Aquaculture Studies, 21(2), 55-62
http://doi.org/10.4194/2618-6381-v21_2_02

RESEARCH PAPER

Management Strategies for Nile Tilapia (*Oreochromis niloticus*) Hatchery in the Face of Climate Change Induced Rising Temperature

S. M. Ashiqul Alam[1], Md. Shirajul Islam Sarkar[2], Md. Mahbubul Alam Miah[3], Harunur Rashid[1,*]

[1]Bangladesh Agricultural University, Department of Fisheries Management, Mymensingh- 2202, Bangladesh.
[2]Bangabandhu Sheikh Mujibur Rahman Agricultural University, Department of Fisheries Technology, Gazipur-1706, Bangladesh.
[3]Scientist (Hub Manager), WorldFish, Mymensingh, Bangladesh.

How to cite

Alam, S.M.A., Sarkar, S.I., Miah, M.A., Rashid, H. (2021). Management Strategies for Nile Tilapia (*Oreochromis niloticus*) Hatchery in the Face of Climate Change Induced Rising Temperature. *Aquaculture Studies*, *21*, 55-62. http://doi.org/10.4194/2618-6381-v21_2_02

Article History
Received 03 November 2020
Accepted 14 January 2021
First Online 08 February 2021

Corresponding Author
Tel.: +8801924429971
E-mail: rashid@bau.edu.bd

Keywords
Nile tilapia
Aquaculture
Climate change
Water quality
Hatchery management

Abstract

In the quest for appropriate management strategies for less egg production in Nile tilapia (*Oreochromis niloticus*) due to climate change induced increasing temperature, five treatments (T): shade with cloth over brood hapa (T1), increase in pond depth (T2), aeration (T3), combination of above three interventions (T4) and control (no intervention) (T5) were investigated in a commercial hatchery in Mymensingh, Bangladesh during April to September. Mean egg production in T1, T2, T3, T4 and T5 was 20488, 15369, 3596, 21021 and 3979 eggs/hapa, respectively. T1 was the best strategy considered due to efficiency and simplicity. In May T1, T2, T3, T4 and T5 produced highest 30859, 36119, 8997, 45876 and 5506 eggs/hapa at 29.69°C, 30.12°C, 29.96°C, 29.61°C, and 31.26°C temperature, respectively. The most suitable water temperature for highest egg production (20365 eggs/hapa) was 29-31°C. Egg production above 32°C was found to be very low (179 eggs/hapa). Suitable ranges of dissolved oxygen, pH, alkalinity, ammonia and turbidity for egg production were found to be 4.5-6.0 mg/L, 8.0-8.8, 105-150 mg/L, 0-0.5 mg/L and 15-35 cm, respectively. In high temperature months commercial fish hatcheries should use shed with cloth over brood hapa to produce higher amount eggs.

Introduction

Tilapia is being farmed in fresh and brackish waters in 135 countries and territories on all continents (El-Sayed, 2006; Fitzsimmons, 2006; Shelton & Pompa, 2006; FAO, 2014). In 2016, 4,200 million tons production placed *Oreochromis niloticus* as the 4th major species produced globally (FAO, 2018). FAO (2014) reported that less expensive fishes particularly tilapia and *Pangasius* are substantially expanding traditional ground fish market by reaching out new consumer groups and it is expected that tilapia production will increase as much as 7.3 million tons by 2030. Since 2005, there have been increasing number and variety of tilapia value added products (breaded, seasoned, stuffed etc.) around the world. Another important global trend is continued spread of tilapia into the multinational food services (Fitzsimmons, 2008).

In Bangladesh, tilapia breeds from February to November when water temperatures remain around 22-30°C (Hussain, 2004). Depending upon environmental conditions, female tilapia tends to spawn asynchronously every 3 to 4 weeks (Rana, 1988; Macintosh & Little, 1995; Coward & Bromage, 2000). Commercial hatchery operators in Bangladesh have to keep and manage a large number of brood fish to fulfill the demand of tilapia fingerlings because of the fact that female *Oreochromis* produces small clutches of eggs

Published by Central Fisheries Research Institute (SUMAE) Trabzon, Turkey.

(Bhujel *et al.,* 2007). For instance, about 50,000 working brood fish are required to produce 0.8–1 million fry per week (Hussain, 2004; personal connection). Therefore, broodstock management is one of the most important aspects of tilapia seed production (Bhujel, 2000).

Temperature possesses a very critical role on fish growth and development (El-Sayed *et al.*, 1996; Van Ham *et al.*, 2003; Chatterjee *et al.*, 2004; Larsson and Berglund, 2005). Tilapia feed and grow less at higher or lower temperature beyond optimum and feeding and growth are halted at 20°C or less (Caulton, 1982). Nile tilapia does not lay eggs when water temperature is below 19°C (Brummett, 1995). The most productive period coincide with the rise in water temperature to 22-27°C where about 40% and 73% spawning rate are seen under dark and natural photoperiod conditions, respectively (Brummett, 1995). Tilapia egg production start to decline at high temperature of 33°C and stops at 35°C (Hossan *et al.*, 2013)

In Bangladesh, maximum ambient summer temperature ranges between 30°C to 40°C (Weather Online UK, 2020). Recent studies suggest that changing climate has increased temperature of Bangladesh from May to September and in February (Rouf *et al*., 2011; Basak *et al*., 2013). In a country like Bangladesh where tilapia hatchery operation starts in February and continues till October-November, it is important to find out easy and cheap climate-smart interventions to combat against rising temperature hampering tilapia hatchery production in Bangladesh. Therefore, this field experimentation was designed to find out management options to improve reproductive performance of tilapia during high temperature seasons in Bangladesh.

