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Standardizing Pen Culture of Small Indigenous Fish *Labeo bata* in the Tropical Floodplain Wetland of the North Eastern Region, India: A Step towards Sustainable Fisheries Management

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Abstract: *Labeo bata* fry were reared in high-density polyethylene (HDPE) pens at different stocking densities to determine growth, survival, feed utilization efficiency and economics in Borkona beel, Barpeta, Assam. Pens (500 m^2 each) were stocked with fry at four stocking densities, 3 (SD3), 5 (SD5), 7 (SD7) and 9 (SD9) no. m^{-2} in triplicates. Feeding was performed twice a day at a rate of 3–5% body weight with floating pelleted feed containing 28% crude protein. Fish grew from 2.38 ± 0.30 g to 82.78 ± 3.18, 75.94 ± 0.89, 71.94 ± 0.89 and 61.81 ± 3.35 g at stocking densities of 3, 5, 7 and 9 no. m^{-2}, respectively. Weight gain per cent ranged from 2491.85 ± 140.56 to 3371.33 ± 133.16 and specific growth rate from 1.41 ± 0.02 to 1.55 ± 0.02, both of which decreased with increasing stocking density. The net and gross yields increased with increasing stocking density and were highest at SD9. The benefit-cost ratio was maximum at SD7 (1.42), followed by SD9 (1.41). Post-pen culture, the monthly income of fishers increased by 6.10% (SD3) to 40.50% (SD9). Significant differences ($p > 0.05$) in water quality parameters were not observed between treatments (inside pens) and reference site (outside pen at 10 m distance). Weight gain exhibited a significant positive correlation with temperature ($r = 0.92$; $p = 0.029$) and alkalinity ($r = 0.95$; $p = 0.014$). The present study can provide impetus towards species diversification in pen enclosures, income enhancement of small-scale wetland fishers and sustainable ecosystem-based floodplain wetland fisheries management.

Keywords: floodplain wetland; *Labeo bata*; pen culture; small-scale fishers; sustainable management

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1. Introduction

Enclosure culture is a popular management choice for fish production from open water bodies [1–3]. A pen is a type of fixed enclosure, enclosed on all sides except the bottom which is the water body bed [1] and with water circulation ensured from at least one side. Pens are installed in marginal areas of open water bodies. Pollution-free sites with moderate wind action, favorable soil and water quality parameters, sufficient water depth and adequate water circulation are some of the criteria required for pen culture [4]. Pen culture is a viable option for raising quality fish seed and for table fish production [5] from open water systems of the country, particularly floodplain wetlands. Increased fish production has been realized in floodplain wetlands through supplementary stocking of pen-raised fingerlings [6]. There are reports of pen-raised fishes with a high rate of survival, a high growth rate and a high degree of disease resistance [7]. The pen culture of several species—*Labeo catla*, *L. rohita*, *Cirrhinus mrigala*, *Hypophthalmichthys molitrix* and *Puntius javanicus* [8], *Macrobrachium rosenbergii* [9], *Penaeus monodon*, *Chanos chanos*, *Etroplus suratensis*, *Mugil* sp., *Lates calcarifer* and *Polynemus* sp. [4]—have been reported from the fresh and brackish waters of India.

Floodplain wetlands are biodiverse, ecologically productive and nutrient-rich aquatic resources [3,8]. In India, these resources are concentrated in Ganga-Brahmaputra basin, covering an area of 0.5 million ha [3]. Locally known as beels, floodplain wetlands in Assam with an area of 100,815 ha [8,10] are among the major fisheries resources of the state, with a high production potential of 1000–1500 kg ha^{-1} yr^{-1} [8,11]. These resources are amenable to different types of management protocols such as stock enhancement [12], species enhancement [13], culture-based fisheries [14,15] and enclosure culture [16,17]. However, the realized production from these resources—254.3 kg ha^{-1} yr^{-1} from unstocked beels and 539.1 to 704.60 kg ha^{-1} yr^{-1} from stocked beels [12,14] is far below their actual potential [18]. This may be attributed to poor management practices followed in these water bodies [12,14,19]. In this context, pen culture holds significant importance both as a means for raising stocking materials and table fish, towards improving production and profitability in floodplain wetlands of the region, simultaneously improving socio-economic status of wetland-dependent fishers [19].

Small-scale fishers (SSF) refer to fishers operating labor-intensive traditional crafts and gears [20]. The small-scale fisheries sector delivers employment opportunities to a sizeable population (56 million inland, 52 million marine) worldwide and plays significant role in food and livelihood security [21]. Floodplain wetlands are among the major fisheries resources of India, providing source of livelihood to sizeable SSF population [22].

Stocking density influences the growth, survival, production and economics of culture systems [23]. Fish reared in high densities tend to have low growth rates, while fish reared in low stocking densities tend to have high growth rates [24–26] but low production owing to poor utilization of existing space [27].

The economics of cultured species is generally driven by end-user preference and market demand [28]. *Labeo bata* commonly known as bata and locally known as bhangon in Assam is among the most consumer preferred high-value minor carps [16,29–31]. Datta et al. [32] reported that *L. bata* in the size range of 15–150 g is marketable and >50 g-sized fish fetch a high market price in India [31].

