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Culture Possibilities of Certain Brackishwater Species at Freshwater: A Climate Change Adaptation Strategy for Salinity Intrusion Prone Areas of Indian Sundarban Delta

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Abstract

Salinity intrusion into coastal mainland or freshwater habitat because of recent climatic changes is exacerbating production risks and challenging the coping capacity of freshwater fish farmers of Sundarban coastal delta in India. Hence, an experiment was conducted to evaluate the survival and growth performance of certain commercially important brackish water species in freshwater, and subsequent low salinities (5 g l^{-1} and 10 g l^{-1}). Species like *Scatophagus argus*, *Chelon parsia*, *Terapon jarbua*, *Etroplus suratensis*, and *Penaeus monodon* showed the highest specific growth rate (SGR) at 10 g l^{-1} salinity. However, the growth rates were not differed significantly (P>0.05) compared to freshwater. *Chelon planiceps* and *Mystus gulio* exhibited the highest SGR at 5 g l^{-1} salinity, although growth rates of the fish were not differed significantly (P>0.05) with freshwater treatments. Comparable survival and growth of all species in the freshwater condition indicated their ability of healthy acclimation at freshwater ponds. Therefore, these euryhaline fish species can be promoted in the Indian Sundarban for culture in freshwater ponds as climate-resilient adaptation strategies. This study could be useful in decision making during species and farm site selection which eventually will minimize the risks from total crop loss during saltwater inundation.

Introduction

Saltwater intrusion in freshwater and coastal mainland caused by climate change-induced sea-level rise as well as frequent extreme weather events (storm surge, cyclone, etc.) are now a major concern in many tropical deltas (Dubey *et al.,* 2017). This salinity intrusion is impacting freshwater fisheries and aquaculture which limits the production efficiencies and sustainability of the aquatic food production system (Ahmed & Diana, 2015). Although salinity is an important environmental determinant for the physiology of aquatic organisms, changes in ambient salinity can impacts negatively on fish growth as well as in other physiological processes (Boeuf & Payan, 2001; Nordlie, 2009).

Crowned with World Heritage Site and Ramsar site, Sundarban is a unique mangrove-dominated transboundary landscape traversed between India and Bangladesh. Located at the mouth of the Bay of Bengal, Sundarban has been formed mainly by the continuous deposition of silt carried down by the Ganga, Brahmaputra, and Meghna river system as well as its other freshwater tributaries. This coastal deltaic ecosystem sustains marvelous faunal and floral assemblages and supports millions of livelihoods who depend on the vibrant natural resources of Sundarban. Apart from the numerous crisscross networks of tidal creeks and rivers, the Sundarban is endowed with a vast expanse of often inland waters in the form of canals, lakes, ponds, tanks, wetlands, and paddy fields which always have attracted attention for its fish culture potentials. Currently, the Indian part of Sundarban is home to 4.5 million people, and agriculture followed by aquaculture is the main source of livelihood. It is a designated climate change hotspot that has experienced various environmental changes associated with climatic variables (UNESCO, 2009). This lower part of the Gangetic tidal delta is susceptible to coastal flooding and saltwater inundation during extreme weather events. In many areas inside the Sundarban islands, freshwater ponds have been inundated frequently by brackishwater during coastal flooding mainly after embankment breaching, which is converting freshwater fishponds into oligohaline ponds. In these transformed scenarios, several brackishwater species (euryhaline) have a huge culture potential into freshwater ponds where saline water inundation is a common phenomenon and as one of the important climate-resilient adaptation strategies. This makes the case of the paper.

Canagaratnam (1959) studied the growth of several brackishwater and marine fishes in low salinity. Oren (1981) extensively documented aquaculture possibilities of brackishwater species like grey mullets (Mugilidae). Sarig (1981) explored the possibilities of mullets inclusion in freshwater as well as brackishwater polyculture in Israel. Bok (1984) documented the extensive culture of two mullet species in freshwater impoundments in the Eastern Cape, South Africa. Culture of the euryhaline species especially under the Mugilidae family in estuarine and coastal regions is reported from many countries like China (Chang et al., 2004), Egypt (Bishara, 1978; Saleh, 2008), Israel (Lupatsch *et al.,* 2003), Italy (Luzzana *et al.,* 2005), New Zealand (Wells, 1984), Nigeria (Anyanwu *et al.,* 2007), Sri Lanka (De Silva & Perera, 1976; De Silva & Silva, 1979), Taiwan (Chang *et al.,* 2000), Tunisia (Khériji *et al.,* 2003), etc. Apart from fish species, Collins and Russell (2003) reported that black tiger shrimp *Penaeus monodon* adapted quite well to freshwater conditions in Australia because of its wide range of salinity tolerance. Similarly, Saoud *et al.* (2003) studied the use of inland well waters for the Pacific white shrimp, *Litopenaeus vannamei* culture. Araneda *et al.* (2008) evaluated the growth performances of *L. vannamei* in freshwater at different densities.

