Biocontrol of *Oreochromis mossambicus* population by *Notopterus chitala* (Hamilton, 1822) in a composite carp culture system of Purulia district in West Bengal, India

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ABSTRACT:

Aims: Composite carp culture-based fisheries are traditionally practiced in the Purulia district in West Bengal, India. Pond-based carp production here is confronted with several socio-economic, technical and climatic challenges, among them, the recruitment of the *Oreochromis mossambicus* population was found as an important issue to be addressed. This study aimed to establish an alternative semi-intensive carp production method for the Purulia district by controlling excessive recruitment of *O. mossambicus* through an endangered (EN) and native predatory fish, *Notopterus chitala*.

Study design: Present study has been conducted on two numbers of perennial water resources with 1 ha effective water area for pisciculture where annual production of Indian Major Carps and impact of *O. mossambicus* and *N. chitala* on the same culture system have been compared.

Place and Duration of Study: This study was conducted in farm conditions for two consecutive years, 2018 and 2019, in a freshwater earthen pond locally known as Gosai Bundh (N23.47737/E86.79032) and Bara Notun Bundh (N23°46439/E86°65080), at Uluberia village under Kashipur Block of Purulia district in West Bengal, India.

Methodology: In 2018, in the first phase of the study, the stocking density of locally procured Indian Major Carp (IMC) fingerlings was maintained at 8000 numbers per ha (T1) and later, it was found that, due to *O. mossambicus* contamination and excessive recruitment annual productivity and profitability of IMC hampered significantly. However, farmers targeted to eradicate such unwanted tilapia variety through netting processes but failed after successive attempts and few *O. mossambicus* larvae still existed in the culture pond. In the 2019, in second phase of the study, to overcome such an unwanted situation, wild *N. chitala* juveniles have been introduced at a stocking density of 800 numbers per ha, along with 8000 numbers per ha of IMC fingerlings in that similar pond (T2). Observations and results of T1 and T2 have been compared with an adjacent control pond (C) containing IMC fingerlings only.

Results:

Conclusion: Results demonstrate that farmers may cultivate *N. chitala* to control excessive recruitment of the *O. mossambicus* population in a pond-based composite IMC culture system in the Purulia district. However, further optimization is required to enhance the economic viability of this technology.

Keywords: Poly-culture, Predatory fish, Production, Profitability

1. INTRODUCTION

Global aquaculture production is expanding rapidly, where different varieties of carp play the most important role as the leading contributor and dominate related domestic and international trades (Naylor et al., 2021)[1]. Composite carp culture has been recognized as an effective livelihood option for improvement of rural socio-economy status and addressing malnutrition in developing countries by supplying easily assessable and good-quality dietary protein (Chen et al., 2015[2]; Wijenayake et al., 2016[3]; Farquhar et al., 2019[4]; FAO, 2020[5]). Purulia is a drought-prone district and is considered the most backward region of West Bengal, India, regarding socio-economic development (Mishra, & Chatterjee, 2018)[6]. 70% community in this district belongs to the rural hemisphere, and a substantial portion of them suffer with poverty and malnutrition (Government of India, 2015[7]; Dirapa, 2018)[8]. Monsoon is the only source of water supply in these regions for agriculture, fisheries, animal husbandry and regular household utilization purposes (Haldar, & Saha, 2015)[9]. Such a condition enhances the importance of perennial water bodies within the district. Due to high demand in the local market, using such kinds of water resources for extensive and semi-intensive composite carp culture activities has now been practiced by some farming communities of Purulia. There are several challenges in this district to the development of sustainable and economically viable culture-based fisheries due to various unorganised and unscientific approaches by farming communities in extreme climatic conditions **(**Biswas et al., 2019**)[10].** Among these challenges, invasion and excessive recruitment of non-native fish, *O. mossambicus* in some of the Indian Major Carp (IMC) based composite perennial culture ponds was an important issue to be addressed. Invasion of non-native fish species into novel habitats increases globally (Olden, 2006)[11]. Many of these introductions are found to show negative impacts on natural aquatic communities (Mills et al., 2004; Olden, 2006)[11]. Among them, *O. mossambicus* (Mozambique tilapia) is listed as an important invasive alien species in various countries and considered to be a 'model invade' due to their advanced biological features, such as tolerance to various environmental conditions, nonspecific dietary requirements, rapid reproduction and competitive behaviour with native fish species (Pe´rez et al., 2006[12]; Thuesen et al., 2011)[13]. Many of the members of the *Oreochromis* genus were found to deteriorate indigenous fishes habitat and productivity in several countries (Doupe´et al., 2009[14]; Starling et al., 2002)[15]. In composite culture systems superiority of *Oreochromis niloticus* over indigenous carp through voracious eating and uncontrolled reproduction was reported to hamper net yield and profitability (Shrestha et al., 2011)[16]. A similar problematic situation was also observed in Purulia due to the excessive recruitment of *O. mossambicus*, which was also considered a weed fish in Purulia due to its poor socio-economic acceptances among the local communities. However, its impact on the composite carp culture system has not yet been properly documented.