L. bata is deemed as a potential species for rearing in enclosures in inland open water bodies of India [31]. Considering its demand in eastern and north-eastern India, feasibility studies of its culture have been carried out in cages in floodplain wetlands [16,31] and reservoirs [23] of the country. However, standardization of its pen culture practice in floodplain wetlands has not been attempted. Although listed under the 'Least Concern' IUCN category [33], this species is declared endangered in Bangladesh [31], with severe population decline witnessed from natural water bodies [34]. The development of economically viable pen culture protocols for this important and prized small indigenous fish (SIF) in floodplain wetlands will help in reducing fishing pressure on its natural stocks.

Considering these aspects, the present experiment was undertaken with the following objectives: (i) to document the growth, survival rate, feed utilization efficiency and economics of table fish production of *L. bata* in pens in floodplain wetland(s) and (ii) to improve the income of SSF through pen culture in floodplain wetland(s).

2. Materials and Methods

2.1. Study Area

This study was conducted at Borkona beel (Lat. 26°21′6″ N; Long. 91°15′45″ E), a seasonally open floodplain wetland located in Barpeta district, Assam, India during November 2020 to February 2021 (Figure 1). The wetland has a water spread area of 85 ha.

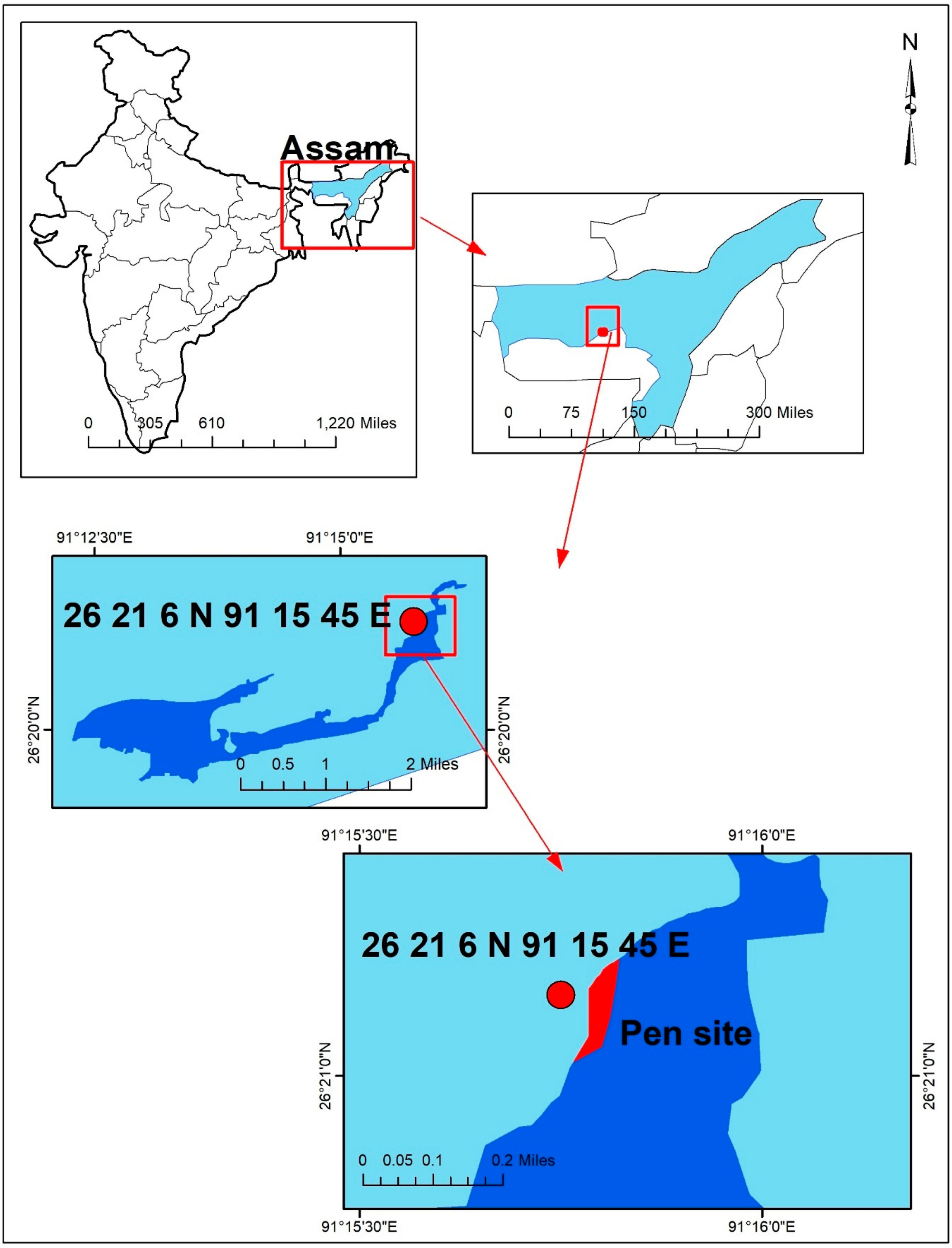

Figure 1. Study area, Borkona beel, Barpeta, Assam.