Materials and Methods

Experiment Design

This study was carried out for a period of 6 months from April to September at a commercial monosex tilapia hatchery in Tarakanda, Mymensingh, Bangladesh. Mature and healthy (200-300 g) 25 male and 75 female (male: female = 1:3) GIFT, the 14th generation strain of Nile tilapias (*Oreochromis niloticus*) were stocked in experimental hapas (3m×6m×1m) as per design of experiment shown in Figure 1. Distance between hapa and pond bottom was 6 inches. Water area of every pond was 364.21 m^2. In aeration, 1 aerator was used. Standard feeding was applied (25% protein, twice a day, 3% of body weight) in the breeding hapas.

Environmental Parameters

Water temperature was recorded twice daily using a Celsius thermometer. Dissolved oxygen (mg/L) and pH were recorded weekly using Lutron PDO-519 Dissolved Oxygen Meter and a pH meter (Model: HI9124, Hanna Instruments), respectively. Dissolved ammonia and alkalinity (mg/L) were recorded weekly by Ammonia test kit (Model: NI-SA, HACH) and Alkalinity Kit Box (Model: AL-DT, HACH), respectively. Turbidity (cm) was measured weekly using Secchi disk.

Egg Collection and Count

Fertilized eggs/hatched out spawns/swimmer fries with yolk sac from the mouth of female tilapia were

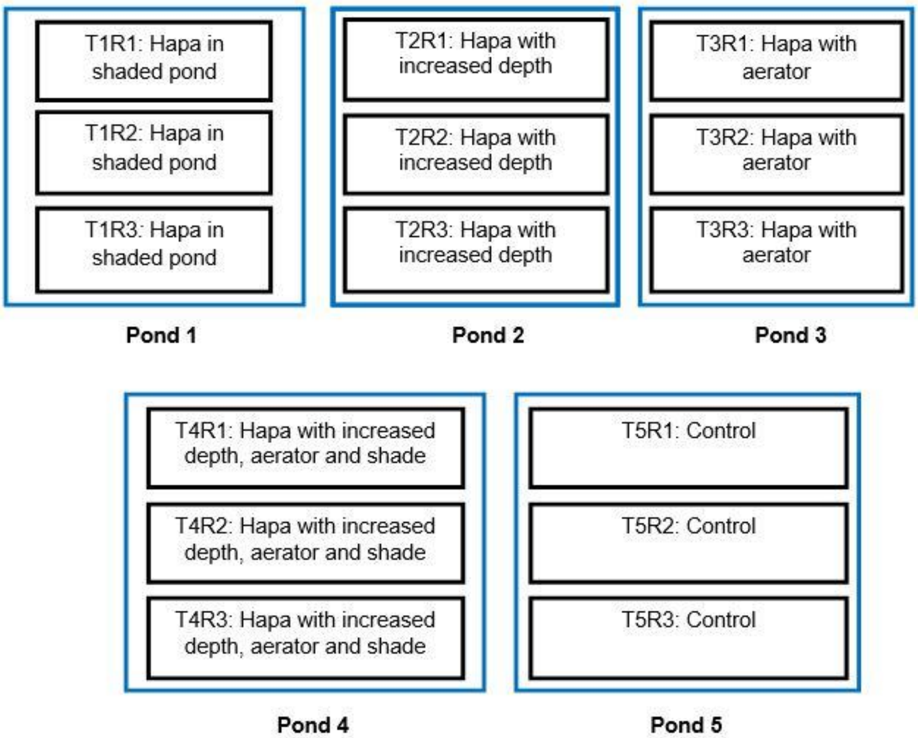

Figure 1. Different treatment on replicated hapas in experimental ponds (T=Treatment, R= Replication).

collected for the first time after 2 weeks of brood-fish stocking in hapas and then carried out once 7 days thereafter. Collected eggs or hatchlings were kept in a metal bowl. Separate bowls were used for different treatments and all bowls contained equal volume of water. By a spoon, 1 ml egg or hatchling sample of 4 available stages from bowls was counted and then multiplied the number of eggs or hatchlings per ml with total volume of water taken into a bowl to get total number of eggs produced per week.

Statistical Analysis

Experimental data were compiled and analyzed using single-factor analysis of variance (ANOVA) to see whether the impacts of treatments are significantly different or not. Post-hoc t-test was carried out to determine which specific groups differed from each other. Statistical difference was considered at P<0.05. To determine cause and effects, linear regression analysis was used. Microsoft Excel (2013) was used for the statistical analyses.