Uses of native predatory fish as biocontrol agents are considered worldwide as an eco-friendly solution for controlling the growth and reproduction of unwanted aquatic organisms, including invasive alien fish species (Hobbs et al., 2006[17]; Beckmann et al., 2011[18]; Madenjian et al., 2011[19]; Mohamed et al., 2021)[20]. Such approaches could be a sustainable alternative solution instead to using locally available piscicides to avoid any post-toxic impacts on the perennial water resources of Purulia, which may minimize the chances of compromising the regular use of water by the communities. *Notopterus chitala* belonging to the family Notopteridae, is an indigenous freshwater fish of India, naturally found in well oxygenated riverine water but also can survive in confined low oxygenated water bodies and tolerate a wide range of temperature and pH fluctuation (Mitra et al., 2018)[21]. They are known for their piscivorous feeding habit with a significant role in the regulation of common carp, minnows and insects population in freshwater habitats (Chaudhuri, 1975[22]; Sadhale, & Nene, 2005)[23]. However, depending on the availability, it can also show efficiency in the utilization of alternative nutritional resources (Sarkar, & Deepak, 2009)[24], which is an important characteristic of *N. chitala* to be promoted as a new candidate species for diversified freshwater aquaculture in India (Ponniah, & Sarkar, 2000[25]; Ayyappan et al., 2001[26]; Mitra et al., 2017)[27]; (Mitra et al., 2014)[28]. Due to its rare availability, *N. chitala* is considered one of the most commercially important, high-priced food fish with excellent nutritive value (Sarkar et al., 2009[29]; Mitra et al., 2018) [21]. Despite all these culture and economy-based importance; over-exploitation, natural habitat loss and pollution have affected its population density in the wild and categorized it as endangered (EN) (Ayyappan et al., 2001[26]; Sarkar et al., 2007)[30]. Major challenges of *N. chitala* farming includes slow growth rate in captivity and non-availability of a standardized protocol for field-level cultivation. Even though, Mitra et al., (2018) [21] suggested its polyculture with carps for better profitable ventures and to enhance the possibilities of rescuing this fish from being EN.

Several attempts made worldwide mainly focused on controlling excessive recruitment of *O. niloticus* in aquaculture ponds by using predatory fish species in various countries to enhance sustainability and economic viability (Little, & Hulata, 2000[31]; Wang, & Lu, 2015[32]; Shrestha, & Lin, 2004[]; Shrestha et al., 2011[16]; Yadav, Shrestha, & Pandit, 2007[33]; Sherstha et al., 2018) [34]. Through checking excessive recruitment of *O. niloticus* by predatory *Tor putitora*, composite carp culture became more profitable in Nepal (Sherstha et al., 2018) [34]. Samad et al., (2017) [35] found *N. chitala* and *O. niloticus* polyculture profitable with an ideal prey and predator relationship establishment in a freshwater pond environment in Bangladesh. However, the application of *N. chitala* as a biocontrol agent to control recruitment of *O. mossambicus* population in an IMC-based composite carp culture environment has not yet been reported. In the present study, a field-level trial has been made with an objective to examine whether the addition of *N. chitala* can control excessive the recruitment of the *O. mossambicus* in a perennial semi-intensive composite carp culture pond of a farming community in the North-Eastern region of the Purulia district. Impacts of such new species combination in an IMC-based composite system have also been examined with an aim toward greater fish yield, profitability and sustainability compared to traditional semi-intensive practices. In addition, for the first time ever *N. chitala* cultivation at a commercial scale could motivate farmers towards adoption of such an important technology for producing a nutrient-rich high-value fish within the Purulia district.

2. MATERIAL AND METHODS

2.1. Experimental conditions

This study was conducted in farm conditions for two consecutive years, 2018 and 2019, in a freshwater earthen pond locally known as Gosai Bundh (N23.47737/E86.79032) at Uluberia village under Kashipur Block of Purulia district in West Bengal, India. The water body was perennial with 1 ha effective water area for pisciculture and an average depth of 7.00 feet. This work has been conducted with household corpus of the fish farming community of Uluberia village. The observation and results of Gosai Bundh has been compared with an adjacent perennial freshwater earthen pond locally known as Bara Notun Bundh (N23°46439/E86°65080), which possessed similar physical characters and 1.2 ha effective water area for fish culture and was maintained by the same farming community. Both ponds were rain-fed, well exposed to sunlight and equipped with the water inlet and outlet facilities. During the study period, data were collected by several interviews of fish farmers using standardized questionnaires on a weekly basis, either by physical visits or telephonic interviews.