2.2. Pen Culture

The Indian Council of Agricultural Research-Central Inland fisheries Research Institute (ICAR-CIFRI) developed high-density polyethylene (HDPE) pens that were used in this study as they have higher durability and ease of installation. A total of 12 pens each with an area of 500 m^2 were installed in a marginal area of the wetland with 1–2 m water depth. Fry of *L. bata* (0.47 $\pm$ 0.22 cm, 2.38 $\pm$ 0.30 g) were procured from Medhi Fish Farm, Nalbari district, Assam and were stocked in pens at four different stocking densities *viz.* 3 no. m^{-2} (SD3), 5 no. m^{-2} (SD5), 7 no. m^{-2} (SD7) and 9 no. m^{-2} (SD9) in triplicates following a completely randomized design.

Fishes were fed with floating pelleted feed (CIFRI CAGEGROW®, Guwahati, India) containing 28% crude protein and 5% fat twice daily (09.00 h; 14.30 h). Initially, fishes were fed at a rate of 5% body weight and then the feeding rate was adjusted to 4% and 3%. Fishes were cultured in pens for 100 days. Feeding was ceased 24 h prior to each sampling. Feeding and pen maintenance were carried out with the help of randomly selected beel fishers (one fisher assigned per pen), where they dedicate 0.5–1 h daily.

2.3. The Analysis of Water Quality Parameters

Physico-chemical properties of water were analyzed at 20-day intervals from inside all pens. Dissolved oxygen (DO), water temperature, pH, electrical conductivity and total dissolved solids (TDS) were measured using multiparameter water quality probe (Model 9829, HANNA, Salaj, Romania), while other parameters such as dissolved carbon dioxide (CO_2) and total alkalinity were measured following APHA [35]. Water quality parameters outside the pen structure at 10 m distance from the pens (reference site) were analyzed in triplicates to verify any possible changes in physico-chemical properties due to pen culture activity.

2.4. Growth Analysis

Length (cm) and weight (g) of randomly collected fish (n = 30) from each pen were measured during sampling carried out at 20-day intervals. The growth performance of fish is calculated in terms of weight gain per cent (WG%), the specific growth rate (SGR) and daily weight gain (DWG), following Yengkokpam et al. [16] and Karnatak et al. [36]. WG%, the SGR and DWG are calculated as WG% = [(FW−IW)/IW] × 100; SGR = [(In FW−In IW)/number of culture days] × 100; DWG = FW−IW)/number of culture days; where, FW = final weight (g) and IW = initial weight (g). The feed conversion ratio (FCR) is calculated as FCR = dry feed supplied (g)/wet weight gain (g), where dry feed supplied is the total amount of feed given, not corrected for feed loss [36]. The protein efficiency ratio (PER) is calculated using the formula, PER = body weight gain (wet weight in grams)/crude protein fed (%) [31]. The coefficient of variation (CV) was calculated using the formula, CV = standard deviation of fish weight / average weight (g). The daily mortality of fish was recorded and the rate of survival was calculated using the formula, survival (%) = (number of fish harvested / number of fish stocked) × 100. Total biomass per pen (kg pen^{-1}) was calculated as gross biomass = number of fish harvested × mean body weight (kg). Net biomass per pen (kg pen^{-1}) was estimated as net biomass = biomass harvested (kg)−biomass stocked (kg).

2.5. Economic Analysis

The economic analysis of pen culture operation was performed to find out net revenue generated and benefit–cost ratio (BCR) of the whole culture operation. The total capital cost for pen culture operation was calculated by adding up the cost of pen, labor charges for installation and taking into account shelf life of pens (5–6 years for nets; 12–15 years for poles). The total operational cost was obtained by adding up cost of seed, feed and labor charges for feeding. The total cost was determined by adding the capital cost and the operational cost. Gross revenue was obtained from sale of fish. Net revenue generated was calculated as net revenue = gross revenue−total cost. The benefit–cost ratio (BCR) was calculated as BCR = gross revenue/total cost. All values were expressed in terms of USD. Fish yield per unit cost (YPC) was calculated as YPC (kg USD^{-1}) = gross fish yield (kg)/total cost (USD). Similarly, cost per unit yield (CPY) was calculated as CPY (USD kg^{-1}) = total cost (USD)/gross fish yield (kg), following Debnath et al. [31].

2.6. Fishers' Income

Information on the monthly income of SSF of Borkona beel was collected using a structured questionnaire. In addition to basic information, the daily/weekly/monthly income of SSF from different sources was recorded based on nature of income generating activities.

A one-group pre- and post-test design was used for this study, wherein single group of randomly selected small-scale fishers (n = 12; one fisher engaged per pen) were measured on the dependent variable (average monthly income), both pre- and post-technological intervention [37].

2.7. Statistical Analysis

The assumptions of the analysis of variance (ANOVA) were tested prior to data analysis. Test of normality on residuals was performed using the Shapiro–Wilk test and variance homogeneity was tested using Levene's test. Survival data were arcsine transformed to eradicate homogeneity in variance. Comparisons among stocking densities for water quality parameters, the growth of fish, the FCR, survival and yield were analyzed using ANOVA followed by Duncan's Multiple Range Test (DMRT) to verify if a statistically significant difference ($p < 0.05$) between treatments exists [38]. The relationship between fish growth (weight gain/ 20 days) and water quality parameters was established using Pearson's correlation coefficient (r). The average income of SSF before and after technological intervention was tested using a paired-samples t-test. Statistical analysis was performed using R 3.5.3 [39]. Data are presented as the mean ± standard error (SE).

