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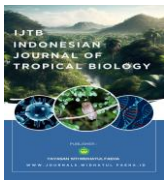

Original Research Paper

Growth and Survival of *Mytilopsis adamsi* During Larval to Early Juvenile Transition Under Different Salinity Conditions

Dina Ahyani[1], Alis Muhklis[1*], Bayu Priyambodo[2]

[1] Aquaculture Study Program, Department of Fisheries and Marine Science, Faculty of Agriculture, University of Mataram, Jl. Pendidika No. 37 Mataram, 83125, West Nusa Tenggara, Indonesia.

[2] Lombok Marine Aquaculture Development Centre, Giligenting Hamlet, West Sekotong Village, Sekotong District, West Lombok Regen 83365, West Nusa Tenggara, Indonesia.

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Corresponding Author: Alis Muhklis
Author Name: Dina Ahyani
Email: alismukhlis@unram.ac.id
Number Hp: +62 852-3867-4743

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Abstract

Mytilopsis adamsi, a small filter-feeding bivalve mollusk, has become an invasive species cultivated in Indonesia as natural feed for economically valuable crustaceans. This study determined optimal salinity levels for growth and survival of *M. adamsi* during larval to early juvenile transition. Using a completely randomized design, four salinity treatments (10, 20, 30, and 40 ppt) were tested with three replicates each. Larvae were reared for 28 days with *Nannochloropsis* sp. and *Pavlova lutheri* as feed, developing from 50.4 µm to 140.17 ± 6.12 µm. Treatments at 20 and 30 ppt demonstrated optimal performance with identical specific growth rates (SGR) of 3.90% per day. Survival rates showed no significant difference ($p > 0.05$) between treatments, ranging from 24.6% to 27.8%, with highest values at 40 ppt (27.8 ± 0.4%). Statistical analysis revealed a quadratic relationship for SGR ($y = -0.0014x^2 + 0.0615x + 3.2576$, $R^2 = 0.8753$) with theoretical optimum at 22.0 ppt. The optimal salinity range for *M. adamsi* cultivation is 20–30 ppt based on growth performance. These results provide baseline data for commercial cultivation protocols and environmental management strategies.

Keywords: *Mytilopsis adamsi,* salinity, specific growth rate, survival rate

INTRODUCTION

Bivalve mollusks are filter-feeding organisms that play an important role in maintaining the balance of aquatic ecosystems. Through filtration mechanisms, bivalves are able to consume zooplankton, phytoplankton, and suspended organic matter, thereby reducing particle concentrations and increasing water clarity (Rong et al., 2021). This ecological function makes bivalves not only valuable for conservation but also potentially useful in supporting sustainable aquaculture activities. Therefore, understanding the ecobiology and environmental tolerance of bivalves is essential for the development of aquaculture as well as for mitigating their ecological impacts.

One of the bivalves that has attracted considerable attention is *Mytilopsis adamsi*, commonly known as the false mussel, which originates from the tropical Pacific coasts of Central America. This species has now spread widely and become invasive in various regions of East Asia, South Asia, and Southeast Asia (Marelli, 2021; Rodrigues et al., 2022; Tan & Tay, 2020). The genus *Mytilopsis* exhibits a high adaptive capacity to tropical aquatic conditions, with salinity being a key parameter influencing its survival and distribution (Queiroz et al., 2020; Sa-Nguansil & Wangkulangkul, 2020). Its tolerance to a broad range of abiotic conditions, along with its ability to colonize substrates, contributes to the successful invasion of *M. adamsi* in brackish water ecosystems (Rodrigues et al., 2022).

In Indonesia, although *M. adamsi* has been identified as an invasive species with the potential to disrupt local ecosystems, efforts have begun to explore its utilization as a natural feed with high nutritional value for economically important crustaceans such as crabs and lobsters (Juniyastuti et al., 2025). However, the development of *M. adamsi* culture faces technical challenges, particularly in determining the optimal conditions for its growth and survival. Information regarding the physiological responses of this species to salinity gradients remains limited, despite salinity being a crucial parameter for the success of aquaculture. Therefore, experimental approaches are needed to elucidate the salinity tolerance thresholds of *M. adamsi* in order to support the development of effective and environmentally friendly culture systems.

