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Stocking density affects growth and economics of rearing Amur carp (*Cyprinus carpio haematopterus*) in floating cage in floodplain wetland of the River Brahmaputra

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Abstract

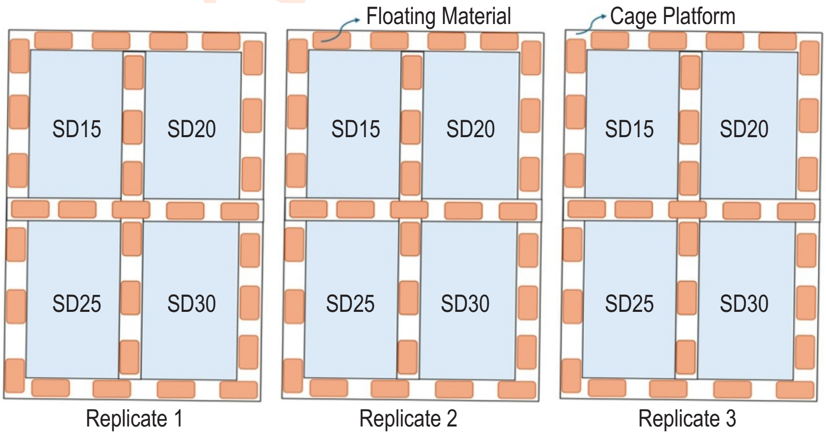
Aim: The study evaluates the effect on growth-and related economic benefits of rearing commercially important food fish, Amur carp, *Cyprinus carpio haematopterus* fry, in a cage culture system, influenced by stocking densities.

Methodology: A 90 day long rearing experiment was conducted in a seasonally opened ecologically sensitive floodplain wetland of the Brahmaputra riverine system at Jaluguti Beel. Floating cages of 6×4×2 m with an effective volume of 40 m^{-3} were used for rearing the fish. Experimental fish (n = 10800) of initial weight and length 0.17 ± 0.01 g and 1.90 ± 0.05 cm (mean ± SE), respectively, were distributed among four different stocking densities: SD15 (15 fish m^{-3}), SD20 (20 fish m^{-3}), SD25 (25 fish m^{-3}), and SD30 (30 fish m^{-3}) executed in triplicates, following a completely randomized design.

Results: The overall growth of fish was significantly ($P<0.05$) influenced by varied stocking densities. The specific growth rate of reared fish in different stocking densities were 3.43 ± 0.04, 4.20 ± 0.06, 2.96 ± 0.02, and 2.71 ± 0.02, in SD15, SD20, SD25 and SD30, respectively. The biomass (kg per cage) achieved in different stocking densities were 35.90 ± 0.20, 38.50 ± 0.31, 37.20 ± 0.35 and 35.40 ± 0.50.

Interpretation: The present findings found an inverse relation between growth performance and stocking density. The study also proposes that rearing of Amur carp fry at a stocking density of 20 fish m^{-3} in a wetland-based cage aquaculture system yields a better growth response without compromising the benefit cost ratio.

Key words: Amur carp, Cage culture, Flood plain wetland, River Brahmaputra, Stocking density, Wetland conservation



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Introduction

Amur carp, *Cyprinus carpio haematopterus* is a commercially important farmed freshwater fish known for its high nutritional value, great delicacy and extensive history of domestication. These productive carps are widely disseminated throughout the freshwater zones of the globe and have a dominant presence, particularly in the Indian sub-continent. Along with Indian major carps, this modified common carp has gained popularity for producing a bountiful crop in pond aquaculture systems. Yet, there has been no attempt to monoculture Amur carp in floating cages for the judicial utilization of the wetland's potential. Productivity within any culture system is greatly influenced by the densities of individuals stocked. Previous studies have shown that growth related performance, survival, productivity, social- behaviour, health status, and water quality are collectively influenced by stocking densities (Kozłowski and Piotrowska, 2024; Li *et al.,* 2012). Gomes *et al.* (2000) and El-Sayed (2002) discovered that rearing carps at lower densities improved growth performance and survivability. Fish development is affected by stocking densities as they contribute to stress, food and space competition (Leatherland and Cho, 1985; Ellis *et al.,* 2002). Understocking reduces fish productivity and underutilizes fish cultivation space (Rahman *et al.,* 2006). A cage culture with proper stocking density is more cost-effective (Biswas *et al.,* 2015).

