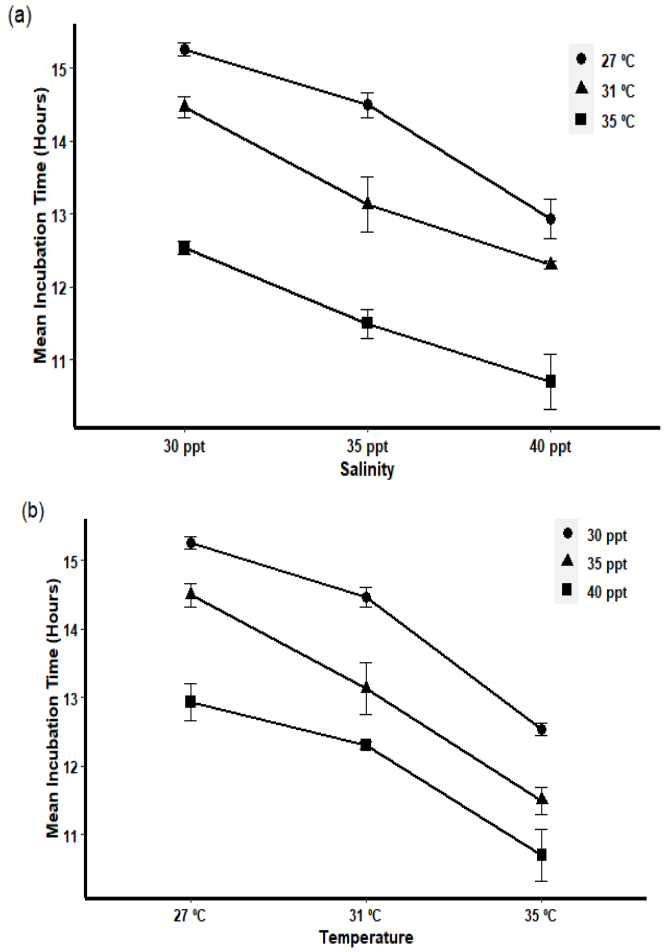

Figure 1: Effects of (a) salinity at different temperatures, and (b) temperature at different salinities, on incubation time of *Penaeus monodon* eggs. Error bars indicate Standard Error of Mean (SEM), n = 3.

Hatching success

The effects of temperature on hatching success of *P. monodon* eggs were much more pronounced than those of salinity (Figure 2). But generally, hatching success decreased with increasing salinity. Within each salinity group, eggs incubated at highest temperature (35 °C) had the lowest hatching success than those incubated at lower temperatures (27 °C and 31 °C). The highest percentage hatching success of 85.28% was observed at 31 °C and 30 ppt followed by 81.90% recorded at 31 °C and 35 ppt ($p > 0.05$). The hatching success observed at 31 °C and 30 ppt was comparable to that recorded at 31 °C and 35 ppt ($p > 0.05$). Generally, the interaction effect between temperature and salinity on hatching success was significant ($p < 0.05$).