In India, researches on the rearing of brackishwater fishes (mainly mullets) began probably in the 1920s (Campbell, 1921; Hornell, 1922). From the 1940s onwards emphasis was given on the feasibility of acclimating mullet juveniles to freshwater and developing polyculture technology (Oren, 1981). As per the existing literature, the first acclimation experiments were undertaken in Madras with *Mugil troschelli* (currently *Liza macrolepis*) and *Mugil waigiensis* (currently *Liza vaigiensis*) at fresh water (Devanesan & Chacko, 1943; Job & Chako, 1947). After that, Mookerjee *et al.* (1946) performed acclimatization studies with *Mugil parsia* (currently *Chelon parsia*) in West Bengal and Ganapati and Alikunhi (1949) studied with *Mugil cephalus* and *Mugil seheli* (*Moolgarda seheli*) in Madras. James *et al.* (1985) tried monoculture of grey mullets in coastal saltwater ponds in the Mandapam area. Jana *et al.* (2004) and Barman *et al.* (2005) evaluated the growth performance of grey mullet in inland saline groundwater ponds in Haryana. Biswas *et al.* (2012a; 2012b; 2017) cultured striped grey mullet *Mugil cephalus* in brackishwater pond with under different management practices in Sundarban, West Bengal. Recently Mondal *et al.* (2016) evaluated the growth performances of tade mullet, *Liza tade (*currently *Chelon planiceps*) in the brackishwater farming system at Sundarban. Culture of other brackishwater euryhaline fish species also been performed by various researchers like long whiskers catfish *Mystus gulio* (Begum *et al.,* 2008), pearl spot *Etroplus suratensis* (Padmakumar *et al.,* 2009; Biswas *et al.,* 2012c), and spotted scat *Scatophagus argus* (Biona *et al.,* 1988a; Biona *et al.,* 1988b; Chang *et al.,* 2005; Mookkan *et al.,* 2014; Biswas *et al.,* 2016). In 1977 – 78, Sundararajan et al. (1979) performed monoculture of *P. monodon* in brackishwater ponds in Madras, India. Saha *et al.* (1999) and Chakraborti *et al.* (2002) evaluated the production of *P. monodon* in the tide-fed low saline ponds of Sundarban, West Bengal. Ramanathan *et al.* (2004) studied the culture performance of *P. monodon* in freshwater ponds in Tamil Nadu. Ray (1993) documented brackishwater fish culture in low saline water traditional impoundments in the Sundarban delta.

Amid several efforts, consolidate data on survival and growth performances of brackishwater fish in freshwater fishponds is still unavailable that can be useful in devising climate resilient aquaculture strategy. Considering the above, the present study aimed to assess the survival and growth performance of certain brackishwater fish species in freshwater in Sundarban coastal environments. The study could be helpful during the farm site and species selection in freshwater environments prone to coastal flooding in tropical deltas like Sundarban.

Materials and Methods

Acclimatization of Species

Seven brackishwater or estuarine species viz., *Scatophagus argus*, *Terapon jarbua*, *Chelon parsia*, *Chelon planiceps*, *Etroplus suratensis*, *Mystus gulio* and black tiger shrimp *Penaeus monodon* were chosen in this study. The fish were procured locally from hatcheries located in Sundarbans. The fish were kept in 10 g l^{-1} saline water and kept for one week. During this acclimatization period, fish were fed with supplementary pelleted feed in required quantities twice daily (9 am and 4 pm). The specification of feed was: crude protein-30%, crude fat-8%, crude Fiber-6%, NFE (Nitrogen Free Extract)-38%, ash-8% and moisture-10%. The gross energy content of feed was 383.2 kcal/kg which was calculated based on standard physiological fuel values. The feeding was stopped 24 hours (h) before the beginning of the experiment.

Experiment Design and Setup

The approach of the study design was followed Chand *et al.* (2015) and Dubey *et al.* (2016) with necessary modification. A total of six rectangular earthen ponds were used for this study and a completely randomized design was followed. The ponds were located at Bishnupur village of the Sagar island (latitude 21°42'6.08"N and longitude 88° 4'54.97"E), extreme western sector of Indian Sundarban (Figure 1). The earthen ponds were sized at about 0.02 ha and the experiment was conducted in the pre-monsoon year of 2015. The trial was performed in two phases. Experiments with six species were commenced in ponds while a trial with one species *M. gulio* was performed in FRP tanks (L: W: H = 1.8: 0.8: 0.6 m). Before commencing trials, proper pond preparations were done following standard procedures. two ponds of each were filled with freshwater (0 g l^{-1}), 5 g $l^{-1,}$ and 10 g l^{-1} salinities water to perform the study. Salinities were monitored through a refractometer and optimized periodically. The freshwater (0 g l^{-1}) was achieved from a groundwater source. The brackishwater was achieved from the tidal creek namely *Bishnupur khal* connected to the river Muriganga (average salinity 20 – 30 g l^{-1}).

In each pond with different salinities, nine *hapas* (the cage made of fine nylon net) (L: W: H = 3.65: 2.45: 1.20 m) were installed with the support of bamboo frames. The average water depth of the ponds was 1.2 m. Each *hapa* fitted inside different saline water ponds was stocked by 40 acclimatized fish individuals and left them for two months under ideal farm management. In each pond, three *hapas* containing the same group of fish are considered as replicates. In case of *Mystus gulio*, the experiment was conducted in 200 l identical FRP tanks (L: W: H = 1.8: 0.8: 0.6 m) in which 150 l water volumes were maintained. A total of 2520 numbers of fish individuals (3 replicates for 3 treatments X 40 individuals in each replicates X 7 species) were used in this study. More than 50% of stocks of induvial species were maintained separately. During the culture period, rations were provided twice daily (8 am and 4 pm) with supplementary pellet feed. The specification of feed as follows: crude protein-35%, crude fat-8%, crude Fiber-6%, NFE (Nitrogen Free Extract)- 33%, ash-8% and moisture-10%. The gross energy content of the feed was 385.4 kcal/kg which was calculated based on standard physiological fuel values. The daily feed amount was calculated using the formula: stocking nos. X average body weight X percentage of body weight feeding rate. The percentage of body weight feeding was 2.5%. Mortality was observed regularly while the fish were sampled 15 days intervals to check the growth. The bodyweight of 10 randomly sampled individuals from each *hapa* was measured and the growth patterns were

