The Culture Potential of *Pangasius* Catfish in Brackish (Hyposaline) Waters of the Greater Barishal Regions in Southern Bangladesh

Production System Design and Best Management Alternatives/Experiment/13BMA02NC

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ABSTRACT

The river catfish (*Pangasius hypophthalmus*) was introduced to Bangladesh in the 1990s from Thailand and has since become a thriving aquaculture industry with more 3 million tons produced annually. The aim of this investigation was to assess the potential for expanding the culture of *Pangasius* catfish to hyposaline waters in Southern Bangladesh. If *Pangasius* culture can be introduced to coastal regions of Bangladesh, it may significantly improve food security and the economic viability of its communities. Therefore, this investigation assesses the potential to culture *Pangasius* in hyposaline waters endemic to the coastal in-land regions of Southern Bangladesh (0.5–12 ppt), as well as other regions where seawater incursion is expected to increase and where the livelihood of coastal communities have relied on culture of freshwater fishes for their livelihoods (e.g., Lower Mekong Delta).

An on-farm experiment was conducted in 18 ponds of different salinity levels for a period of 160 days from May through October 2014 in the coastal Patuakhali district. The experiment consisted of three treatments with salinity ranges of 0–0.5 ppt, 5–7 ppt and 10–12 ppt each replicated in six ponds. The average size of ponds was 400 m^2 with an average water depth of 1.3 m. Prior to stocking ponds were prepared by liming and fertilization. Overwintered fingerlings of *Pangasius* (~6 g) were stocked in all ponds at a density of $2/m^2$. Fish were fed with commercial feed (Mega floating feed, 28% CP, 7% fat) at an initial rate of 10% body weight (bw)/day down to 3% bw/day. Feed was provided twice daily at 09:00 and 14:00 h.

Water-quality parameters among the different treatments were within suitable ranges for *Pangasius* culture. Average salinities were 0, 6.5 and 10.8 in T_1, T_2 and T_3 respectively. No significant differences (p>0.05) were observed in survival rate, weight gain, specific growth rate (SGR), feed conversion ratio (FCR), yield, and benefit cost ratio (BCR) among the treatments. The results indicate that *Pangasius* catfish show similar survival and growth in hyposaline waters up to 10-12 ppt as is seen in freshwater.

A second on-farm experiment was subsequently undertaken to assess the effect of increased stocking density and of a commercial and formulated feed on *Pangasius* production over six months in ponds with an average salinity of 10 ppt. Fish (12 ponds, 4 ponds/group) were stocked at a density of $2/m^2$ and fed a formulated (28% CP, T1 group) and commercial feed (CP Mega floating feed, 28% CP; T2 group). In a third treatment (T3) fish were stocked at $3/m^2$ and fed the commercial feed. Fish were fed at an initial rate of 10% body weight (bw)/day down to 3% bw/day.

No significant differences were observed in survival rate, weight gain, SGR, and feed conversion ratio (FCR) among the treatments. Significantly higher production was observed in T3 (23,264 kg/ha) followed by T1 (15,538 kg/ha) and T2 (15,622 kg/ha). Because formulated feed is substantially cheaper than commercial feed net profit was greater in T1 (US$11,438/ha) than in T2 (US$8,275/ha). Total cost was higher in T3 than in T2 due to higher stocking densities, but net profit was higher in T3 (US$12,104/ha) than in T2 (US$8,275/ha).

Collectively, the results indicate for the first time that *Pangasius* can be grown in salinities as high as 10 ppt. The adoption of formulated feeds rather than commercial pelleted diets or of a higher stocking density of 3 fish/m^2 can provide additional profits of as high as 40%. The work demonstrates brackish water culture of *Pangasius* can provide an alternative livelihood for coastal communities including those impacted by water salinization associated with global climate change.

INTRODUCTION

In Bangladesh, *Pangasius* catfish is considered as one of the most successful aquaculture species due to its relative ease in culture, high-market demand, and suitability to local climate conditions (Rahman et al. 2005, Rahman et al. 2012, Sarker 2000). The focus of this investigation is to assess the potential for expanding the culture of *Pangasius* to Southern regions containing significant amounts of brackish (hyposaline) waters, the areas that are severely impacted by overfishing and global climate change (e.g., seawater encroachment, storms) and are currently underutilized for fish production. Production of *Pangasius* could theoretically ease poverty reductions for millions of low-income people in Southern Bangladesh by creating better employment opportunities through development of activities with backward and forward linkages to the market chain. Additionally, we will assess if indigenous mullet species (striped and goldspot mullet) can be incorporated into *Pangasius* culture to achieve better production yields (therefore better income earnings), potential improvements in environmental water quality through more efficient nutrient utilization, and improving nutrition through greater diversification of food resources in the coastal regions (greater Barisal District).