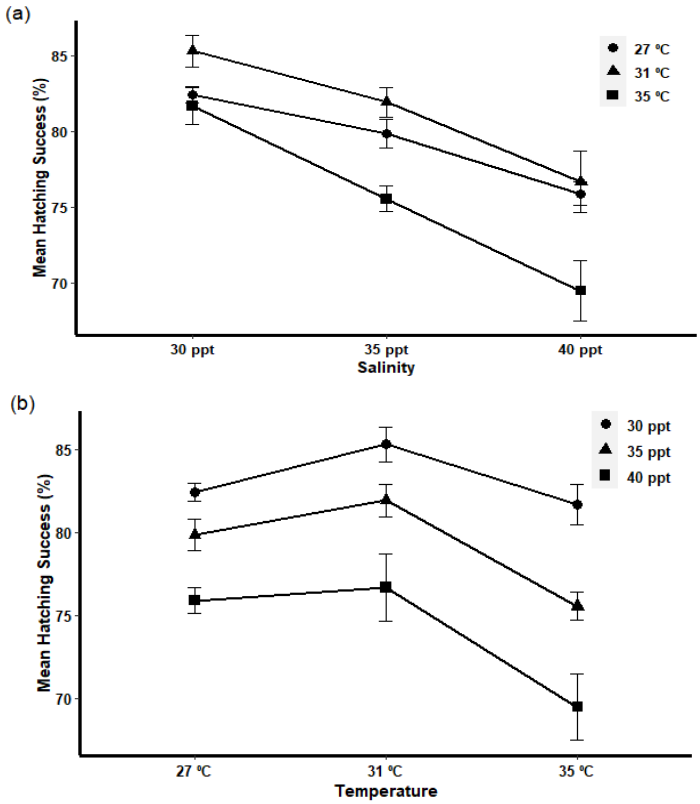

Figure 2: Effects of (a) salinity at different temperatures, and (b) temperature at different salinities, on hatching success of *Penaeus monodon* eggs. Error bars indicate Standard Error of Mean (SEM), n = 3.

Survival of the naupliar larval stages

Generally, survival decreased with increasing temperature and salinity and the conditions in which nauplii larvae had high survival was similar to that of hatching eggs (Table 1). Metamorphosis throughout all stages was successful at all salinity and temperature levels, and survival was above 50% despite some minor variations. The lowest survival rate (68.57 ± 0.54%) was recorded at the highest temperature (35 °C) and the highest salinity (40 ppt). The highest survival rate of nauplii larvae (90.53 ± 1.08%) was recorded at 31 °C and 30 ppt which did not differ significantly ($p > 0.05$) from that recorded at 27 °C and salinity of 35 ppt (90.2 ± 2.79%). Temperature, salinity, and their interactions significantly affected the survival of *P. monodon* to mysis larval stage through protozoeal stages ($p < 0.05$).

Survival of the protozoeal stages

At this stage, both temperature and salinity affected larval survival significantly ($p < 0.05$). Survival percentage at the highest temperature (35 °C) and salinity (40 ppt) of 39.11 ± 1.14% was the lowest compared to other experimental temperatures-salinity settings (Table 1). The highest percentage survival of protozoea larval stage (80.01 ± 1.42%) was recorded at 31 °C and 30 ppt. The separate effects of temperature and salinity on survival at this stage were significantly different ($p < 0.05$). However, the interaction of the two factors were comparable ($p > 0.05$). The response in survival conditions of the protozoea was similar to that of hatching success of eggs and nauplii survival, as maximum survival occurred at the temperature and salinity levels of the rearing medium of eggs and nauplii larvae.

Survival of the mysis stages

For the mysis larvae, the separate effects of temperature and salinity on survival were significantly different ($p < 0.05$), while the interaction effects of the two factors did not differ significantly ($p < 0.05$). Among temperature levels, 35 °C resulted in the lowest survival (43.04 ± 2.78%) compared to others (Table 1). Highest survival (77.71 ± 4.1%) was recorded at 31 °C and 30 ppt, while the lowest survival rate was obtained at 40 ppt regardless of temperatures.

Table 1: Survival percentage of *P. monodon* larval stages in various temperature and salinity combinations (Mean ± Standard Error, n = 3).

Temperature (°C)	Salinity (ppt)	Percentage larval survival		
		Nauplii	Protozoea	Mysis
27	30	88.70 ± 4.49^{ac}	74.58 ± 5.17^{ab}	68.68 ± 4.10^{a}
	35	90.20 ± 2.79^{ac}	70.24 ± 2.69^{ad}	69.00 ± 1.33^{a}
	40	83.30 ± 1.29^{b}	61.54 ± 2.04^{c}	58.21 ± 0.70^{cb}
31	30	90.53 ± 1.08^{c}	80.01 ± 1.42^{b}	77.71 ± 4.10^{ab}
	35	85.52 ± 2.52^{b}	71.30 ± 0.63^{d}	60.14 ± 0.94^{c}
	40	78.01 ± 2.01^{cd}	57.96 ± 3.42^{c}	48.85 ± 5.91^{d}
35	30	84.88 ± 1.28^{b}	67.51 ± 4.21^{d}	63.96 ± 3.45^{c}
	35	82.34 ± 3.27^{bd}	61.77 ± 1.13^{c}	56.28 ± 1.73^{d}
	40	68.57 ± 0.54^{e}	39.11 ± 1.14^{e}	43.04 ± 2.78^{d}

Survival of the postlarval stages

In comparison with other earlier developmental stages, there were marked changes in responses of postlarvae to the combined effects of temperature and salinity. For postlarvae, the effects of both temperature and salinity, and their interactions were significantly different ($p < 0.05$). Survival was reduced in lowest temperature of 27 °C and highest temperature of 35 °C (Figure 3). Postlarvae survival rate was generally low at all temperatures with the lowest (31.70%) being at 35 °C regardless of salinity. The highest salinity (40 ppt) resulted in a very low postlarvae survival. The highest postlarvae percentage survival (77.70%) was recorded at 31 °C and 35 ppt.