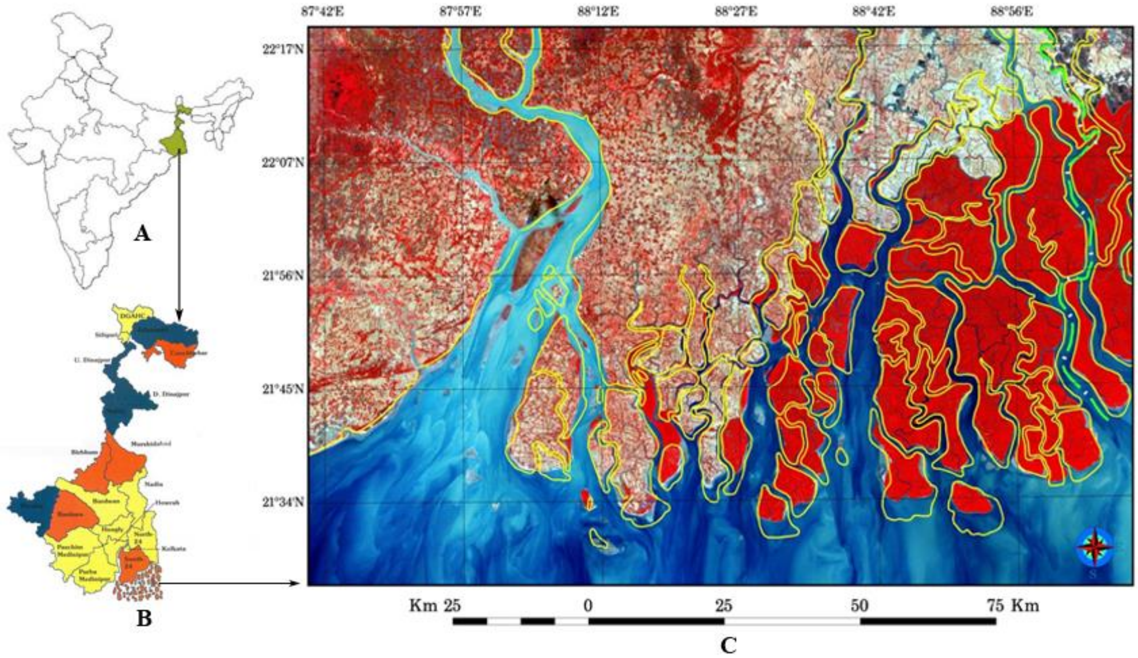

Figure 1. Map of the study sites. A: India; B: West Bengal; C: Sundarban, respectively. White circle indicates the Sagar island.

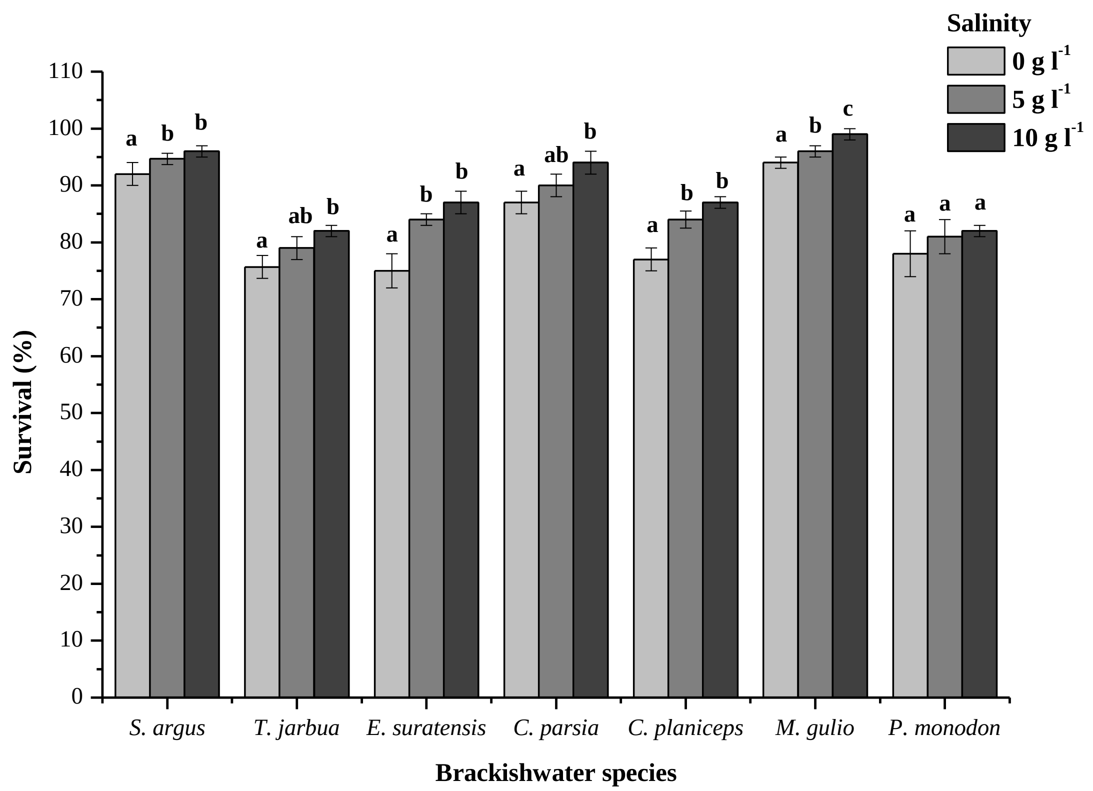

Figure 2. Survival (%) of some brackish water aquaculture species in fresh water and low salinities.

assessed in terms of average daily growth (ADG, g d^{-1}), weight gain, specific growth rate (SGR; % d^{-1}), and body weight gain (BWG %) following Dubey *et al.* (2016).