3. Results

3.1. Growth

Fish cultured in pens grew from 2.38 ± 0.30 g to 82.78 ± 3.18, 75.94 ± 0.89, 71.94 ± 0.89 and 61.81 ± 3.35 g after 100 days at stocking densities of 3, 5, 7 and 9 no. m^{-2}, respectively. A statistically significant difference ($p < 0.05$) was observed in final weight, WG%, the SGR, DWG and survival percentage between SD3, SD7 and SD9. For the above-mentioned parameters, SD5 did not show any statistically significant variation with SD3 and SD7 ($p > 0.05$), but showed a statistically significant difference with SD9 ($p < 0.05$) (Table 1). Details of change in the average body weight and average WG% over the culture period of 100 days are given in Figures 2 and 3, respectively, while details of change in the SGR and DWG are given in Figure 4.

Table 1. Growth, the FCR and yield of *L. bata* reared under different stocking densities over the culture period of 100 days in pens.

Parameters	Stocking Densities			
	SD3	**SD5**	**SD7**	**SD9**
Final length (cm)	20.31 ^{a} ± 0.11	19.84 ^{ab} ± 0.13	19.26 ^{bc} ± 0.01	18.82 ^{c} ± 0.46
Final weight (g)	82.78 ^{a} ± 3.18	75.94 ^{ab} ± 0.89	71.94 ^{b} ± 0.89	61.81 ^{c} ± 3.35
WG%	3371.33 ^{a} ± 133.16	3084.78 ^{ab} ± 37.66	2917.03 ^{b} ± 37.66	2491.85 ^{c} ± 140.56
SGR	1.55 ^{a} ± 0.02	1.50 ^{ab} ± 0.01	1.47 ^{b} ± 0.01	1.41 ^{c} ± 0.02
DWG	0.80 ^{a} ± 0.03	0.74 ^{ab} ± 0.01	0.70 ^{b} ± 0.01	0.59 ^{c} ± 0.03
FCR	2.32 ± 0.19	2.34 ± 0.19	2.35 ± 0.19	2.37 ± 0.18
PER	1.52 ± 0.30	1.42 ± 0.27	1.35 ± 0.26	1.20 ± 0.22
CV	0.37 ± 0.06	0.42 ± 0.07	0.47 ± 0.08	0.34 ± 0.07
Survival (%)	95.60 ^{a} ± 0.81	94.30 ^{ab} ± 0.86	92.30 ^{b} ± 1.01	89.70 ^{c} ± 0.70
Gross yield (kg pen^{-1})	118.70 ^{c} ± 4.55	179.04 ^{b} ± 2.12	232.42 ^{a} ± 2.90	249.48 ^{a} ± 13.53
Net yield (kg pen^{-1})	115.28 ^{c} ± 4.55	173.42 ^{b} ± 2.12	224.71 ^{a} ± 2.90	239.85 ^{a} ± 13.53

WG%—weight gain percent; SGR—specific growth rate; DWG—daily weight gain; FCR—feed conversion ratio; PER—protein efficiency ratio; CV—coefficient of variance of final weight; different letters in superscripts in the same row signify statistically significant differences ($p < 0.05$); data are expressed as the mean ± SE; n = 30 for length and weight measurements.

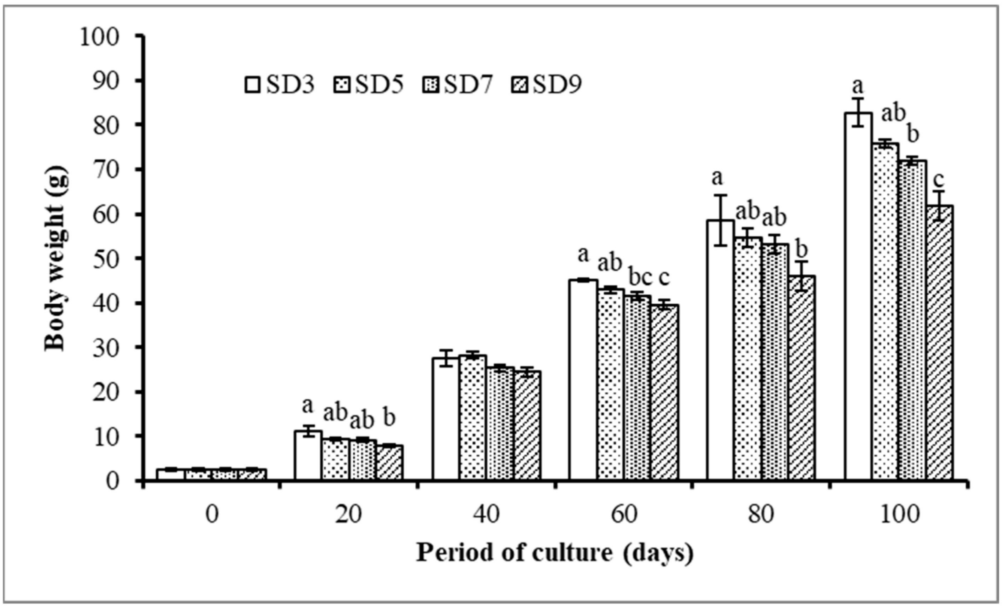

Figure 2. Change in the average body weight of *L. bata* over the culture period of 100 days in pens. Different letters for the same culture period signify statistically significant differences ($p < 0.05$); data are expressed as the mean ± SE.

