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ORIGINAL RESEARCH

Ionic composition of inland saline groundwater and its impact on growth performance and body composition of some sympatric mullet species grown in polyculture

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Abstract This study investigated the ionic composition of inland saline groundwater (ISGW) and its effects on the growth, survival, and body composition of four sympatric mullet species in a 100-day polyculture. While ISGW holds significant potential for sustainable aquaculture, analysis revealed it has significantly higher total hardness than seawater—primarily due to elevated calcium and magnesium bicarbonates—but lower concentrations of sodium and potassium. Fish were reared across four salinity treatments (10, 15, 20, and 25‰). and for qualitative reference**,** a freshwater control (0‰) was also maintained. Growth performance generally peaked at 15‰ and declined at higher salinities**.** Survival rates remained high across all saline groups. *Mugil cephalus* achieved optimal daily growth at a salinity of 10‰, *Planiliza planiceps* (*L. tade)* and *Planiliza macrolepis* (*L. macrolepis)* exhibited a steady increase in growth up to a salinity of 15‰, whereas *Planiliza parsia* (*L. parsia)* showed no significant growth variations across treatments. Overall growth performance ranked: *M. cephalus* > *Planiliza planiceps (L. tade)* > *Planiliza macrolepis (L. macrolepis)* > *Planiliza parsia* (*L. parsia)*. Salinity significantly influenced body composition in *M. cephalus* and *Planiliza planiceps (L. tade),* whereas *Planiliza macrolepis* (*L. macrolepis)* and *Planiliza parsia* (*L. parsia)* remained unaffected. Reduction in growth at higher salinities is likely due to the energetic cost of osmoregulation in a potassium-deficient environment. When salinity exceeds the optimal range, fish must divert energy from protein synthesis to active ion transport (e.g., sodium and chloride) to maintain homeostasis. Environmentally, nutrient levels, phytoplankton density, net primary productivity (NPP), and chlorophyll '*a*' decreased above 10‰, while zooplankton populations increased. These results demonstrate the feasibility of using ISGW for mullet polyculture, offering a viable strategy for diversifying aquaculture in saline-affected regions and enhancing food security.

Keywords Carcass composition . Growth. Hydrobiological factors . Ionic composition . Inland saline groundwater . Mullets. Polyculture

Introduction

The conventional aquaculture primarily relies on freshwater; the increasing availability of inland saline groundwater, often unsuitable for traditional agriculture, provides a promising avenue for sustainable seafood production by cultivating euryhaline fish and shellfish species. However, the inherent variability in the ionic composition, quality, and quantity of inland saline water across diverse geographical locations, coupled with the exacerbating effects of inefficient surface water management on salinisation, poses con-

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siderable obstacles (Singh et al. 2017).

The utilization of inland saline water resources presents a complex scenario for aquaculture, offering both significant challenges and substantial opportunities, particularly in arid and semi-arid regions facing water scarcity (Allan et al. 2001; Singh et al. 2017). Inland saline groundwater aquaculture holds considerable potential for sustainable seafood production, facilitating the productive utilisation of abandoned salt-affected lands. This approach can contribute to environmental remediation while generating valuable income, employment opportunities, and food security.

The majority of current brackishwater (both coastal and inland) aquaculture production is centred on shrimp farming. However, achieving genuine sustainability and continued expansion requires strategic diversification. As a direct result of challenges and failures encountered in exclusive shrimp operations, a segment of the farming community is turning its attention to the polyculture of brackish water finfish species.

Fluctuations in environmental salinity and ionic composition present a primary challenge for aquaculture, as conditions often deviate substantially from standard seawater (Boyd and Thunjai 2003; Saoud et al. 2003). These variations are decisive factors in the life cycle and geographic distribution of fish, directly influencing survival, nutrition, reproduction, and growth (Seale et al. 2024; Loi et al. 2022). Despite potential physiological disruptions, fish possess adaptive mechanisms that can be leveraged by manipulating salinity to species-specific levels to optimize biological performance. However, this tolerance is not static and varies significantly across different life stages (Holliday 1971; Cardona 2000).

For euryhaline organisms, salinity fluctuations impose a significant metabolic demand. When energy is diverted toward the physiological work of osmoregulation, it often results in a measurable reduction in growth rates (Wootton 1990). The mullet is a primary example of a species that thrives under these pressures. Their broad salinity tolerance, paired with a low trophic level, has established them as a cornerstone species in modern aquaculture (Thomson 1966).

Mullets (Family: Mugilidae) are globally distributed across tropical and subtropical coastal regions, offering significant opportunities for industry expansion due to their remarkable adaptability. Historically cultivated for centuries (Pillay and Kutty 2005; Ayyappan 2006), these fish possess key biological advantages, including environmental resilience as euryhaline and eurythermal organisms that thrive in marine, brackish, and freshwater habitats. Critically, mullet species are widely farmed in both coastal brackish and freshwater systems, utilizing both monoculture and polyculture systems. Beyond their economic efficiency—driven by satisfactory growth on low-cost feed—mullets provide ecological utility as benthic feeders that act as bio-remediators (Abdel-Tawwab et al. 2005), improving sediment quality and managing detritus in polyculture systems. In the Indian context, while highly valued for their flavour, scientific farming has been hindered by bottlenecks such as a lack of hatchery-produced seeds and relatively slow growth rates, leading to their continued use in traditional, extensive mono- and polyculture systems (Bhowmik et al. 1990; Anil et al. 2010; Biswas et al. 2012a, b; Dayal et al. 2017; Hotos and Avramidou 2020).

Historically, research on mullet aquaculture has centred on coastal brackish environments, leaving a significant knowledge gap regarding their physiological performance in inland saline waters. While the utilization of inland saline groundwater (ISGW) for euryhaline species has been explored globally (Forsberg et al. 1996; Allan et al. 2009), and proven viable in India for species such as grey mullet (*Mugil cephalus*), milkfish (*Chanos chanos*), and pearlspot (*Etroplus suratensis*) (Barman et al. 2005; Jana et al. 2006a; Kumar et al. 2009a), these studies are largely restricted to monocultures.

To mitigate slow growth rates, mullets are frequently integrated into polyculture systems. Such multi-species systems generally yield higher profit margins and ecological stability compared to monocultures (Biswas et al. 2012a; Crosetti 2016). For instance, *Penaeus monodon* achieves superior growth when paired with *Mugil tade* (Anil et al. 2010), and *Mugil cephalus* has demonstrated high productivity in tide-fed brackishwater polycultures (Biswas et al. 2012b). Furthermore, the high market demand and resilience of mullets make them ideal candidates for diversifying aquaculture in semi-arid regions (Cardona 2006).