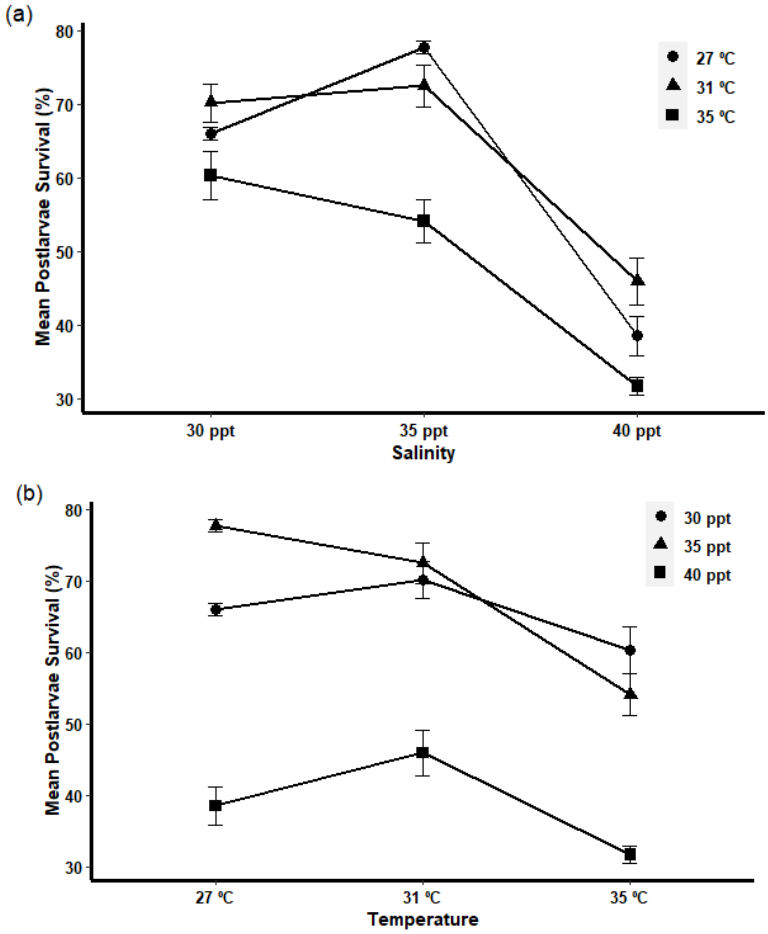

Figure 3: Effects of (a) salinity at different temperatures, and (b) temperature at different salinities, on survival of *Penaeus monodon* postlarvae. Error bars indicate Standard Error Mean (SEM), n = 3.

Cumulative effects of temperature and salinity on the survival of *P. monodon* from nauplii larvae to postlarvae

Cumulative survival was determined from the nauplii larval stage followed by the subsequent stages, to the termination of the experiment at postlarval stage five (PL_5). At nauplii larval stage, the cumulative survival rate was high (90.53%) at 31 °C and 30 ppt, followed by 90.2% at 27 °C and 35 ppt, and lowest (68.57%) at 35 °C and 40 ppt. On termination of the experiment, the highest cumulative survival rate at PL_5 was 39.49% recorded at 31 °C and 30 ppt, while the lowest rate of 3.66% was recorded at 35 °C and 40 ppt (Figure 4). The coefficients of multiple regression analysis demonstrated that both temperature and salinity were significant larvae survival predictors in all stages with the relationship being negative in both temperature and salinity ($R^2 = 0.767$, $p < 0.05$). The contribution of temperature and salinity to the observed trend of postlarvae survival was 40.3% and 77.8% ($r = -0.403$ and $r = -0.778$), respectively (Table 2).