In the 1st year (2018) of the study on Gosai Bundh, it was considered to be Treatment 1 (T1). At the primary phase of the study, the application of any piscicides and weedicides was avoided due to the dependency of villagers on pond water and the absence of undesirable organic load, in addition absence of tilapia population also being recorded by the farmers. The pond preparation process has been started by farmers with application of hydrated lime ($Ca(OH)_2$) to adjust the water pH at 7.5. Following this after 3 days pond fertilization was done by using a mixture of cow dung manure and Single Super Phosphate (SSP) at the rate 3 t/ha and 30 kg/ha, respectively. After one week of the initial pond fertilization process locally available Indian Major Carp (IMC) fingerlings were stocked by farmers at the rate 8000 numbers / ha by maintaining 4:3:3 ratio of Catla (*Catla catla,* 30 gm average body weight), Rohu (*Labeo rohita,* 27 gm average body weight) and Mrigala (*Cirrhinus mrigala,* 26 gm average body weight). To reduce post stocking stress, inoculation of fingerlings was done in morning when water temperature was low and fingerlings were gradually acclimated in the pond environment, for which necessary care has been taken by farmers. During stocking, instead of IMC non availability of other fish species was reported by the farmers. Feeding has been suggested to be done between 7:00 am to 8:00 am (IST) by hand feeding method (broadcasted on the surface of the pond) at the rate 1% of body weight basis per day with supplementary feed (20% crude protein) containing mustard oil cake (28% CP) and rice bran (12% CP) at 1:1 ratio. Adjustment of feed quantity was made on a monthly basis depending on the average body weight of inoculated fish and by assuming 100% survival. Post stocking fertilization was carried out on a monthly basis with the application of hydrated lime to maintain pH between 7.0-7.2 following which a mixture of cow dung (0.5 t/ha), SSP (15 kg/ha) and urea (10 kg/ha) applied. Monthly netting has been conducted periodically for fish growth performance checking and for the 1st time, the netting process availability of the tilapia (larvae/fry) population was recorded by the farmers in T1. Based on such report verification has been made and the existence of the *O. mossambicus* population was observed in T1. Growth performance of inoculated carp species also been verified. Following this, from the next month, approximately 10% of the stocked population of each inoculated species was collected on a monthly basis by using seines and each variety was weighed individually to measure fish growth performance for maintaining the required dose of supplementary feed periodically. Measurement of population density of naturally recruited tilapia (*O. mossambicus*) has been done by random sampling method on a quarterly basis by using seines and covering 100 m^2 effective water area, after data collection the value has been multiplied by the total effective water area of the existing water body to get actual population density in T1. After sample collection; the number, size and body weight of *O. mossambicus* population were recorded. Observations have been compared with Bara Natun Bundh and considered it as control pond (C); prepared, stocked and treated by the similar materials and methods like T1. Monitoring and sample collection method also remains same in C, while the source of fingerling procurement is different from T1 but from local farm and during stocking existence of *O. mossambicus* has not been reported by the farmers. After 360 days cultivation harvesting have been completed in both C and T1 on 2019. After harvesting, existence of *O. mossambicus* larvae/fry at substantial quantity observed in T1. In the 2nd year of the study, the farmers were asked to introduce Chitala (*Notopterus Chitala*) at the rate 800 number of fingerlings (average 22 gm body weight) /ha, along with IMC fingerlings in Gosai Bundh again in 2019 and this time it was considered as Treatment 2 (T2). Stocking density of *N. chitala* has been maintained below the suggested quantity as mentioned by Samad et al., (2017) [35] for an *O. niloticus* based polyculture system. In T2, similar quality, quantity and species combinations of IMC were maintained, as done in T1. In T2, liming, pond fertilization, fingerling inoculation, monitoring and management strategies were similar as mentioned earlier, only *N. Chitala* was additionally introduced, while a similar supplementary feeding strategy has been suggested. The wild variety of *N. chitala* fingerlings procured by the farmers from an authentic vendor of the neighboring district (North 24 Parganas, West Bengal, India), transported under well-oxygenated condition and released on the same day and in the same manner as maintained for IMC fingerlings. Farmers sampled fish throughout the trial period to assess fish growth performance and to adjust feeding schedules accordingly in similar manner as done previously. Like the previous year (2018), observations and results of T2 were compared with the a similarly maintained Bara Natun Bundh (Control / C) in 2019 as well. IMC fingerlings under 2019 have been procured from a similar source (local farm) for both T2 and C.

2.2. Data Analysis

After 360 days, cultivation harvesting was completed in C, T1 and T2 by drag netting and 10% of each species type was individually weighed. Fish growth performances were evaluated by weight gain percentage (WG) and specific growth rate (SGR) by using standard methods (Steffens, 1989)[36]. Total fish yield (TFY) and survival of each species was calculated by following method of Shrestha et al., (2018)[37]. Partial budgeting of input costs and value of output has been determined by following the strategy as proposed by Mondal et al., (2011)[38]. Input values were calculated based on the current market price (USD) of materials used for cultivation. The average market price of IMC fingerlings was Rs. 4.67 per piece for C and T2 while Rs. 4.59 per piece for T1, *N. chitala* fingerlings were rs. 25 per piece. Similarly, average market price of supplementary feed, lime, Organic fertilizer, SSP and urea were rs. 14 per Kg, rs. 10.48 per Kg, rs. 10 per Kg and rs. 10 per Kg respectively. Instead of these materials expenditure is also made by farmers for pond management purposes, which includes cost of netting, prophylactics and security arrangements. All these different kinds of aquaculture related activities were done at the field level by the farmers. Calculation of output values (USD) were based on farm gate price of different fish species.

Temperature (◦C) , pH and transparency (cm) of water were recorded in between 06:30 am to 07:30 am (IST) by the farmers on weekly basis at field condition by using Temperature Meter, Digital pH Meter and Secchi Disk respectively. Water sampling was done on every two week basis by collecting water from 0.2 m depth in between 06:30 am to 07:30 am (IST) during cultivation process for determination of dissolved oxygen (DO mg L^{-1}), free carbon dioxide (mg L^{-1}), alkalinity (mg L−1) and hardness (mg L−1) of water by titration method following the standard procedures (APHA, 1995)[39].

Mean values of survival (%), production, input costs (USD), total output (USD), gross margin (USD) and profit (%) of different treatments were compared. Values of WG (%), SGR (% day^{-1}), total tilapia biomass (Kg/Ha), average body weight (Kg) of different fish species and physicochemical properties of water have been collected and analysed on triplicate basis and subjected to one-way analysis of variance (ANOVA) followed by least significant difference (LSD) test between mean values of each treatment (Gomez, & Gomez, 1984) by using SPSS V 16.0 (SPSS Inc., 2007). Differences were considered significant when $P < 0.05$. For control (C) mean values of both consecutive years (2018 and 2019) were selected for comparison and analysis purposes.