Water Quality Monitoring

Water quality parameters like temperature (°C), pH, and dissolved oxygen (mg l^{-1}) were measured fortnightly through a multi-parameter water analyzer instrument (HANNA, HI 9828, Germany). The ammonia-nitrogen, NH_3-N (mg l^{-1}), nitrate-nitrogen, NO_3-N (mg l^{-1}), nitrite-nitrogen, NO_2-N (mg l^{-1}), phosphate-phosphorus, PO_4^--P (mg l^{-1}) were measured using HACH Spectrophotometer (DR 2800, Germany). Total alkalinity (mg $CaCO_3$ l^{-1}) and total hardness (mg $CaCO_3$ l^{-1}) were measured as per APHA (2012). Salinity (g l^{-1}) was monitored daily.

Statistical Analysis

Data attained from the experiment like survival, growth performance, and water quality data for each salinity treatment were analyzed using one-way analysis of variance (ANOVA) followed by Tukey (HSD) test to determine statistical variations among different salinity treatments (Zar, 1999). The difference was considered statistically significant at $P \leq 0.05$. The analyses were performed using IBM SPSS 20.0 statistical software.

Results

Survival and Growth Analysis

The results of the study indicated a good survival of all brackishwater fish species in freshwater condition and their ability to healthy acclimation at freshwater ponds. The survival of seven brackishwater species in freshwater and subsequent low salinities is depicted in Figure 2. The survival rate increased at the highest salinity (10 g l^{-1}) compared to the freshwater, and in most cases, survival (%) of the fish exposed to fresh water and 5 g l^{-1} salinity was not differed significantly (P>0.05) (Figure 2). For instance, survival (%) of *S. argus* significantly depended (P<0.05) on salinity and varied between 92% (freshwater) to 96% (10 g l^{-1} salinity). In case of *C. parsia* and *T. jarbua*, differences of survival (%) were not significant (P>0.05) when cultured at fresh water and 5 g l^{-1} salinity treatment. Interestingly, *P. monodon* showed 78% survival in freshwater to 82% in 10 g l^{-1} salinity treatments and differences among them were not significant (P>0.05) (Figure 2).

The growth parameters of all experimented fishes in freshwater as well as saline water are presented in Table 1. *S. argus* showed the highest SGR at 10 g l^{-1} salinity (1.17% d^{-1}). However, the growth rates between 5 g l^{-1} salinity and 10 g l^{-1} salinity were not differed significantly (P>0.05). In case of *C. parsia*, the highest SGR was observed in the fish cultured at 10 g l^{-1} salinity

(1.48% d^{-1}) and the growth rates between fresh water and 5 g l^{-1} salinity were not differed significantly (*P*>0.05). It is fascinating to note that the growth rates of species like *E. suratensis*, *C. planiceps*, *M. gulio*, and *P. monodon* in fresh water and saline water were statistically similar (*P*>0.05). However, the growth rates of *T. jarbua* are significantly dependent on salinity (*P*<0.05) and differed with freshwater treatment. The BWG (%) of fish exposed to different salinity ponds is given in Figure 3. In terms of BWG (%), the best growth performance in freshwater was observed for *T. jarbua* followed by *C. planiceps*, *P. monodon*, *C. parsia*, *S. argus*, *M. gulio* and *E. suratensis* (Figure 3).

Water Quality

Water quality parameters were found to be suitable throughout the experimental period (Table 2). In the ponds, Total alkalinity values showed a significant difference during the culture period (*P*<0.05). The average water temperature (°C) over the study period was found to be 31.96, 31.53, and 30.87 at freshwater (0 g l^{-1}), 5 and 10 g l^{-1} salinity treatment, respectively. Water pH showed a static stage throughout the treatment and ranged from 7.15 to 7.17. The dissolved oxygen was found to be highest (7.03 mg l^{-1}) at freshwater followed by 6.98 mg l^{-1} in 10 g l^{-1} and 6.96 mg l^{-1} in 5 g l^{-1} salinity treatment. Total alkalinity showed significant rising trends with increasing salinity and was found to be 103.5 mg l^{-1} at freshwater followed by 110.75 mg l^{-1} at 5 g l^{-1} and 115.14 mg l^{-1} at 10 g l^{-1} salinity treatment. Total hardness showed a static state (*P* > 0.05) throughout the treatment and ranged from 110.50 mg l^{-1} to 111.57 mg l^{-1}. NH_3-N (mg l^{-1}) and NO_2-N (mg l^{-1}) concentrations were uniforms throughout the study length being highest at fresh water and 5 g l^{-1} salinity, respectively. NO_3-N concentration (mg l^{-1}) was found to be lower in freshwater followed by and 5 g l^{-1} salinity and 10 g l^{-1}, respectively.