The urgency of this research lies in the pressing need to establish a scientific basis for optimizing the productivity of *M. adamsi* culture as a high-quality natural feed source for the crustacean aquaculture industry. This study aims to determine the optimal salinity level that supports the growth and survival of *M. adamsi* under controlled culture conditions. The findings are expected to provide practical recommendations for the

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development of sustainable aquaculture technologies and to open up opportunities for the commercial utilization of the false mussel as a potential aquaculture resource.

RESEARCH METHODS

Time and Location of Research

This research was carried out from February to March 2025 at the Marine Aquaculture Fisheries Center (BPBL) located in Gili Genting Village, Sekotong District, West Lombok Regency, West Nusa Tenggara Province. Geographically, the research location is located at coordinates of around 8°44'12" S and 115°55'48" E.

Research Design

This study uses an experimental method with the aim of determining the influence of salinity variations on the growth and survival of *Mytilopsis adamsi*. The experimental design applied was the Complete Random Design (CRD), which consisted of four salinity treatments, namely 10 ppt (A), 20 ppt (B), 30 ppt (C), and 40 ppt (D), with each treatment being carried out three times. This experimental approach allows controlled control of environmental conditions and minimizes the influence of external factors, so that the results obtained can be more accurate in determining the salinity tolerance of the species studied.

Research Population and Sample

The population of this study comprised *Mytilopsis adamsi* at the egg stage obtained from broodstock spawning with a dorsal-ventral length of 28–30 mm. The samples were purposively selected from the spawning results to ensure the quality and uniformity of the individuals observed. The number of samples was adjusted for each salinity treatment with three replicates per treatment, providing a sufficient total sample size for statistical analysis (Cochran, 1977). The study variables included growth (dorsal-ventral length) and survival of *M. adamsi* larvae, which were measured through microscopic observation using binocular stereo microscopy and larval counting using a Sedgewick Rafter counting chamber.

Data were collected periodically with systematic recording for each treatment. The equipment used included 9-liter plastic containers, an aeration system, digital pH meter (±0.01), digital DO meter (±0.1 mg/L), optical refractometer (0–100 ppt), and mercury thermometer (±1°C). The research materials consisted of natural seawater (35 ppt), fresh water, *M. adamsi* eggs, commercial sea salt, and live feed consisting of microalgae *Pavlova lutheri* (8–10×10⁶ cells/mL) and *Nannochloropsis* sp. (15–20×10⁶ cells/mL). Sampling techniques and data collection procedures were carried out systematically to ensure adequate accuracy and replication, in accordance with aquaculture research standards (APHA, 2017).

Research Procedure

Salinity adjustment

Salinity adjustment of the medium was conducted using a dilution method involving the mixing of seawater and freshwater at specific proportions. For the 40 ppt salinity treatment, sea salt was added to natural seawater. The dilution method adopted from Ramadhan et al. (2024) employed the following formula:

$$(V_s \times N_s) + V_p \times N_p) = (V_f \times N_f) \quad \text{.....(1)}$$

***Information:**

- Vs = Volume of seawater stock before dilution (ml)
- Ns = Salinity of seawater stocks before dilution (ppt)
- Vp = Volume of diluting water (ml)
- Np = Diluent water salinity (ppt)
- Vf = Desired final volume (ml)
- Nf = Desired final salinity (ppt)

Spawning, incubation and egg dispersal

The broodstock of *M. adamsi* (Figure 1) is spawned naturally by the stimulus of temperature changes. Eggs that have gone through the fertilization process are screened using a multi-level sieve with mesh sizes of 160 µm and 40 µm, then incubated at 29±1°C for 21 hours until hatching. The hatched larvae (Figure 2) were stocked with an average density of 1,600 ± 280 individuals per liter (n=10) in a 9-liter container containing 3 liters of seawater. Sampling was carried out using a simple random sampling method (Warse et al., 2019).

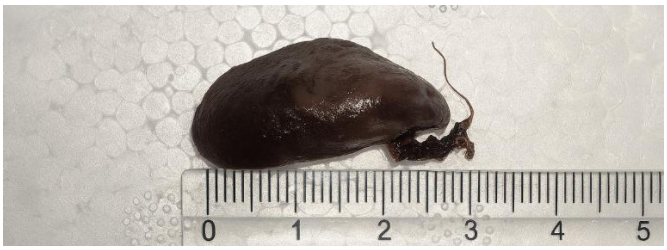

Figure 1. The broodstock of the false mussel *Mytilopsis adamsi* with a dorsal-ventral length of about 29 mm.