3. RESULTS & DISCUSSION

3.1. Impact of *O. mossambicus* recruitment and it's biocontrol

Investigation of fish growth, production and economic performances have been made in the present study with inclusion of *N. chitala* as a biocontrol agent in an *O. mossambicus* recruited IMC based composite carp culture pond in Purulia district. The results partly supported the hypothesis made regarding this study, as the *N. chitala* established itself as a potential predator for reducing *O. mossambicus* population significantly. Although, survival percentage of the all targeted fish species (carps) also been compromised.

Recruitment of *O. mossambicus* population (fry, fingerling and adult) has been compared between T1 and T2 (Figure 1). Results showed increasing cultivation time period gradually enhanced numbers and total biomass (Kg) of *O. mossambicus* in T1. After conformation about the presence of *O. mossambicus* larvae; population density assessment has been made at primary level after 90 days cultivation; when existence of about 22±0.6 Kg/ha *O. mossambicus* fry (1 inch average size) and 44±0.3 Kg/ha of fingerlings (2 inch average size) in T1 recorded. After 360 days cultivation the volume of *O. mossambicus* fry and fingerling population showed an exponential increment up to 48±0.9 Kg/ha and 112±19 Kg/ha respectively in T1.

From 180 days assessment period noticeable quantity (70±0.63 Kg/ha) of adult *O. mossambicus* (5 inch average size) has been recorded in T1, which also showed exponential growth and after 360 days cultivation 211±0.81 Kg/ha quantity has been recorded, where quantity of adult male population (135±21 Kg/ha) was significantly higher than female. After completion of harvesting process in T1 existence of *O. mossambicus* fry and fingerling population found in Gosai Bundh at an unmanageable quantity, which motivated us towards its biological control through predatory fish *N. chitala* and considered it as T2 for next 360 days field level trial. Reduction in both fry and fingerling of *O. mossambicus* population has been observed in T2 after 180 days cultivation period with the introduction of *N. chitala*, when its average body weight was 0.51±0.07 Kg. Similar kinds of phenomenon has been continued in a gradual manner and after 360 days cultivation average body weight of *N. chitala* recorded to be 1.2±0.06 Kg and quantity of both fry and fingerlings reduced significantly in T2 as compared to T1. While, growth of adult *O. mossambicus* population showed similar increasing trend as observed in T1 but the amount (62±14 Kg/ha) was significantly lower and dominated by 82% male population (51±18 Kg/ha) after 360 days cultivation. In T2 inversely proportional relationship has been observed between the total biomass of *O. mossambicus* and body weight gain (Kg) of *N. chitala*.

In the present study significant reduction of tilapia fry population after addition of *N. chitala* in a composite carp culture system indicates that it is a suitable candidate to check recruitment of *O. mossambicus*. Increasing body weight of *N. chitala* showed contrasting impact on *O. mossambicus* fry and fingerling population. However population density of fry remains high up to 90 days of cultivation period when body weight of *N. chitala* found to be 0.12 Kg. Which indicate non-predatory behaviour of *N. chitala*, as they do not prefer fish larvae in their diet at early life stages (Mitra et al., 2018) [21]. Assessment made on 180 day of cultivation period showed rapid reduction of *O. mossambicus* fry and fingerling population and continued throughout cultivation period, indicates predatory impact of *N. chitala*. Samad et al., (2017) [35] also reported similar kinds of phenomenon where *N.*

chitala significantly reduced *O. niloticus* population. Instead of that, possibilities of cannibalism by *O. mossambicus* adult male population for quantitative reduction of larval population cannot be ruled out (Macintosh, & De Silva 1984)[40]. *Cichlasoma urophthalmus* is a native predatory fish of America, showed similar effects by preying on *O. niloticus* larvae population (Hernandez at al., 2014)[41]. Fischer & Grant, (1994)[42] developed a model using native predator *Chichla monoculus* to control overcrowding of tilapia where predatory fish mainly hunts on fry populations. Sambhu Chithambaran, (2019)[43] reported that polyculture of tilapia with *Lates calcarifer* was ideal to control the prolific breeding and population explosion of sabaki tilapia in culture ponds. Predator species such as *Lates niloticus*, *Hemichromis fasciatus* and *Clarias lazera* also been reported to show effective results regarding addressing tilapia recruitment issue in aquaculture pond by reducing fry and fingerling population (Felix et al., 2019)[44]. However, linear growth of adult population in T2 was found to be a homogeneous phenomenon as observed in T1, while significant reduction of population density may be resulted due to gradual reduction of fingerling population. Significantly higher number of adult male population in T2 indicates higher survivality of that particular sex; might be happed due to non-predation of *N. chitala*. As, external morphology of male *O. mossambicus* advanced fry and fingerlings were equipped with pointed dorsal and anal fins, known to be utilized for self-defensive purposes (Oliveira, & Almada, 1994)[45], which it may applied against *N. chitala* attack, thus substantial quantity has been survived up to adulthood. *N. chitala* can widen the food spectrum depending availability of nutrients in the culture system (Mitra et al., 2018) [21]. In the present study survival of a substantial quantity of *N. chitala* fingerlings without any adverse effects on *O. mossambicus* population, indicates utilization of supplementary feed by the fish in its regular diet during early life stages. Growth performances of *N. chitala* at fry stages reported to be satisfactory, by utilizing supplementary feed enriched with 27.5% crude protein (Samad et al., 2016)[46]. However, use of both *O. niloticus* as a source of live feed producer and 22% crude protein containing supplementary feed together in a culture system showed best results for marketable *N. chitala* production (Samad et al., 2017) [35]. In a polyculture pond, a similar kind of supplementary and live feed (*O. niloticus* fry) based model showed promising results for predatory *Tor putitora* production along with different carp species in Nepal (Sherstha et al., 2018) [34].

