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Original Article

Effects of salinity on rearing performance of bighead catfish (*Clarias macrocephalus* Günther, 1864) juveniles

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Abstract: Expanding the production of bighead catfish (*Clarias macrocephalus* Günther, 1864), a key freshwater species in Vietnamese aquaculture, into brackish water environments is essential in light of increasing saline intrusion into freshwater ecosystems driven by global climate change. A completely randomized design with three replicates was conducted in 0.5 m³ composite tanks to evaluate the effects of salinities (0, 2, 4, 6, and 8‰) on the rearing performance of juvenile *C. macrocephalus*. The juveniles (11.21 g and 11.49 cm) were stocked at a density of 45 individuals per tank (ind tank^{-1}) and fed Aquagreen commercial pellets containing 30% crude protein. After 180 days of culture, the highest growth performance was observed at 2‰ salinity and declined significantly at salinities ≥ 4‰ ($P \le 0.05$), likely contributing to significantly reduced productivity at 8‰ ($P \le 0.05$). Survival rates remained stable between 2 and 8‰ ($P \ge 0.05$) and were significantly higher than those at 0‰ ($P \le 0.05$). Although growth performance at 0‰ was only slightly lower than that at 2‰ ($P \ge 0.05$), the significantly lower survival rate at this salinity likely contributed to the significant decrease in productivity ($P \le 0.05$). The coefficient of variation in weight (CV_W) was significantly higher at salinities of 2-4‰ compared to other treatments ($P \le 0.05$), but it ranged from 3.33 to 6.64% in tested salinities (0-8‰), which fell within the ideal range for fish culture. Based on the findings, 2‰ salinity is recommended as optimal for juvenile *C. macrocephalus* culture.

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Introduction

Fish production represents a significant source of animal protein for humans, with more than 60% of the global population depending on it for a healthy diet. A clear correlation has been shown between population growth and total fish consumption (Garlock et al., 2020). The Clariidae family, which is known as clariid catfish, is widely distributed across freshwater regions of Africa and Asia, including Vietnam (Hien et al., 2018; Lisachov et al., 2023). These fish have developed auxiliary breathing organs that enable them to survive in extreme environments, such as low oxygen levels, high salinity, and high ammonia (NH_3) concentrations, thanks to specialized physiological adaptations (Lisachov et al., 2023).

The Vietnamese Mekong Delta freshwater region is currently cultivating and exploiting various catfish species, including *C. macrocephalus*, *C. batrachus*, *C. gariepinus*, and hybrid catfish. Among them, the bighead catfish (*C. macrocephalus*) is especially popular due to its ease of farming and high economic efficiency (Duong et al., 2017; Hien et al., 2018; Hien et al., 2021). In addition to its high tolerance to adverse environmental conditions, this species exhibits efficient bottom-feeding behavior and demonstrates adaptability to numerous farming systems, including ponds, rice fields, cement tanks, and wastewater environments. It is also well-suited for polyculture with other species, such as carp and tilapia, even at high stocking densities (Lisachov et al., 2023; Saha et al., 2023). Specifically, it has superior meat quality compared to hybrid catfish and other *Clarias* species (Na-Nakorn and Brummett, 2009). Thus, this species has been domesticated and cultured in several other

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Asian countries, such as the Philippines (Mollah and Tan, 1983a, b) and Thailand (Na-Nakorn, 2004; Duong et al., 2023; Lisachov et al., 2023), Cambodia, China, Malaysia, Guam, and Myanmar (Aaqillah-Amr et al., 2023). However, the wild population of bighead catfish has recently declined due to overexploitation, habitat degradation, and the impacts of introduced species. As a result, *C. macrocephalus* is now classified as "threatened" in its native range across Southeast Asia (Na-Nakorn and Brummett, 2009; Vidthayanon and Allen, 2013; Thao et al., 2017; Vidthayanon and Allen, 2020).