The river catfish (*P. hypopthalamus*) was introduced to Bangladesh in 1990s, and since then it has become a thriving aquaculture industry with more 300,000 tons produced annually (Ali et al. 2011, Edward and Hossain 2010, Munir 2009). Currently, much of the *Pangasius* production comes from the North and Central regions of Bangladesh (e.g., greater Mymensingh). In these regions, *Pangasius* are cultured both intensively with commercial feeds, semi-intensively (with limited feed), and in extensive (no feed) polyculture with both tilapia and carp (Ahmed et al. 2010). High disease resistance, along with high stocking density with greater production rates (up to 120 fish /m^2, average 40 tons/ha; UNFAO 2010), make *Pangasius* an ideal cultivar for increasing aquaculture production in Bangladesh, particularly in regions unfamiliar with farming this species, as well as reducing the burden of population growth. The greater Barisal district is one such region, which has traditionally relied on fishing or aquaculture of marine species (*e.g.*, shrimp) for their economic livelihoods. Through overfishing and the increasing frequency of natural calamities like cyclones (e.g. Sidr, Aila), this region is nearing depletion of wild fish stocks and currently over half a million fishermen have been suffering from severe poverty. Introducing *Pangasius* aquaculture to these coastal communities, whose water resources are largely underutilized, may significantly enhance the dietary consumption of protein for low-income families, as well as provide new sources of income and employment in an area.

Some studies suggest *Pangasius* sp. may be tolerant of salinity (David 1962). Recently, juveniles of *Pangasius* catfish are reported to tolerate salinities up to 13 ppt without significant mortality (Castaneda et al. 2010). Before significant resources can be allocated for promoting this industry in coastal regions, the growth performance of *Pangasius* in hyposaline waters must first be evaluated. Through increasing tidal (seawater) encroachment and storms, nearly 40 percent of the farmable water bodies in the greater Barisal district are now hyposaline (0.5–7.5 ppt), and this percentage is expected to increase in future years. This has significantly impacted culture of traditional freshwater species in the area. If *Pangasius* culture can be achieved in greater Barisal and other coastal regions, the production levels of this fish could effectively double (600,000 metric tons), thus may significantly impact the diet and economic viability of coastal communities. As similar problems exist for the lower Mekong Delta in Vietnam (Halls and Johns 2013), a better understanding of growth performance and salinity tolerance can benefit aquaculture production throughout South-East and Central Asia. This investigation will focus on the salinity ranges endemic to coastal in-land regions of Southern Bangladesh (0–8 ppt) to assess the economic feasibility of *Pangasius* culture in these locales.

OBJECTIVES

- Evaluate whether freshwater *Pangasius* catfish can be successfully cultured in seawater-encroached hyposaline waters of coastal Southern region of Bangladesh;
- Assess effect of increased stocking density and formulated diet on *Pangasius* culture in hyposaline waters; and
- Evaluate potential economic impacts for *Pangasius* culture in hyposaline environments.

MATERIALS AND METHODS

Study 1 — Effect of short-term acclimation to different salinity ranges on *Pangasius* survival. This initial experiment (Table 1) was done for seven days in May 2014 at the Itbaria fish farm in Kalapara Upozila of the Patuakhali district in Bangladesh. Eighteen ponds were selected for this short-term experiment on the basis of salinity. The average size of ponds was 10 decimal (400 m^2) with an average water depth of 1.3 meter. There were six treatment having three replications of each.

Pond preparation. All ponds were completely dried, and all unwanted species were removed from pond prior to the start of experiment. Liming was done at a standard rate of 1 kg per decimal. Lime was mixed with water and kept overnight and distributed on the pond surface early in the morning. After three days of liming, the ponds were filled in with water from adjacent saline water lake and freshwater reservoir. Freshwater was mixed with saline water to prepare the water of different salinity.

Stocking. Fingerling *P. hypophthalmus* (Thai pangas or river catfish) of an average size 5.78 g were stocked at a density of 10/decimal (0.25 fish/m^2).

Feeding. Fish were fed a Mega floating feed (Spectra Hexa Feeds Ltd.) at the rate of 10% of body weight (bw)/day. Feed was applied twice daily at 09:00 and 16:00 h. The feeds were dispersed by hand broadcasting over the water.

Study 2 — Evaluate the growth performance of *Pangasius* catfish cultured in brackish (hyposaline) water of different salinities. This study assessed whether *Pangasius* catfish can be successfully cultured in the brackish water ponds of Southern Bangladesh (greater Barisal region). The experimental design (Table 2) encompassed salinity ranges found in surface water salinities in this farming region (2–12 ppt). Ponds were selected on the basis of salinity from participating farmers in Kuakata, Kalapara and Amtoli Upzila of Patuakhali and Borgona districts. WorldFish aided in selection of farmers and 13 of the owners have cooperated with the WorldFish Center in Bangladesh. Of the selected ponds, 55% were operated by women (Table 4). The study contrasted *Pangasius* production under three different salinity treatment ranges, each replicated in six ponds. The average size of ponds was 10 decimal (400 m^2) with an average water depth of 1.3 m. Ponds were selected based on initial salinity ranges of 0–0.5 ppt, 5–7 ppt and 10–12 ppt in T1, T2 and T3 groups, respectively. Ponds were stocked at 2 fish/m^2 and fed at a standard rate. The growout study was conducted for 160 days from May through October 2014.