Larval maintenance

The larvae were kept for 28 days by feeding a mixture of microalgae (1:1) with an initial density of 14,000 cells/ml increased by 1,000 cells/ml daily. Water change is carried out 30% every 7 days with daily container cleaning. The calculation of live feeding follows Septiani et al. (2023):

$$V_1 = (V_2 \times N_2)/N_1 \quad \text{.....(2)}$$

***Information:**

- V_1 = Required volume of plankton stock (ml)
- V_2 = Culture medium volume (ml)
- N_1 = Stock density of plankton (cells/ml)
- N_2 = Desired density of plankton (cells/ml)

Water quality observation

Water quality observation is carried out before water change, including temperature, pH, dissolved oxygen (DO), ammonia (NH_3-N). Water change is carried out partially by 30% every 7 days.

Growth and survival measurements

Growth was measured on 5 randomly selected samples from each experimental unit at the beginning and end of the study, while survival was calculated by comparing the number of early juveniles alive at the end of the study with the number of newly hatched larvae aged 21 days stocked at the beginning of the experiment. The specific growth rate was calculated using a formula derived from Huisman (1976):

$$SGR = [(L_t/L_0)^{1/t} - 1]x100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

***Information:**

SGR = Specific Growth Rate (%/day)
Lt = Average shell length at the end of the experiment (mm)
L0 = Average shell length at the beginning of the experiment (mm)
t = Trial duration (days)

$$SR\ (\%) = (N_t/N_0) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(4)$$

***Information:**

SR = Survival rate
Nt = Number of juveniles alive at the end of the study (individual)
N0 = The total number of eggs stocked at the beginning of the study (individual)

Data Analysis

The study variables included the specific growth rate and survival rate of *M. adamsi* during the larval to early juvenile stages. The data were analyzed using one-way ANOVA with SPSS software, and significant differences (p<0.05) were followed by the Least Significant Difference (LSD) test.

RESULTS AND DISCUSSION

Results

Daily Specific Growth Rate (SGR)

The daily specific growth rate (SGR) of *Mytilopsis adamsi* provides important information regarding the physiological response of larvae to variations in osmotic conditions of the culture medium. Growth data showed a transformation from the initial larval size of approximately 50.4 µm to early juveniles with an average of 140.17±6.12 µm over a 28-day cultivation period (Figure 2). Quantitative analysis revealed a response pattern that followed a parabolic distribution to the media salinity gradient, indicating the existence of an optimal zone and a clear physiological tolerance limit. The daily specific growth rate of *M. adamsi* showed a parabolic response pattern to the salinity gradient, with the highest values achieved at salinities of 20 ppt and 30 ppt (SGR 3.90 ± 0.08% and 3.90 ± 0.05% per day), followed by salinity of 10 ppt (3.75 ± 0.09% per day), and the lowest at 40 ppt salinity (3.51 ± 0.03% per day), where data variability showed the highest consistency of response under hypersaline conditions despite reduced growth performance.

The results showed that salinity had a significant effect on the daily specific growth rate of *M. adamsi* (p<0.05), with a quadratic response pattern following the equation $y = -0.0014x^2 + 0.0615x + 3.2576$, which reached optimum at a salinity of 22.0 ppt. These optimal conditions were achieved in the salinity range of 20-30 ppt with identical SGR values (3.90% per day), indicating a stable osmotic tolerance zone for metabolic energy allocation. A quadratic regression model with a coefficient of determination R^2=0.8753 confirms a strong deterministic relationship, where 87.53% of growth variability can be explained by salinity factors (Figure 3).

The results of the LSD test showed that the salinity treatments of 20 ppt and 30 ppt (notation c) did not differ significantly from each other, indicating that these two salinity conditions provide similar and optimal osmotic conditions for the growth of *M. adamsi*. These two optimal treatments were significantly different from extreme salinity treatments, namely 10 ppt (notation b) and 40 ppt (notation a), suggesting that hyposaline and hypersaline conditions exert osmotic pressure that inhibits growth rates. Furthermore, the results of the LSD test revealed that the salinity treatment of 10 ppt was significantly different from the salinity of 40 ppt, with a salinity of 10 ppt showing better performance than a salinity of 40 ppt. This pattern indicates that *M. adamsi* has better tolerance to hyposaline conditions than to hypersaline conditions, possibly related to the natural habitat origin of the species that tends to migrate to estuarine environments with varying salinity.