In recent decades, climate change has significantly influenced weather patterns, such as temperature, wind, and rainfall, throughout Southeast Asia, resulting in substantial environmental effects in the lower Mekong River basin. In Vietnam's southern Mekong Delta, these shifts have intensified saltwater intrusion into inland areas (Xiao et al., 2021), which has a local impact on freshwater aquaculture production. These challenges promote adaptive strategies, such as diversifying species and promoting aquaculture practices suited to brackish and marine water conditions (Mandal et al., 2020; Abisha et al., 2022). Many freshwater fish species have been demonstrated to thrive under brackish water conditions. Examples include *Cyprinus carpio* (Wang et al., 1997), *Tilapia rendalli* (Kang'ombe and Brown, 2008), *Clarias batrachus* (Sarma et al., 2013), Nile tilapia (*Oreochromis niloticus*) (Yue et al., 2023), and striped catfish (*Pangasianodon hypophthalmus*) (Mugwanya et al., 2023).

Given the rising saltwater intrusion caused by climate change in vulnerable regions such as Vietnam's Mekong Delta, understanding the effects of salinity on the growth and survival of *C. macrocephalus* is vital. Such knowledge is essential for determining optimal salinity conditions that support this species' efficient cultivation and long-term expansion of aquaculture.

Materials and Methods

Experimental materials: Bighead catfish juveniles, averaging a size of 11.21±1.54 g and 11.49±0.49 cm, were sourced from a local artificial hatchery at 0‰ salinity and transported to the aquaculture experimental hatch of Tra Vinh University using a closed transport system (Lekang, 2019; Erikson et al., 2022). Upon arrival, fish were acclimated in 1 m³ aerated composite tanks for one week. Initially held in freshwater (0‰), they were gradually exposed to higher salinity levels (2, 4, 6, and 8‰) by increasing salinity by 1‰ every 12 hours using 110-120‰ bittern water from a local salt field. After reaching the target salinities, fish were maintained at these levels for three days before the experiment began. During acclimation, fish were fed once daily with the same feed used in the trial, and uneaten feed and waste were removed at 9:00 PM to ensure water quality. All fish remained behaviorally normal throughout the period. Two water sources, freshwater and saltwater, were used in the study. Freshwater was sourced from a river, settled for sediment removal, disinfected with potassium permanganate ($KMnO_4$) at 5 mg L^{-1}, and aerated for three days. Saltwater (110-120‰), obtained from local salt fields, was treated with chlorine at 30 mg L^{-1} and aerated for four days. The two sources were mixed to achieve target salinities of 2, 4, 6, and 8‰. The mixing ratio of freshwater and saltwater was calculated using the formula $C_1V_1 = C_2V_2$, where C_1 is the salinity of the saltwater, V_1 is the volume of saltwater, C_2 is the desired salinity, and V_2 is the total volume of the mixture. The Aquagreen commercial pellets (28-30% protein), produced by Greenfeed Vietnam Joint Stock Company, were fed to the experimental fish. Moreover, the 0.5 m³ composite tanks, each containing 300 liters of water, were used for the experiment.

Experimental design: This study was conducted at the Aquaculture Experimental Hatchery of Tra Vinh University in southern Vietnam from October 2022 to May 2023. The experiment lasted 90 days using a completely randomized design with three replicates. The objective was to evaluate the culture performance of *C. macrocephalus* juveniles under five different stocking densities. The experimental setup is detailed: Five salinity levels (0, 2, 4, 6, and 8‰) were tested using fifteen rearing tanks. A total of 675 healthy juvenile bighead catfish were randomly distributed among the tanks, with a stocking density of 45 ind $tank^{-1}$. During the experiment, fish were fed commercial pellets (30% protein) at 5-7% of their body weight daily, divided into two feedings at 07:00 and 16:00. A mixed mineral supplement was added weekly at a rate of 1-2% of the total feed. Continuous aeration was provided in all tanks to maintain dissolved oxygen levels near saturation. Uneaten feed and fecal waste were removed daily by siphoning at 18:00. Additionally, 30% of the water volume in each tank was replaced weekly using water adjusted to the respective salinity levels.