In addition to providing fish for the nation, floodplain wetlands support a variety of aquatic species. Wetland area of 0.5-million-hectare associated with Ganga, Brahmaputra, or Barak River system is most prevalent (Sarkar *et al.,* 2021). The floodplain wetlands in Assam, commonly called "beels", are vast of water resources (Das *et al.,* 2009; DAHDF-GoI, 2014; Bhattacharjya *et al.,* 2015; Das 2018; DoF-GoI, 2019). According to Debnath *et al.* (2022) these wetlands havethe potential to generate 1000-1500 kg ha^{-1} y^{-1} of fish, however, the average yearly output is only 254.3 kg ha^{-1} which may be utilized for culture based fisheries activities (Borah *et al.,* 2022). This provides for the inefficiency of the sector to meet the actual potential and satisfy the demand (Yadav *et al.,* 2020). Cage aquaculture is an age-old practice of raising aquatic organisms in an environment that is surrounded by water on all sides (including the bottom) and allows water to circulate freely through the mesh of the cages.

According to Radhakrishnan *et al.* (2019), out of 70 species currently being raised in freshwater cages around the world, the most common ones are *pangasius* (41.1%), *oreochromis niloticus* (26.7%), *cyprinus carpio* (6.6%), *oreochromis* spp. (5.1%), *oncorhynchus mykiss* (4.1%), and *salmo* spp. (3.7%). Cage can also be effectively utilized to raise fish fry in these wetlands to table-size (Bhattacharjya *et al.,* 2008). It is one of 56 most effective approaches for exploiting undeveloped water sources, with 55 successful deployments in the Indian states of Jharkhand and Tamil Nadu (Kumari and Sharma, 2022). Cage aquaculture can be expanded up to 1% of Assam's wetlands, which at present is limited up to only 0.54 ha of the total 100,815 ha of floodplain wetland (Das *et al.,* 2014; Das *et al.,* 2018). Therefore, the present research assessed the performance of Amur carp fry in cages to find the best cost-effective stocking density for profitably growing and utilizing as a stocking material in floodplain wetlands.

Materials and Methods

Fish and Experimental setup: A healthy hatchery-reared Amur carp fry (n= 10900) was procured from a local fish farm in Nalbari district, Assam, India. The initial body weight (g) and total length (cm)of the experimental fish (n = 30) prior to the onset of the experiment was 0.17 ± 0.01 g and 1.90 ± 0.05 cm (mean ± SE) respectively. The fish were allowed to acclimatize for two weeks in a circular FRP tank of 10000 l capacity, at a water depth of 0.8 m. The experiment was conducted for a period of 90 days in low-cost galvanized iron framed floating cages (6×4×2 m), developed by ICAR-CIFRI, Barrackpore, West Bengal, India, and installed in a seasonally open, ecologically important floodplain wetland, Jaluguti Beel (26º 25'21" N, latitude 92º34'23" E, longitude) of the Brahmaputra riverine system. A battery of twelve cages with an individual cage volume of 48 m^3 and an effective water volume of 40 m^3, were employed to assess the influence of four altered stocking densities:SD15 (15 fish m^{-3}), SD20 (20 fish m^{-3}), SD25 (25 fish m^{-3}) and SD30 (30 fish m^{-3}) in triplicate, following a Completely Randomized Design (CRD).

