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LOGISTIC GROWTH AND DENSITY-DEPENDENT SPATIAL AND TEMPORAL INVASION PREDICTIONS OF NON-NATIVE TILAPIA, *Oreochomis niloticus* (Linnaeus 1757), IN THE GANGA RIVER (INDIA)

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ABSTRACT

The changes in fishery yield owing to the exponential and logistic growth of non-native tilapia *Oreochomi niloticus,* was studied and its concrete and predictive invasion worked out so as to find out future level of invasion and yield from the Ganga river, India. The results showed that the abundance of *O. niloticus* ranged from 3.07 to 15.05% during 2009 to 2018 which increased continually at eight studied locations. At the same time, the average biomass yield day^{-1} also increased significantly ($p < 0.05$) in the same period. The calculated mean abundance by weight (MAW) showed that the average biomass was 51.95 kg day^{-1} km^{-1} during 2009 which increased to 151 ± 3 kg day^{-1} km^{-1} in 2018 showing 292% rise within a decade. The biomass-dependent tilapia population revealed significant ($p < 0.05$) increase in exponential and logistic growth over the years even in the degraded water quality having higher BOD and COD. The predicted increase in the mean abundance by weight-based biomass showed significant change and the annual-regression was $p < 0.419$ considering the incremental exponential and logistic growth. The predictive forecast of invasive tilapia catches for the period of 2018 to 2028 at 95% confidence limit suggests stable production from the Ganga river inviting attention of scientists and managers towards its management.

Keywords: Abundance, growth, logistic biomass, prediction, tilapia

INTRODUCTION

Riverine fishery of the Ganga basin supports one of the largest fishing populations in India (Sarkar *et al.*, 2017). However, its fish resources are rapidly declining due to large dams, barrages and hydropower projects causing severely altered river flows, fragmentation of hydrological connectivity between rivers and wetlands, alarming levels of pollution, riverfront encroachment, rampant sand mining (Sarkar *et al.*, 2012; Joshi, 2017), unregulated overexploitation and non-native fish invasions (Singh and Lakra, 2011; Singh *et al*., 2013). The Ganga river system exhibits great species diversity in terms of composition, abundance and phylogeny. As per the recent database developed by the ICAR-National Bureau of Fish Genetic Resources (NBFGR), Lucknow, India (Anon., 2019) there are 3535 finfishes of which 3035 are native and 500 are non-native to India representing 46 orders, 252 families and 1,018 genera. Out of 3035 native fishes, 1016 are freshwater, 113 brackish and 1906 marine fish species.

Fish invasion is a relatively young branch of science dealing with the establishment and spread of an introduced non-native species (Leprieur *et al.*, 2008; Singh *et al.*, 2013; Alexander *et al*., 2015).

Unintentional releases and escape of tilapia is now-a-days infused in the Ganga river (Singh *et al.*, 2014). Some studies have proposed that increased global temperatures could exacerbate the effects of species invasion by allowing colonization of a non-native species to newer areas (Hellmann *et al.*, 2008). Hydrological conditions have also been documented conducive to the invasion of aquatic species, where poor environmental flow conditions are more suitable to invaders than natives (Joshi, 2017; Xia *et al.*, 2019). The contribution of major carps and large catfish (important commercial species) has drastically lowered while non-native common carp and tilapia have increased sharply in recent times in the Ganga river particularly in the mid-stream (Singh *et al.*, 2013; Sarkar *et al.*, 2017).

The invasion impacts of non-native tilapia on fishery has not so far adequately been addressed especially considering the logistic growth and fishery dynamics of a large freshwater Ganga river system of the country. A total of ten introduced non-native fish species *viz*., *Oreochromis mossambicus, O. niloticus, Cyprinus carpio, Hypopthalmicthys molitrix, Ctenopharyngodon idella, Clarias gariepinus, Aristichthys nobilis, Pterygoplichthys disjunctivus*, *Piaractus brachypomus*, *Pangasianodon hypophthalmus,* have been reported from the Ganga river (Singh and Lakra 2011; Singh *et al.*, 2013). Amongst the non-native fish species, Nile tilapia *Oreochromis niloticus* has relatively largely gravitated into the Ganga river and its population is not only phytophagous but herbivorous having potential to exert direct impacts on a wide range of native fish species through predation and changes in aquatic environment and trophic conditions (Zambrano *et al*., 2006; Singh *et al*., 2013). In this study, the changes in fishery yield, owing to exponential and logistic growth of non-native tilapia, *O. niloticus,* has been presented and its concrete and predictive invasion has further been worked out so as to find out future level of invasion and yield from the Ganga river during the next decade. The objective of this study has been accomplished from hyperbolic growth function by calculating logistic growth and density-dependent factors showing data fits for the period from 2009 to 2018 and to predict future invasion changes during the upcoming decade 2019-2028.

MATERIALS AND METHODS

Location

The study area covered approximately 450 km stretch downstream of the Ganga river starting from Kanpur and covering the districts of Kannauj, Unnao, Prayagraj, Mirzapur, Varanasi, Ghazipur and Ballia of Uttar Pradesh (India). The entire study area harbours a rich aquatic biota including fish, plankton and benthic invertebrates, which are very sensitive, and highly influenced by intense anthropogenic activities, including bathing, pilgrimage and boating activities (Fig. 1).