Results

Acceptable Hatchery Management Strategies

Mean egg production in T1, T2, T3, T4 and T5 was 20488, 15369, 3596, 21021 and 3979 eggs/hapa, respectively. At P<0.05, single factor ANOVA analysis suggested that the egg production among all these treatments were significantly different (Figure 2). Post hoc analysis showed that egg production among T1, T2, T4 were not significantly different. Again, egg production between T3 and T5 were not significantly different. But egg production performance was much higher in T1, T2, and T4 than T3, T5, so, T3 and T5 was excluded from acceptable hatchery management strategies. In comparison with T1 and T4, T2 produced less eggs. Between T1 and T4, difference in number of egg production was low (533 eggs/hapa) but T4 required 3 components i.e. shade over brood hapa, increase in pond depth and aeration system whereas T1 required just shade over brood hapa. So, considered efficiency and simplicity T1 was the best treatment.

Egg Production Performance & Monthly Temperature

In all the treatments, highest egg productions were obtained in May with a peak in early May and corresponding water temperature was 30.22°C and then dropped in June with a peak in late May at 30.23°C and declined to lowest egg production in mid-August while water temperature was 31.18°C. Egg production rose from late August till mid-September with a peak in mid-September and corresponding water temperature was 31.09°C. Other than any month, in May T1, T2, T3, T4 and T5 at 29.69°C, 30.12°C, 29.96°C, 29.61°C, and 31.26°C temperature produced highest 30859, 36119, 8997, 45876 and 5506 eggs/hapa, respectively. In T1 and T4, egg production remained high throughout the study period with highest in T1 during early May (Figure 3).

Relationships between temperature and egg production are shown in Figure 4 for different treatments. It was observed that, with the increase in temperature the egg production decreased. The most suitable water temperature for egg production (20365 eggs/hapa) was found at temperature ranges between 29°C to 31°C. Egg production above 32°C was very low (179 eggs/hapa) and at temperature above 33°C egg production ceased. Among all the treatments, T1 was the best. In the present study, the highest number of eggs was observed in the month of May when average water temperature was 29.6°C and the lowest number of eggs was observed at the month of August when average water temperature was 31°C.

Water Quality Parameters

Different treatments which cause change of temperature in all treatments and oxygen content in T3 and T4 also change the water quality parameters.

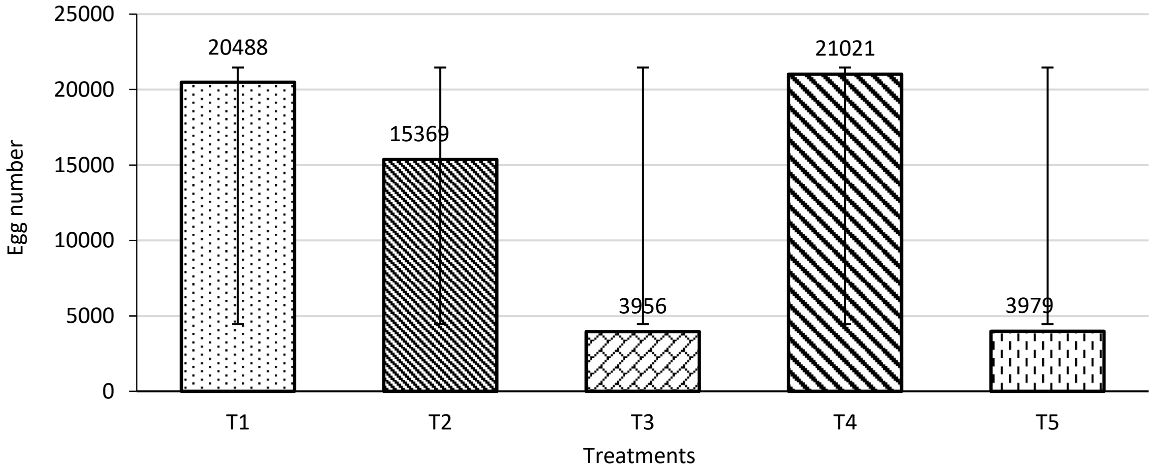

Figure 2. Mean egg production in different treatments.

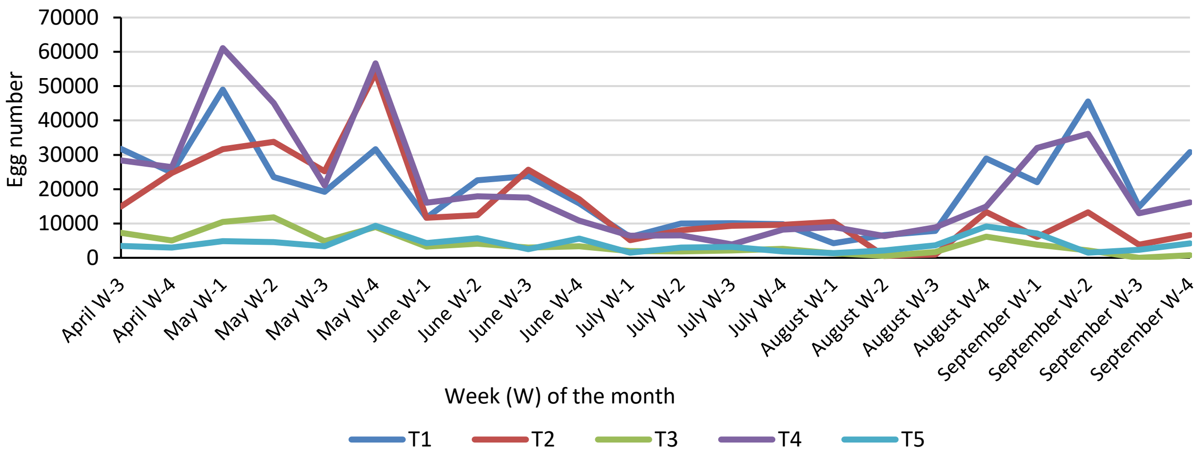

Figure 3. Seasonal variation in egg production by female Nile tilapia in different treatments.