Pond preparation. All ponds were completely dried, and all unwanted species were removed. Ponds were surrounded by a filter net to avoid the escape of fish during any potential natural disaster, namely flooding. Following drying, liming was done at a standard rate of 1 kg per decimal (2.5 g/m^2 $CaCO_3$). Lime was mixed with water and kept overnight and distributed on the pond surface the next morning. After liming ponds were filled with surface water from the adjacent river and lakes. All ponds were fertilized initially with urea and triple super phosphate (TSP) at the rates of 150 g urea/decimal (3.75 g/m^2) and 75 g TSP/decimal (1.875 g/m^2). After six days, fish were stocked into ponds.

Stocking. Fingerling *Pangasius* of an average size of 6 g were obtained from the Chanchal Hatchery, Bauphol, Patuakhali, Bangladesh and stocked at a density of 80/decimal (2.0 fish/m^2).

Feeding. *Pangasius* were fed a Mega floating feed (28% CP, 7% fat; Spectra Hexa Feeds Ltd.) at the rate of 10% of bw/day down to 3% bw/day. Feed was applied twice daily at 09:00 and 16:00 h. The feeds were dispersed by hand broadcasting over the water.

Sampling. Fortnightly subsampling of the experimental fish was done by using cast net to measure growth of experimental fish and to adjust feeding rate. After 160 days of the growth trial, a subsample of fish weights and lengths and the total number of fish harvested for each pond was determined.

Water quality. Parameters such as water temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, nitrite and salinity were recorded fortnightly. Water pH was measured by a direct reading digital pH meter, temperature and oxygen with portable digital probes, hardness and alkalinity by test kits (Hanna Instruments), and ammonia and nitrite by colorimetry.

Production parameters. Weight gain of experimental fish was calculated as final fish weight (g) – mean initial fish weight (g). Length gain of experimental fish was calculated as mean final fish length (cm) – mean initial fish length (cm). SGR is the instantaneous change in weight of fish calculated as the percentage increase in body weight per day over a given time interval. It was calculated as $[(\ln W_2 - \ln W_1)/(T_2 - T_1) \times 100]$, where W_2 is the weight at the end of the growth interval (harvest weight) and W_1 is the weight at the beginning of the growth interval (initial stocking weight), while T_2–T_1 represents the duration (days) of the growing interval.

FCR is calculated as the amount of dry feed fed to fish divided by fish weight gain. Percentage survival rate is calculated as the number of fish that survived at harvesting divided by the number of fish stocked multiplied by 100.

Statistical analysis. Treatment differences in variables measured was evaluated by ANOVA (SPSS 11.5 software) followed by Duncan's new multiple range test (Duncan 1955) Results are shown as mean ± SD and statistical significance was set at a level of $p \leq 0.05$.

Study 3 — Evaluate the effect of increased stocking density and of formulated diet on growth performance of *Pangasius* catfish in brackish (hyposaline) water. Results from Study 2 showed that *Pangasius* survival, growth and production in salinities ranging from 5–12 ppt is similar to that of fish raised in fresh water. We then assessed (Table 3) if increasing density by 50% and applying a formulated diet as feed might provide further cost savings or economical benefit to *Pangasius* culture in brackish (hyposaline) waters of 10–12 ppt.

Ponds were selected based on surface water salinities on participating farms in Kuakata, Patuakhali. Of the selected ponds 60% were operated by women (Table 4). The average size of ponds was ~10 decimal (~400 m^2) with an average water depth of 1.3 m. Ponds were selected based on an initial salinity range of 10–12 ppt. The grow-out study was conducted for 6 months from May through October 2015.

Pond preparation. Ponds were prepared as described under Study 2.

Stocking. Fingerling *Pangasius* of an average size of 65 g were stocked at a density of 80 fish/decimal (2.0 fish/m^2) in treatments 1 and 2 (T1 and T2) and at 120 fish/decimal for treatment 3 (T3).

Feeding. For the T1 group, *Pangasius* was fed a formulated diet containing 28% crude protein (CP). Ingredients include 30% fish meal, 20% mustard cake oil and rice bran, 15% wheat bran, 3% wheat flour, 2.5% molasses, and 0.5% vitamin mix (Table 5). The diet was produced at a small community mill receiving technical support through WorldFish (Figure 1). Ingredients were pelleted by a press. The feed was distributed to all the farmers. For the T2 and T3 groups, fish were fed a 28% CP commercial diet (Mega floating feed). Fish were fed formulated and commercial feeds at the rate of 10% of bw/day down to 3% bw/day. Feed was applied twice daily at 09:00 and 16:00 h. The feeds were dispersed by hand broadcasting over the water.

Sampling. Fortnightly subsampling of the experimental fish was done by using cast net to measure growth of experimental fish and to adjust feeding rate. After 160 days of the growth trial, a subsample of fish weights and lengths and the total number of fish harvested for each pond was determined.