Discussion

Climate change has a dramatic effect on freshwater fisheries and aquaculture which limits the production efficiencies and sustainability of the aquatic food production system. Hence, climate-resilient aquaculture provides a means to ensure sustainable fish supply to those who experience negative impacts of

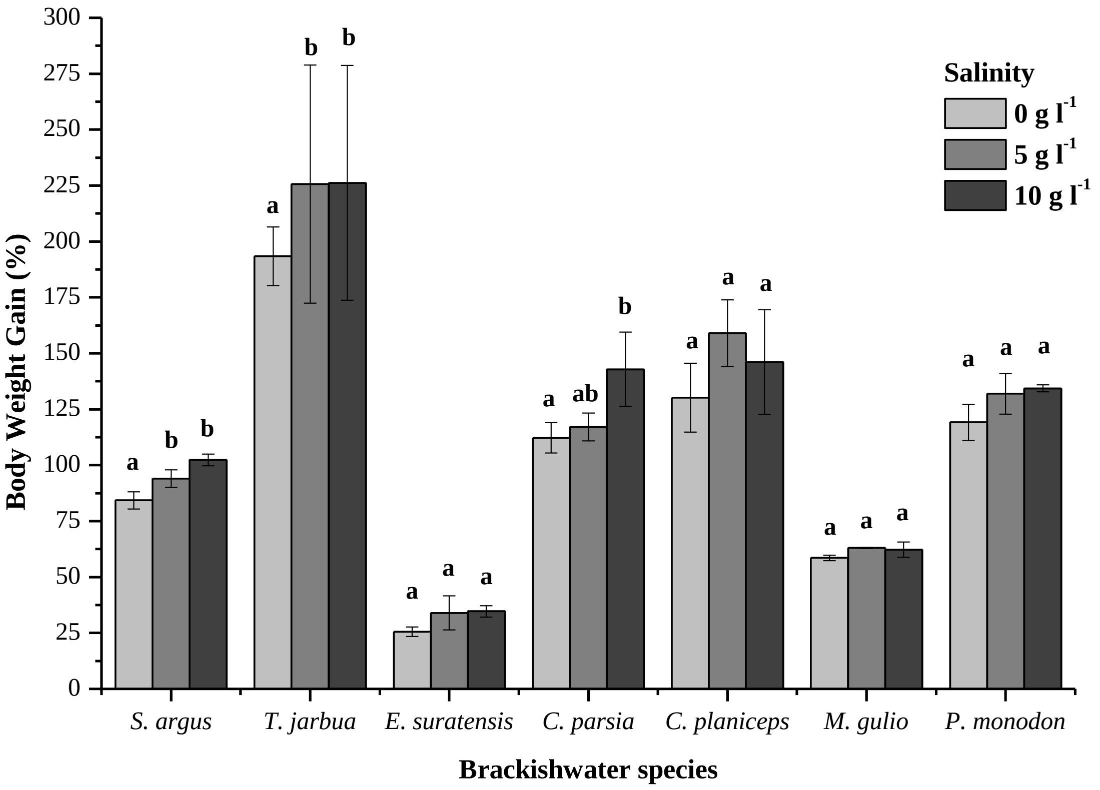

Figure 3. Body Weight Gain (%) of some brackish water aquaculture species in fresh water and low salinities.

Table 1. Growth performances of some brackish water aquaculture species in fresh water and low salinities.

Species	Fresh water (0 g l^{-1})				5 g l^{-1}				10 g l^{-1}			
	IW	FW	WG	SGR	IW	FW	WG	SGR	IW	FW	WG	SGR
S. argus	46.09±0.68^{a}	84.91±0.53^{a}	38.82±1.20^{a}	1.02±0.03^{a}	47.15±1.35^{a}	91.45±0.88^{b}	44.30±0.70^{b}	1.10±0.03^{b}	49.34±0.84^{b}	99.82±0.87^{c}	50.48±0.71^{c}	1.17±0.02^{b}
T. jarbua	10.34±0.04^{a}	30.33±0.32^{a}	20.0±0.38^{a}	1.79±0.01^{a}	10.33±0.02^{a}	33.65±5.51^{ab}	23.32±5.51^{ab}	1.95±0.26^{b}	10.34±0.03^{a}	33.72±5.49^{ab}	23.39±5.47^{ab}	1.96±0.26^{b}
E. suratensis	11.36±0.57^{a}	14.27±0.88^{a}	2.91±0.35^{a}	0.38±0.03^{a}	11.47±0.90^{a}	15.32±0.46^{a}	3.85±0.56^{a}	0.49±0.09^{a}	11.42±0.52^{a}	15.37±0.43^{a}	3.95±0.15^{a}	0.50±0.03^{a}
C. parsia	13.85±0.30^{a}	29.38±0.35^{a}	15.53±0.61^{a}	1.25±0.05^{a}	13.77±0.26^{a}	29.88±0.51^{a}	16.11±0.63^{a}	1.29±0.05^{ab}	13.43±1.02^{a}	32.51±0.39^{b}	19.07±0.74^{b}	1.48±0.11^{b}
C. planiceps	4.75±0.26^{a}	10.95±1.32^{a}	6.20±1.07^{a}	1.39±0.11^{a}	4.80±0.64^{a}	12.38±1.29^{a}	7.59±0.76^{a}	1.58±0.10^{a}	5.04±0.41^{a}	12.38±1.29^{a}	7.34±1.12^{a}	1.50±0.16^{a}
M. gulio	6.45±0.10^{ab}	10.23±0.08^{a}	3.78±0.03^{a}	0.77±0.01^{a}	6.32±0.04^{b}	10.30±0.05^{a}	3.98±0.01^{ab}	0.81±0.00^{a}	6.61±0.05^{a}	10.72±0.15^{b}	4.11±0.20^{b}	0.81±0.03^{a}
P. monodon	6.18±0.25^{a}	13.56±1.02^{a}	7.38±0.78^{a}	1.31±0.06^{a}	6.10±0.49^{a}	14.12±0.61^{a}	8.02±0.13^{a}	1.40±0.06^{a}	6.19±0.33^{a}	14.50±0.85^{a}	8.31±0.53^{a}	1.42±0.01^{a}