Despite this potential, current literature remains predominantly based on coastal ecosystems (Hotos and Avramidou 2020). The vast reserves of ISGW in inland regions—with salinities reaching 30 ppt—remain largely untapped for mullet cultivation. Crucially, the unique ionic composition of ISGW often differs significantly from seawater, presenting specific physiological challenges that remain poorly characterized. Research regarding the specific impact of these ionic profiles on the growth and body composition of sympatric mullet species in polyculture is virtually non-existent. In light of these gaps, the present study

was designed to: i) analyse the ionic profile of inland saline groundwater in comparison to seawater, ii) evaluate the growth performance and body composition of four sympatric mullet species—*Mugil cephalus*, *Planiliza planiceps*, *Planiliza macrolepis*, and *Planiliza parsia*—within polyculture systems across various salinity gradients.

By addressing these objectives, this research seeks to optimize management strategies for utilizing inland saline resources to support sustainable fisheries development.

Materials and methods

Experiment-1: Determination of the ionic composition of inland saline groundwater

Ten replicate water samples were collected from each of the eight source wells (1-8) to quantify water quality parameters. The ionic composition of the inland saline water was determined using analytical methods specified in APHA (2017). Salinity measurements were obtained with a portable handheld salinity refractometer.

Experiment-2: Effect of different salinity levels on the growth performance of four sympatric mullet species grown in polyculture under field conditions using inland saline groundwater

Studies were conducted at the brackish water fish pond facility of the Department of Zoology and Aquaculture, CCS Haryana Agricultural University, Hisar (lat. 29 10ºN; long. 75_46ºE), India. The experiment was conducted in ponds measuring 375 m^2 each. Due to facility-wide logistical constraints, the freshwater control was maintained in 25 m^2 ponds as larger units were unavailable.

Experimental design

Before the experiment was initiated, the ponds were cleaned, sun-dried, and quicklime (CaO) was applied to the pond bottom at 200 kg ha^{-1} yr^{-1}. After one week, the ponds were filled with inland saline groundwater drawn from two borewells with salinities of 10 ppt and 30 ppt.

Four salinity treatments (10, 15, 20, and 25 ppt), each replicated twice, were established by mixing water from the two borewells. Due to pond size constraints, the freshwater control (0 ppt) was maintained in smaller 25 m^2 ponds. To ensure comparability, we strictly standardized all other variables, including stocking density (fish/m^2), fertilization rates, feeding protocols, and sampling frequency across all groups.

Subsequently, partially dried cow manure was applied as fertilizer at a rate of 10,000 kg ha^{-1} yr^{-1} (equivalent to 15.6 kg per 375 m^2 every two weeks), and poultry droppings were applied at 3000 kg ha^{-1} yr^{-1} (equivalent to 4.7 kg per 375 m^2 every two weeks). Before application, both the cow manure and poultry droppings were pre-dissolved in pond water.

Stocking

Two weeks following manure application, six-week-old fingerlings of four mullet species – (*Mugil cephalus*, *Planiliza planiceps (Liza tade*), *Planiliza macrolepis* (*Liza macrolepis*) and *Planiliza parsia* (*Liza parsia*) – pre-adapted to 15 ppt seawater were obtained through wild collection from the southern coast of India.

Before stocking, the fingerlings were acclimated to the target salinity for each treatment group by gradually increasing salinity over 7 days. Following the acclimation period, the fingerlings of the four species were stocked in the experimental ponds (375 m^2 each) filled with inland saline groundwater at a density of 5000 fish per hectare (equivalent to 190 fish per 375 m^2 or 1.97 fish per m^2).

The fish were fed twice daily (08:00–09:00 and 15:00–16:00 h) at a daily ration of 5% body weight (BW). The diet consisted of extruded sinking pellets containing approximately 40% crude protein (Table 1). To ensure the ration remained accurate to the fish's growth, bulk weight measurements of 50 fish per treatment were conducted every 30 days; daily feed amounts were then recalculated based on these new mean weights.

Feed preparation

The experimental diet was formulated to achieve a 40% crude protein content using locally sourced ingredients. Fish meal and groundnut oil cake served as the primary protein sources (Table 1). To ensure nutritional adequacy, each batch was supplemented with a specialized mineral and amino acid premix, specifically enriched with methionine and lysine. The ingredients were processed through a mechanical pelletizer to produce 0.5 mm pellets. To maintain stability and prevent spoilage, the pellets were oven-dried at a temperature range of 60°C–62°C before being stored for subsequent use.

Sample collection and water quality monitoring

For the analysis of physicochemical water quality parameters, triplicate water samples were collected from each experimental treatment before sunrise. Water temperature (°C), salinity, and pH were recorded daily, while dissolved oxygen (DO) and conductivity were monitored weekly using a microprocessor (F-set 3, Merck Ltd.). All other water quality parameters, including chlorides, calcium and magnesium (Table 5) were monitored three times (on days 30, 60, and 100) during the 100-day experimental period (APHA 2017). Because Na and K were characterized in the initial source water analysis (Expt. 1), they were not monitored individually during the grow-out phase; instead, our monitoring focused on total salinity.

Biotic communities and chlorophyll

To assess both the qualitative and quantitative composition of planktonic communities, water samples were collected in triplicate from each experimental treatment at 30, 60, and 100-day intervals. Plankton samples were concentrated by filtering 20 litres of water, collected from five spatially distributed locations within each treatment, through a plankton net with a 125 µm mesh size. Plankton densities were subsequently determined using a Sedgwick-Rafter counting chamber under a binocular microscope, adhering to established methodologies (Wetzel and Likens 1979). Plankton species diversity (d) was calculated using the Shannon-Weaver diversity index, a widely recognized metric for ecological diversity (Washington 1984). Taxonomic identification of plankton to the genus level was performed using established taxonomic keys and monographs (Ward and Whipple 1959; Needham and Needham 1963; Bellinger 1992). Net primary productivity (NPP) was determined using the light and dark bottle method, following standard protocols outlined in APHA (2017). Chlorophyll concentrations were measured by filtering a known volume of water through the Whatman No. 40 filter paper and subsequently analyzed according to the methodology described by Boyd (1990).