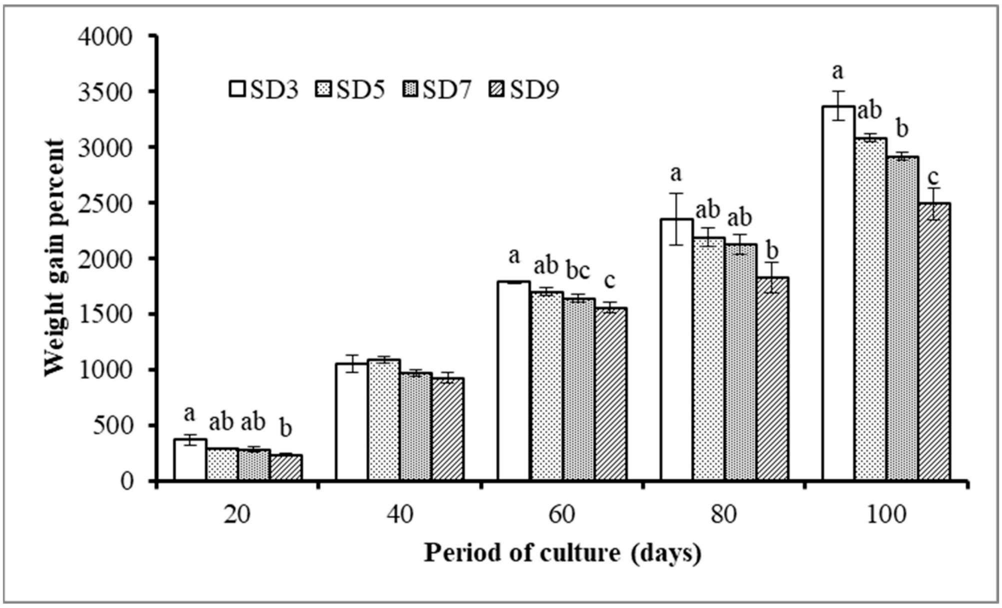

Figure 3. Change in average weight gain percent of *L. bata* over the culture period of 100 days in pens. Different letters for the same culture period signify statistically significant differences ($p < 0.05$); data are expressed as the mean ± SE.

The highest average body weight, WG%, the SGR and DWG were obtained at the lowest stocking density and the lowest values at the highest stocking density. The growth of fish (the SGR and DWG) and stocking density were found to be inversely proportional (Figure 4). An increased stocking density resulted in comparatively lower values of the SGR and DWG, verified by the negative regression equations (SGR, $y = -0.0407x + 1.5852$; DWG, $y = -0.0669x + 0.8746$). The CV ranged from 0.37 ± 0.06 to 0.47 ± 0.08 and did not differ significantly across treatments ($p > 0.05$). The FCR and the PER ranged from 2.32 ± 0.19 to 2.37 ± 0.18 and from 1.20 ± 0.22 to 1.52 ± 0.30 and did not show any statistically significant differences across treatments ($p > 0.05$). The highest gross yield (249.48 ± 13.53 kg pen^{-1})

and net yield (239.85 ± 13.53 kg pen^{-1}) were obtained at SD9, which indicated that yield increased with increasing stocking densities. A statistically significant difference ($p < 0.05$) in gross yield and net yield was observed between treatments, except for SD7 and SD9 ($p > 0.05$) (Table 1).

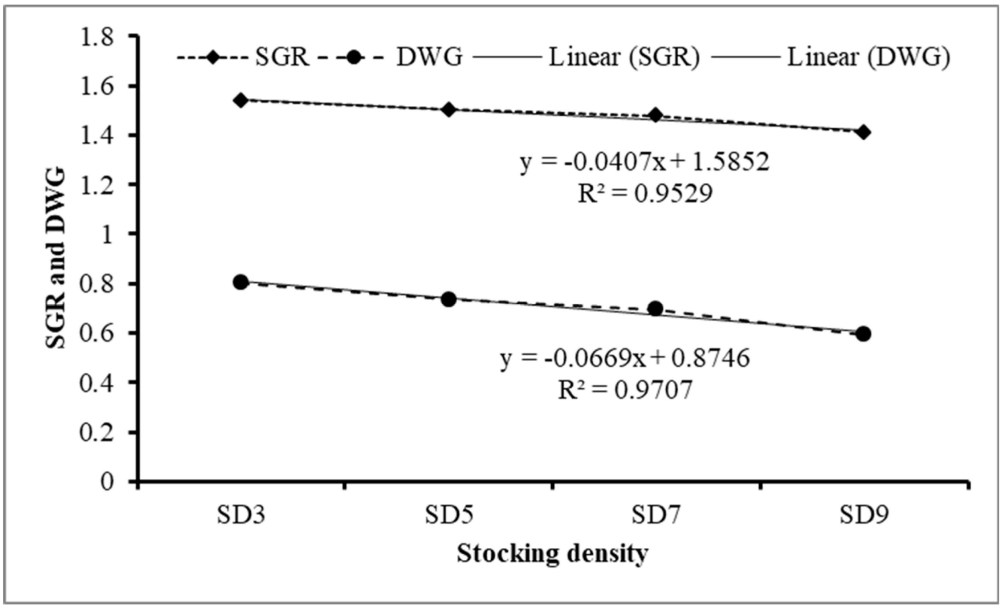

Figure 4. Change in the average specific growth rate and daily weight gain of *L. bata* at different stocking densities over the culture period of 100 days in pens.