IW: Initial weight (g); FW: Final weight (g); WG: Weight gain (g); SGR: Specific Growth Rate (%)
Data are presented as Mean ± SD of three replicates. Figures in parenthesis represent the range of the parameters. Values of same superscripts within a row under each category did not differ significantly ($P > 0.05$).

Table 2. Water quality parameters of culture ponds and FRP tanks during survival and growth performance trial of brackish water aquaculture species in fresh water at Sagar field site.

Parameters	Salinity treatments						P - value	
	Fresh water (0 g l^{-1})		5 g l^{-1}		10 g l^{-1}			
	Earthen pond	FRP tank	Earthen pond	FRP tank	Earthen pond	FRP tank	Earthen pond	FRP tank
Temperature (°C)	31.96±1.52^{a} (29.9 - 34.5)	31.57±1.1^{a} (30.1-33.1)	31.53±1.06^{a} (29.7 - 33.1)	31.72±1.11^{a} (29.8-33.5)	30.87±1.81^{a} (28.4 - 33.4)	31.70±1.19^{a} (30.1-33.5)	0.38	0.96
pH	7.17±0.23^{a} (6.8 - 7.5)	7.05±0.30^{a} (6.6-7.5)	7.15±0.32^{a} (6.7 - 7.6)	7.05±0.20^{a} (6.7-7.5)	7.17±0.26^{a} (6.8 - 7.5)	6.95±0.25^{a} (6.6-7.3)	0.98	0.75
Dissolved oxygen (mg l^{-1})	7.03±0.29^{a} (6.45 - 7.4)	6.73±0.3^{a} (6.1-7.1)	6.96±0.3^{a} (6.5 - 7.5)	6.70±0.32^{a} (6.3-7.2)	6.98±0.36^{a} (6.5 - 7.5)	6.85±0.12^{a} (6.7-7.1)	0.91	0.52
Total alkalinity (mg $CaCO_3$ l^{-1})	103.5±2.26^{a} (100 - 106)	103.75±7.51^{a} (95-120)	110.75±3.61^{b} (105 - 116)	105.62±5.3^{a} (99-115)	115.14±3.02^{c} (109 - 118)	109.85±5.42^{a} (102-118)	0.0001	0.18
Total hardness (mg $CaCO_3$ l^{-1})	110.5±5.42^{a} (101 -118)	112±3.77^{a} (106-117)	111.37±4.03^{a} (105 - 115)	106±2.92^{b} (102-110)	111.57±4.11^{a} (105 - 117)	107.71±3.72^{ab} (105-114)	0.89	0.008
Ammonia-Nitrogen NH_3-N (mg l^{-1})	0.21±0.04^{a} (0.15 - 0.3)	0.20±0.04^{a} (0.15-0.31)	0.21±0.03^{a} (0.17 - 0.25)	0.18±0.06^{a} (0.1-0.29)	0.20±0.03^{a} (0.14 - 0.24)	0.18±0.04^{a} (0.11-0.24)	0.72	0.58
Nitrate-Nitrogen NO_3-N (mg l^{-1})	0.24±0.03^{a} (0.2 - 0.31)	0.25±0.06^{a} (0.14-0.35)	0.27±0.03^{a} (0.2 - 0.31)	0.23±0.07^{a} (0.15-0.35)	0.26±0.03^{a} (0.21 - 0.31)	0.21±0.03^{a} (0.18-0.25)	0.32	0.50
Nitrite-Nitrogen NO_2-N (mg l^{-1})	0.02±0.01^{a} (0.01 - 0.05)	0.03±0.01^{a} (0.02-0.05)	0.02±0.01^{a} (0.01 - 0.05)	0.03±0.01^{a} (0.01-0.05)	0.02±0.01^{a} (0.01 - 0.04)	0.05±0.01^{b} (0.03-0.08)	0.96	0.02
Phosphate-Phosphorus PO_4^{-}-P (mg l^{-1})	0.25±0.02^{a} (0.21 - 0.29)	0.27±0.02^{a} (0.25-0.31)	0.25±0.02^{a} (0.21 - 0.3)	0.27±0.03^{a} (0.22-0.31)	0.25±0.04^{a} (0.19 - 0.3)	0.26±0.02^{a} (0.22-0.3)	0.96	0.68

Data are presented as Mean ± SD of three replicates during the 60-day culture period. Figures in parenthesis represent the range of the parameters. Values with the same superscripts within a row do not differ significantly ($P > 0.05$).

climate change. In the present study, all experimented brackishwater species survived and grew well in freshwater conditions. Species such as *S. argus*, *C. parsia*, *T. jarbua*, *E. suratensis*, and *P. monodon* showed the SGR at 10 g l^{-1} salinity water ponds. However, the growth rates were not differed significantly (*P*>0.05) compared to freshwater ponds. *C. planiceps* and *M. gulio* exhibited the highest SGR at 5 g l^{-1} salinity water ponds, although growth rates of the fish were not differed significantly (P > 0.05) with freshwater ponds.