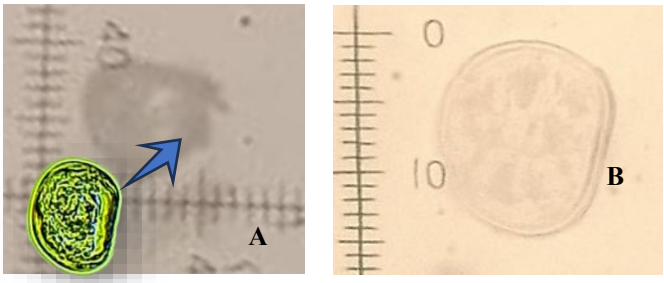

Figure 2. Developmental stages of *M. adamsi* larvae from larval (A) (size 50-70 µm) to early juvenile stage (B) (size 140-148 µm).

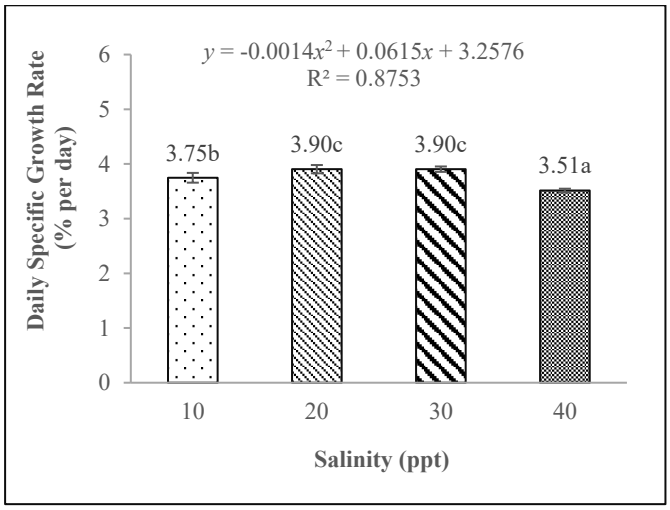

Figure 3. Daily Specific Growth Rate (SGR) of *Mytilopsis adamsi* from larval to early juveniles stage during 28 days of maintenance at different salinity levels (10, 20, 30, and 40 ppt). The data are presented as mean ± standard deviation (n=3). Different superscript letters indicate statistically significant differences between treatments (p<0.05).

Survival Rate

The survival rate (SR) of *Mytilopsis adamsi* during the transition from larval stage (21 hours post-fertilization) to early juvenile stage (day 28) showed relatively narrow variation between salinity treatments. At a salinity of 10 ppt, the survival rate reached 27.7 ± 5.5%, while at salinities of 20 ppt and 30 ppt, slightly lower values of 25.7 ± 2.0% and 24.6 ± 1.4% were observed, respectively. The highest survival rate was obtained in the 40 ppt salinity treatment with a value of 27.8 ± 0.4% (Figure 4). Statistical analysis using the ANOVA test with a significance level of 5% showed that the difference in survival rate between salinity treatments was not statistically significant (p > 0.05).

This indicates that *M. adamsi* has fairly wide tolerance to salinity variations during the critical period of transition

from larvae to early juvenile stage, with the ability to maintain relatively stable survival rates in the salinity range of 10-40 ppt. Although statistically not significantly different, there was a tendency for slightly higher survival rate values at extreme salinities (10 ppt and 40 ppt) compared to intermediate salinities (20 ppt and 30 ppt).