Water quality. Parameters such as water temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, nitrite and salinity were recorded fortnightly. Water pH was measured by a direct reading digital pH meter, temperature and oxygen with portable digital probes, hardness and alkalinity by test kits (Hanna Instruments), and ammonia and nitrite by colorimetry.

Production parameters. Production parameters, including weight, length, weight gain, SGR, FCR and yield were measured as described in Study 2.

Statistical analysis. Treatment differences in variables measured was evaluated by ANOVA (SPSS 11.5 software) followed by Duncan's new multiple range test (Duncan, 1955) Results are shown as mean ± SD and statistical significance was set at a level of $p \leq 0.05$.

On-farm training. All farmers in this and the previous studies were trained on all aspects of the research by the Patuakhali University of Science and Technology PI, graduate students, and a WorldFish field supervisor. The training included workshop discussions and presentations to outline the research and goals, and courtyard and on-farm sessions on how to prepare and manage ponds, methods for stocking and feeding fish, water quality and harvesting. All farmers were provided record keeping books to document activities including the amount of feed applied to their ponds.

RESULTS AND DISCUSSION

Study 1 — Effect of short-term acclimation to different salinity ranges on *Pangasius* survival. The survival rate of *Pangasius* catfish fingerlings is presented in Figure 2. In T1 (0–5 ppt) and T2 (7–8 ppt), survival rate was 100%. In the T3 group, fingerlings were stocked after acclimatization in 6 ppt saline water survival rate was 100%, but in T4 where fingerlings were stocked directly in 10–12 ppt saline water, survival rate was 87% with mortalities occurring as early as 5 days. In fish acclimated to 12–15 ppt (T5 group), survival rate was 30%. In the highest salinity (T6 group), all fingerlings died within one day. Based on these results, *Pangasius* catfish can easily survive up to 12 ppt saline water when provided a prior 24-h acclimation to moderate salinities of 6–7 ppt. Based on this work, *Pangasius* growth and production was assessed during a full grow-out trial in three salinity ranges up to 12 ppt.

Study 2 — Evaluate the growth performance of *Pangasius* catfish cultured in brackish (hyposaline) water of different salinities. The ability to culture *Pangasius* in the low-salinity waters would allow production of an additional species in the low lying coastal region of Bangladesh, where significant seawater incursion exists and communities are threatened by frequent calamities and declines in shrimp production. Preliminary studies in tanks suggest that *Pangasius* can survive in salinities as high as 13 ppt for up to 22 days (Castaneda et al. 2010). However, it is unknown whether this species can be grown for extended periods in hyposaline, brackishwater environments. Therefore this study contrasted *Pangasius* growout performance in freshwater and in ponds with salinities as high as 12 ppt. We found that *Pangasius* growth, production and yield in brackish water ponds, reflective of coastal surface waters, is similar to that of fish grown in fresh water.

The average salinity in the on-farm growth trials was 0 ppt, 6.5 ppt and 10.8 ppt in in T1, T2 and T3 groups, respectively (Table 6). In the T3 ponds, salinity fluctuated over the course of the experiment. It was initially at ~12 ppt in May and declined slowly to 7 ppt in August and then rose again to 9 ppt at termination of the experiment. These changes coincide with the monsoon rainy season (June to September) in the region. As expected, hardness and alkalinity increased with salinity, while ammonia and nitrite levels declined in ponds at the higher salinity, the latter likely due to the naturally greater tidal water exchange that occurs closer to the sea (Table 6). Collectively, all water quality parameters were well within the acceptable range for *Pangasius* culture and that of other fishes (Bhatnagar and Devi, 2013).

Production of *Pangasius* grown in different salinities is shown in Table 7. We found no significant mortalities in the experiment with survival of around 96% in all groups (Table 7). Growth performance and yield of *Pangasius* did not vary with salinity and was similar to that of fish grown in fresh water (Huq et al. 2004, Azad et al. 2004, Khan et al. 2009). No significant differences were observed in survival rate, weight gain, SGR, FCR, yield, and BCR among the treatments ($p > 0.05$). At the termination of the 160-day trial the average body weight (684–687 g), weight gain (677–680 g), and SGR (2.868–2.871 %/day) at higher salinities were remarkebly similar to that of freshwater cultured fish. Likewise the FCR of experimental groups ranged from 1.61–1.63. Total yield ranged from 12,998 kg/ha to 13,239 kg/ha. A marginal economic analyses also indicates the benefit cost ratio which ranged from 1.32 to 1.36 was similar across the different groups (Table 8). Collectively, the work demonstrates that *Pangasius* can be grown in salinities as high as 11 ppt (10–12 ppt) with no negative impacts on fish growth and yield or profits.