3.2. Water Quality

Important water quality parameters influencing fish growth recorded during the culture period are given in Table 2.

Table 2. Average water quality parameters inside pens and reference site over the culture period over the culture period of 100 days.

Parameter	Inside Pens	Reference Site
Water temperature °C)	23.93 ± 0.28	23.85 ± 0.60
pH	7.18 ± 0.28	7.24 ± 0.27
DO (mg L^{-1})	7.62 ± 0.34	7.79 ± 0.52
Electrical conductivity (µS cm^{-1})	176.50 ± 11.76	172.13 ± 14.31
TDS (mg L^{-1})	116.94 ± 8.67	108.38 ± 12.92
CO_2 (mg L^{-1})	3.90 ± 0.42	3.25 ± 1.89
Alkalinity (mg L^{-1})	20.63 ± 2.20	20.25 ± 3.31
Transparency (cm)	47.88 ± 4.45	48.50 ± 6.96

DO—dissolved oxygen; TDS—total dissolved solids; CO_2—dissolved carbon dioxide.

A statistically significant difference was not observed ($p > 0.05$) across treatments and reference site (outside pen at 10 m distance). The average water temperature inside and outside pens was recorded to be 23.93 ± 0.28 and 23.85 ± 0.60 °C, respectively. The mean DO value inside and outside pens was found to be 7.62 ± 0.34 and 7.79 ± 0.52 mg L^{-1}; pH 7.18 ± 0.28 and 7.24 ± 0.27; TDS 116.94 ± 8.67 and 172.13 ± 14.31 mg L^{-1}; CO_2 3.90 ± 0.42 and 3.25 ± 1.89 mg L^{-1}; alkalinity 20.63 ± 2.20 and 20.25 ± 3.31 mg L^{-1}, respectively, during the culture period. Analysis revealed weight gain in fish has a statistically significant positive correlation with temperature (r = 0.92; $p = 0.029$) and alkalinity (r = 0.95; $p = 0.014$) (Figure 5).

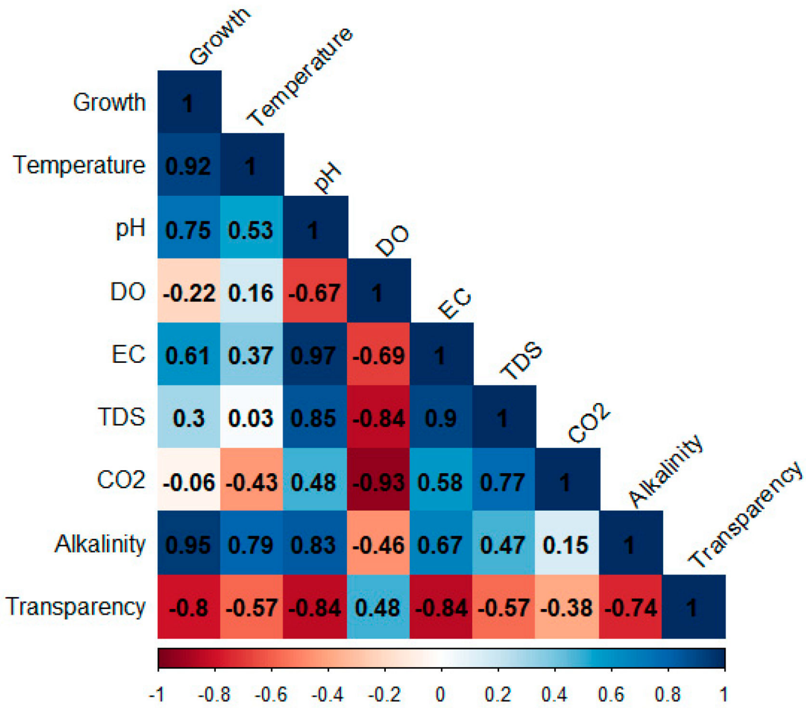

Figure 5. Correlation between water quality and the growth of *L. bata* reared in pens. DO—dissolved oxygen; EC—electrical conductivity; TDS—total dissolved solids; CO_2—dissolved carbon dioxide.

3.3. Economics

The economics of culturing *L. bata* in pens for 100 days is given in Table 3. The total cost (operational cost + capital cost) was found to be higher at higher stocking densities. Gross and net revenue also increased with increasing stocking densities and were found to be highest at SD9 (USD 672.27 and 197.63, respectively). The BCR was found to be highest (1.42) at SD7 followed by at SD9 and SD5, and least at SD3 (1.10). The BCR increased as stocking density increased, reaching a maximum at SD7 and then decreasing slightly at SD9 (1.41). A similar trend was also noticed for YPC, with the maximum value recorded at SD7 (0.53 kg USD^{-1}) and then it decreased slightly at SD9 (0.52). The CPY value decreased with increasing stocking density and the lowest value was obtained at SD7 (1.90 USD kg^{-1}), then it increased slightly as stocking density increased to SD9 (1.91 USD kg^{-1}).