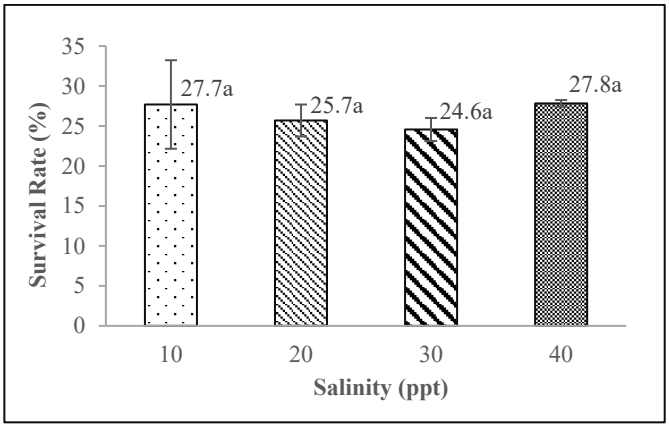

Figure 4. The survival rate of *Mytilopsis adamsi* maintained for 28 days at various salinity levels (10, 20, 30, and 40 ppt). The data are presented as mean ± standard deviation (n=3). The same superscript letter indicates no statistically significant difference between treatments (p>0.05).

The variability of the data indicated by the standard deviation values showed an interesting pattern, where the salinity of 10 ppt had the highest variability (5.5%), while the salinity of 40 ppt showed the lowest variability (0.4%). This pattern of variability suggests that although the average survival rate at salinity of 10 ppt was quite high, individual responses were more varied than at high salinity.

The low variability at a salinity of 40 ppt indicates more uniform physiological response consistency under high salinity conditions, which likely reflects the activation of more standardized osmoregulatory mechanisms in response to extreme osmotic stress. This uniform response can be interpreted as a conservative survival strategy, in which *M. adamsi* individuals allocate metabolic energy in a similar pattern to maintain internal homeostasis, thereby reducing individual variation in survival rates.

In contrast, high variability at salinity of 10 ppt (±5.5%) indicates the presence of heterogeneity of individual responses, which may reflect differences in adaptive capacity or metabolic flexibility between individuals when facing hyposaline conditions. The ability of *M. adamsi* to maintain a relatively stable survival rate under various salinity conditions during the transition phase from larvae to early juveniles indicates a physiological plasticity that favors the successful colonization of this species in different types of estuarine waters, with different adaptation strategies depending on the level of osmotic pressure encountered.

Disccussion

Growth of *M. adamsi*

The results of this study demonstrated that salinity had a significant effect on the specific growth rate of *Mytilopsis adamsi*, with optimal growth achieved at salinities of 20 ppt and 30 ppt, which resulted in identical SGR values of 3.90% per day. This phenomenon can be explained through the concept of osmotic regulation, where the growth of aquatic organisms is greatly influenced by osmotic pressure in the physiological system. The greater the osmotic gradient between the environment and body fluids, the higher the energy allocation required for the osmoregulatory process, which ultimately reduces the energy available for somatic growth. The genus *Mytilopsis* has an optimal salinity range for growth (Queiroz et al., 2020; Sa-Nguansil & Wangkulangkul, 2020), where the energy used for osmoregulation is minimal so that more energy can be allocated for somatic growth. This condition is confirmed at salinities of 20 ppt and 30 ppt where the SGR reaches a maximum value of 3.90% per day. *M. adamsi* exhibits characteristics as a euryhaline species that is able to tolerate a wide range of salinity (10-40 ppt), but has an optimal preference for moderate to high salinity with a theoretical optimum of 22.0 ppt based on a quadratic regression model ($y = -0.0014x^2 + 0.0615x + 3.2576$, $R^2 = 0.8753$). The observed growth response pattern showed a hierarchy of salinity tolerance, where a salinity of 10 ppt showed better performance than a salinity of 40 ppt. This indicates that *M. adamsi* has a higher tolerance to hyposaline conditions than to hypersaline conditions, possibly related to evolutionary adaptations to estuarine habitats whose salinity characteristics tend to vary from freshwater to brackish conditions.

Comparative studies with species belonging to the same genus *Mytilopsis* show significant differences in salinity tolerance. van der Gaag et al. (2016) reported that the optimal salinity range for the survival of adult *M. leucophaeata* is 0.2-17.5 ppt with maximum reproductive and survival limits below 18-21 ppt. These findings were confirmed by Verween et al. (2007) who showed that the early embryonic stage (4 h) of *M. leucophaeata* is sensitive to salinity above 20 ppt and temperatures below 15°C, confirming the low tolerance limit in the early stages of development. A recent field study by Fernandes et al. (2024) in Brazil shows that *M. cf. sallei* is found to live in waters with salinity below 20 ppt, confirming the *Mytilopsis* species' preference for oligohaline (0.5 - < 5 ppt) to low mesohaline (5 - < 10 ppt) conditions.