Collecting data: Water quality in the rearing tanks was monitored before and throughout the experimental period. Salinity was measured immediately after each water change using a salinometer (YSI, Japan). Temperature and pH were recorded twice daily, at 07:00 and 14:00, using a HANNA tester (Model HI98103, Romania). In addition, concentrations of total ammonia nitrogen (TAN) and nitrite ($N\text{-}NO_2^-$) were assessed every three days at 07:00 using Sera test kits (Germany).

Initial growth parameters were recorded prior to stocking, and subsequent measurements were taken on a monthly basis. At each sampling set, fifteen fish were randomly selected from each tank. Wet weight was measured using an electronic balance (±0.01 g) after blotting the fish dry with filter paper, while total length was measured to the nearest millimeter using a graduated ruler. Survival rate and productivity were evaluated at the end of the experiment. The following formulas were used to calculate the monitored parameters (Stickney, 2000; Ly et al., 2024):

Mean weight (MW, g) = total weight of 15 fish / 15

Mean length (ML, cm) = total length of 15 fish / 15

Weight gain (WG, g) = final weight - initial weight

Length gain (LG, cm) = final length - initial length

Daily weight gain (DWG, g day^{-1}) = (final weight - initial weight) / number of rearing days

Daily length gain (DLG, cm day^{-1}) = (final length - initial length) / number of rearing days

Specific growth rate in weight (SGR_W, % day^{-1}) = ((ln(final weight) - ln(initial weight)) / number of rearing days) × 100

Specific growth rate in length (SGR_L, % day^{-1}) = ((ln(final length) - ln(initial length)) / number of rearing days) × 100

Survival rate (%) = (final fish number / initial fish number) × 100

The coefficient of variation in weight (CVw, %) = (standard deviation /mean body weight) × 100

Productivity (ind m^{-3}) = final number/rearing volume

The animal experiments were conducted in accordance with relevant national and international guidelines and regulations. Only the bighead catfish juveniles underwent weighing and measuring during the experiment, ensuring no harm was caused. After the experiments, the fish were returned to the storage tanks for further investigation.

Analyzing data: A one-way ANOVA was used to evaluate differences among groups, with Duncan's multiple range test employed to identify significant differences at the $P \leq 0.05$ level. Variance homogeneity was checked using Levene's test, and percentage data were transformed using the arcsine function prior to analysis. Statistical analysis was performed using SPSS for Windows (version 20.0).

Results

Water quality parameters: During the rearing period, water quality parameters remained relatively stable, with only minor fluctuations. The water temperature ranged from 26.03 to 27.73°C, while the pH exhibited minimal diurnal variation, remaining between 7.89 and 8.07. Nitrite ($N\text{-}NO_2^-$) and total ammonia nitrogen (TAN, $N\text{-}NH_4^+$) concentrations ranged from 0.19 to 0.26 mg L^{-1} and 0.10 to 0.18 mg L^{-1}, respectively (Table 1).

Rearing performance: Between days 30 and 75 of the culture period, the highest MW_{30-75} and ML_{30-75} were recorded at a salinity of 2‰. Both exhibited a decreasing trend at other salinity levels, with a consistently significant reduction observed at 8‰ ($P \leq 0.05$, Tables 2, 3).

By the end of the experiment, the highest growth parameters for weight (MW_{60}, DWG, SGRw) and length (ML_{90}, DLG, SGRL) were also maintained at a

Table 1. Water quality parameters during 90 days of rearing under various salinities.

Parameters	Test Time	Salinities (‰)				
		0	2	4	6	8
Temperature (°C)	7:00	26.03±0.78	26.00±0.69	26.03±1.33	26.16±1.14	26.25±1.04
	14:00	27.73±0.96	27.55±1.06	27.74±0.98	27.66±1.06	27.61±1.05
pH	7:00	7.91±0.21	7.89±0.07	7.9±0.05	8.01±0.05	8.06±0.32
	14:00	7.9±0.02	7.91±0.41	8.0±0.11	8.04±0.31	8.07±0.26
TAN (mg L^{-1})		0.19±0.05	0.26±0.07	0.20±0.05	0.24±0.07	0.22±0.06
NO_2^- (mg L^{-1})		0.08±0.02	0.13±0.05	0.18±0.06	0.17±0.06	0.16±0.04

Table 2. Initial mean weight (IMW) and mean weight (MW) of *Clarias macrocephalus* juveniles during 90 days of rearing under various salinities.