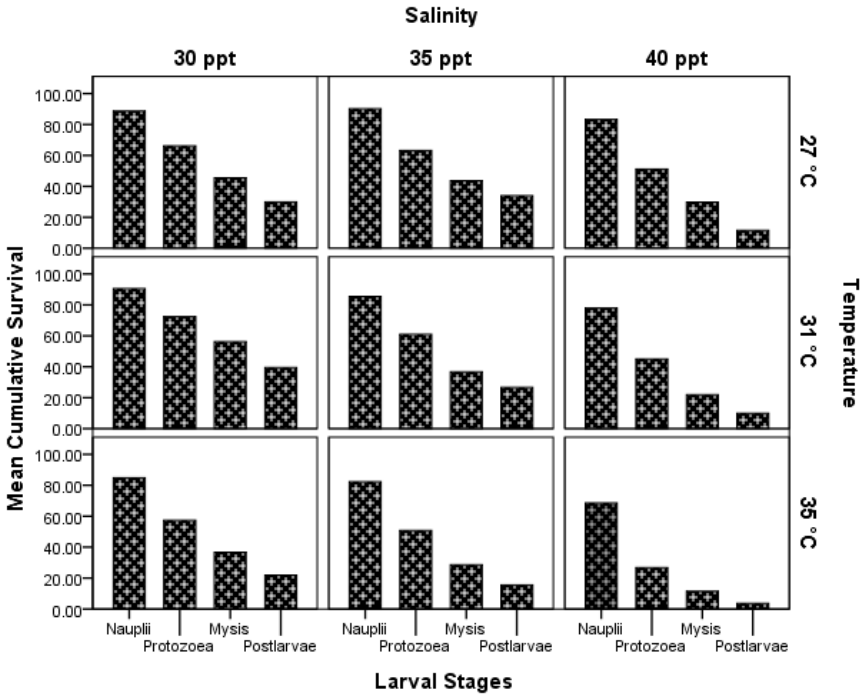

Figure 4: Cumulative survival rate of early developmental stages of *P. monodon* at different temperature and salinity.

Table 2: Coefficients of multiple regression on *Penaeus monodon* postlarvae cumulative survival rate

Coefficients						
		Unstandardized Coefficients		Standardized Coefficients		
Model	Factors	B	Std. Error	Pearson correlation (r)/Beta	t	Significance (P)
1	% Survival	143.046	14.655		9.761	0
	Temperature	-1.431	0.35	-0.403	-4.09	0
	Salinity	-2.208	0.28	-0.778	-7.891	0

Discussion

The present study was conducted to determine the effects of the combinations of three different temperature levels (27 °C, 31 °C and 35 °C) and three salinity levels (30 ppt, 35 ppt and 40 ppt) on incubation time, hatching success, larvae and postlarvae survival of *Penaeus monodon.* The highest temperature and salinity chosen for this study were relatively higher than those found in the Rufiji Delta (8.2–31.2 °C and 2–32 ppt) (Minu et al. 2020), where the *P. monodon* broodstock were taken. The results of the study indicate reduced incubation time for *P. monodon* eggs at high temperature and high salinity combinations which could be linked to increased egg development rate due to increased metabolic rates (Bett and Vinatea 2009). Short incubation time in high salinity could be due to salt absorption, which creates more internal pressure that facilitates easy egg membrane rapture (Soundarapandian 2008). Fast egg development at high temperature increases the hatching success. The effect of temperature on incubation time in the present study correlates with a study on *Metapenaeus monoceros* where longest incubation time (17.2 hours) at 24 °C,

medium (14 hours) at 28 °C, and shortest (11.2 hours) at 32 were reported (Aktas and Çavdar 2012). Similar findings were also reported on *Penaeus semisulcatus* in which longest incubation time of 17.5 hours was recorded at 24 °C and shortest time of 14.5 hours and 11.5 hours at 28 °C and 32 °C, respectively (Aktas et al. 2004). The findings of the present study are also in line with that of Chaitanawisuti et al. (2013) that reported longest incubation time of 26 days at 26 °C and shortest time of 18 days from 30–34 °C, while salinities were kept at 6 ppt for both treatments.