3.2. Impact on IMC survivality & production

At the end of 360 days, data on survival, growth performance and production of different fish species are presented in Table 1. Survival percentages of IMC were much higher in control as compared to other treatments, while the poorest survivability was observed in T2. *C. catla* showed highest survivality, while *C. mrigala* showed minimum survival rate among all treatments. However, in case of *N. chitala* survival percentage was higher in comparison to IMCs. Weight Gain (WG) percentages among the different IMC species were significantly high in control and significantly low in T1. Among the three different species WG percentage of *C. catla* was significantly high in all treatments as compared to *L. rohita* and *C. mrigala*. Specific Growth Rate (SGR) of *C. catla* was significantly high in C and T2, in addition to that there was no significant difference of SGR value of *L. rohita* with *C. catla* in C, but significantly decreased in T1 and T2. While, in *C. mrigala* SGR value was significantly lower than other carp species in all treatments. Total production of *C. catla*, *L. rohita* and *C. mrigala* ranged from 784 Kg to 1444 Kg, 528 Kg to 867 Kg and 398 Kg to 642 Kg respectively, where lowest value for each species category observed in T2 as compared to control. Production value of *C. catla* was much higher in comparison to other IMC varieties among all the treatments.

The survival rate of IMC in every treatment affected greatly might be due to extreme climatic condition, poor quality maintenance and improper management practices, which were considered to be some of the common factors responsible for hampering fish productivity in Purulia district (Biswas et al., 2019)[10]. However, survival rate of IMCs in T1 clearly indicated that excessive recruitment of *O. mossambicus* shows stressful impacts over IMCs by its invasive characteristics (Perez et al., 2006[12]; Thuesen et al., 2011)[13], while in T2 excessive recruitment of tilapia upto three months cultivation period along with presence of *N. chitala* additionally may have created an over populate situation and further affected survivality of IMCs as compared to T1. Since, in a composite carp culture system optimum population density has been reported to be an important factor for survival of fish at an ideal range (Sharma et al., 1999[47]; Das et al., 2020[48]; Costa et al., 2017)[49]. In terms of survival rate *C. catla* showed best results might be due to its higher initial body weight and stocking density respectively, similar phenomenon also reported in a composite carp culture systems in Pakistan (Chatta et al., 2015)[50]. However, the present result contradicted with several other studies where mostly *L. rohita* and *C. mrigala* dominated over *C. catla* in terms of survivality in a polyculture condition (Ahsan et al., 2012[51]; Najero et al., 2010[52]; Sah et al,. 2018[53]; Ahmed, et al., 2012[54]; Khan et al., 2017[55]; Ingtipi et al., 2021[56]). Reduced survivality of both *L. rohita* and *C. mrigala* respectively may be resulted due to shortage of essential planktonic and benthic communities, indicating improper fertilizer management during cultivation (Chaudhuri, 1975[22]; Nandeesha, 1993[57]), however Shrestha et al., 2018[37] found such pond fertilization protocol effective in a carp based polyculture system in Nepal. In addition to these, broadcasting of supplementary feed on the surface of water also found to be a probable reason for such kinds of undesirable phenomenon where *C. catla* may have added advantage as being a surface feeder and may showed interspecific competition with other IMC varieties regarding utilization of supplementary feed. Such kinds of competitive behaviour of different fish species also reported by Kumar et. al., (2018) in an IMC and *Piaractus brachypomus* based polyculture system. As compared to C significantly lower growth rate of different carp species in T1 and T2 correlated with the survival rate. However, despite of ideal stocking density and ratio maintenance (Mohanty, 2004)[58], WG% and SGR values remained low even in C if we compare this results with some other related works (Kohinoor et al., 2005[59]; Basak et al., 2017[60]; Sah et al., 2018[53]; Verma, & Mandal, 2018[61]; Samad et al., 2017[35]; Ingtipi et al., 2021[56]; Mazid et al., 1997[62]). Based on such observations, it has been predicted that shortage of required supplementary feed is a potential reason for such unsatisfactory outcomes, as similar kinds of feed ingredients combinations showed ideal fish growth by utilizing them at the rate of 2-5% of total biomass on daily basis (Mazid et al, 1997[62]; Shrestha et al. 2018[37]; Ingtipi, et al., 2021[56]). In the present study, non-availability of required amount of corpus has been found to be the main reason of improper feed management by farmers during cultivation. *C. catla* known for its fast growing nature in an IMC based composite system (Chatta et al., 2015)[50], and in the present study similar phenomenon also been observed where average WG% and SGR values of *C. catla* remained significantly high among all treatments. Such phenomenon coincides with several other studies where higher stocking density was found to be potential growth promoter for *C. catla* in a composite IMC based culture system (Haque et al., 1993[64]; Verma & Mandal, 2018[61]; Ingtipi, et al.,2021[56]). Present study also represented poor growth performance of *C. mrigala* in comparison with other IMC, such situation coincides with some other works where similar types of variation among weight gain and SGR values of IMC varieties were reported (Verma & Mandal, 2018[61]; Azim et al., 2001[63]; Sahu et al., 2007[65]; Khan et al., 2012[66]; Ingtipi et al., 2021[56]). Fruitful adoption of Chitala fish in composite carp culture system has been developed at farmers level in India for their piscivorous characteristics, but scientifically published data regarding the same not available yet (Sarkar et al., 2006[67]; Mitra et al., 2018) [21]. In the present study, for the first time we found that *N. chitala* can significantly improve survivality and growth performance of all IMC varieties with significant reduction of *O. mossambicus* recruitment in culture system, thus WG% and SGR values of all IMCs significantly increased in T2 as compared T1. However, significantly lower WG% and SGR of all IMC in T2 as compared to C, indicates chances of interspecific competition and improper feed management as we found in C pond. The present results shows both contradictions and similarities with a field level polyculture trial of Nepal, where a *T. putitora* effectively enhanced growth performances of different carp varieties like silver carp, bighead carp, common carp, grass carp, rohu, and mrigala as well as effectively reduced *O. niloticus* recruitment in the pond based polyculture system (Shrestha et al., 2018)[37]. The present results regarding survivality and growth performances of