Analytical techniques

The feed ingredients, experimental diets, and fish carcasses (initial and final) were analyzed following the procedure of AOAC (2005). Dry matter (after desiccation in an oven at 105 °C for 24 h), ash (incineration at 550 °C for 4 h in a muffle furnace), and nitrogen were determined using the micro-Kjeldahl method; the crude protein content was estimated by multiplying nitrogen by a factor of 6.25. Crude fat contents were determined by petroleum ether extraction (Soxhlet's apparatus). Phosphorus from the feed/carcass was de-

Table 1 Ingredient contents (g kg^{-1}) and proximate composition (% dry weight basis) of the diet

S.No.	Ingredients	Quantity	Proximate composition (% dry wt. basis)	
1	Groundnut oilcake	650.0	Constituents	Contents
2	Rice bran	40.0	Dry matter	93.1
3	Wheat flour	40.0	Crude protein	40.0
4	Fish meal	260.0	Crude fat	7.4
5	Mineral premix and amino acids*	10.0	Crude fiber	5.8
* Each kg has a nutritional value: Copper 312 mg, cobalt 45 mg, magnesium 2.114 g, iron 979 mg, zinc 2.13 g, iodine 156 mg, DL-Methionine 1.920 g, L-Lysine Monohydrochloride 4.4 g, calcium 30%, phosphorus 8.25%.			Ash	10.5
			Nitrogen-free extract	29.4
			Phosphorus	1.0
			Gross energy kj g^{-1}	17.42

termined spectrophotometrically after acid digestion (nitric acid: perchloric acid, 10:1). NFE% was calculated by subtracting the total percentage of crude protein, crude fat, ash, moisture, and crude fibre from 100.

Data collection

At a hundred days post-stocking, the ponds were completely drained, and all the fish were harvested. The total bulk weight and number of fish recovered from each pond were recorded. The total length (in cm) was recorded with a slide calliper, while body weight (W, g) was measured using a digital electronic balance.
Measurement of growth parameters and nutritional indices: The following formulae were applied to the data:
Survival (%) = (Final no. of fish harvested/ Initial no. of fish stocked) ×100
i). Weight gain (%) = (W2 – WI) /100/WI
ii). Specific Growth Rate: Specific Growth Rate (SGR)

$$\text{Specific growth rate (SGR \% g d-1)} = \frac{\ln W2 - \ln W1}{t} \times 100$$

Where,
W2 =Final weight (g)
W1 =Initial weight (g)
t = Duration of experiment in days

$$\text{iii) Growth \% gain in body weight} = \frac{W2-W1}{W1} \times 100$$

Where,
W1= Initial weight
W2= Final weight
iv) Condition factor =To evaluate the well-being of the fish, condition factor (k) was calculated as follows:
Condition factor (K) = 100 X W (g)/TL^3 (cm)
Where:
W stands for the weight of the fish in grams (g)
TL stands for the total length of the fish in centimetres (cm)
L stands for the length of the fish in centimetres (cm) - In this specific formula, L is used as TL (Total Length)
v) Growth d^{-1}: Daily weight gain is a function of weight and time, and was calculated
As follows:
Mean daily weight gain (g/day) = (W_F – W_I) /days,
Where W_F and W_i are the average final and initial weights at time *t*.
Plankton species diversity (d) was determined using the diversity index formula of Shannon and Weaver (Washington 1984):
$d = -\sum (ni/N) \log_2 (ni/N)$
where, d = species diversity; ni = no. of individuals of ith species; N = total number of individuals.

Statistical analysis

Statistical analyses were performed using IBM SPSS software (version 16.0). Data are expressed as Mean ± Standard Error (SE). The pond served as the experimental unit; therefore, all individual observations were averaged at the pond level before analysis.

The study design included four salinity treatments (10, 15, 20, and 25 ppt), each with two replicates (375 m^2 ponds), and a freshwater control (0 ppt, 25 m^2 ponds). A one-way analysis of variance (ANOVA) was used to evaluate the effect of salinity (fixed factor) on physicochemical, biological, and fish growth parameters. The freshwater control was included as an additional treatment level. However, since the control

ponds differed in size from the treatment ponds, results involving the control were interpreted with caution to account for potential scale-related effects.

Before analysis, data were tested for normality and homogeneity of variance; transformations were applied where these assumptions were not met. When significant differences were detected ($p < 0.05$), Duncan's Multiple Range Test (Duncan 1955) was employed for post-hoc multiple comparisons.

Pearson's correlation coefficients were calculated to examine relationships among physicochemical, biological, and growth variables. Additionally, multiple regression analysis was conducted to determine the influence of physicochemical parameters (independent variables) on biological and productivity outcomes (dependent variables). Assumptions regarding linearity, independence, and multicollinearity were verified before interpreting the regression models. All statistical tests were conducted at a significance level of $p < 0.05$.

Results

Experiment-1: Determination of the ionic composition of inland saline water

Inland Saline Water Chemistry: A Distinct Composition: Analysis of the water samples has revealed that there is a corresponding increase in conductivity and total hardness, primarily due to an increase in the concentration of Ca_2+ and Mg_2+ ions, often associated with their bicarbonate and carbonate salts. Sulphate concentrations remain relatively stable. Notably, inland saline water is characterised by exceptionally high total hardness, reaching up to 11,050 mg l^{-1} at 24.5‰ salinity, primarily attributed to elevated levels of calcium and magnesium bicarbonates and carbonates. This contrasts sharply with seawater, which exhibits significantly lower hardness. Conversely, inland saline water exhibits substantially reduced levels of sodium, potassium (Figure 1), and sulphates than seawater (Table 2).

In contrast, seawater is characterized by very high concentrations of sodium, potassium (Figure 1), and chlorides.

Experiment-2: Effect of different salinity levels on the growth performance of four sympatric mullet species grown in polyculture under field conditions using inland saline groundwater

This experiment investigated the effects of varying salinity levels on the growth performance of four mullet species in a polyculture system. Over a 100-day trial, survival rates and growth metrics were assessed (Table 3).

All species acclimated well to the inland saline watery environment and showed no signs of stress. Notably, no fish diseases were observed, and salinity did not significantly impact mortality. However, a slightly higher mortality rate was recorded in freshwater control ponds. Survival rates varied among species. *Mugil cephalus* exhibited slightly lower survival (76-82%), followed by *Planiliza macrolepis* (*Liza macrolepis*) (78-86%). *Planiliza parsia*(*Mugil parsia)* showed a survival rate of 83-88%, while *Planiliza planiceps (Liza tade)* had the highest survival (88-92%).

Statistical analysis using ANOVA confirmed that salinity significantly influenced growth ($P < 0.05$).

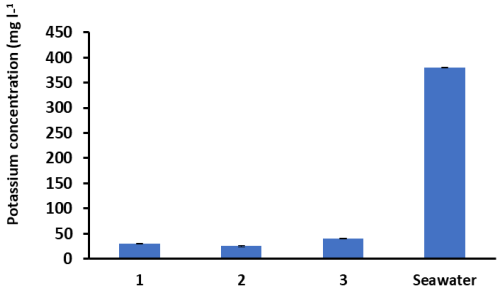


Figure 1 Comparison of Potassium Ion (K^+) Concentration in Saline Water Samples. The figure displays the measured concentration of potassium (K^+) in three distinct inland saline water samples, benchmarked against a seawater control (Salinity: 34.48‰). The inland samples are categorized by salinity levels: (1) 9.55‰, (2) 10.5‰, and (3) 24.15‰.