Feeding and husbandry of fish: Feeding of the experimental fish was initiated a day post stocking to avoid physico-metabolic stress. Feeding was carried out twice daily at 08:00 hr and 17:00 hr initially at 5% body weight, divided into two equal rations. The feeding rate was gradually adjusted in compliance to the daily consumption and growth data (recorded fortnightly), with 0.2 mm commercially available pellet feed (Biorock Magnite, 32% crude protein).

Water quality parameters: Water samples were collected at fortnightly intervals, in the morning hours (06: 00 hr to 07: 00 hr) for the estimation of quality parameters, from all experimental units. Collections were carried from 0.5 to 1 m below the surface and pooled for evaluation. A wooden plank-built boat was used for movement in the beel area during sample collection. Important water quality parameters viz. pH, temperature (ºC), dissolved oxygen (mg l^{-1}), free carbon dioxide (mg l^{-1}), hardness (ppm), phosphate-P, total alkalinity, nitrate-N and ammonia-N were documented throughout the experimental phase. The water temperature (ºC) was recorded on the spot and dissolved oxygen was fixed at the site. The samples were collected in plastic bottles with appropriate precautions and brought to the laboratory of the College of Fisheries, Raha for analysis of other parameters following standard methods (APHA,2017).

Growth, nutrient utilization, and survival: At fortnightly intervals,30 randomly caught fish from each individual cage were measured for total length (cm) and body weight (g). The growth-performance was evaluated by the following equations:

$$\text{SGR (\%)} = \mathit{ln}\,[W_t(g)\text{-}W_0\,(g)/\text{Total number of days}] \times 100$$

Table 1: Differences in water quality parameters of experimental cage under varying stocking densities in cage culture of Cyprinus carpio Haemapterus fry in floodplain wetland of theBrahmaputra River.

Physico-chemical parameters	Experimental groups							
	Inside the cage					Outside cage		
	SD15	SD20	SD25	SD30	P value	1 m	5 m	P value
Temperature (^{0}C)	24.44±0.60	24.53±0.61	24.66±0.59	24.93±0.59	NS^{a}	24.67 ± 0.59	24.85 ± 0.58	NS
Transparency (cm)	72.21 ± 0.59^{d}	68.39 ± 0.58^{c}	64.36 ± 0.62^{b}	60.55 ± 0.73^{a}	0.0001	63.56 ± 0.68^{b}	81.00 ± 0.67	0.0001
pH	6.77 ± 0.01^{c}	6.88 ± 0.01^{b}	6.84 ± 0.02^{b}	6.70 ± 0.03^{a}	0.0001	6.62 ± 0.03^{b}	7.05 ± 0.02	0.0001
Do^{b} (mg l^{-1})	4.00 ± 0.01^{c}	3.83 ± 0.00^{b}	3.74 ± 0.02^{b}	3.57 ± 0.04^{a}	0.0001	3.47 ± 0.05^{b}	4.38 ± 0.01	0.0001
Free CO_2^{c} (mg l^{-1})	9.20 ± 0.05^{a}	9.33 ± 0.01^{a}	9.37 ± 0.01^{a}	10.19 ± 0.16^{b}	0.0001	9.58 ± 0.02^{a}	8.85 ± 0.07	0.0001
Alkalinity (mg l^{-1})	77.30 ± 0.06^{d}	76.72 ± 0.09^{c}	76.10 ± 0.11^{b}	73.19± 0.25^{a}	0.0001	75.34 ± 0.09^{b}	75.84 ± 0.25	0.0001
Hardness (mg l^{-1})	81.49 ± 0.48^{a}	82.82± 0.58^{a}	83.18 ± 0.63^{a}	84.69± 0.81^{b}	0.0005	83.67 ± 0.12^{a}	79.36 ± 0.47	0.0005
Nitrate-N (mg l^{-1})	0.02 ± 0.001^{a}	0.03± 0.001^{b}	0.04 ± 0.001^{c}	0.05 ± 0.001^{d}	0.0001	0.04± 0.001^{c}	0.01 ± 0.001	0.0001
Ammonia (mg l^{-1})	0.008 ± 0.001^{a}	0.009 ± 0.001^{a}	0.01 ± 0.001^{a}	0.02 ± 0.001^{b}	0.0001	0.02 ± 0.001^{b}	0.004 ± 0.001	0.0002
Phosphate (mg l^{-1})	0.01 ±0.001^{b}	0.01± 0.00^{ab}	0.01 ± 0.001^{a}	0.02 ± 0.001^{b}	0.0001	0.02 ± 0.001^{a}	0.007±0.001	0.0001