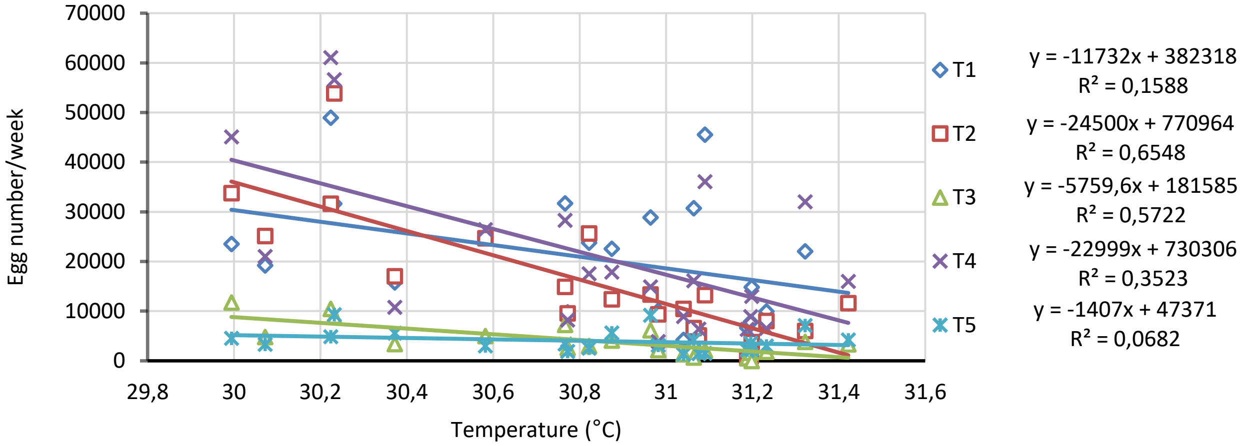

Figure 4. Relationship between Nile tilapia egg production and water temperature.

Variation of DO content in water under different treatments is shown in Figure 5. Egg production was highest (20365 eggs/hapa) when DO level was 4.6 mg/L and at low DO level (2.9 mg/l) egg production was low (179 eggs/hapa). So, optimum DO level for egg production was 4.5 to 6 mg/L.

Variation of pH content in water under different treatments is shown in Figure 6. In this study, egg production (3489-20365 eggs/hapa) in all treatments showed highest value when pH was within 8-8.8 range and at pH above 9.3 egg production was low (179 eggs/hapa). So, optimum pH level for egg production was 8.0 to 8.8.

Variation of alkalinity in water under different treatments is shown in Figure 7. Egg production showed higher values (3887-20365 eggs/hapa) when alkalinity range was 105 - 150 mg/L and at both very low (66 mg/L) and very high (165 mg/L) alkalinity, egg production was low (179 eggs/hapa and 1514 eggs/hapa, respectively).

Ammonia value (0-0.5 mg/L) was more or less same during the study period. Variation of water turbidity under different treatments is shown in Figure 8. In this study, egg production showed the highest value (10577-20365 eggs/hapa) when turbidity range were within 15-35 cm.

Discussion

Acceptable Hatchery Management Strategies

In this study, T1 (shade over brood hapa) and T4 (combination of shade over brood hapa, pond depth increase and aeration) were the best strategies. Bhujel *et al*. (2001) found that, among different treatments: cooling of pond water with ice, aeration, shading, salinity (5 and 10 ppt) and water depth (1.5 and 2.1 m), cooling of pond water with ice and shading was the best treatment; which produced 7.5 and 2.4 times higher number of eggs and yolk-sac fry than control. Bhujel and Perera (2017) found that, hapas shaded with black net produced 9 % more eggs than control. All these strategies maintained as much as possible optimum temperature for egg production of Nile tilapia throughout the study period, that's why highest number of eggs was found. Present study suggested that T1 was better than T4 because T1 was easy to operate.

Egg Production Performance & Monthly Temperature

Present study found that Nile tilapia laid highest and lowest number of eggs in early May and mid-August