Salinities (‰)	0	2	4	6	8
IMW (g ind^{-1})	11.21±1.54^{a}	11.21±1.54^{a}	11.21±1.54^{a}	11.21±1.54^{a}	11.21±1.54^{a}
MW_{15} (g ind^{-1})	14.78±2.47^{a}	14.16±3.23^{a}	14.44±3.23^{a}	14.61±3.49^{a}	13.85±3.50^{a}
MW_{30} (g ind^{-1})	17.29±3.89^{ab}	19.48±2.79^{c}	18.79±4.51^{bc}	18.75±3.98^{bc}	16.66±4.05^{a}
MW_{45} (g ind^{-1})	22.18±4.08^{ab}	23.29±4.17^{b}	22.61±4.42^{ab}	22.02±4.95^{ab}	20.97±4.35^{a}
MW_{60} (g ind^{-1})	33.96±8.56^{cd}	37.12±9.57^{d}	32.49±7.36^{bc}	29.28±7.91^{ab}	28.51±8.22^{a}
MW_{75} (g ind^{-1})	41.84±6.95^{c}	42.56±9.12^{c}	40.48±6.26^{bc}	38.15±7.39^{ab}	36.38±7.20^{a}
MW_{90} (g ind^{-1})	55.78±10.91^{bc}	60.32±9.12^{c}	54.13±9.11^{b}	47.06±15.22^{a}	42.88±13.81^{a}

Values are presented as mean±SD. Values with different letters (a, b, c, and d) in the same row show a significant difference (P≤0.05).

Table 3. Initial mean length (IML) and mean length (ML) of *Clarias macrocephalus* juveniles during 90 days of rearing under various salinities.

Salinities (‰)	0	2	4	6	8
IML (cm ind^{-1})	11.49±0.49^{a}	11.49±0.49^{a}	11.49±0.49^{a}	11.49±0.49^{a}	11.49±0.49^{a}
ML_{15} (cm ind^{-1})	11.55±1.41^{a}	12.10±1.41^{a}	12.04±1.27^{a}	11.95±1.13^{a}	11.75±1.15^{a}
ML_{30} (cm ind^{-1})	12.86±1.50^{a}	13.72±1.19^{b}	13.47±1.02^{b}	13.38±1.10^{ab}	12.92±1.23^{a}
ML_{45} (cm ind^{-1})	14.02±1.29^{ab}	14.08±1.32^{b}	14.06±1.34^{ab}	13.91±1.15^{ab}	13.53±0.77^{a}
ML_{60} (cm ind^{-1})	16.04±1.53^{b}	16.24±2.09^{b}	15.59±1.48^{b}	14.76±1.30^{a}	14.36±1.20^{a}
ML_{75} (cm ind^{-1})	18.16±1.74^{bc}	18.70±2.19^{c}	17.74±1.92^{b}	16.71±1.81^{a}	16.66±1.52^{a}
ML_{90} (cm ind^{-1})	19.23±1.49^{c}	19.43±1.69^{c}	18.21±1.47^{b}	16.75±1.64^{a}	16.47±1.78^{a}

Values are presented as mean±SD. Values with different letters (a, b, c) in the same row show a significant difference (P≤0.05).

Table 4. Survival rate, coefficient of variation in weight (CVW), and productivity of *Clarias macrocephalus* juveniles after 90 days of rearing under various salinities.