Study 3 — The effect of increased stocking density and a formulated diet on growth performance of Pangasius catfish in brackish (hyposaline) water. We then evaluated if increasing the density of fish by 25% and feeding less costly formulated diet might further improve profits for farming *Pangasius*. As with the previous study, the growout trial was done on local farms, but here we evaluated performance and economic benefits in fish cultured over six months in ponds with an average salinity of 10 ppt. Fish (12 ponds, four ponds/group) were stocked at a density of $2/m^2$ and fed a formulated diet produced at a local, small-scale community feed mill (28% CP, T1 group) and commercial feed (CP Mega floating feed, 28% CP; T2 group). In a third treatment (T3), fish were stocked at $3/m^2$ and fed the commercial feed. All fish were fed similarly at an initial rate of 10% body weight (bw)/day down to 3% bw/day.

Pond salinity among the three treatments was similar averaging 9.5, 9.7 and 9.8 ppt in T1, T2, and T3 groups, respectively (Table 9). There were no significant differences in water quality among groups with mean values in the range of 5.17–5.23 mg/L for dissolved oxygen, 7.75–7.82 for pH, and 153–159 mg/L and alkalinity (153–159 mg/L) (Table 9). Temperature averaged around 30°C which is close to the optimal for *Pangasius* (Baras et al. 2011). Ammonia levels were very low and well below the 4 mg/L threshold impacting fish growth (Stone and Thomforde 2004). Likewise nitrite levels were around 0.05 mg/L and again was similar among groups.

Growth parameters are presented in Table 10 and a marginal cost benefit analysis in Table 11. At the termination of the six-month grow-out trial the average body weight of *Pangasius* was 786.34, 790.62

and 784.89 g in T_1, T_2 and T_3 respectively. Neither weight gain nor SGR of Pangaius was affected by the higher density or usage of formulated feeds. Mean SGR was 2.871, 2.869 and 2.868 in T1, T2 and T3, respectively, values that were more or less similar with the findings of Azad et al. (2004) and others. Feed conversion ratio estimates for experimental fishes under T_1, T_2 and T_3 were 1.63, 1.62 and 1.64, respectively, which is similar to (Kader et al. 2003) or better (lower FCR) than that of various other studies using supplemental feeds for *Pangasius* culture in fresh water (Ahmed et al. 1996, Azimuddin 1998, Halder and Jahan 2001, Maniruzzaman 2001, Sayeed et al. 2008, Khan et al. 2009, Kader et al. 2011). This suggests that the formulated feed was of adequate quality as that of the more expensive commercial diet and raises the possiblity that culture in salinity isosmotic to the fish's internal milieau may have additional benefits on growth and feed efficiency.

Pangasius survival was ~95% and again no significant differences were found among treatments ($p > 0.05$). Considering similar survivorship and growth, the production of *Pangasius* was proportionally higher in ponds stocked at a density of 3 fish/m^2 (23,264 kg/ha) versus those stocked at 2 fish/m^2 (T3, 15,538 kg/ha; T2, 15,622 kg/ha). These results suggests that *Pangasius* can be grown semi-intensively in brackish water ponds at a density of as high as 3 fish/m^2 with little impact on performance or survival. Whether higher densities can be employed requires further study.

We found with the higher stocking density net profit exceeded that of the lower stocking density for fish grown on commercial feeds. However, it costs substantially more for feeds in T3 relative to T2 group (Table 11), which is why the BCR did not differ between the groups. Therefore, the T3 strategy requires a higher level of investment compared to that of T2 with a relatively modest net profit. For small scale operations T2 might be recommended, whereas higher stocking density in T3 might be more appropriate for larger scale operations that have more capitol to invest and can accept the risk associated with that investment and for those who desrire to make a greater profit. Regardless, both stocking densities were profitable showing a 50% return on investment.

Use of formulated and commercial feed was compared under the same stocking density (2/m^2), in T1 and T2 groups, respectively. Total cost for *Pangasius* culture was higher in T2 ($15,782/ha) than in T1 ($12,490/ha) due to the higher price of commercial ($0.54/kg) than formulated feed ($0.41/kg), but total yield of fish was similar among the two groups. Hence a significantly higher net profit was found in T1 ($11,438/ha) than in T2 ($8,275/ha). The BCR was also significantly higher in fish fed the formulated (BCR = 1.91) versus the commercial diet (BCR = 1.53). Collectively, the results indicate that *Pangasius* grown on the formulated diet provides a a 38% increase in profit over fish grown on commercial feeds.