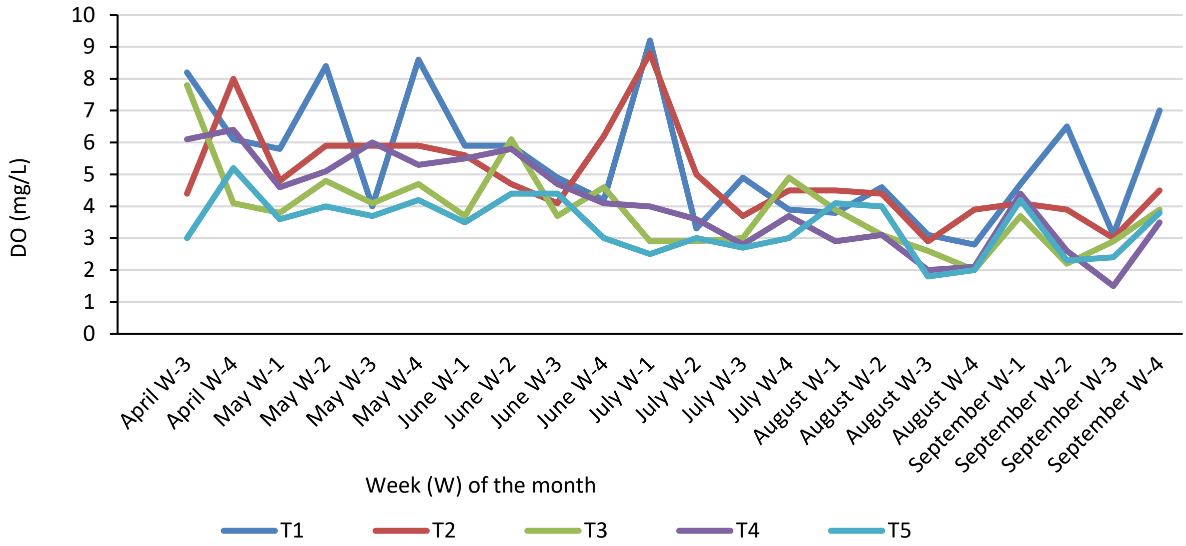

Figure 5. Weekly variation in dissolved oxygen of water under different treatments.

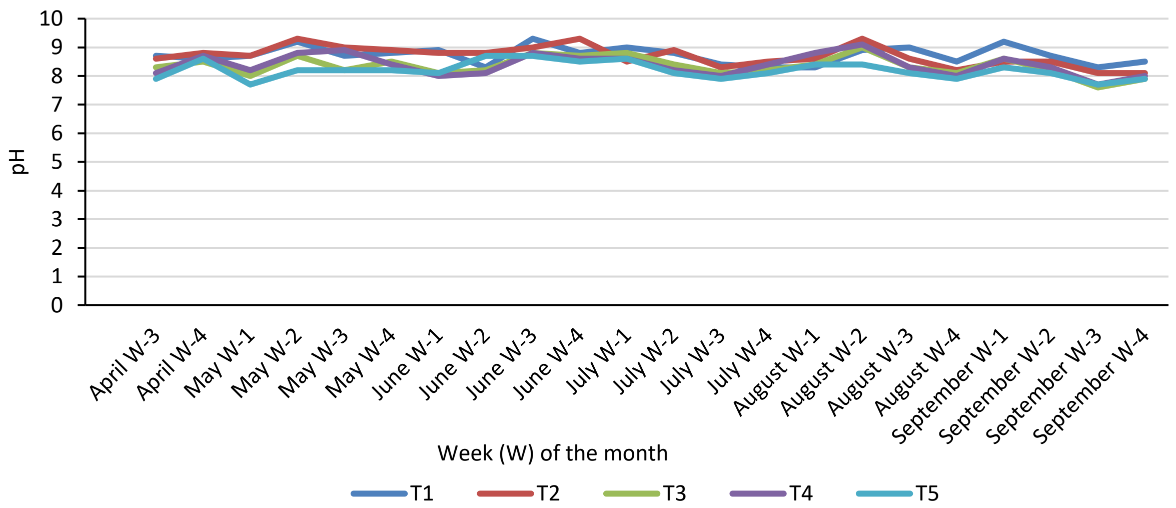

Figure 6. Weekly variation of water pH under different treatments.

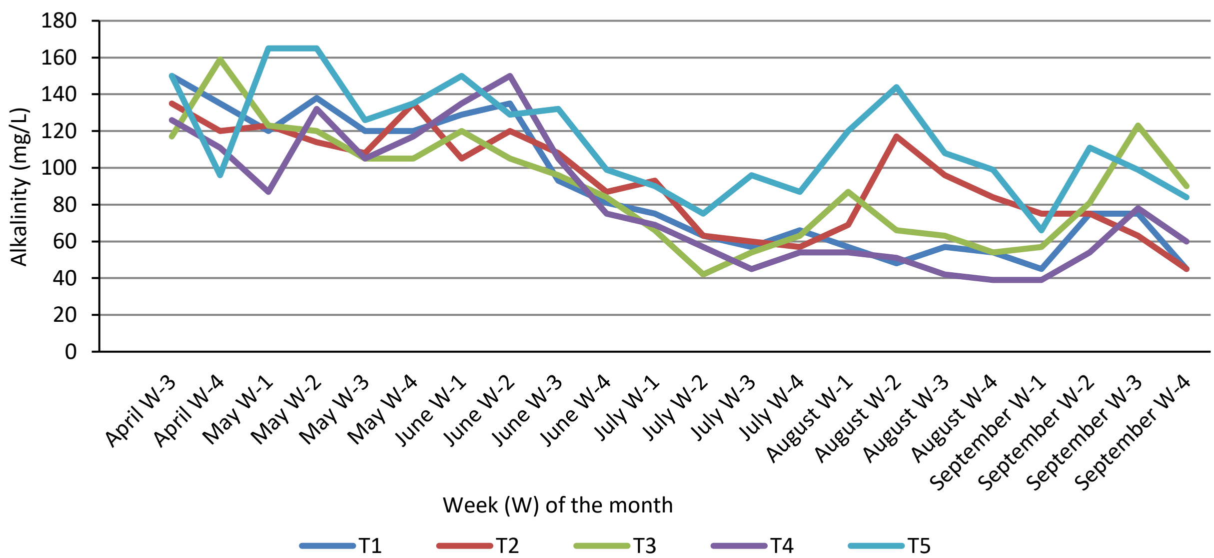

Figure 7. Weekly variation of alkalinity under different treatments.