As euryhaline, spotted scat *S. argus* thrives well in freshwater and coastal habitats (Barry & Fast, 1992). The spotted scat has a broad salinity tolerance range and is more tolerant of transfers to lower salinities and freshwater (0 g l^{-1} salinity) (Macahilig *et al.,* 1988). Such a pattern of survival probably reflects the ability of the scat to osmoregulate better at lower osmotic pressures than in a hypersaline environment (Macahilig *et al.,* 1988). The growth of *S. argus* was almost comparable in both fresh water and brackishwater when it co-cultured with milkfish *Chanos chanos* and did not affect the growth and production of milkfish (Biona *et al.,* 1988a). In line with the present study, better survival, and growth rate of *S. argus* were also noticed when cultured in 5 g l^{-1} salinity than higher salinity (10, 15, 20, 25, and 30 g l^{-1}) (Mookkan *et al.,* 2014).

Like scats, species under the family Mugilidae (mullets) show a great deal of euryhalinity and have a broad salinity tolerance range (Thomson, 1966). Being the lowest trophic level fish and omnivorous feeding habit, mullets are suitable for monoculture and compatible with other species in polyculture (Biswas *et al*., 2012b). In India, mullets are potential candidate species suitable for culture in brackishwater ponds and have a high consumer preference due to their unique taste. However, the pond culture of mullet in traditional and semi-intensive systems mainly relies on wild seed collection from tidal estuaries (Biswas *et al.,* 2012a; 2017). Flathead grey mullet *Mugil cephalus* was successfully cultured in fresh water and various salinities (10, 15, 20, and 25 g l^{-1} salinity) using inland saline groundwater (Barman *et al.,* 2005). The study revealed that SGR was significantly enhanced in fish maintained at 10 g l^{-1} salinity (SGR 4.70 % d^{-1}) in comparison with freshwater (SGR 3.12 % d^{-1}) which supported the findings of the present study.

Peral spot *E. suratensis* can thrive in marine, estuarine and freshwater environments (Rao *et al.,* 2000), and is a euryhaline species with a high salinity tolerance from 1 - 70 g l^{-1} (Wallace, 1975). However, to date, little attention has been paid to the culture practice of *E. suratensis* in captivity. Due to its good taste and flesh quality, the pearl spot has high consumer preference in the local as well as international markets (Biswas *et al.,* 2012c). Euryhaline nature and omnivorous feeding habits make *E. suratensis* compatible to be farmed in polyculture with both brackishwater and freshwater fish and prawns (Jayaprakas *et al.,* 1990). Padmakumar et al. (2009) evaluated the production performance of pearl spot inside cage enclosures (salinity ranged from 0.06 to 1.28 g l^{-1}) in the Vembanad estuarine system, on the southwest coast of India and found SGR ranged from 0.28 to 0.75% d^{-1}. The growth performance of pearl spots is remarkable in the context of the present study (SGR ranged from 0.38 to 0.50% d^{-1}) as the pearl spots are generally considered slow-growing species, growing hardly to 120 - 130 g in pond conditions (Thampy, 1980; Padmakumar *et al.,* 2009). *M. gulio* is a euryhaline fish, occurring mostly in fresh water and has also been found to thrive in brackishwater or backwaters of low salinity (Pandian, 1966; Talwar & Jhingran, 1991). Begum et al. (2008) cultured *M. gulio* at 4-5 g l^{-1} salinity in nursery ponds and observed SGR ranged from 4.91 to 5.10% d^{-1}.

Several studies reported the effect of salinity on the growth of black tiger shrimp *P. monodon* (Verghese *et al.,* 1975; Rajyalakshmi, 1980; Chakraborti *et al.,* 2002). Studies suggest that *P. monodon* adapted well to the freshwater condition due to its wide salinity tolerance range (Shivappa & Hambrey, 1997; Collins & Russell, 2003). Navas and Sebastian (1989) reported that low salinity of the water is more favorable for *P. monodon* during the early stages, while a medium range of salinity is conducive for faster growth in the later stages.

Shivappa and Hambrey (1997) reported that *P. monodon* can be cultured successfully using inland freshwater in Thailand having a salinity of less than 5 g l^{-1}. In Australia, Collins and Russell (2003) observed satisfactory growth of *P. monodon* in freshwater with an average survival of 56 – 78%, which is very similar to the present study. Sundarajan *et al.* (1979) found SGR 0.39% d^{-1} while farming of *P. monodon* in brackishwater (10 g l^{-1} salinity) monoculture system. Saha *et al.* (1999) also found satisfactory growth performances of *P. monodon* while culturing in low saline water. Ramanathan et al. (2004) studied the culture performances of *P. monodon* under extensive and semi-intensive systems in freshwater conditions. In an extensive system, average daily growth and survival were 0.18 g and 55% respectively. In contrast, under semi-intensive systems, average daily growth and survival were 0.16 g and 46% respectively (Ramanathan *et al.,* 2004). These observations coincide well with the finding of the present study of possibilities of *P. monodon* culture in freshwater or low saline conditions.