IMC in T1 both parameters decreased as compared to control, while in T2 increasing growth performances of IMCs as compared to T1 but with lower survival rate, indicated further necessity of technological improvements for better yield of IMCs in such conditions. In the present study poor survivality of *N. chitala* also indicates that there will be further requirement for stocking density optimization in such condition. Standardized protocols regarding ideal stocking density of *N. chitala* under similar environment not yet been available. However, by maintaining stocking density of 12356 numbers per ha of *O. niloticus* and 2470 numbers per ha of *N. chitala* together showed 100% survivality under experimental condition (Samad et al., 2017) [35], while present study did not show any correlation with such outcomes. Under supplementary feed and live feed based polyculture system wild caught Chitala juveniles has been reported to grows from 1-2 kg/year (Sarkar et al., 2006[67]), based on that in the present study average body weight of *N. chitala* found to be 1.2 kg, which was in normal range, whereas the ecosystem have ensured that only the fittest candidates can survive and grows normally by using their piscivorous skills and voracious feeding habit. However, survivality and growth performances of IMCs and *N. chitala* may get improved in similar conditions with proper stocking density and feed management, which are yet to be developed.

3.3 Impact of environmental parameters

All the physico-chemical water quality parameters among different treatments during cultivation were presented in Table 2. The significant variation observed among pH, dissolved oxygen (DO), alkalinity values and recorded significantly lower in T1. While, water transparency values were recorded to be significantly higher in T1 as compared to both C and T2. Wide fluctuation of water temperatures among different treatments has been recorded during cultivation. Temperature dropped below 20° C was found to a major reason for reducing growth performances of warm water fishes (Dhawan & Kaur, 2002 [68]; Nazish & Mateen, 2011)[69], similar unavoidable circumstances also observed during this study and considered to be a potential reason which affected overall fish productivity as temperature dropped below its ideal range for at least two months during on-going of cultivation in winter, considered to be a common environmental condition of Purulia (Dutta et al., 2017)[70]. Farmers have faced challenges during maintaining pH level above 7.00 in all treatments, which was a natural phenomenon in the north eastern region of Purulia as ground water their possessed acidic nature (Kundu & Nag, 2018)[71]. Such condition may also enhanced liming cost significantly as compared to normal lime requirement for semi-intensive carp culture system, to maintain pH at an ideal range. Though, mismanagement on liming may have created significantly lowest pH level in T1 for a while. In the present study significantly high water transparency (cm) in T1 might be happened due to higher population density of *O. mosambicus*, as it is known for voracious and omnivorous feeding habit, such characteristics were found to be effective for reducing organic load and improve water quality parameter in aquaculture ponds (Wang & Lu, 2016)[32]. While in the present study significant reduction of DO level in T1 may result due to increasing biomass (Chang & Ouyang, 1988[72]), which may get improved by reducing tilapia recruitment in T2. However, despite of sharp temperature drop in winter, other water quality parameters showed acceptable ranges for pisciculture, indicating obedience of farmers towards water quality management, especially in C and T2**.**

3.3. Economic analysis

Overall economic performance greatly varied among C, T1 and T2 with the recruitment of *O. mossambicus* and *N. chitala* respectively in an IMC based composite carp culture system. Variable costs among the different treatments consisted fish seed, feed, lime, fertilizers and pond management, represented in Table 3. Although, set of protocols were given to the farmers but in field condition they did not always follow it especially regarding application of supplementary feed. With the inoculation of *N. chitala* and maximum utilization of supplementary fish feed; total input cost increased in T2. However, total output in terms of product value based on farm gate price; differed due to variation of body weight (Kg) of different carp species among C, T1 and T2 (Figure 2). With significantly higher body weight of IMC average farm gate price found to be rs. 120 per Kg in C and T2, while in T1 it was rs. 115 per Kg because of significantly lower body weight of IMCs. Additional variable costs were added by *O. mossambicus* and *N. chitala* in T1 and T2 as per current farm gate price of rs. 50 per Kg and rs. 500 per Kg respectively. Gross margin and profit percentage remains high for two consecutive years in C and increased in T2 as compared to T1.