Table 2 Ionic composition of inland saline water and seawater

Parameters	Inland saline groundwater								
	1	2	3	4	5	6	7	8	Seawater
Salinity ppt	0.3±0.0	1.9±0.0	2.5±0.0	5.9±0.0	7.2±0.0	9.55+0.03	10.3±0.0	24.15±0.35	34.48
Conductivity mS cm^{-1}	1.04±0.0	3.8±0.0	4.58+0.	10.34±0.0	12.83+7.37	16.49±0.03	17.27±0.03	38.55±0.11	44.48
pH	7.6±0.0	7.12±0.0	7.15±0.0	7.2±0.0	7.37±0.0	7.22±0.002	7.38±0.0	7.09±0.02	8.86
Sodium mg l^{-1}	20.0+1.65	33.3±1.44	51.3±1.21	114.67±1.09	170.67±1.44	278.66±2.22	250.67±1.09	390.0±1.65	10556.1
Potassium mg l-1	2.0±0.58	5.33±0.27	6.8±1.18	15.0±0.94	17.67+0.23	30.4±0.0	25.33±0.54	40.0±0.94	380.0
Calcium mg l-1	196.21±4.47	378.22±19.81	462.27+34.31	686.86±11.45	525.0±14.89	420.31±7.43	609.0±14.8	1082.83±5.25	400.1
Magnesium mg l-1	34.97+13.61	52.30±6.48	67.91±7.64	175.68±11.50	826.55±8.21	1360.29±12.72	933.91±0.43	2183.46±114.7	1272.0
Total hardness mg l-1	600.0+47.14	1100±57.73	1433.33+54.3	2400+47.14	4700.0±70.36	4625.0±6.95	5350.0±35.46	11050.+134.63	1715.57
Chlorides mg l-1	231.93±13.53	811.77+35.79	1259.67+13.53	1838.9±23.43	4646.25+123.92	4709.1+20.60	6038.55±52.89	9008.12+20.60	18979.9
Sulphate mg l-1	87.48±12.12	92.31±8.7	95.8±3.6	97.25±0.72	97.28±0.13	95.68±1.36	85.67±8.21	93.34+0.55	2648.6
Carbonates mg l-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.0
Bicarbonates mg l-1	195.12+1.21	180.62+2.1	201.63±1.8	198.3±1.6	208.16±1.6	140.5±0.82	156.31±1.61	158.0±0.70	139.7
Total alkalinity mg l-1	195.12±1.21	180.62+2.1	201.63±1.8	198.3±1.6	208.16+1.6	140.5±0.82	156.31±1.61	158.0±0.70	167.7
Orthophosphate mg l-1	0.07±0.02	0.07±0.0	0.06±0.02	0.05±0.01	0.04+0.01	0.034±0.001	0.03±0.0	0.092+0.001	0.001-0.1

Ten replicate water samples were collected from each of the eight source wells (1-8) to quantify water quality parameters.

Both low and high salinity levels resulted in reduced weight gain. Conversely, salinity levels within the range of 10-25 ppt positively correlated with mean fish weight, specific growth rate (SGR), percentage weight gain, and daily growth rate (d^1) across all species. Fish in freshwater exhibited poor growth.

Species-specific responses: *Planiliza parsia* consistently demonstrated the lowest growth rates across all salinity treatments. *Mugil cephalus* showed optimal growth at 10 ppt, while *Planiliza planiceps* and *Planiza macrolepis* performed best at 15 ppt. A general trend of increased growth with rising salinity up to 15 ppt was observed, followed by a decline at higher salinities (Figure 2).

In terms of daily growth rate (d^{-1}), *Planiza parsia* remained the slowest-growing species, with rates ranging from 0.05 d^{-1} to 0.08 d^{-1} across salinity treatments. *M. cephalus* exhibited the highest daily growth at 10 ppt (0.99 d^{-1}) and 15 ppt (0.87 d^{-1}).*Planiliza planiceps* (0.81 d^{-1}) and *Planiza macrolepis* (0.48 d^{-1}) showed increasing daily growth rates up to 15 ppt, followed by a decline at higher salinities (Table 3). The overall growth hierarchy was: *M. cephalus* >*Planiliza planiceps* > *Planiza macrolepis* >*Planiza parsia* .

At the end of the 100-day culture period, no definite trend in condition factor (k-values) was observed among the different mullet species kept at different salinity treatments. In other words, condition factor values did not coincide with the growth parameters.

Body composition

Body composition analyses demonstrated a significant effect of water salinity ($P<0.05$). Across salinity gradients, an inverse relationship was observed: as salinity increased, moisture and ash content significantly ($P<0.05$) increased, while crude protein, crude fat, phosphorus, and energy levels significantly decreased (Table 4). Furthermore, *Mugil cephalus* reared at 10 ppt and *Planiliza planiceps* at 15 ppt, displayed significantly elevated levels of protein, fat, energy, and phosphorus, coupled with significantly reduced moisture and ash content ($P<0.05$).

Conversely, *Planiliza macrolepis* and *Planiza. parsia* did not show any significant variations in body composition across the tested salinity levels (Data not shown).

Water quality characteristics

The experimental ponds exhibited significant variability in water temperature, which ranged from 12.6 ^{0}C to 29.8 ^{0}C. Electrical conductivity was directly proportional to salinity, demonstrating a clear increase with higher salt concentrations. Other key water quality parameters generally remained within acceptable ranges across all experimental conditions. (Table 5).

Dissolved oxygen levels were relatively consistent, fluctuating between 6.30 ± 0.60 mg l^{-1} and 6.80 ± 0.45 mg l^{-1}. Biochemical oxygen demand (BOD mg1^{-1}) remained stable, ranging from 4.30 ± 0.50 mg l^{-1} to 4.40 ± 0.60 mg l^{-1}. The pH values displayed minimal variation among the various treatments, staying within

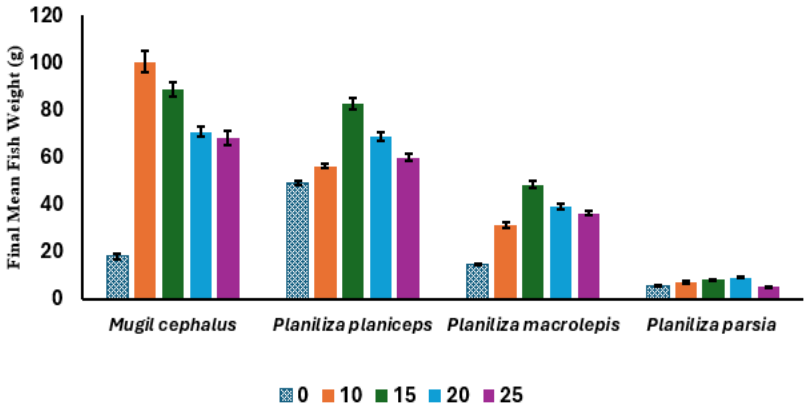


Figure 2 Growth performance of *Mugil cephalus*, *Planiliza planiceps*, *Planiliza macrolepis*, and *Planiliza parsia* at five different salinities (0, 10, 15, 20, and 25 ppt) under field conditions (culture period: 100 days). Bars with the same letter for the same species are not significantly different (Duncan's Multiple Range Test).