CONCLUSION

Through increased tidal (seawater) encroachment and frequency of storms that are linked to global climate change nearly 40 percent of the farmable water bodies in the greater Barisal region of Southern Bangladesh are now hyposaline (0.5 to 7.5 ppt). Coastal communities have also been impacted by overfishing, declines in shrimp farming, and frequent calamities. Farming and fishing communities need additional cultivars that can grow in low saline waters for income generation and household nutrition. The river catfish is a thriving aquaculture industry with over 300,000 tons produced annually in Bangladesh. It is the third largest finfish industry in the country. Because of its relatively low cost it is a seafood favorite among the poor. To date, *Pangasius* culture has been limited to freshwater systems. This study assessed the potential for expanding the culture of *Pangasius* catfish to hyposaline waters in Southern Bangladesh. Working with farmers in the Barisal region of Bangladesh we demonstrate that *Pangasius* can easily survive and can be profitably grown in salinities up to 10–12 ppt with similar efficiency as in freshwater. The studies also show that formulated feeds produced locally in small scale mills and at a substantially lower cost is as effective as commercial feeds in growout of *Pangasius* in 10 ppt hyposaline waters. This, along with increases in stocking density from 2–3 fish/m^2 can enhance profits by 40%. Adoption of *Pangasius* culture in brackish water regions in the Southwest and Southern districts of Bangladesh has opened up the potential for mass scale culture and production of *Pangasius* catfish as an alternative livelihood and nutrition for communities. The new technology could effectively double *Pangasius* production in Bangladesh and other coastal regions affected by rising salinity (e.g., Mekong Delta). This work was demonstrated to the farming community in the most effective way, by conducting the research on their farms. AquaFish personnel provided extensive training to farmers through the day-to-day research activities, workshops and pond side discussions. Future work should assess if other fishes tolerant to low saline waters can be effectively cultured in brackish waters either alone or with *Pangasius*.

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TABLES AND FIGURES

Table 1. Study 1 Experimental Design.

Parameters	**Salinity**	**Conditioning at 6 ppt**
T1	0–5 ppt	No conditioning
T2	7–8 ppt	No conditioning
T3	10–12 ppt	Conditioning before stocking
T4	10–12 ppt	No conditioning
T5	12–15 ppt	Conditioning before stocking
T6	18–22 ppt	Conditioning before stocking

Table 2. Study 2 Experimental Design.

Parameter	Treatment 1	Treatment 2	Treatment 3
Pangasius stocking density	80/decimal (2.0/m^2)	80/decimal (2.0/m^2)	80/decimal (2.0/m^2)
Salinity range (ppt)	0–0.5	5–7	10–12
Feeding	commercial feed	commercial feed	commercial feed
Replicates (*n*)	6	6	6

Table 3. Study 3 Experimental Design.

Parameter	Treatment 1	Treatment 2	Treatment 3
Pangasius stocking density	80/decimal (2.0/m^2)	80/decimal (2.0/m^2)	120/decimal (3.0/m^2)
Salinity range (ppt)	10–12	10–12	10–12
Feeding	Formulated Diet	Commercial Feed	Commercial Feed
Replicates (*n*)	4	4	4

Table 4. Location and number of ponds for assessing salinity effects on growth of *Pangasius* in the coastal greater Barisal region of Southern Bangladesh.

Area	Pond distance from sea	Salinity	Pond Number	Women owners
Amtoli (Borgona District)	40 km	0 ppt	6	4
Kalapara (Patuakhali District)	23 km	5-7 ppt	6	1
Kuakata (Patuakhali District)	5 km	10-12 ppt	6	5
Total			18	10 (55%)

Table 5. Ingredients of formulated feed used in Study 2 to compare growout of *Pangasius* in hyposaline waters with commercial feed of similar crude protein levels.

Ingredients	% in feed	Amount of protein (%) in the ingredient	Protein contribution in the feed
Fishmeal	30%	60%	18 %
Mustard oil cake	20%	32%	6.4%
Rice bran	20%	7.5%	1.50%
Wheat bran	15%	11%	1.65%
Wheat flower	3%	15%	0.45%
Molasses	2.5%	–	
Vitamin mineral premix	0.5%	–	
Total	**100%**		**28%**

Table 6. Water quality parameters of ponds where *Pangasius* were grown at different salinities (0, 6.5, and 10.8 ppt) over 160 days in earthen ponds (Study 2). (Mean ± SE)

Parameters	T1	T2	T3
Water Temperature (°C)	30.18 ± 0.95	30.10 ± 0.42	30.52 ± 0.41
Dissolved Oxygen (mg/L)	5.16 ±0.12	5.24 ± 0.13	5.98 ± 0.21
pH	7.77 ± 0.37	7.49 ± 0.26	7.67 ± 0.14
Alkalinity (mg/L)	90.5 ± 6.12	110 ± 6.61	130 ± 5.15
Ammonia (mg/L)	0.67 ± 0.02	0.64 ± 0.03	0.02 ± 0.03
Nitrite (NO_2) (mg/L)	0.37 ± 0.02	0.24 ± 0.23	0.00
Hardness (mg/L)	70 ± 3.12	240 ± 5.12	560 ± 4.12
Salinity (PPT)	0	6.5	10.8

Table 7. Production parameters of *Pangasius* grown at different salinities (0, 6.5, and 10.8 ppt) over 160 days in earthen ponds (Study 2).