These findings contrast with the results of studies on *M. adamsi* which showed tolerance and preference at much higher salinity (20-30 ppt). These differences likely reflect habitat-specific adaptations, where *M. leucophaeata* is more adapted to oligohaline environments (0.5-5 ppt), while *M. adamsi* exhibits higher plasticity to mesohaline (5 - < 18 ppt) to polyhaline (18 - < 30 ppt) conditions. A salinity gradient study by van der Gaag et al. (2024) in the Netherlands confirmed that the distribution of *Mytilopsis* species in the field is highly dependent on salinity tolerances that have been established through laboratory experiments, demonstrating the relevance of laboratory research results to natural conditions.

Morphological growth evaluation showed consistent progression from an early larval size of 50.4 µm to a early juvenile with an average of 140.17 ± 6.12 µm over a 28-day period. This growth represents a 178% increase in size during the transition period from larvae to early juveniles. This growth performance can be compared with literature data from species in the same genus. Neto et al. (2020) reported growth parameters of *M. leucophaeata* with a growth coefficient of K = 0.5 per year in Brazilian tropical natural conditions, while Gaag et al. (2017) recorded an average growth rate of 89 µm/day during the summer period for the same species. The obtained quadratic regression model ($R^2 = 0.8753$) showed

that 87.53% variability in specific growth rates could be explained by salinity variations, confirming that salinity is a major determinant factor in the growth of *M. adamsi* during the larval to early juvenile stage. This high determination coefficient provides validation of the accuracy of the predictive model and can be applied to the optimization of aquaculture conditions in controlled aquaculture systems.

Survival Rate of *M. adamsi*

The survival rate (SR) of *Mytilopsis adamsi* during the transition from larval stage (21 hours post-fertilization) to early juvenile stage (day 28) showed a different response pattern compared to growth parameters. Although statistical analysis using the ANOVA test showed no significant differences between salinity treatments ($p > 0.05$), there were variations in absolute values and patterns of variability that provided important information about the physiological response of this species. A salinity of 40 ppt showed the highest survival rate (27.8 ± 0.4%), followed by a salinity of 10 ppt (27.7 ± 5.5%), a salinity of 20 ppt (25.7 ± 2.0%), and a salinity of 30 ppt (24.6 ± 1.4%). This pattern indicates that *M. adamsi* has wide tolerance to salinity variations during the critical transition period from larvae to early juveniles, with the ability to maintain relatively stable survival rates in the salinity range of 10-40 ppt.

The non-significant differences in survival rates between salinity treatments can be explained through the concept of high physiological plasticity in larval to early juvenile stages. Mussels of the genus *Mytilopsis* in the family Dreissenidae show significant adaptation potential to various salinity conditions (Khanthasimachalerm & Wangkulangkul, 2024). Therefore, *Mytilopsis adamsi* species have an osmoregulatory capacity that allows them to be cultivated at various levels of salinity, from estuarine conditions to full-ocean waters.

This physiological flexibility provides an ecological advantage for *Mytilopsis* spp. in exploiting habitats with high salinity variability, a common characteristic of estuarine environments. This adaptability not only has ecological implications, but also economic implications in the context of aquaculture, where species can be cultivated in locations with varying salinity conditions without experiencing mass mortality. However, it should be noted that although *Mytilopsis* spp. exhibits wide salinity tolerance, optimal performance in terms of growth suggests that *Mytilopsis* spp. is still dependent on a certain salinity range, indicating that the mussels require more energy to regulate their body salt levels under less than ideal conditions.

Although statistically not significantly different, the pattern of data variability provides important in-depth understanding. Salinity of 10 ppt showed the highest variability (SD = 5.5%), indicating a heterogeneous individual response to hyposaline conditions. Stevick et al. (2021) explain that the high variability in survival rates under osmotic stress conditions reflects genetic variation in osmoregulatory abilities between individuals in the population.