Table 3 Growth performance of *Mugil cephalus, Liza tade, Liza macrolepis* and *Mugil parsia* at five different salinities (0, 10, 15, 20 and 25 ppt) under field conditions (culture period 100 days).

Salinity (ppt)	Species	Stocking density/375 m^2 pond	Initial mean* Fish weight (g) and (mean length-cm)	Final fish stock		Weight gain (g)	SGR	Growth per cent gain in body weight	Condition factor (cf)	Growth g d^{-1}
				Survival (%)	Mean fish weight(g) and (mean length-cm)					
0 (Control)	*Mugil cephalus*	48	1.00±0.05(4.34 ±0.10)	76	18.2±1.2(13.16±0.05)	17.2	2.844	1720	0.79	0.17
	Liza tade	48	1.67±0.1(5.40± 0.05)	88	49.31±0.86(15.00±1.3)	47.64	3.863	2852.69	1.46	0.48
	Liza macrolepis	47	0.14±0.05(1.90±0.00	78	14.98±0.28(11.4± 0.10	14.84	2.697	10600	1.01	0.15
	Liza parsia	47	0.43±0.02(3.3± 0.03)	88	5.61±0.22((9.20±0.04)	5.18	1.644	1204.65	0.72	0.05
10	*Mugil cephalus*	48	1.22±0.04(5.28±0.10)	82	100.6±4.5(22.50± 0.34)	99.4	4.598	8145.90	0.88	0.99
	Liza tade	48	1.68±0.08(5.40± 0.05)	92	56.29±0.98(16.00±1.3)	54.61	4.000	3250.59	1.37	0.55
	Liza macrolepis	47	0.14±0.07(1.90±0.00	86	31.54±-1.14(14.00±1.2)	31.40	3.446	22428.57	1.14	0.31
	Liza parsia	47	0.45±0.02(3.3±0.03)	84	7.18±0.41(10.0± 0.00)	6.73	1.906	1495.55	0.71	0.07
15	*Mugil cephalus*	48	1.89±0.03(5.77±0.04)	81	88.8±3.2(20.55± 0.30)	86.9	4.464	4598.41	1.02	0.87
	Liza tade	48	1.68±0.09(5.40± 0.05)	92	82.57±2.34(18.52±0.30)	80.89	4.393	4814.88	1.29	0.81
	Liza macrolepis	47	0.14±0.09(1.90±0.00	86	48.41±1.54(14.05±1.3)	48.27	3.876	34478.57	1.74	0.48
	Liza parsia	47	0.45±0.02(3.3 ±0.03)	85	8.47±0.28(12.4±0.5	8.02	2.081	1782.22	0.44	0.08
20	*Mugil cephalus*	48	1.75±0.04(5.77±0.04)	80	70.9±2.0(18.00±0.34)	69.1	4.236	3951.42	1.21	0.69
	Liza tade	48	1.68±0.12(5.40± 0.05)	90	68.83±1.7(17.35±0.32)	67.15	4.206	3997.02	1.31	0.67
	Liza macrolepis	47	0.14±0.05(1.90±0.00	80	39.14±1.13(13.3± 0.12)	39.00	3.663	27857.14	1.66	0.39
	Lizal parsia	47	0.46±0.03(3.3 ±0.03)	85	9.25±0.16(12.3±1.4)	8.79	2.173	1910.86	0.49	0.09
25	*Mugil cephalus*	48	1.52±0.04(5.40±0.05)	79	68.3±3.0(17.30±0.34)	66.8	4.201	4393.42	1.31	0.67
	Liza tade	48	1.68±0.12(5.40 ±0.05)	90	60.03±1.58(16.95±0.32)	58.35	4.066	3473.21	1.23	0.58
	Liza macrolepis	47	0.49±0.08(3.4±0.03)	78	36.46±1.10((13.3± .12)	36.32	3.582	7340.81	1.54	0.36
	Liza parsia	47	0.46±0.03((3.3 ±0.03)	83	5.50± 0.22(9.0±0.04)	5.04	1.617	1095.65	0.75	0.05

*All values are mean ±S.E. of mean. Note: Control group results should be interpreted qualitatively due to differences in pond scale. Revised binomial nomenclature with old names in parentheses: *Planiliza planiceps (Liza tade)*, *Planiliza macrolepis* (*Liza macrolepis*) *and Planiliza parsia* (*Liza parsia*).

Table 4 Effect of different salinity treatments on body composition (% wet weight) of *Mugil cephalus* and *Planiliza planiceps* (*Liza tade)*

	Mugil cephalus at different salinity levels(ppt)						*Planiliza planiceps* (*Liza tade)* at different salinity levels (ppt)					
Carcass composition	Initial	control	10	15	20	25	Initial	control	10	15	20	25
Moisture	76.00± 0.70	68.70± 0.38	68.60^{ab}±0.37	68.30^{ab} ± 0.40	70.30^{ab} ±1.00	70.50^{ab} ±0.70	76.00±0.70	$68.70^{b\pm}$0.30	67.30^{ab}± 0.35	67.30^{ab} ±0.40	70.20^{ab} ±1.00	70.00^{ab} ±0.70
Crude protein	17.00± 0.70	18.00± 0.36	18.11^{a}±0.37	17.70^{a}± 0.35	16.60^{b}±0.10	16.60^{b}±0.18	17.00±0.60	17.01±0.36	17.11^{a}± 0.37	18.70^{a}±0.35	16.50^{b}±0.10	16.50^{b}±0.10
Crude fat	3.20± 0.25	3.90± 0.10	4.00^{a} ± 0.10	3.70^{ab}± 0.05	3.40^{ab}±0.05	3.40^{b}±0.14	3.30±0.20	3.70±0.20	3.60^{a} ±0.10	3.80^{ab}±0.05	3.30^{ab}±0.04	3.40^{b}±0.12
Ash	3.50± 0.14	3.20± 0.02	3.20^{b}± 0.02	$3,40^{b}$± 0.02	3.40^{b}±0.10	3.80^{a}±0.15	3.50± 0.14	3.30^{a}±0.02	3.20^{b}±0.02	$3,30^{b}$±0.02	3.70^{a}±0.15	3.60±0.14
Phosphorus	0.39± 0.02	0.68± 0.01	0.69^{a}± 0.02	0.66^{a}± 0 .03	0.65^{b}±0.02	0.64^{a}±0.01	0.38±0.02	0.66±0.02	0.66^{a}±0.01	0.68^{a}±0 .02	0.65^{b}±0.02	0.65^{a}±0.01
Gross energy (Kjg^{-1})	5.40± 0.06	6.70± 0.02	6.80^{a}± 0.02	6.60^{a}± 0.10	6.30^{ab}±0.16	6.00^{b}±0.20	5.30±0.06	6.70±0.02	6.70^{a}±0.02	6.80^{a}±0.10	6.40^{ab}±0.16	6.10^{b}±0.20