^{a}NS – Non significant; ^{b}DO - Dissolved Oxygen; ^{c}Free CO_2 – Free carbon dioxide; data expressed as mean ± standard error, with different superscripts varies significantly ($P<0.05$).

FCR = Dry weight of feed given to fish (g)/Wet weight gain by fish body (g)

$$GMW = (W^{t} \times W^{0})^{0.5}$$

$$DGI = W_t^{1/3} - W_0^{1/3} \times 100$$

$$FR = F/(GMW \times N \times t) \times 100$$

Where, W_0 and W_t is mean body weight (g) initially and after time t, respectively. F is used for food consumption and N stands for total number of fish. Daily mortalities were recorded to compute survival (%) towards the end of the study. Survival (%) was computed based on the number of individuals harvested / no. of individuals stocked (stocking density) x 100. Batch weighing method, based on absolute harvesting was used to calculate the biomass (kg cage^{-1}) of every individual cage.

Economics: To calculate the profit and loss generated from the cage culture business, an economic assessment was conducted, and the benefit/cost ratio (BCR) was estimated for every experimental density. Factoring in the price of cage units (CIFRI GI), at an estimated life span of 12 years allowed us to calculate the capital expenditure for the experimental period. Feed and the cost of fish fry are all components of the projected operational expenses. After deducting the whole cost (including operational and capital costs) from the gross revenue generated from the trade of commodities (experimental fish), the net returns were measured. The benefit/cost ratio was estimated by dividing the gross revenue generated by the total cost incurred for the operation.

Statistical Analysis: IBM-SPSS version 24.0 was used for One-way analysis of variance (ANOVA) and Turkey- HSD for determining the significant differences between the treatments. The experiments were carried out in triplicates and the results were expressed as mean ± SE.

Results and Discussion

The values of essential water quality parameters, recorded from within or outside (1m and 5m) of the cage are depicted in Table 1. No significant ($P>0.05$) alterations were recorded for any water quality parameter, throughout the course of the experiment, as depicted in Table 1. All essential parameters of water quality were within the optimum range, necessary for the sound growth of the carp fry. The range of different parameters were as follows: Temperature- 24.10 to 25.35̊C, pH- 6.5 to 6.7, Dissolved oxygen- 4.74 to 6.38 mg l^{-1},Total alkalinity-73.19 to 77.72 mg l^{-1}, Total hardness – 78.20 to 85.56 mg l^{-1}, Nitrate N – 0.00 to 0.01 mg l^{-1}, Phosphate – 0.00 to 0.01 mg l^{-1}, respectively. Similar to what was shown in the floodplain wetlands of Assam, India, water quality parameters can alter over time, as shown in studies conducted in different months (Yengkokpam *et al.,* 2017; Das *et al.,* 2018). In accordance with Boyd (1982), all water quality parameters were deemed adequate for the purpose of tropical fish rearing.