The present study found that temperature and salinity combination of 31 °C and 30 ppt, respectively, resulted in the highest hatching success (85.28%). This is possibly due to the fact that optimal conditions induced embryonic development than extreme salinities and temperature that vary significantly from the normal oceanic levels. These findings are consistent with those reported on the same species (i.e., 90.5% at 30 °C and 30 ppt) by Chaitanawisuti et al. (2013). However, the findings from the present study are different from those of Aktas and Çavdar (2012) on *M. monoceros* where high hatching success of 91.67% at 32 °C and 35 ppt were reported. Furthermore, salinity between 30–35 ppt was found to be the optimum range for *P. monodon* incubation. These findings support earlier findings in which 35 ppt was reported as the optimal salinity for successful hatching for both *P. monodon* and *P. merguiensis* (Zacharia and Kakati 2004, Aktas and Çavdar 2012). On contrary, increased hatching success (91.33%) for *P. semisulcatus* were observed at lowest temperature of 24 °C and salinity of 40 ppt combinations (Aktas et al. 2004). The observed differences could be attributed to the fact that reproduction in crustaceans is species-specific and dependent on the prevailing environmental factors in which they later become adapted to (Liao 2018). Since in the present study hatching was above 50% in all temperature and salinity groups, it can be generalised that hatching of *Penaeus monodon* can take place successfully over a wide range of temperatures and salinities. It is also worth noting that reduced hatching success at high salinities and high temperatures may have been also contributed by the immediate transfer of eggs from the spawning tank to experimental aquaria. The high temperatures and salinity may have resulted in death of some embryos due to heat and salinity shock resulting in low hatching success.

Moreover, the present study indicated reduced larval survival rates at extreme salinity and temperature conditions. This pattern could be explained by the fact that increasing salinity and temperature to a certain point increased moulting frequency while decreasing penaeid prawn survival due to low protein content deposited in body tissues (Kumlu and Eroldogan 2000). These findings are consistent with other studies done on prawns including that on *M. monoceros* which found low larval survival at high salinities of 40 ppt and 45 ppt than at 35 ppt (Aktas and Cavdar 2012). Similarly, a study on *M. dalli* found a low survival rate at high temperatures of 32.6 °C and a high survival at low temperatures of 29.4 °C (Crisp et al. 2017). Furthermore, the present study indicated optimal salinity-temperature combination for survival of the different stages of *P. monodon* larvae of between 30–35 ppt and 27–31 °C. These findings are in conformity with those of Kumlu and Eroldogan (2000) which demonstrated optimal salinity and temperature combination for survival during the protozoea larval stages of *P. semisulcatus* to be at 30 ppt and 30 °C. This study demonstrated maximum survival rate at 31 °C and 30 ppt which was not significantly different from that at 27 °C and 35 ppt in all larval stages. The observed variations in survival rates are most likely due to the penaeid larvae body chemistry having a lethal limit, with temperature and salinity above or below it having an effect on larval survival (Crisp et al. 2017).

The present study also found that salinity tolerance varied depending on larval stages with nauplii and protozoea stages being less tolerant to salinity variations compared to subsequent larval stages. There was a notable abrupt decrease in survival rate at protozoea

stage towards mysis. However, on reaching the mysis stage, there was a marked increase in survival despite the differences in temperature and salinity. The relative survival differences among different larval stages are probably explained by the physiological capacity of osmoregulation to combat temperature and salinity stress (Palacios and Racotta 2007).

Temperature and salinity are reported to play significant roles in the survival of the larval and juvenile penaeid species by affecting their structural, functional, and physiological responses, and therefore influencing their growth, survival, and distribution (Soundarapandian 2008, Aktas and Çavdar 2012). Kumlu and Eroldogan (2000) demonstrated influences of high temperatures which increased metabolic rates of aquatic organisms consequently increasing their moulting frequency compared to lower temperatures. Chaitanawisuti et al. (2013) reported survival of postlarvae (PL_5) of *P. monodon* at salinity between 25–35 ppt and temperature 29 °C which correlates with the present study. Besides, the findings of the present study also agree with that of Bett and Vinatea (2009) who demonstrated that elevated temperatures between 34 °C and 35 °C were suitable for the growth of aquatic animals but had negative effects on their survival. Likewise, the present study is in line with the study on juveniles of *P. esculantus* and juvenile *Litopenaus vannamei* that demonstrated optimum growth and survival at 30 °C and 30 ppt (Bermudes-Lizárraga 2017).

Conclusion

Based on the findings of the present study, the ideal incubation temperature and salinity ranges for successful hatching and survival of *P. monodon* larvae and postlarvae are 27–31 °C and 30–35 ppt. Similar temperature-salinity or different combinations for successful hatching of *P. monodon* could probably apply given similarities or differences in physicochemical and other environmental conditions where the parent prawn (the broodstock) originated.

Conflict of interest

There is no conflict of interest to declare.

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