Means with the same letter/s in the same row are not significantly (P<0.05) different.

a narrow range of 7.80 ± 0.04 to 8.45 ± 0.17. Free carbon dioxide was consistently undetectable.

Bicarbonate and total alkalinity showed elevated levels in ponds with 10 ppt and 15 ppt salinity, while lower values were observed at 20 ppt and 25 ppt. Conversely, as salinity increased, a corresponding rise in conductivity, chloride, total hardness, calcium, and magnesium concentrations was observed. Sodium and potassium levels were not monitored. Despite the ponds being nutrient-rich, the concentrations of total Kjeldahl nitrogen, nitrate-nitrogen (NO_2-N), and available phosphorus (o-PO_4) decreased with increasing salinity. In contrast, total ammonia nitrogen (TAN), specifically as the unionized ammonium ion (NH_4-N), increased with higher water salinity.

Notably, total Kjeldahl nitrogen, nitrate-nitrogen (NO_2-N), nitrite-nitrogen (NO_3-N), and orthophosphate (o-PO_4) exhibited strong negative correlations with conductivity and salinity. In contrast, ammonium-nitrogen (NH_4-N) levels increased with rising salinity. Sulphate concentrations, however, did not show any statistically significant differences ($p < 0.05$) across the different salinity treatments.

Net primary productivity and biotic community response to salinity

Optimal net primary productivity (NPP) was recorded in ponds with salinities of 10 and 15 parts per thousand (ppt), demonstrating a statistically significant increase ($P<0.05$). This enhanced NPP statistically exhibited positive correlations with alkalinity, turbidity, and chlorophyll *a* concentration, with r values between 0.43 to 0.69.

Notably, peak chlorophyll '*a'* level, measured after 100 days, was observed at 10 ppt salinity, followed by a decline at higher salinity levels. Analysis of plankton communities revealed distinct responses to varying salinity gradients. Phytoplankton abundance and diversity were generally higher in control ponds and those maintained at 10 ppt compared to higher salinity treatments. All ponds showed significant. filamentous algal growth, primarily *Enteromorpha*. The phytoplankton community consisted of two dominant groups: Chlorophyceae, represented by *Ulothrix*, *Cladophora*, *Oedogonium*, *Chroococcus*, and *Closterium*, and Bacillariophyceae, represented by *Navicula*, *Synedra*, and *Nitzschia.* The numerical value of species diversity was highest in the control and decreased with increasing salinity till 20‰ (Table 5). In contrast, zooplankton abundance and diversity increased with rising salinity, reaching maximum levels at 20 ppt. The zooplankton community was dominated by copepods, including *Cyclops*, *Diaptomus*, *Mesocyclops*,

Table 5 Mean values (30,60, and 100 days) of hydro-chemical and biological characteristics of experimental ponds stocked with fingerlings of Four mullet species viz., *Mugil cephalus*, *Liza tade*, *Liza macrolepis* and *Liza parsia* at different salinity levels (0,10,15,20 and 25%)

Parameter	Water salinity ‰ of fish ponds				
	Control (0)	10	15	20	25
Conductivity mS cm^{-1}	5.80±1.06	15.55±0.45	23.00±0.35	27.00±2.20	31.50±0.50
pH	8.00±0.10	7.80±0.04	8.40±0.05	8.40±0.04	8.45±0.17
Dissolved oxygen $mg1^{-1}$	6.30±0.60	6.40±0.60	6.20±0.60	5.80±0.55	6.80±0.45
BOD $mg1^{-1}$	4.30±0.50	5.80±0.50	4.80±0.70	5.00±0.68	4.40±0.60
Total alkalinity $mg1^{-1}$	236.00±24.00	198.80±14.00	198.76±15.00	170.50±9.00	145.77±10.30
Chlorides $mg1^{-1}$	1660.00±408.50	4070.70±100.40	6586.48±125.37	9035.47±121.78	9878.64±201.00
Total hardness $mg1^{-1}$	4590.00±683.28	7083.65±794.00	9880.45±900.00	11880.00±1460.50	13520.75±1590.50
Calcium $mg1^{-1}$	725.56±150.35	984.85±150.00	1604.23±305.85	1820.26±308.00	2130.30±392.60
Magnesium $mg1^{-1}$	695.50±108.44	1095.00±120.45	1447.56±121.53	1819.65±167.48	1987.86±223.49
Total Kjeldahl nitrogen $mg1^{-1}$	12.35±0.78	11.00±0.51	7.72±0.38	7.53±0.39	7.65±0.43
NO_3-N $mg1^{-1}$	2.80±0.28	2.00±0.20	1.60±0.18	1.35±0.16	1.00±0.10
NO_2-N $mg1^{-1}$	0.75±0.11	1.20±0.15	0.32±0.04	0.18±0.02	0.14±0.01
NH_4-N $mg1^{-1}$	0.27±0.06	1.21±0.16	1.40±0.22	1.90±0.36	2.47±0.50
o-PO_4 $mg1^{-1}$	0.26±0.02	0.11±0.01	0.08±0.01	0.07±0.01	0.035±0.01
SO_4 $mg1^{-1}$	116.38±5.70	143.75±6.60	128.47±6.85	140.46±7.90	130.56±9.45
Turbidity NTU	7.40±0.17	8.20±0.30	8.20±0.04	6.97±±0.04	7.60±0.04
NPP mg C1-1 d^{-1}	1.40±0.07	2.68±0.05	2.70±0.05	1.85±0.05	2.10±0.04
Chlorophyll 'a' $\mu g1^{-3}$	0.60±0.001	0.64±0.001	0.50±0.001	0.45±0.001	0.30±0.001
Phytoplankton nos. 1^{-1}	2800.00±630.00	3029.17±642.34	2105.56±260.00	1950.44±180.30	1500.70±189.00
Zooplankton $nos1^{-1}$	2019.00±100.00	2488.79±251.23	3459.44±195.70	7354.89±665.00	7523.73±739.67
Phytoplankton(d^e)	0.52±0.42	0.51±0.41	0.41±0.24	0.16±0.13	0.32±0.26
Zooplankton(d^e)	1.15±0.16	1.18±0.10	1.16±0.17	1.81±0.35	1.51±0.32

All values are mean ± S.E. of mean. Water temperature during the experimental period increased from 12.6 to 29.8^0 C *Liza macrolepis* (Revised binomial nomenclature: *Planiza macrolepis*), *Liza parsia* (Revised binomial nomenclature: *Planiliza parsia).*

and nauplii, as well as rotifers, notably *Brachionus.* This suggests that while fish successfully adapted to increased salinity, this adaptation likely came at a metabolic cost, potentially diverting energy away from growth.