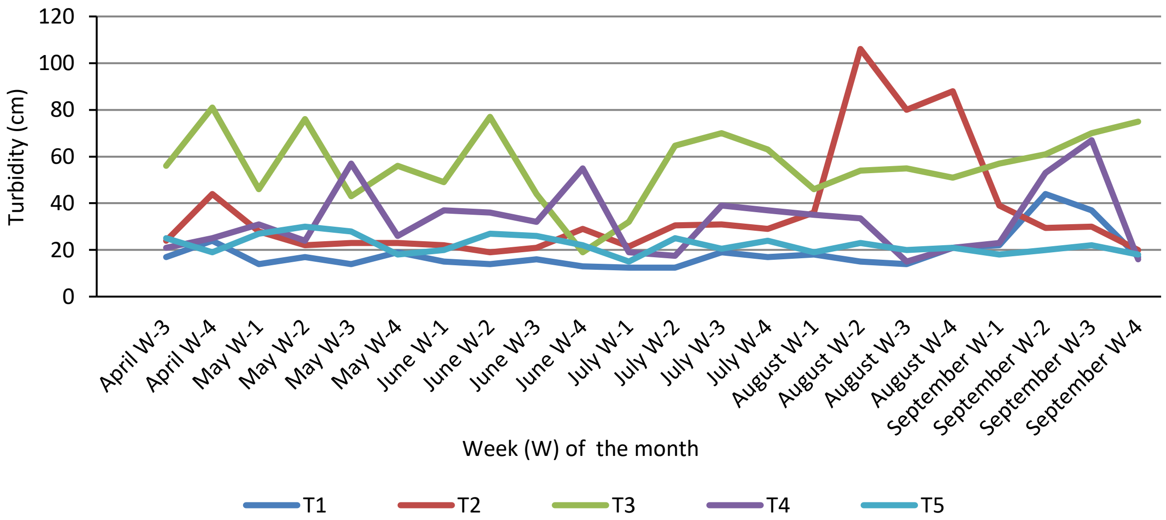

Figure 8. Weekly variation of water turbidity under different treatments.

when water temperature was 30.22°C and 31.18°C, respectively. Faruk *et al.* (2012) conducted a study on effect of temperature on egg production and growth of monosex *Oreochromis niloticus* fry for nine months from January to September, 2011 and reported that the highest number of eggs was observed in May when average water temperature was 25°C and the lowest number of eggs was observed August when average water temperature was 29°C. Monthly temperature altered egg production of Nile tilapia.

In this study it was observed that egg production of Nile tilapia was dependent upon water temperature. Most suitable water temperature for egg production was 29°C to 31°C, egg production was lowered at 32°C and ceased at 33°C. Hossain *et al*. (2013) reported similar findings that egg production was high when water temperature was 31.5 to 33°C with highest at 32°C; egg production gradually decreased at temperature above 33°C and ceased at 35°C. El-Naggar *et al.* (2000) reported that female tilapia did not lay eggs when water temperature decreased below 19°C. Those authors concluded that the most productive period coincided with a rise in water temperature range from 22 to 27°C. Present study results varied from results of El-Naggar *et al.* (2000) due to geographical differences. Fryer and Iles (1972) reported that temperatures above 20°C trigger the development of secondary sexual characteristics and nest building. Temperature was one of the most critical factors for egg production of Nile tilapia.

Water Quality Parameters

In the present study, highest (20365 eggs/hapa) and lowest (179 eggs/hapa) number of eggs was produced when DO levels was 4.6 mg/L and 2.9 mg/l, respectively. Kolding (2008) reported that growth, size at maturity, gonadosomatic index (GSI), egg size, and absolute fecundity of Nile tilapia (*O. niloticus*) were significantly affected by DO levels. In this study DO level maintained usual relationship with egg production as expected.

This study showed that, highest (3489-20365 eggs/hapa) and lowest (179 eggs/hapa) number of eggs was produced when pH was 8-8.8 and 9.3, respectively. Tam and Payson (1986) reported that in hatchery reared brook trout (*Salvelinus fontinalis*) egg production was higher at pH values of 7.34 and at lower acidic pH egg production was low. Sapkale *et al*. (2011) observed that increase in pH value from 5.5 to 8.8, decrease hatchability of *Cyprinus carpio* eggs. Present study was consistent with these reports.

Highest number of eggs (3887-20365 eggs/hapa) was observed in this study when alkalinity range was 105-150 mg/L. Wurts and Durborow (1992) reported total alkalinity for fish culture and egg production should be between 75 and 200 mg/L. Alkalinity of the present study value was acceptable.

Ammonia value was 0-0.5 mg/L in this study. Burkhalter and Kaya (1977) reported that effects of ammonia on fertilized egg and resulting sac fry of rainbow trout (*Salmo gairdneri*) were good at concentrations of un-ionized ammonia ranging from 0.05 to 0.37 mg/L. Ammonia value of this present study was expected.