Table 3. Economics of rearing *L. bata* at different stocking densities over the culture period of 100 days in pens (USD/100 days).

Sl. No.	Particulars	Stocking Densities (No. m^{-2})			
		3	5	7	9
1	Seed cost (USD)	20.21	33.68	47.16	60.63
2	Feed cost (USD)	127.97	193.71	252.08	272.06
3	Labor cost (USD)	13.47	13.47	13.47	13.47
4	Total operational cost (1 + 2 + 3) (USD)	161.65	240.87	312.72	346.17
5	Total capital cost (USD)	128.47	128.47	128.47	128.47
6	Total cost (4 + 5) (USD)	290.12	369.34	441.18	474.64
7	Gross fish yield (kg)	118.70	179.04	232.42	249.48
8	Gross revenue (USD)	319.87	482.45	626.29	672.27
9	Net revenue (8–6) (USD)	29.75	113.12	185.11	197.63
10	BCR	1.10	1.31	1.42	1.41
11	YPC (kg USD^{-1})	0.41	0.48	0.53	0.52
12	CPY (USD kg^{-1})	2.45	2.06	1.90	1.91

BCR—benefit-cost ratio; YPC—fish yield per unit cost; CPY—cost per unit yield.

3.4. Fishers' Income

A paired t-test was applied to observe change in the monthly income of SSF before and after technological intervention. Mean monthly income post-technological intervention (USD 187.68 per month) was significantly higher prior to intervention (USD 147.86 per month) (t = 4.963, p = 0.002). Post-pen culture, the monthly income of SSF increased by 6.10% (SD3) to 40.50% (SD9), with a mean increase of 26.93%. Hence, it can be concluded that pen culture has a significant positive effect on the monthly income of SSF.

4. Discussion

The ICAR-CIFRI has demonstrated and standardized pen culture for raising stocking materials for stock enhancement and culture-based fisheries in floodplain wetlands as well as for table fish production [40]. Pen culture has been successfully carried out in floodplain wetlands of Assam [8,40–43], Uttar Pradesh [44], Manipur [45] and West Bengal [36]. Pen culture has gained wide popularity as a means of raising carp fingerlings in situ in floodplain wetlands [41–43,46]. Chandra et al. [6] reported that fish production and the productivity of floodplain wetlands of Assam have increased significantly post-adoption of pen culture technology for raising fingerlings. Pen culture has the potential to produce 10,500 tons of table fish from floodplain wetlands of Assam [19], which can contribute significantly towards reducing the existing fish demand and the supply gap in the state. However, the literature survey revealed limited instances of raising table fish through pen culture in floodplain wetlands of Assam. Earlier reports indicated that the polyculture of Indian major carps (*L. catla*, *L. rohita*, *C. mrigala*), exotic carps (*H. molitrix*, *Ctenopharyngodon idella*, *Cyprinus carpio*) and others such as *Osteobrama belangeri* and *Puntius javanicus* has been successfully carried out in pens in floodplain wetlands [8,41,45,46]. Pen culture has been carried out in floodplain wetlands of Assam during post-monsoon and winter seasons, when flood recedes [8]. The present experiment is the first attempt at standardizing stocking density towards the monoculture of *L. bata* for table fish production in pens in floodplain wetlands. Owing to high market demand [31] and consumer preference [29], *L. bata* has garnered tremendous interest in the fisheries sector. Attempts have been successfully made to standardize the stocking density of this species for fingerling production [16] and raising table fish [31] in cages in floodplain wetlands and for table fish production in cages in reservoirs [23].

In the present study, fishes were fed with CIFRI CAGEGROW® feed containing 28% crude protein and 5% fat. CIFRI CAGEGROW® feed has been used in the successful culture of Indian major carps and grass carp in pens [36] and *L. bata* in cages [16,31]. Paul et al. [47] observed that the growth performance of *L. bata* was found to be optimum when fed with feed that has 29.70% protein. For the present experiment, we used feed with 28% protein content, which is near its optimum range. Recommended feeding practice in carp culture is to provide feed at 3–5% of body weight [48], which has been followed in the present experiment.

Carps have been deemed suitable for culture in pens in floodplain wetlands [40,45,49]. Sugunan and Bhattacharjya [8] reported that growth rate decreases with increasing stocking density in pens. In the present study, it was observed that the growth performance of *L. bata* in terms of WG%, the SGR and DWG decreased linearly with an increase in stocking density. This may be due to increased crowding stress [26] and increased competition for food and space [50]. Further, these stress factors might have also played a role in influencing the FCR and the PER of cultured fish. We have observed that the FCR increased and the PER decreased with increasing stocking density. Similar observations have also been made in the species (*L. bata*) reared in cage enclosures in floodplain wetland [16,31] and in reservoir [23], where growth performance declined with increasing stocking density. Another aspect affecting the growth of fish in higher stocking densities is the competitive feeding habit of fish, where large-sized fish tend to dominate the environment and chase away the smaller ones when feed is delivered [31]. In the present study, it was observed that almost all fishes had a uniform size in the highest stocking density group (SD9), as inferred from the lowest CV value of 0.34 ± 0.07 among all four treatments. Thus, it can be ascertained that competitive feeding is not a factor influencing fish growth in the highest stocking density group. The absence of competitive feeding in *L. bata* reared in high stocking densities in cage enclosures has also been reported by Debnath et al. [31]. To overcome crowding stress, certain fish species such as *Carassius auratus* and *Cyprinus carpio* release a hormone, which in turn inhibits their growth [51]. Detailed studies on the biological, physiological and behavioral aspects of *L. bata* at different stocking densities may be helpful in drawing concrete inferences on parameters influencing the growth of the species in pen enclosures at higher and lower stocking densities.