Discussion

Importance of ionic composition of inland saline water in aquaculture

A comparative analysis has revealed substantial chemical divergences between inland saline water and seawater. The salinity and specific ionic composition of inland saline water exhibit significant variability, primarily influenced by the geological origin of the water. While Inland saline groundwater shares a general ionic profile with seawater, its precise chemical composition varies substantially across regions.

Notably, a consistent global trend reveals a deficit in potassium levels within saline groundwater compared to seawater of similar salinity (Fielder et al. 2001; Rahman et al. 2005). Potassium is an essential element for fish, acting as the primary intracellular cation and playing critical roles in osmotic balance, ionic regulation, and acid-base homeostasis (Marshall and Bryson 1998; Evans et al. 2005). It is well-established that fluctuations in salinity and ionic composition exert a profound influence on the survival and growth of aquaculture species. Studies have documented that specific ionic imbalances and varying salinity levels have detrimental effects on the growth and survival of several fish and shrimp species, including red drum (*Sciaenops ocellatus*) (Forsberg et al. 1996), sea bream (*Pagrus auratus*) (Fielder et al. 2001), black tiger shrimp (*Penaeus monodon*) (Collins and Russell 2003; Rahman et al. 2005; Raizada et al. 2015), and *Litopenaeus vannamei* (Roy and Davis 2010; Jahan et al. 2018). Conversely, certain species—including the blacktip grouper (*Acanthopagrus butcheri* (Sarre et al. 1999), milkfish (*Chanos chanos* (Jana et al. 2006a, b), flathead mullet (*Mugil cephalus* (Kalla et al. 2003; Barman et al. 2005), pearlspot (*Etroplus suratensis* (Garg et al. 2007; Kumar et al. 2009a), and Nile tilapia (*Oreochromis niloticus* (Garg et al. 2007; Kumar et al. 2009b)—tolerate these ionic variations better and can grow to their full potential. These observations prompted an investigation into how inland saline water influences the growth performance of four sympatric mullet species within a polyculture system. The ability of euryhaline species to tolerate a wide range of salinities comes at a metabolic cost, as the energy allocated to osmoregulation often becomes unavailable for growth and other metabolic activities, thus impacting growth and metabolism (Wootton 1990).

Effect of inland water salinity on growth performance of different mullet species under polyculture

This study demonstrates that mugilid fry collected from coastal ecosystems can be successfully reared in a semi-intensive polyculture framework using inland saline groundwater. While all species exhibited substantial weight increases over 100 days, their growth trajectories were not uniform.

Salinity as a modulator of growth and metabolism

Salinity profoundly influences fish growth by modulating feed intake, digestion, and nutrient assimilation (Resley et al. 2006). The optimal salinity range for growth and metabolic efficiency varies with ontogenetic stage and is species-specific (Morgan and Iwama 1991).

The species-specific growth responses observed in this polyculture system suggest a salinity-tolerance gradient influenced by varying isosmotic points. While *Mugil cephalus* reached peak growth rates at 10 ppt (consistent with Barman et al. 2005), its congeners, *Planiliza planiceps (Liza tade)* and *Planiliza macrolepis (Liza macrolepis)*, required slightly higher salinities of 15 ppt to maximize performance.

The observed growth retardation at salinities exceeding these ranges (20–25 ppt) is likely rooted in the energetic cost of osmoregulation. When environmental salinity deviates from a species' isotonic point—the range where internal and external osmotic pressures are balanced—fish must divert metabolic energy away from somatic growth (protein synthesis) to fuel ion pumps (Na^+/K^+-ATPase) required for water balance (Boeuf and Payan 2001). Our findings align with the reported isotonic range of 9–13 g/L for many euryhaline species, explaining why growth performance was generally superior at 10–15 ppt compared to freshwater (0 ppt) or hypersaline conditions. Regarding interspecific performance and adaptability, a

clear growth hierarchy emerged where *M. cephalus* consistently demonstrated superior growth, reaching a peak Daily Growth Rate (DGR) of 0.99 d^{-1}, followed by *Planiliza planiceps* and *Planiliza macrolepis*. In comparison, *Planiliza parsia* displayed the slowest growth rates (0.05 to 0.08 d^{-1}) regardless of the salinity treatment. Ultimately, the overall success and system viability of this polyculture highlight the robust survival and adaptability of these species to formulated feeds (40% protein) within inland saline environments; however, despite identical dietary and environmental conditions, the observed interspecific variability suggests that inherent growth potentials and competitive efficiencies differ significantly among these sympatric mullet species. The varying growth performance observed in different mullet species under different salinity conditions likely stems from their natural presence in low-salinity environments such as estuaries, backwaters, and river mouths (Bardach et al. 1972).

It is noteworthy that fish growth in the inland saline groundwater treatments significantly exceeded that of the freshwater control, despite the latter's advantage of a smaller pond size and the associated 'edge effect.' This disparity suggests that the physiological benefits of the saline mineral profile—likely due to reduced osmoregulatory stress—outweighed the physical and aeration advantages of the control environment. Furthermore, these results underscore the potency of managed inputs in optimising productivity in saline ecosystems, confirming that such environments are not merely viable but potentially superior for the cultivation of these species.

Physiological mechanisms: Digestion and nutrient utilization

Beyond energy partitioning, salinity affects the physical process of digestion. Marine fish must ingest water to maintain osmotic balance, which can alter gut motility and enzymatic efficiency. Previous research indicates that digestion rates in *M. cephalus* are salinity-dependent, typically proceeding faster at higher salinities to compensate for metabolic demands (Perera and De Silva 1978). However, our results suggest a trade-off: while higher salinity may increase food intake or digestion speed, it often results in lower food conversion efficiency (FCE). For example, in *M. cephalus*, the metabolic rate may be elevated at suboptimal salinities, meaning that even if the fish eats more, the net energy available for growth is diminished. This explains why growth peaks at moderate salinities (10–15 ppt) where the metabolic "overhead" of living in a saline environment is minimized.