Parameters	T1, 0 ppt	T2, 6.5 ppt	T3, 10.8 ppt
Mean initial weight (g)	6.56 ± 0.53	6.56 ± 0.53	6.56 ± 0.53
Initial length (cm)	9.18 ± 0.68	9.18 ± 0.68	9.18 ± 0.68
Mean final weight (g)	686.76 ± 50.26	684.67± 52.25	683.89±56.80
Final length (cm)	38.94 ±4.33	38.50±5.30	37.86±5.29
Survival Rate (%)	96.76±2.67	96.56±2.78	96.12±2.85
Mean weight gain (g)	680.2±2.41	678.11±2.64	677.33±2.21
SGR (% per day)	2.871±0.27	2.869±0.25	2.868±0.23
FCR	1.61±0.23	1.62±0.26	1.63±0.32
Yield (kg/ha)	13,139±1293	13072±1374	12998 ±1347

Table 8. Cost benefit analyses of *Pangasius* grown at different salinities (0, 6.5, and 10.8 ppt) over 160 days in earthen ponds (Study 1). Values are in Bangladesh currency (BDT). Benefit-cost ratio is calculated as gross income/total cost. Values shown reflect combined data of all replicates within each treatment. The higher value of fish from the 10 ppt group was attained because the *Pangasius* supply in markets closest to the sea is more limited than inland regions.

Investment Costs	T1, 0 ppt	T2, 6.5 ppt	T3, 10.8 ppt
Pond Preparation (lime, fertilizer)	14,500	14,500	14,500
Fingerling	38,400	38,400	38,400
Total feed used (kg)	5152	5152	5152
Feed cost @ 46 BDT/Kg	236,992	236,992	236,992
Total cost	289,892	289,892	289,892
Returns			
Total Fish production (kg)	3,189.64	3,173.36	3,155.39
Retail price of fish/kg	120	120	125
Income (from fish sales)	382,756	380,803	394,423
Net profit (return)	92,264	90,911	104,531
Benefit-Cost Ratio (BCR)	1.32	1.31	1.36

Table 9. Water-quality parameters in ponds from Study 3 that assessed the effect of increased stocking density and of formulated diet on growth performance of Pangasius catfish in brackish (hyposaline) water (mean ± SE).

Parameters	**T1 Formulated Feed 2 fish/m^2**	**T2 Commercial Feed 2 fish/m^2**	**T3 Commercial Feed 2.5 fish/m^2**
Water Temperature (°C)	29.50 ± 0.42	29.50 ± 0.42	29.50 ± 0.42
Dissolved Oxygen (mg/L)	5.17 ± 0.12	5.20 ± 0.13	5.23 ± 0.12
pH	7.81 ± 0.32	7.82 ± 0.29	7.75 ± 0.34
Alkalinity (mg/L)	152.5 ± 2.12	155.3 ± 2.61	158.7 ± 2.15
Ammonia (mg/L)	0.05 ± 0.02	0.04 ± 0.03	0.05 ± 0.03
Nitrite (NO_2) (mg/L)	0.06 ± 0.02	0.05 ± 0.01	0.05 ± 0.01
Salinity (PPT)	9.6 ± 0.7	9.4± 0.6	9.7± 0.6

Table 10. Production parameters of *Pangasius* catfish in Study 3 (mean ± SE).

Parameters	**T1 Formulated Feed 2 fish/m^2**	**T2 Commercial Feed 2 fish/m^2**	**T3 Commercial Feed 2.5 fish/m^2**
Mean initial weight (g)	65.56 ± 4.53	65.56 ± 4.53	65.56 ± 4.53
Initial length (cm)	21.18 ± 1.68	21.18 ± 1.68	21.18 ± 1.68
Mean final weight (g)	786.34 ± 45.21[a]	790.62 ± 45.21[a]	784.89 ± 51.80[a]
Final length (cm)	42.87 ± 5.31	43.10 ± 5.23	41.96 ± 6.22
Survival Rate (%)	95.71 ± 3.64[a]	95.45 ± 3.12[a]	95.12 ± 2.85[a]
Weight gain (g)	720.78 ± 36.41[a]	725.06 ± 35.64[a]	719.33 ± 37.21[a]
FCR	1.63 ± 0.26[a]	1.62 ± 0.28[a]	1.64 ± 0.39[a]
Yield (kg/ha)	15,538[a]	15,622[a]	23,264[b]

Table 11. Marginal cost-benefit analyses of Study 3. Values in US$. Different letters reflect significant difference among treatments. Values reflect means of 4 replicates/group and costs and returns are based on 1 hectare of fish production. Benefit-cost ratio is calculated as gross income/total cost.

Investment Costs (US$)	**T1 Formulated Feed 2 fish/m^2**	**T2 Commercial Feed 2 fish/m^2**	**T3 Commercial Feed 2.5 fish/m^2**
Pond reparation (lime, fertilizer)	80	80	80
Fingerling	2,026	2,026	3,040
Total feed used (kg)	25327	25327	38,152
Feed cost (commercial feed $0.54/kg; formulated feed $0.41/kg)	10,384	13,676	20,602
Total cost	12,490 [a]	15,782 [b]	23,722 [c]
Returns			
Total fish production	15,538 [a]	15,622 [a]	23,264 [b]
Retail price of fish/kg	1.54	1.54	1.54
Income (from fish sale)	23,928 [a]	24,057 [a]	35,826 [b]
Net profit	11,438 [a]	8,275 [b]	12,104 [c]
Benefit-Cost Ratio (BCR)	**1.91** [a]	**1.53** [b]	**1.51** [b]