There are various reports on the acclimation and growth of estuarine and marine species in low salinities or freshwater. For example, fish species like thick lip grey mullet *Chelon labrosus* (Ben-Yami, 1981), juvenile Atlantic halibut *Hippoglossus hippoglossus* (Imsland *et al.,* 2008), European flounder *Platichthys flesus* and turbot *Scophthalmus maximus* (Gutt, 1985; Gaumet *et al.,* 1995; Imsland *et al.,* 2001), Juvenile golden pompano *Trachinotus ovatus* (Ma *et al.,* 2016), Juvenile pompano *Trachinotus marginatus* (Abou Anni *et al.,* 2016), juvenile Florida pompano *Trachinotus carolinus* (Weirich *et al.,* 2009), cobia *Rachycentron canadum* and the gilthead sea bream *Sparus aurata* (Woo & Kelly, 1995; Laiz-Carrión *et al.,* 2005; Resley *et al.,* 2006), Juvenile black bream *Acanthopagrus butcheri* (Partridge & Jenkins, 2002), Red drum *Sciaenops ocellata* (Crocker *et al.,* 1981), and milkfish *Chanos chanos* (Alava, 1998) that exhibit satisfactory survival and growth rate in low salinities to freshwater. Similarly, *L. vannamei* has been grown in inland saline waters ranging in salinity from 2 g l^{-1} to freshwater (0 g l^{-1}) (Samocha *et al.,* 1998; Davis *et al.,* 2004; Araneda *et al.,* 2008).

When fish encounter stressful conditions, their ionic and osmoregulatory stability disrupts and this can be termed as 'Osmo-respiratory compromise' (Myrick, 2011). In freshwater, fish experience the passive gain of water and loss of ions, which is accomplished through the production of large volumes of dilute urine and active uptake of ions across the gills. In saltwater, fish offset the passive gain of ions and loss of water. This is accomplished by drinking seawater, absorbing water, and salts across the gut, and excreting monovalent ions across the gills and divalent ions through the kidney (McCormick, 2011). Nearly 95% of extant stenohaline teleost species are osmoregulators, which means they maintain their extracellular body fluids at a relatively constant osmolality of $\sim$300 mOsmol kg^{-1} (isosmotic to 9 g l^{-1} salinity). The remaining 5% of euryhaline fishes are osmoconformers having the capacity to tolerate a wide range of salinities (Kültz, 2015). Nonetheless, euryhaline fish have developed special biochemical and physiological mechanisms to thrive in a changing salinity regime. They can intellect osmotic stress, which induces the instigation of osmosensory signaling mechanisms that, in turn, regulate osmoregulatory effectors to alleviate osmotic stress in saline water (Fiol & Kültz, 2007). Although this study did not measure biochemical parameters of fish in a different saline environment, euryhaline teleost fishes can regulate and maintain plasma ionic composition and osmotic concentration in changing salinity regimes (Nordlie, 2009; Aragão *et al.,* 2010). Lin *et al.* (2003) found no significant difference in plasma osmolality, sodium, or chloride concentrations of milkfish *C. chanos* adapted fresh water and various strengths of saline water thus prove the extremely euryhalinity of brackishwater fishes.

In 2009, both parts of Sundarban (West Bengal in India and Bangladesh) has witnessed severe tropical cyclone *Aila* which caused massive inland salinization and damage freshwater farmlands. This salinity still remains in many inland areas of the delta. Very recently, super cyclone *Amphan* in 2020 again struck the Sundarban and pushed coastal floodwater up to 15 km inland inside the various inhabited islands. This causes huge damage to the freshwater homestead pond-based aquaculture inside the islands of Sundarban. The study has two broad implications. First, in this changing climatic scenario, certain euryhaline species have a wider potentiality for culture in many freshwater areas of the Indian Sundarban delta as well as other tropical deltas where coastal flooding is a common occurrence. Second, frequent saline water intrusion into the coastal inland area largely due to climatic changes is converting freshwater into the oligohaline zone that opens the avenue of polyhaline aquaculture. Nevertheless, the low saline traditional shrimp farming system can be further diversified through the inclusion of more brackishwater fish species.

Conclusion

The study indicated that brackishwater fish and shrimp could acclimate and grew well in fresh water and low saline water conditions. Moreover, majorities of experimented species are considered as candidate species in terms of flesh texture, taste, and market price. However, this potential can only be apprehended by the successful artificial propagation of juveniles from hatcheries. Considering the current and future climate variables, more coastal areas of India are going to become exposed to climate change impacts. Under such a scenario, these brackish water species can be promoted in the Indian Sundarban for culture in freshwater ponds as climate-resilient adaptation strategies. This study will help farmers to make a decision on species selection that can minimize risks from total crop loss during saltwater inundation. However large-scale hatchery-reared seed production and standardization of culture techniques through farmers' trials for enhanced production should be recommended.

Ethical Statement

The study was carried out in accordance with the recommendations in CPCSEA (Committee for the Purpose of Control and Supervision on Experiments on Animals) Guidelines for Laboratory Animal Facility and Guidelines for Care and Use of Animals in Scientific Research Govt. of India. The experiment was performed in a sustainable and responsible manner with the minimal use of species.

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Author Contribution

Raman Kumar Trivedi: Conceptualization, Funding Acquisition, Project Administration, Resources, Supervision, Writing – Review & Editing; Bimal Kinkar

Chand: Experimental Design, Methodologies, Writing – Review & Editing; Sourabh Kumar Dubey: Research Investigation, Data Analysis, Writing – Original Draft Preparation. All Authors Read and Approved the Final Manuscript.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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