The introduction of *N. chitala* for the first time ever in an IMC based composite carp culture was a promising option for Purulia's farmers, where an excessively recruited population of *O. mossambicus* coexisted and played major role in mitigating live food requirement. During cost analysis utilization of supplementary feed depicted to be the key factor regarding controlling expenditure value in every treatment during the study period. Where, maximum mismanagement and minimum utilization of supplementary feed in T1 reduced over all expenditure and thus affected annual productivity. Despite of maximum utilization of supplementary feed net production hampered due to reduced growth rate of carps in T2, but such issues has been supplemented by *N. chitala* due to its high market demand and price, thus significantly high profit margin has been obtained in T2 as compared to T1 but still remain lower than C. While, poor growth rate of carp species and absence of *N. chitala* have created economic crisis in T1 as compared to C and T2, as the body weight of IMC was an important issue based on which market price varied significantly. However, due to logistical and financial difficulties and personal preferences, farmers did not entirely follow proposed protocols and thus production and profitability was much lower than the hypothesised data, which was quite an obvious characteristic of farmers who belongs to a socio-economically deprived region (Shoko et al., 2014[73]; Shrestha et al., 2018)[37]. It has been well reported that enhancement of profitability is possible by the addition of several non-cyprinid aquatic organisms in a carp based polyculture system (Wang & Lu, 2016[74]; Islam et al., 2008[75] ; Alagappan, 2020[76]; Alam et al., 2019[77]; Ali et al., 2018[78]; Hossain et al., 2018)[79]. However, the present study contradicted with the proposed model of Shrestha et al., (2018), where coexistence of carps, tilapia and predatory sahar fish has been predicted to enhance 70-80% profitability in Nepal. The Such phenomenon also indicated that, in Purulia *N. chitala* can be promoted as a new candidate fish by farmers through IMC based polyculture system, but further technical optimization and management may enhance economic viability of the perennial water resources.

4. Conclusion

It is concluded from this present study that the addition of a native predator *N. chitala* can reduce *O. mossambicus* recruitment substantially in an IMC-based composite carp culture pond. The Synergistic relationship of IMC and *N. chitala* growth performance makes this technology feasible without any negative impact on pond environmental conditions. Even though optimization of stocking density of the targeted fish species and proper management practices have been suggested for further technical improvement and betterment of survival rate of targeted fish species for making this technology economically viable and sustainable. Despite all these, the present study also unleashed a new avenue of *N. chitala* cultivation, which may become beneficial for rescuing such an endangered yet commercially important food fish through aquaculture. In addition, the feasibility of cultivation in Purulia's extreme climatic conditions may motivate farmers to cultivate and make such delicacies available to the local consumers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence this paper related reported work.

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Table 1. Growth performance and production of different fish species after 360 days cultivation period, data are mean ± SD (n = 05).

Type of Fish Species	Treatments											
	C				T1				T2			
	Survival (%)	WG (%)	SGR (% day^{-1})	Production (kg/ha)	Survival (%)	WG (%)	SGR (% day^{-1})	Production (kg/ha)	Survival (%)	WG (%)	SGR (% day^{-1})	Production (kg/ha)
Catla	56	2577±50a	0.39±0.002a	1444	43	2137±98b	0.37±0.005b	923	35%	2255±134c	0.38±0.006ab	784
Rohu	52	2476±81d	0.39±0.002a	867	41	2057±75e	0.37±0.004b	572	36%	2182±81f	0.37±0.004b	528
Mrigala	47	2094±68e	0.37±0.003b	642	38	1683±83f	0.34±0.004c	422	33%	1816±67g	0.35±0.004c	398
Tilapia	-	-	-	-	-	-	-	371	-	-	-	83
Chitala	-	-	-	-	-	-	-	-	37	5392±308	0.48±0.006	290

Dissimilar superscripts in a row indicate significant difference (P < 0.05).

Table 2. Minimum (Min) and maximum (Max) values of water quality parameters recorded during cultivation, data are mean ± SD (n = 05).

Treatments	**Parameters**													
	Temperature (°C)		pH		Transparency (Cm)		Dissolved oxygen (mg L^{-1})		Free carbon-di-oxide (mg L^{-1})		Alkalinity (mg L^{-1} as $CaCO_3$)		Hardness (mg L^{-1} as $CaCO_3$)	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
C	15.9	29.0	6.97 ^{a}	7.52	21.6 ^{a}	27.4 ^{a}	4.90 ^{a}	5.23^{a}	0.70	1.88^{a}	60.54^{a}	66.1^{a}	152	156
T1	16.2	29.0	6.76 ^{b}	7.5	24.0 ^{b}	29.6 ^{b}	4.72 ^{c}	5.11^{b}	0.75	1.75^{b}	57.55^{b}	62.38^{b}	150	157
T2	15.9	29.0	7.00 ^{a}	7.58	21.8 ^{a}	27.2 ^{a}	4.82 ^{b}	5.25^{a}	0.72	1.82^{a} ^{b}	57.09^{b}	61.16^{b}	149	156

Dissimilar superscripts in a row indicate significant difference ($P < 0.05$).

Table 3. Economic analysis (in USD) based on total expenditure and combined yield for each treatment after completion of harvesting processes

Variables Cost (USD/Ha)	**Treatments**		
	C	**T1**	**T2**
Seed	37360	36720	57360
Feed	102188.7 (7299.19 kg)	86404.83 (5957.48 kg)	107506 (7679 kg)
Lime	8897.29 (857.15 kg)	9119.72 (878.58 kg)	9638.73 (928.58 kg)
Organic Fertilizer	8500 (8500 kg)	8500	8500
Inorganic Fertilizer	3050 (305 kg)	3050	3050
Pond Management	25357	17275	26395
Total Input	185353	161069.6	212449.7
Total Output	354360	239005	354350
Gross Margin	169007	77935.4	141900.3
Profit (%)	91.18	48.38	66.79

Fig. 1. Recruitment of *Oreochromis mossambicus* and growth of *Notopterus chitala* cultivation