Hyposaline conditions force the larvae to activate active osmoregulatory mechanisms, which require high metabolic energy and can lead to physiological fatigue in less tolerant individuals. In contrast, a salinity of 40 ppt showed the lowest variability (SD = 0.4%) with the highest survival rate. This low variability indicates a more uniform consistency of physiological responses under high salinity conditions. Haider et al. (2019) explain that hypersaline conditions can induce a more homogeneous stress response in populations, where individuals who are able to survive exhibit similar adaptation mechanisms through osmolyte accumulation and regulation of cell volume.

The difference in response patterns between growth and survival rates indicates a situation in which increased energy investment for one physiological function will reduce the energy available for other functions (complex energetic trade-offs). While optimal growth is achieved at moderate salinity (20-30 ppt), survival rates show wider tolerances with best performance at extreme salinity. This phenomenon can be explained through different energy allocations, where under optimal conditions (moderate salinity), energy is allocated for somatic growth, while under stressful conditions (extreme salinity), energy priority is shifted to survival and homeostasis mechanisms. Peteiro et al. (2018) reported that larval to early juvenile stages of bivalves have high plasticity to salinity fluctuations as an adaptation during the free swimming phase and searching for a place to attach. The ability of *M. adamsi* to maintain stable survival at various salinities indicates high colonization potential in estuarine waters.

Mollusks from the bivalve family have varying abilities to survive in changing salinity conditions, depending on their developmental stages. The survival rate between families varied between 0-27.27%, indicating that the ability to survive at low salinity was influenced by genetic factors with a moderate level of control (Fernandes et al., 2018). Mollusk larvae were more easily stressed than adult mollusks, where the larvae showed the highest activity at 20°C but immediately decreased drastically at 25°C, while adult mollusks did not experience a decrease in activity at high temperatures (Alma et al., 2024). This adaptability suggests that although mussel larvae can adapt to changes in water salt levels as they swim freely and search for a place to attach, they must expend more energy to survive. The conditions experienced by the broodstock also affect the ability of the larvae and early juveniles produced to survive, thus determining how successful they are in colonizing new waters with different salinity conditions.

Implications in Aquaculture

M. adamsi has potential as a successful invasive species, given its ability to survive a wide range of salinity during critical phases of the life cycle. From an aquaculture perspective, although the survival rate does not show significant differences, the stability of the response at a salinity of 40 ppt (low variability) can be considered for commercial applications that require production consistency. In the context of commercial aquaculture, production consistency often has higher strategic value than unstable maximum performance, where although salinity of 20-30 ppt indicates an optimal specific growth rate of 3.90% per day, the stability of the survival response rate at the lowest variability of 40 ppt salinity (standard deviation 0.4%) offers a significant operational advantage as it results in high predictability in the estimated mortality level, which is a critical factor in production planning and commercial-scale economic risk management.

The risk management aspect is a key consideration in large-scale aquaculture operations where capital investment in seeds, feed, and infrastructure reaches substantial values, so that the low survival rate variability at a salinity of 40 ppt

allows cultivators to estimate crop yields with high accuracy, reduce uncertainty in cash flow and facilitate risk calculation for cultivation insurance purposes. The high consistency at a salinity of 40 ppt allows for the development of standardized cultivation protocols with more efficient capacity planning, labor management, and quality control as low variability means deviations are easily identified. Although it produces suboptimal growth (SGR 3.51%) that impacts production efficiency and operational costs, a strategic approach can be implemented with a gradual system: using a salinity of 40 ppt in the nursery phase (0-28 days) to maximize the survival rate, then a gradual transition to optimal salinity (20-30 ppt) in the next growth phase to optimize the growth rate.

CONCLUSION

This study confirms that salinity is a key factor that affects the growth of *Mytilopsis adamsi* during the transition phase from larvae to early juveniles. Optimal growth was achieved in the range of 20–30 ppt with a theoretical optimum of 22.0 ppt, while survival rates were relatively stable across all treatments (24.6–27.8%), indicating wide salinity tolerance. These differences in response patterns indicate the existence of complex energy allocation mechanisms between growth and survival. Ecologically, these findings demonstrate that *M. adamsi* has high adaptability to estuarine salinity fluctuations, indicating great potential for development as an aquaculture commodity in various coastal waters. To support its application at production scale, further research is needed on the application of graded salinity systems, as well as cost analysis and sustainable commercial cultivation techniques.

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