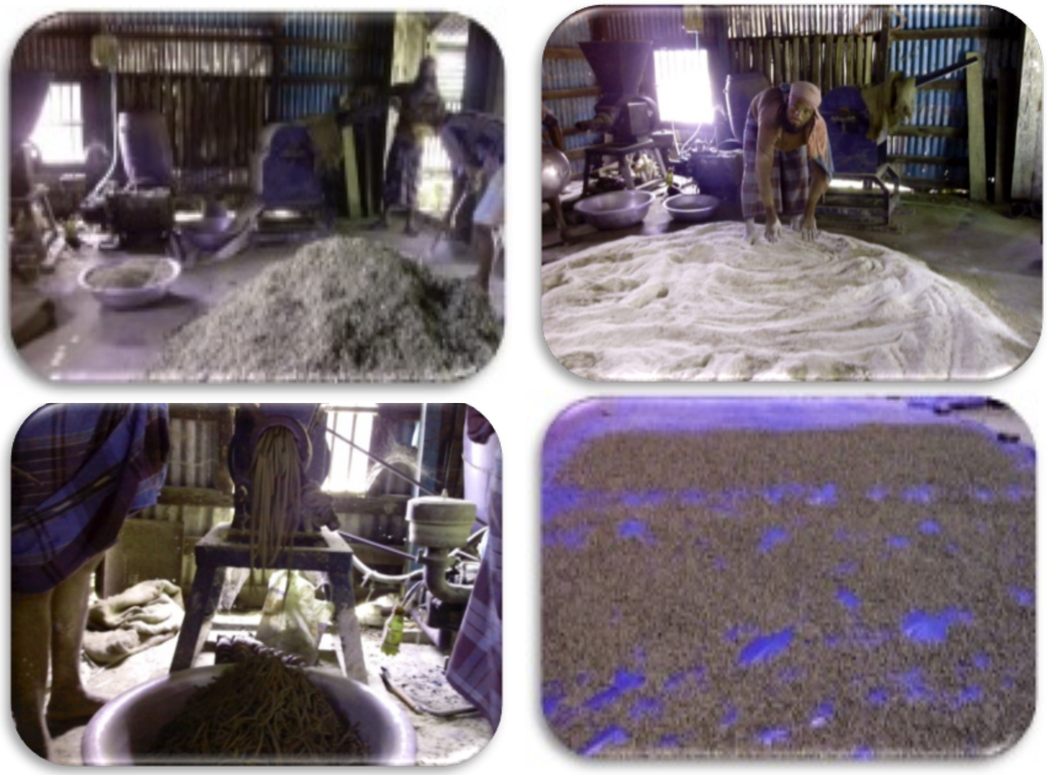

Figure 1. Preparation of formulated feed at a small community mill in Patuakhali district in Southern Bangladesh. The feed was used in Study 2 to compare growout of *Pangasius* fed a less costly formulated feed \$0.41/kg versus a commercial feed (\$0.54/kg).

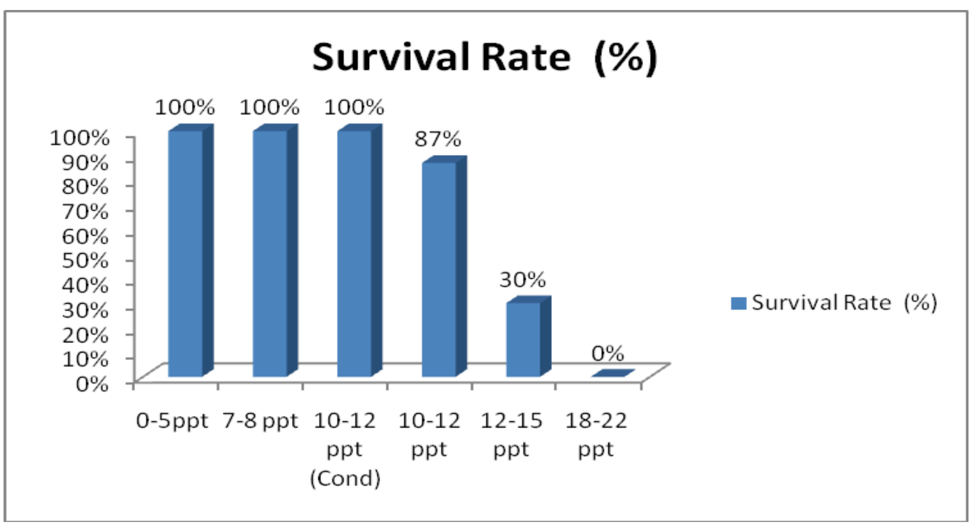

Figure 2. Survival rates of *Pangasius* following 7-day exposure to different salinity ranges in Study 1. For the 10–12 ppt (Cond), 12–15 ppt, and 18–22 ppt group fish were initially conditioned at 6 ppt for 24 h prior to exposure to their respective salinities.