In this study, highest number of eggs (10577-20365 eggs/hapa) produced when turbidity ranges were within 15-35 cm. Clayden *et al*. (2005) reported that egg production was increased by about 72% and 96% in the 100 cm and 140 cm turbidity treatments, compared to control. Turbidity value of this present value was acceptable.

Conclusion

Tilapia is a global aquaculture species. Tilapia hatcheries in Bangladesh often face low; even stunted egg production problems due to high temperature in summer and monsoon seasons. Through this study it can be concluded that rather than pond depth increase or aeration or combination of shed with cloth over brood hapa, increase pond depth and aeration treatment, cloth cover over tilapia brood hapa can potentially keep water temperature within 29°C to 31°C; the most favorable temperature range for tilapia egg production. Month of maximum egg production was May and above 32°C egg production was minimum. Other environmental parameters favor highest egg production were: dissolved oxygen between 4.5 to 6.0 mg/L, pH between 8.0 to 8.8, ammonia between 0-0.5 mg/L, alkalinity between 105 to 150 mg/L and turbidity between 15 to 35 cm. Thus shade treatment over brood hapa to nullify the stressing effect of climate change induced temperature rise on tilapia egg production has recommended for commercial fish hatcheries.

Ethical Statement

No fishes were harmed during this experimentation.

Funding Information

WorldFish, Bangladesh funded this research project.

Author Contribution

Harunur Rashid conceived the research idea. Ashiqul Alam conducted the experiment. Harunur Rashid and Md. Mahbubul Alam Miah supervised the experiment. Md. Shirajul Islam Sarkar interpreted the results and wrote the manuscript with input from all authors.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

Assistance from Dr. Benoy Kumer Barman (Senior Scientist, WorldFish, Bangladesh), Mohammad Mokarrom Hossain (Project Leader, CSISA-BD, WorldFish, Bangladesh), Md. Masud Rana Khan (Managing Director of Nova Hatchery and Fishery, Tarakanda, Mymensingh, Bangladesh) and all of his farm staffs, is thankfully acknowledged.

References

Basak, J.K., Titumir, R.A.M., & Dey, N.C. (2013). Climate change in Bangladesh: A historical analysis of temperature and rainfall data. *Journal of Environment*, 02(02), 41-46.

Bhujel, R.C. (2000). A review of strategies for the management of Nile tilapia (*Oreochromis niloticus*) boodfish in seed production systems, especially *hapa*-based systems. *Aquaculture,* 181, 37–59.

Bhujel, R.C., Little, D.C., & Hossain, A. (2007). Reproductive performance and the growth of pre-stunted and normal Nile tilapia (*Oreochromis niloticus*) broodfish at varying feeding rates. *Aquaculture*, 273, 71–79. https://doi.org/10.1016/j.aquaculture.2007.09.022

Bhujel, R.C., & Perera, A. (2017). Shading of breeding hapas enhances reproductive performance of nile tilapia (*Oreochromis niloticus*) and seed output. *Journal of Aquaculture in the Tropics*, 32(3-4), 187-197.

Bhujel, R.C., Turner, W.A., Yakupitiyage, A., & Little, D.C. (2001). Impacts of environmental manipulation on the reproductive performance of Nile tilapia (*Oreochromis niloticus*). *Journal of Aquaculture in the Tropics*, 16(3), 197-209.

Brummett, R.E. (1995). Environmental regulation of sexual maturation and reproduction in tilapia. *Reviews in Fisheries Science*, 3, 231–248.

Burkhalter, D.E., & Kaya, C.M. (1977). Effects of prolonged exposure to ammonia on fertilized eggs and sac fry of rainbow trout (*Salmo gairdneri*), *Transactions of the American Fisheries Society*, 106(5), 470-475. https://doi.org/10.1577/1548-8659(1977)106<470:EOPETA>2.0.CO;2

Caulton, M.S. (1982). Feeding, metabolism and growth of tilapias: Some quantitative considerations. In: R.S.V. Pullin & R.H. Lowe-McConnell (Eds.), *The biology and culture of tilapias* (pp. 157–184). International Center for Living Aquatic Resources Management, Philippines.

Chatterjee, N., Pal, A.K., Manush, S.M., Das, T., & Mukherjee, S.G. (2004). Thermal tolerance and oxygen consumption of *Labeo rohita* and *Cyprinus carpio* early fingerlings acclimated to three different temperatures. *Journal of Thermal Biology*, 29, 265-270. https://doi.org/10.1016/j.jtherbio.2004.05.001

Clayden, P., Rakocy, J.E., & Diana, J.S. (2005). Mitigating the effects of high temperature and turbidity on seed production of Nile tilapia from hapa-in pond system. (Twenty-Second Annual Technical Report). Oregon State University.

Coward, K., & Bromage, N.R. (2000). Reproductive physiology of female tilapia broodstock. *Reviews in Fish Biology and Fisheries*, 10, 1–25. https://doi.org/10.1023/A:1008942318272

El-Naggar, G.O., El-Nady, M.A., Kamar, M.G., & Al-Kholy, A. (2000). Effect of photoperiod, dietary protein and temperature on reproduction in Nile tilapia *Oreochromis niloticus.* In: K. Fitzsmons & J.C. Filho (Eds.), *Proceedings of the Fifth International Symposium on Tilapia in Aquaculture* (pp. 352-358). University of Arizona. https://hdl.handle.net/20.500.12348/4267

El-Sayed, A.F.M. (2006). Tilapia Culture. CABI Publishing, United Kingdom.