In the present study, the net and gross yields increased with increasing stocking density and the highest values were obtained at the highest stocking density of 9 no. m^{-2} (SD9), followed by SD7, which is in accordance with Jiwyam [52]. Variation in gross and net yield between SD9 and SD7 was found to be statistically insignificant ($p > 0.05$). Higher yields at higher stocking densities in enclosures have been reported for *Oreochromis spilurus*, *Clarias gariepinus* and *O. niloticus* [53–55]. The survival rate was found to be highest in the lowest stocking densities of 3 no. m^{-2} (95.60 ± 0.81 %) and lowest at 9 no. m^{-2} (89.70 ± 0.70 %). High stocking density coupled with a low water temperature during the culture period (winter season) might have resulted in low survival rates as carps are less tolerant to crowding stress. Debnath et al. [31] has also reported low survival rates in *L. bata* at high stocking densities reared in enclosures during winter in Samaguri beel, a floodplain wetland located in Nagaon district, Assam. An inverse relationship between stocking density and survival rates was observed in *C. mrigala* [56].

The economic viability of any culture practice determines its rate of adoption by fishers/fish farmers [57]. In the present study, the economics of culturing *L. bata* in different stocking densities in pens installed in floodplain wetlands has been determined. BCR values in the present study ranged from 1.10 (SD3) to 1.42 (SD7). At a stocking density of 9 no. m^{-2}, the BCR decreased slightly to 1.41, which indicates that a stocking density of 7 no. m^{-2} is economically most viable. Further, the YPC value was highest and CPY was lowest at SD7 among all treatments. The BCR of pen culture operations in floodplain wetlands ranged from 1.35 to 2.15 in Assam [43]; and was found to be 1.69 in Uttar Pradesh [44]; 1.37 in Manipur [45] and 1.53 in West Bengal [36]. Such variation may be attributed to the type of species cultured, stocking density, culture duration [8], pen size [43], climatic conditions and ecological parameters. Post-pen culture, the monthly income of fishers increased from 6.10% to 40.50% compared to the pre-pen culture period. The highest increase in income was observed at SD9 (40.50%) followed by at SD7 (37.94%), which is due to the high net yield obtained at both stocking densities. Haque and Dey [58] reported a significant improvement in the income of floodplain wetland fishers of Bangladesh owing to increased fish production through community based fish culture. An increase in the net income of fishers was also reported from Charan beel [17] and Bamuni beel [59] post-adoption of CIFRI HDPE pen culture technology.

A statistically significant difference ($p > 0.05$) was not observed in water quality parameters between inside pens and reference site. Mean values of water quality parameters reported during the culture period were found to be within the desirable range for carp farming in the tropics [60]. Water quality parameters did not show any statistically significant differences across treatments, which indicates that stocking density and the feeding rate did not have a negative impact on the environment. Similar observations were made by Debnath et al. [31] and Yengkokpam et al. [16] during the culture of *L. bata* in cage enclosures in a floodplain wetland. Abiotic parameters have a definite role in the growth of fish [61]. Identification of critical water quality parameters affecting fish growth is of prime requirement in enclosure culture systems [62]. In the present experiment, fish growth was found to have a statistically significant positive correlation with water temperature and total alkalinity. Water temperature has a significant effect on the feeding rate and body metabolism [63], which impact the growth of fish [64]. An alkalinity of >20 mg L^{-1} ensures good productivity in an aquatic system. Alkalinity has a buffering effect on pH, which is associated with ammonia toxicity and photosynthetic activity and thus regulates fish growth [65].

5. Conclusions

The development of pen culture protocols in floodplain wetlands for indigenous fish species with a high demand across regions can contribute towards better economic gains. *L. bata* is a high–demand food fish in eastern and north-eastern India. Based on the findings of our present study, it can be concluded that the pen culture of *L. bata* in floodplain wetlands is economically and ecologically viable. Economic analysis indicates that a stocking density of 7 no. fry m^{-2} has the highest BCR. Post-pen culture, the monthly income of fishers increased by 6.10 to 40.50%, with the highest increase in a stocking density of 9 no. fry m^{-2}. Based on the BCR, a stocking density of 7 no. fry m^{-2} can be recommended for pen aquaculture in floodplain wetlands. Present findings will contribute towards species diversification in pen culture, increased fish production, and an improvement in the income of SSF from floodplain wetlands as well as adding to ecosystem-based sustainable fisheries management in floodplain wetlands.

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