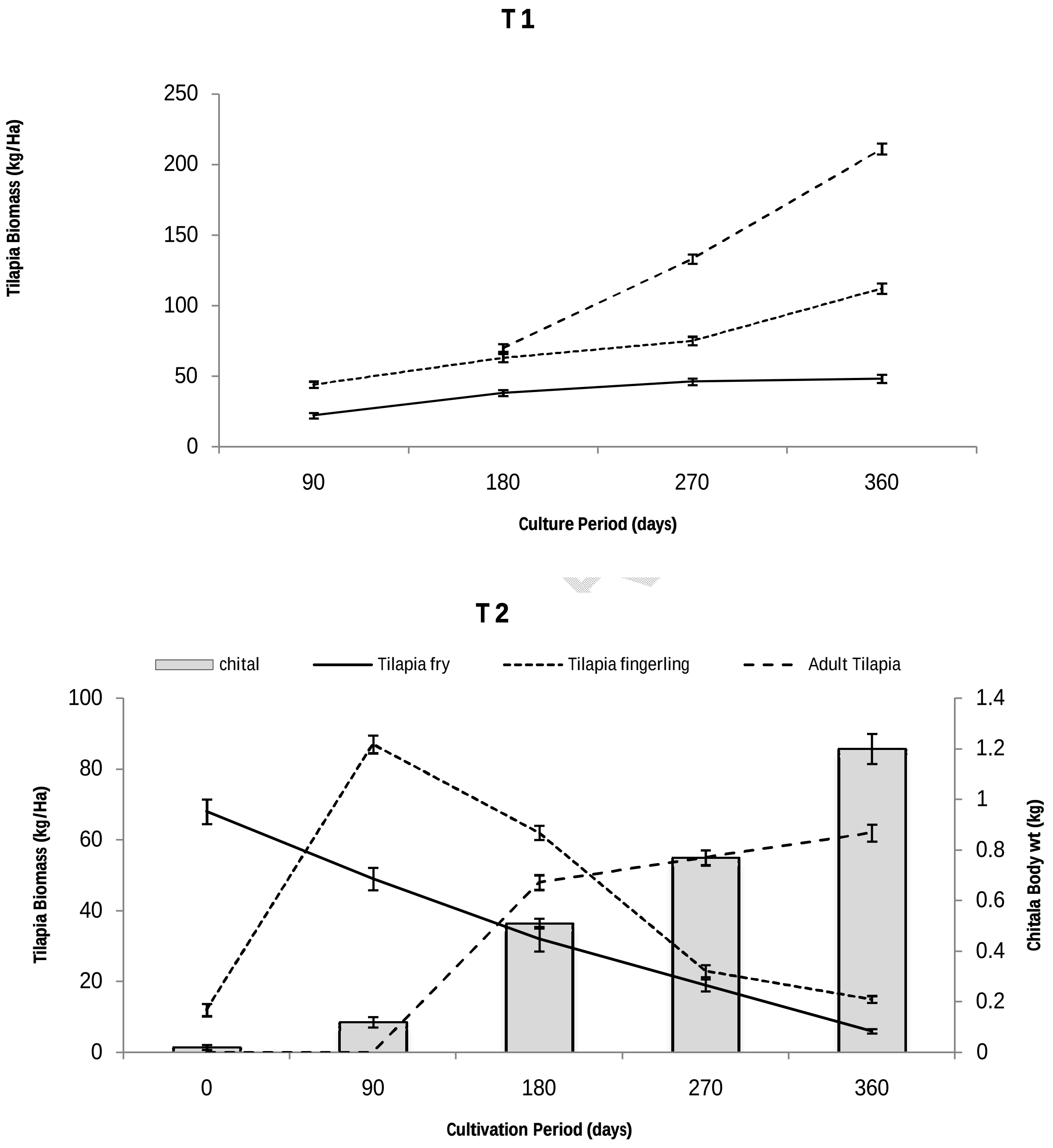
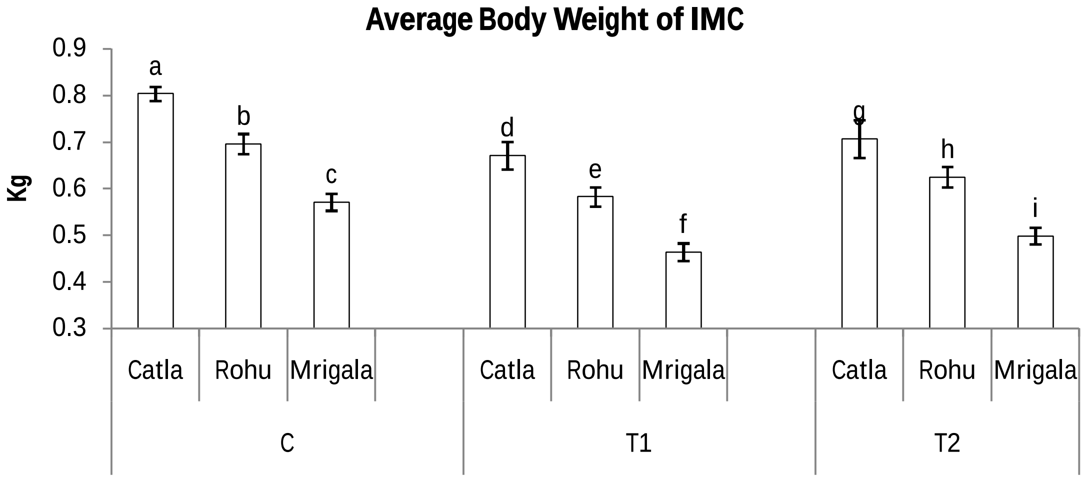


Figure 2. Body weight (Kg) variation of Indian Major Carps among different treatments after harvesting



Average Body Weight of IMC
Kg
0.9
0.8
0.7
0.6
0.5
0.4
0.3
a
b
c
d
e
f
g
h
i
Catla
Rohu
Mrigala
Catla
Rohu
Mrigala
Catla
Rohu
Mrigala
C
T1
T2