Salinities (‰)	0	2	4	6	8
Survival rate (%)	32.67±11.16^{a}	57.33±11.72^{b}	65.33±11.56^{b}	57.33±13.32^{b}	53.33±14.18^{b}
CV_W (%)	3.72±0.10^{a}	6.64±0.29^{b}	6.03±0.51^{b}	3.94±1.07^{a}	3.33±0.41^{a}
Productivity (ind m^{-3})	2.246±241^{a}	3.346±464^{b}	3.200±200^{b}	2.733±350^{b}	2.100±466^{a}

Values are presented as mean±SD. Values with different letters (a, and b) in the same row show a significant difference (P≤0.05).

salinity of 2‰. A slight decrease was observed at 2‰, while significant reductions in MW_{90}, DWG, SGRw, DLG, and SGRL were recorded at salinities ≥ 4‰ (P≤0.05, Tables 2, 3, Figs. 1, 2).

The survival rate did not vary significantly within the salinity range of 2-8‰. It was significantly higher than at 0‰ (P≤0.05), while productivity at 0 and 8‰ was similar and significantly lower than that observed within the 2-6‰ range (P≤0.05, Table 4). In addition, CV_W was not significantly different between salinities of 2-4‰; however, it was significantly higher at these salinities than at 0, 6, and 8‰ (P≤0.05, Table 4).

Discussions

Water quality parameters: Water quality parameters showed minimal variation during the experiment, including temperature (26.03-27.73°C), pH (7.89-8.07), TAN (0.19-0.26 mg L^{-1}), and NO_2^- (0.10-0.18 mg L^{-1}). They were within the suitable range for bighead catfish (Boyd, 1998; Bhatnagar and Devi, 2013; Nho et al., 2018).

Rearing performance: Variations in

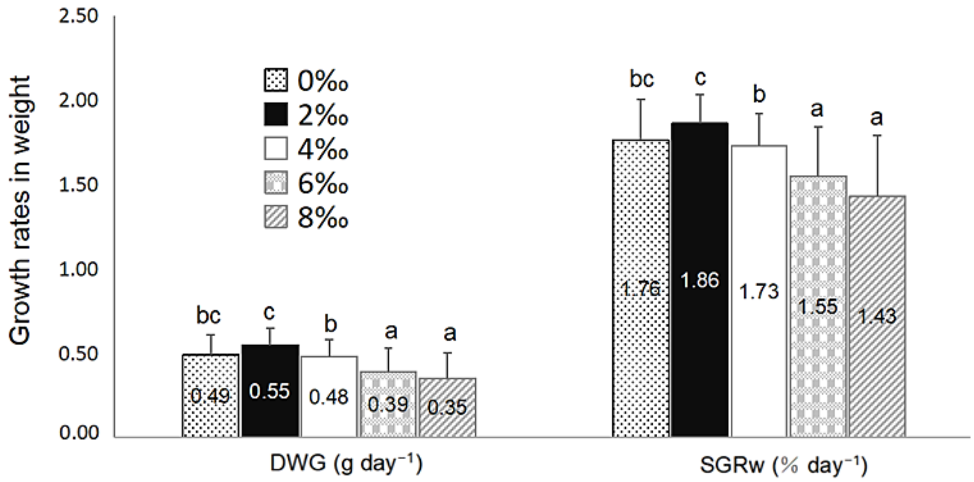

Figure 1. Daily weight gain (DWG) and specific growth rate in weight (SGRw) of *Clarias macrocephalus* juveniles after 90 days of rearing under various salinities. Values are presented as means±SD. The bars with different letters (a, b, and c) in the same group show a significant difference (*P*≤0.05).