Wild fry transition from a pelagic lifestyle to environments of lower salinity than the open sea. Furthermore, the physiological demands of osmoregulation differ between marine and freshwater fish. Marine fish engage in water ingestion for osmotic balance, a process absent in freshwater species. Consequently, digestive efficiency in marine fish may be compromised by alterations in food motility necessitated by osmoregulatory mechanisms.

Studies on the growth of mullet species in aquaculture have revealed substantial variations in performance. For instance, Dayal et al. (2017) observed a significant divergence in final weight between two sympatric mullet species, *Mugil cephalus* and *Liza parsia*, when grown in tidal brackish water polyculture using formulated feed. Despite similar initial weights, *M. cephalus* exhibited a final average weight approximately 5.2 times greater than *L. parsia*, suggesting inherent differences in growth potential under identical conditions. This observation aligns with Biswas et al. (2012a), who also reported superior growth in *M. cephalus* compared to *L. parsia* within a polyculture system including *Planiliza planiceps (L. tade)* and tiger shrimp.

Environmental interactions: Ammonia and ionic composition

A critical finding in this study was the interaction between salinity and water quality. We observed that Total Ammonia Nitrogen (TAN), specifically the toxic unionized form (NH_4-N), increased significantly with rising salinity. This ammonia-induced stress likely acted as a secondary constraint on growth at higher salinities. High ammonia levels are known to disrupt gas exchange and further stress osmoregulatory organs, creating a compounding negative effect on fish health (Yun et al. 2026).

Furthermore, the specific ionic composition of inland saline groundwater may differ from that of natural seawater. This factor may explain why certain species, particularly *Planiliza parsia*, exhibited lower growth in our study compared to coastal saline pond trials. While we studied the effects of total salinity,

the specific ratios of ions in inland groundwater may impose unique physiological challenges that require further investigation.

High ammonia concentrations are known to disrupt osmoregulation and interfere with gas exchange (oxygen and carbon dioxide) in the bloodstream (Alabaster and Herbert 1954; Meade 1985; da Silva et al. 2013). Similarly, Garg (1996) reported increased accumulation of NH_4-N at higher salinity levels, leading to reduced growth in carp.

Given that diatoms are a well-established primary food source for mullets (De Silva and Wijeyaratne 1977; Mondal et al. 2015; Parvez et al. 2017), the improved growth performance of mullets at 10-15 ppt salinity levels in this study could be linked to increased diatom (Bacillariophyceae) and copepod populations. However, the lack of corresponding weight gain at higher salinities, despite high zooplankton availability, implies that high salinity may not promote significant growth in these mullet species.

Ecological interactions and practical implications

In a polyculture system, growth is not only a function of physiology but also of interspecific competition. The superior performance of *M. cephalus* may be attributed to its competitive advantage in resource acquisition. Conversely, the lower growth of *Planiliza planiceps* in this study compared to monoculture reports (Mondal et al. 2016) suggests that competition for food or space may temper the growth potential of sub-dominant species.

The availability of natural food sources, specifically diatoms (Bacillariophyceae) and copepods, also plays a role. While these primary food sources often thrive at 10–15 ppt, their presence at higher salinities did not translate to weight gain in our study. This confirms that for mugilids, environmental salinity and its associated physiological stresses are the primary limiting factors, outweighing the benefits of prey availability at extreme ranges.

Water quality

Maintaining good water quality is crucial for the optimal growth and survival of aquatic organisms in aquaculture. In this study, while inland groundwater salinity affected water quality parameters, the majority still fell within the optimal range for brackish water aquaculture (Boyd 1990). Specifically, nitrite-nitrogen (NO_2-N) and ammonia-nitrogen (NH_4-N) concentrations remained below critical levels. Despite nutrient-rich ponds, total Kjeldahl nitrogen, nitrate-nitrogen (NO_3-N), and available phosphorus (o-PO_4) decreased with increasing salinity. This decline in nitrate-nitrogen is likely due to enhanced denitrification at higher salinities, where nitrate is converted to nitrogen gas. Additionally, increased ion concentrations (sodium and chloride) may compete with nutrient ions (nitrate and phosphate) for binding sites, leading to nutrient leaching from sediments.

Total alkalinity and net primary productivity (NPP) peaked at 10 ppt and 15 ppt salinity, while conductivity, chloride, total hardness, calcium, and magnesium increased with salinity. Peak chlorophyll ‘a’levels were observed at 10 ppt salinity after 100 days, declining thereafter.

Phytoplankton abundance and diversity were highest in control ponds and those at 10 ppt salinity, with Chlorophyceae and Bacillariophyceae being the dominant groups, important food sources for mullets. Conversely, zooplankton abundance and diversity increased with salinity, peaking at 20 ppt. Copepods and rotifers (*Brachionus*) were the dominant zooplankton.

Studies indicate that mullets primarily consume plankton within brackish water habitats across the Indian subcontinent. Diatoms (Bacillariophyceae), followed by blue-green algae (Myxophyceae), and green algae (Chlorophyceae), have been consistently identified as the principal dietary components. (Refer to Mondal et al. 2015 and Parvez et al. 2017, for a compilation of supporting research).

Scale effects as a limitation of the Study. Due to facility-specific logistical constraints, larger units were unavailable for the freshwater phase of the trial. While stocking densities (fish/m^2) and feeding regimes were strictly standardized to minimise variance, pond size is known to influence thermal stability, gas exchange, and the development of natural productivity. Consequently, the performance of the freshwater group serves as a qualitative reference point rather than a direct statistical control. The primary conclusions of this study are therefore drawn from the comparative performance of the fish within the standardized 375

m^2 salinity treatments, where environmental variables were uniform.

Aquaculture applications

A comprehensive understanding of the interplay between salinity, digestion, and food intake holds significant economic and environmental implications for aquaculture. Optimizing salinity levels to enhance digestive efficiency can improve growth rates and feed utilization. Furthermore, tailoring feeding strategies to accommodate size-dependent digestive capabilities across different life stages is crucial. The current findings provide a valuable reference for similar subsequent experimentation involving inland saline groundwater. A review of the literature revealed a lack of relevant published values for these specific sizes.

Conclusions

The observed growth performance highlights *Mugil cephalus* as a promising species for aquaculture in inland saline groundwater. The comparable growth of *Planiliza planiceps* at 10 ppt salinity also suggests its potential. *Planiza macrolepis* exhibited moderate growth, which, despite being less robust, still warrants consideration for cultivation. However, the limited growth of *Planiza parsia* in inland saline groundwater indicates its likely economic unsuitability for farmers and aquaculturists in these conditions.

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Ethical considerations Efforts were made to mitigate potential harm to the animals.

Competing interests The authors declare that there are no competing interests.

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