Body weight gain (Fig. 1) of the experimental fish was significantly enhanced ($P<0.05$) in all experiments under the influence of stocking densities. The influence of stocking densities on performance parameters and survival (%) are represented in Table 2. The overall performance of SD20 group significantly rose ($P<0.05$) to reach 4.96 ± 0.03, 53.03 ± 0.01, 4.20 ± 0.06 and 1.74 ± 0.03 (final length, final weight, SGR and FCR respectively). Similar observations in SD 20 group were recorded for significantly higher ($P<0.05$) GMW and DGI (3.05 ± 0.02 and 19.57 ± 15). However, significantly highest ($P<0.05$) average survival rates (%) were recorded in the SD15 group (96.39 ± 0.17). Interestingly, with the increasing stocking densities survivability was significantly compromised ($p >0.05$) at SD30 group (86.18 ± 0.04) and insignificant alterations were

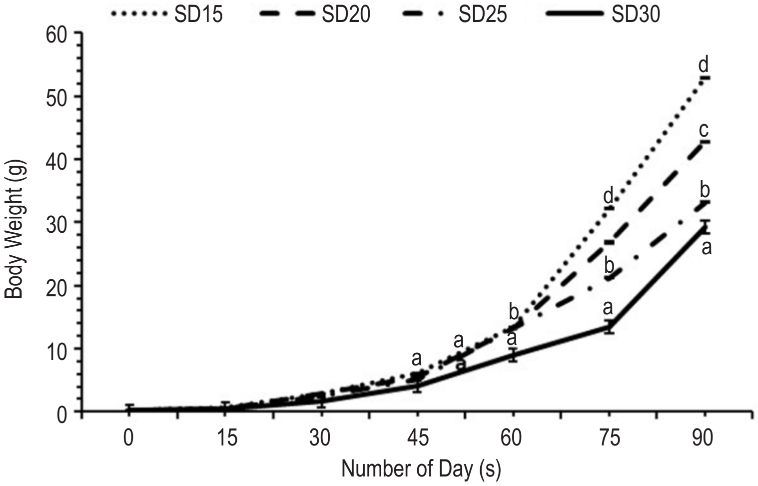

Fig. 1: Body weight gain (g) of Amur carp reared different stocking densities in floating cages in floodplain wetland of the River Brahmaputra.

observed at SD20 and SD25 (95.94 ± 0.08 and 95.75 ± 0.06), respectively. The biomass of the Amur juveniles at SD 20 group (38.50 ± 0.31) was found to be significantly higher ($P<0.05$) than other experimental groups. Though the stocking density is an environmental stimulus to stress that effects fish development (Liu *et al.,* 2017), it was also found to significantly alter the survivability of the stock (Ellis *et al.,* 2002). The proportions of stocking densities evaluated in the present study did not affect water quality, which is otherwise a critical factor for determining the development of organisms. Although few temporal variations were evident at the site of experiment, the overall water quality remained unaffected by varied stocking density in this investigation (Das *et al.,* 2020; Yengkokpam *et al.,* 2017). All recorded values, irrespective of within and outside the cage (1m and/ or 5 m away) were within the permissible limits to allow for optimum growth of the amur fry (Boyd, 1982; Sahani *et al.,* 2022). After completion of the experiment the growth performances evaluated in terms of body weight gain (g) and SGR revealed an inverse relationship with the stocking densities, since both the variables dropped as a result of increased stocking densities. The social interactions exerting a significant stress on the fish negatively regulated their overall growth-related performance (Ellis *et al.,* 2002).