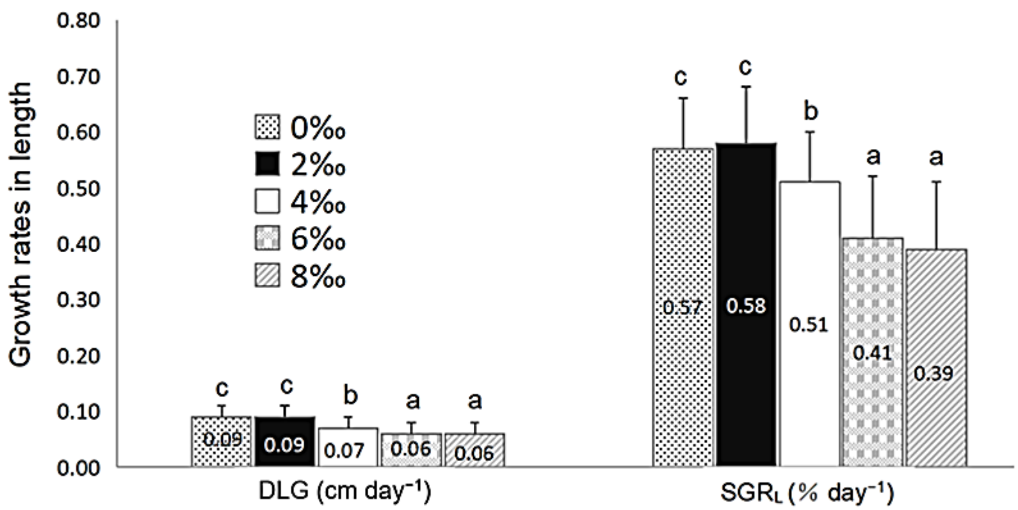

Figure 2. Daily length gain (DLG) and specific growth rate in length (SGRL) of *Clarias macrocephalus* juveniles after 90 days of rearing under various salinities. Values are presented as means±SD. The bars with different letters (a, b, c) in the same group show a significant difference (P≤0.05).

physicochemical factors of the water environment affect the well-being and survival of aquatic species, with fish being especially vulnerable (Menon et al., 2023). Among these factors, salinity has been identified as a critical indicator and a notable abiotic stressor for farmed aquatic animals (Alam et al., 2020; Patel et al., 2023). Therefore, changes in ambient salinity can negatively affect fish growth and other physiological processes (Boeuf and Payan, 2001; Nordlie, 2009).

In the present study, *C. macrocephalus* exhibited the highest growth performance in both length and weight at a salinity of 2‰ throughout the experimental period. However, growth performance declined with increasing salinity. Significant reductions were observed at 8‰ salinity after 30 days and at salinities ≥ 4‰ after 60 days of culture.

Several freshwater fish species cultured in brackish water environments exhibited thriving growth at a species-specific salinity threshold, beyond which growth performance declined. For instance, common carp (*Cyprinus carpio*), Russian sturgeon (*Acipenser guldenstaedti*), and white amur (*Ctenopharyngodon idella*) have also shown improved growth and feed efficiency when cultured at 2‰ salinity (Konstantinov and Martynova, 1993). In other fish species, such as juvenile channel catfish (*Ictalurus punctatus*), salinities ranging from 0.85 to 4‰ have been reported to enhance growth (Allen and Avault, 1970; Lewis, 1972). Salinity levels above 4.5‰ have been shown to affect the growth of freshwater carp negatively, *Labeo rohita* (Sarma et al., 2020), while levels exceeding 6‰ impair both growth and immune function in juvenile grass carp, *Ctenopharyngodon idella* (Mandal et al., 2014; Liu et al., 2023). In contrast, striped catfish larvae adapt well to elevated salinity, with an optimal rearing range below 6‰ (Nguyen et al., 2021).

Salinity affects fish growth by influencing the energy required for osmoregulation (Iwama 1996; Anni et al., 2016). Fish thrive in ideal salinity settings where the exterior osmotic pressure nearly matches the internal environment. Under such conditions, energy consumption for osmoregulation was reduced, resulting in enhanced survival and growth. When salinity deviated from the ideal range, increasing energy demands for osmoregulation diminished available energy for growth, resulting in a slower growth rate (Iwama 1996; Seale et al., 2012). In addition, rearing fish at salinity levels above the optimal threshold can disrupt several fundamental physiological processes, including altered hormone concentrations and impaired energy metabolism (Chainy and Sahoo, 2020; Alam et al., 2020; Patel et al., 2023). Elevated salinity has also been associated with increased lipid peroxidation in tissues and heightened oxidative stress (Bal et al., 2021). Martins et al. (2022) demonstrated that both high and low salinity conditions can alter the expression of appetite-regulating genes. Furthermore, salinity stress can induce inflammation in critical tissues such as the intestines, gills, liver, and kidneys, thereby impairing organ function in Nile tilapia (Dawod et al., 2021; Mohamed et al., 2021). Prolonged exposure to suboptimal salinity, whether excessively high or low, may also result in electrolyte imbalances (Moniruzzaman et al., 2022). These physiological disturbances and other adaptive stress responses may contribute to reductions in body mass index, specific growth rate, and final body weight (Bal et al., 2021).