El-Sayed, A.F.M., El-Ghobashy, A., & Al-Amoudi, M. (1996). Effects of pond depth and water temperature on the growth, mortality and body composition of Nile tilapia, *Oreochromis niloticus*. *Aquaculture Research*, 27, 681-687. https://doi.org/10.1046/j.1365-2109.1996.00776.x

FAO (Food and Agriculture Organization, United Nations). (2014). The state of world fisheries and aquaculture 2014. FAO, Rome, Italy.

FAO (Food and Agriculture Organization, United Nations). (2018). The state of world fisheries and aquaculture 2018. FAO, Rome, Italy.

Faruk, M.A.R., Mausumi, M.I., Anka, I.Z., & Hasan, M.M. (2012). Effects of temperature on the egg production and growth of monosex Nile tilapia *Oreochromis niloticus* Fry. *Bangladesh Research Publication Journal*, 7, 367-377.

Fitzsimmons, K. (2006). Prospect and Potential for Global Production. In: C.E. Lim & C.D. Webster (Eds.), *Tilapia Biology, Culture and Nutrition* (pp. 51-54). The Haworth Press Inc.

Fitzsimmons, K. (2008). Tilapia product quality and new product forms for international markets. 8th International Symposium on Tilapia Aquaculture. https://www.researchgate.net/publication/228832408_TILAPIA_PRODUCT_QUALITY_AND_NEW_PRODUCT_FORMS_FOR_INTERNATIONAL_MARKETS

Fryer, G., & Iles, T.D. (1972). The cichlid fishes of the great lakes of Africa. Oliver and Boyd, London.

Hossan, M.S., Ulka, S.V., Motin, M.A., Tarafder, M.A.K., Sukhan, Z.P., & Rashid, H. (2013). Egg and fry production performance of female tilapia related to fluctuating temperature and size variation. In: M.A.R. Ahad, H. Miyake & Z.P. Sukhan (Eds.), *Proceedings of 4th the International Conference on Environmental Aspects of Bangladesh* (pp.105-108). http://benjapan.org/iceab13/procICEAB13.pdf

Hussain, M.G. (2004). Farming of tilapia: Breeding plans, mass seed production and aquaculture techniques. Habiba Akter Hussain, 55 Kristawpur, Mymensingh 2200, Bangladesh.

Kolding, J. (2008). Effect of ambient oxygen on growth and reproduction in Nile tilapia (*Oreochromis niloticus*). *Canadian Journal of Fisheries and Aquatic Sciences*, 65, 1413-1424. https://doi.org/10.1139/F08-059

Larsson, S., & Berglund, I. (2005). The effect of temperature on the growth energetic, growth efficiency of Aractic charr (*Salvelinus alpinus*) from four Swedish populations. *Journal Thermal Biology*, 3, 29-36. https://doi.org/10.1016/j.jtherbio.2004.06.001

Macintosh, D.J., & Little, D.C. (1995). Broodstock management and fry production of the Nile tilapia *Oreochromis niloticus*. In: N.R. Bromage & R.J. Roberts (Eds.), *Broodfish management and egg and larval quality* (pp. 277-320). Blackwell Science, Oxford.

Rana, K.J. (1988). Reproductive biology and the hatchery rearing of tilapia eggs and fry. In: J.F. Muir & R.J. Roberts (Eds.), *Recent Advances in Aquaculture* (pp. 343–406). Croom Helm, London.

Rouf, M.A., Uddin, M.K., Debsarma, S.K. & Rahman, M.M. (2011). Climate of Bangladesh: An analysis of northwestern and southwestern part using high resolution Atmosphere-Ocean General Circulation Model (AOGCM). *The Agriculturists*, 9(1&2), 143-154. https://doi.org/10.3329/agric.v9i1-2.9489

Sapkale, P.H., Singh, R.K. & Desai, A.S. (2011) Optimal water temperature and pH for development of eggs and growth of spawn of common carp (*Cyprinus carpio*). *Journal of Applied Animal Research*, 39 (4), 339-345, DOI: 10.1080/09712119.2011.620269

Shelton, W.L, & Pompa, T.J. (2006). Biology. In: C.E. Lim & C.D. Webster (Eds.) *Tilapia Biology, Culture and Nutrition* (pp. 1-27). The Haworth Press Inc.

Tam, W.H., & Payson, P.D. (1986). Effects of chronic exposure to sublethal pH on growth, egg production, and ovulation in Brook Trout, *Salvelinus fontinalis*. *Canadian Journal of Fisheries and Aquatic Science*, 43, 275-280.

Van Ham, E.H., Berntssen, H.G., Imsland, A.K., Parpouna, A.C., Bonga, E.W., & Stefansson, S.O. (2003). The influence of temperature and ration on growth, feed conversion, body composition and nutrient retention of juvenile turbot (*Scophthalmus maximus*). *Aquaculture*, 217, 547-558. https://doi.org/10.1016/S0044-8486(02)00411-8

Weather Online. (2020). *Bangladesh*. https://www.weatheronline.co.uk/reports/climate/Bangladesh.htm

Wurts, W.A., & Durborow, R.M. (1992). Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. Southern Regional Aquaculture Center, United States.