The nutrient utilization was also drastically retarded as a consequence of increment in the stoking density. At higher stocking density (SD 25 and SD30) the feed efficiency was compromised as a result of which a raise in FCR values were recorded.As stocking density rises, number of individuals in a unit space raises, causing competition for individual feed consumption, leading to development of stress in fish. These elements have an impact on fish feed intake and feed conversion efficiency (Yengkokpam *et al.,* 2020) which might have contributed to the increasing FCR, as seen in the present study. This finding is consistent with previous reports by Yengkokpam *et al.* (2017), Gibtan *et al.* (2008), and Watanbe *et al.* (1990), where experimental group with the lowest stocking density had the lowest FCR. Similar outcomes were also described in other species of fish, such as tilapia (*Sarotherodon melanotheron*) (Ouattara *et al.,* 2003), catfish (*Clarias lucera*) (Narejo *et al.,* 2005), magur (*Clarias magur* (Borthakur and Goswami, 2007), channel catfish (*Ictalurus punctatus*) (Refaey *et al.,* 2018) The findings of the present study revealed that Amur fry are sensitive to crowding which causes retarded efficiencies in terms of feed utilization resulting in reduced overall growth performances as evident in other carp species as *Labeo catla* and *Labeo rohita* (Biswas *et al.,* 2015; Mane *et al.,* 2019). At higher stocking density, the survivability is also reduced as shown in Table 2. The compromised survivability with cumulative stocking densities has been also reported in various other carp species like *Cirhinus mrigala* (Debnath *et al.,* 2012) and *Labeo rohita* (Biswas *et al.,* 2015). The maximum gross and net output achieved in the SD 20 (20 fish m^{-3}) can be due to the optimum available space at lower stocking densities, which allows maximum room for the movement of fish, which is essential for growth determination. These findings align with the findings of Ahmed *et al.* (2002), who found that rearing of common carp (*Cyprinus carpio* Lin.) in floating net cages at a medium density resulted in maximum growth.

The economic returns from rearing amur fry in the cage culture system are shown in Table 3. As stocking density was raised, operational and total costs also increased in a similar fashion. However, there was a noticeable increase in gross revenue generated from SD 20 in comparison to other experimental groups after which there was little to no further growth. After initially rising as stocking density grew, net revenue (profit) peaked at SD 20 and then diminished again. Similar findings were also evident in terms of BCR. While the capital investment remained consistent across all experimental groups, the operational cost (cost of fry and feed) increased as stocking density increased, leading to an overall rise in the total

Table 2: Growth performance of Amur carp fry reared in different stocking densities in floating cages in floodplain wetland of the River Brahmaputra

Performance	Experimental Groups				
	SD15	SD20	SD25	SD30	Pvalue
Final Length (cm)	14.66 ± 0.03^{c}	14.96 ± 0.03^{d}	13.96 ± 0.03^{b}	13.36 ± 0.03^{a}	0.0001
Final Weight (g)	42.79 ± 0.14^{c}	53.03± 0.01^{d}	33.20 ± 0.10^{b}	29.31 ± 0.10^{a}	0.0001
SGR^{a} (% day^{-1})	3.43 ± 0.04^{c}	4.20 ± 0.06^{d}	2.96 ± 0.02^{b}	2.71 ± 0.02^{a}	0.0001
FCR^{b}	1.75 ± 0.02^{a}	1.74 ± 0.03^{a}	1.98 ± 0.05^{b}	2.11 ± 0.01^{b}	0.0001
GMW^{c} (g day^{-1})	2.82 ± 0.01^{c}	3.05 ± 0.02^{d}	2.4 ± 0.04^{a}	2.27 ±0.13^{b}	0.0001
DGI^{d}	15.78 ± 0.01^{c}	19.57 ± 0.04^{d}	12.23 ± 0.07^{b}	10.79 ± 0.05^{a}	00001
Fr^{e} (% BW Day^{-1})	0.46 ± 0.01^{c}	0.40 ± 0.02^{d}	0.51 ± 0.02^{b}	0.54 ± 0.03^{a}	0.0001
Survival (%)	96.39 ± 0.17^{c}	95.94 ± 0.08^{b}	95.75 ± 0.06^{b}	86.18 ± 0.04^{a}	0.0001
Biomass (kg cage^{-1})	35.90 ± 0.20^{a}	38.50± 0.31^{c}	37.20 ± 0.35^{b}	35.40 ± 0.50^{a}	0.0001

[a]SGR – Specific Growth Rate; [b]FCR – Feed Conversion Ratio; [c]GMW – Geometric Mean Weight; [d]DGI – Daily Growth Index; [e]FR – Feeding Rate; Data expressed as mean ± S.E, with different superscripts varies significantly ($P<0.05$).

Table 3. Effects of stocking densities on economics of rearing *Cyprinus carpio haematopterus* fry reared in cage culture.