Woo and Kelly (1995) found that even in freshwater environments, aquatic animals expend energy to compensate for salt loss through passive diffusion. Furthermore, minerals, i.e., inorganic elements such as calcium (Ca), copper (Cu), iron (Fe), magnesium (Mg), potassium (K), selenium (Se), sodium (Na), and zinc (Zn), are essential nutrients for fish. Since fish cannot synthesize these minerals internally, they must obtain them from their surrounding environment or diet to support key physiological functions, including growth, health, and reproduction (Starling, 2025). However, the mineral composition of aquatic environments varies considerably, ranging from mineral-depleted freshwater to mineral-rich marine ecosystems (National Research Council, 2011). Soft water environments, typically found in natural rivers and lakes, can pose mineral nutrition challenges for some freshwater fish species. In contrast, brackish and marine species are generally less susceptible to mineral imbalances due to the relatively stable and abundant mineral content in these environments (Starling, 2025). Moreover, brackish water conditions may help reduce the prevalence of pathogens harmful to freshwater fish, particularly those with low salinity tolerance. These conditions may eliminate certain harmful microbial threats (Wang et al., 2021; Kashem et al., 2023; Tahir et al., 2025). The information presented above supports the findings of the present study. Although bighead catfish are a freshwater species, rearing them at 0‰ salinity significantly reduced their survival rate and productivity, and there was a tendency to decrease mean weight after 60 days of culture. Meanwhile, the fish exhibited high survival rates in a salinity range of 2 to 8‰. These results agreed with Nguyen et al. (2021), who reported that freshwater striped catfish (*Pangasianodon hypophthalmus*) larvae showed a statistically lower survival rate at 0‰ salinity compared to those reared at 3-6‰.

Moreover, *C. macrocephalus* had the best growth performance and stable survival at 2‰ salinity; however, CV_W was significantly greater in the 2-4‰ range compared to other salinities. This trend was also observed by Boeuf and Payan (2001), who highlighted that under optimal salinity conditions, reduced osmoregulatory stress enables more energy to be directed toward growth for both fast- and slow-growing individuals, which leads to a wider distribution of sizes within the population, thereby increasing the variation relative to the mean. In contrast, suboptimal salinities impose physiological stress that suppresses growth in weaker individuals and may lead to mortality, thereby reducing size variation within the population (Wang et al., 1997). Thus, higher size variation at optimal salinity likely reflects full growth potential rather than poor culture conditions (Boeuf and Payan, 2001). Remarkably, the CV_W of bighead catfish ranged from 3.33 to 6.64% in the tested salinity range, well below the typical 20-35% suggested for most cultured fish species (Gjedrem, 1997).

Conclusions

In conclusion, the study found that rearing juvenile *C. macrocephalus* at a salinity of 2‰ produced the best growth performance. Although survival rates were stable in a salinity range of 2-8‰ and significantly higher than those at 0‰, growth performance significantly declined at salinities ≥ 4‰, leading to a significant decline in productivity at 8‰ salinity. Moreover, although growth performance at 0‰ decreased only slightly compared to that at 2‰ during the rearing period, a significantly lower survival rate at this salinity likely contributed to a significant reduction in productivity. A salinity of 2‰ is therefore recommended for optimal juvenile *C. macrocephalus* culture. Further research is essential to evaluate how salinity affects both the early and later life stages of this species. This is crucial for sustainable bighead catfish aquaculture development, especially given the increasing salinity intrusion into freshwater ecosystems due to climate change.

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