Particulars	Experimental Groups			
	SD 15	SD 20	SD 25	SD 30
Cost of Fry (US $)	8.57	11.43	14.29	17.15
Feed Cost (US $)	27.69	29.96	32.88	37.12
Total operational cost (US $)	54.13	59.27	65.04	72.14
Total capital cost (US $)	76.12	81.25	87.03	94.13
Total biomass produced (kg cage^{-1})	36.80	39.41	38.14	36.37
Gross Revenue generated (US$)	131.50	140.82	136.28	129.96
Net Revenue earned (US $)	55.37	59.57	49.26	35.83
Benefit-cost ratio (BCR)	1.72	1.73	1.56	1.38

INR (₹) 83.95 = 1 USD ($), forex conversion rate as of 03-september-2024.

investment cost. Gross income therefore followed a similar pattern, with an increase in yield attributable to denser stocking. The optimal stocking density is defined as the value that maximizes net revenue, biomass per unit area and BCR. These results were obtained at SD 20 (20 fish m^{-3}). Catfish, in contrast to carps, can endure a greater crowding stress and worsen water quality, which may explain why reports of increased net profit generated with increasing stocking density were made for African catfish (Hengsawat *et al.,* 1997) and Asian river catfish (Jiwyam, 2011). Although no reports of growth retardation were recorded in these studies. According to Hengsawat *et al.* (1997) and Rahman *et al.* (2006), market price and consumer preference regarding fish size can also influence economic production of fish. Alternately, future trials should focus on increasing the stocking size of Amur in order to generate larger table fish and greater returns. The naturally formed channels of the Brahmaputra basin with Jaluguti Beel, which were earlier opened seasonally for allowing auto-stocking of fish seed in the wetland, and used to provide livelihood to the fisherfolks are now blocked as a consequence of anthropogenic activities. The availability of quality fish seeds, thus, became one of the bottlenecks in the proper utilization of wetland water resources. However, management of wetlands through a cage aquaculture system can help to compensate this underutilization of available resources by raising fish fry up to advanced fingerling stage, which can be used later as a stocking material to enhance the productivity and conservation of the vast wetland resources of the region.

The current findings revealed that cage culture of Amur fry is a suitable approach towards enhancing the productivity in ecologically sensitive wetlands. The results revealed that Amur carp @ 20 fish m^{-3} is the ideal stocking density for producing fingerlings in floating cages in seasonally open wetlands. In order to regulate the optimal stocking density, prime factors taken into considerations, include growth and feed efficiency, gross yield, and the computed benefit cost ratio (BCR). Based on the findings of the present study, future development and conservation strategies for utilizing flood plain wetland can be devised. The present study will open an arena to take up culture of other highly valued fish species and determine the actual stocking density for overall improvement of production and productivity in wetlands.

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Authors' contribution: H. Saikia: Conducting the research, data collection, analysis and preparation of the original draft of the manuscript; **J. Abedin:** Preparation of the original draft, data interpretation and visualization; **K. Bhagawati:** Laboratory analysis, supervision, review and editing; **S. Baishya:** Revision and editing, **A.N. Patowary:** Statistical analysis, revision and editing, **J. Thakuria:** Data visualization, revision and editing; **B. Bordoloi:** Revision and editing; **R. Yashmin:** Revision and editing; **P.K. Saharia:** Conceptualizing, methodology, formal analysis, supervision of the research, revision, and editing.

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Ethical approval: All experiments have been conducted as per the Guidelines of the Institutional Animal Ethics Committee, Department of Aquaculture, College of Fisheries, Raha, Assam Agricultural University, Jorhat, Assam, India (approval code: AAU/FY/Dept-AQ-3/2019-20/1752 dated 05/01/2021). However, the fish species used in this study is reared for commercial production. Therefore, use of this animal in research does not require ethical clearance.

Conflict of interest: All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Data availability: The datasets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

Consent to publish: All the authors give their consent to publish the work in *Journal of Environmental Biology.*

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