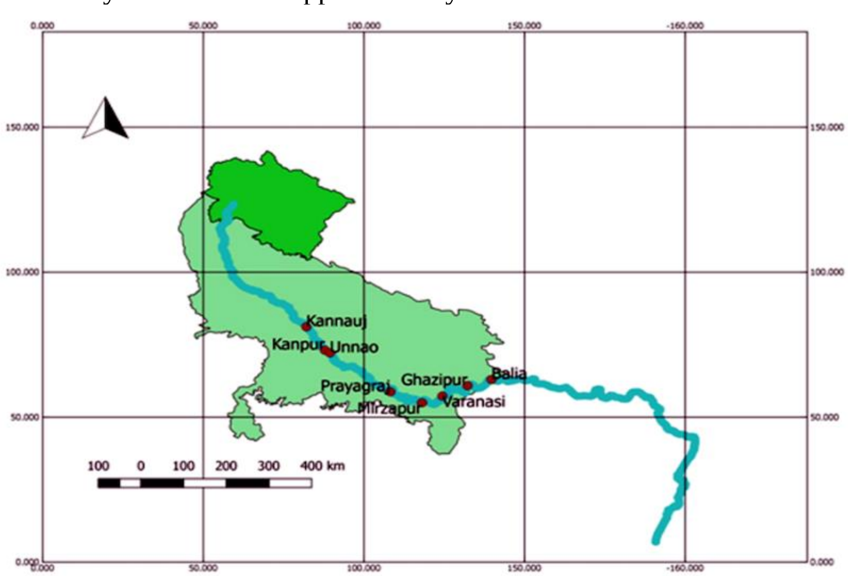

Fig. 1: Map showing study locations along mid-stream of the Ganga river

Fish catch data and tilapia biomass

Data on the catch of non-native *Oreochromis niloticus* was collected in the Ganga river during regular fishing exercise made by fishermen at different fish landing areas of bridge area in Kanpur, Mehdi ghat in Kannauj, Shuklaganj in Unnao, Daraganj in Prayagraj, Adalhat in Mirzapur, Saraimohana in Varanasi, Dadrighat in Ghazipur and Gangaghat in Ballia districts in Uttar Pradesh (India) by using mostly boats, gillnets, castnets and occasionally dragnet. The data were collected on quarterly basis for the study period. The catch per unit effort (CPUE) was calculated for each landing sites following the method described by Bucol *et al.* (2017). We used tilapia presence/absence data from catch statistics collected during the year 2009 to 2018, to build a data-set of tilapia occurrences in the mid-stream stretch of the Ganga river.

The CPUE was further converted as biomass percentage (Pi) of tilapia at individual study locations following the formula Pi = *Wi*/*Wt*, where *Wi* was the weight of tilapia *Wt* was the total weight from all catches. The biomass obtained from each location was then pooled for calculating total biomass (Pf) percentage of tilapia from all the studied locations as per formula: $Pf = Pi1 + Pi2 + Pi3 + Pi4 + P_{in}$ over the years (Arch Miller *et al.*, 2018) and the time rate change of tilapia biomass during the period of 2009 to 2018 was calculated as:

$$dP/dt \propto P \text{ or } dP/dt = aP \text{ the solution was } P = P_0\, e^{at}$$

Where P was the tilapia biomass at time t and P_0 was the initial biomass.

The exponential growth of tilapia biomass was then calculated using differential equation as follows:

$$dP/dt = kP$$

The logistic growth was calculated by the formula given below:

$a - bP / a$, where a and b are the vital coefficients of the tilapia biomass.

The changes in the biomass in subsequent years was then determined as per formula given below:

$$K = a / b$$

The predictive biomass was calculated as per described methodology (Okubo *et al.*, 2017). Mean abundance by weight (MAW) was estimated (Leeseberg and Keeley, 2014). The changes in MAW was then calculated as biomass for the period from 2019 to 2028 (Laplanchea *et al.*, 2018). Logistic regression model-or “sight ability model”-fit to detection/non-detection data from marked population of the invaded tilapia was then extrapolated for the next decade i.e. 2019 to 2028.

For a given predictor p among n predictors, the weight was calculated using the following equation:

$$\text{Weight p} = \frac{\text{range (predicted degradation p)}}{\sum \text{i=1n range (predicted degradation i)}}$$

In this process, data was fitted for all years $t_{fitted} \in \{t_{initial}, \ldots, t_{final}\}$, and then average estimated abundance and weight for all studied areas was used to predict density $d(s, t)$ for all locations during forecast years $t_{forecast} \in \{t_{final} + 1, t_{final} + 2, t_{final} + 3 \ldots n\}$. Finally, population weight prediction was used to calculate the centroid of the population’s distribution:

$$Z(t) = \frac{\Sigma^{ns}_{s=1} Z(s) \times a(s) \times d(s,t)}{\Sigma^{ns}_{s=1} (a(s) \times d(s,t))}$$

Where $a(s)$ was the area associated with each location s, and $z(s)$ is a measure of location (km). The biomass data in terms of weight was pooled for entire stretch of 450 km of Ganga river. The future values of standard errors followed by probability values were calculated. The changes in mean abundance by weight (MAW) was calculated as biomass at $\Delta Y_{MAW} (\Delta t / t_{final})$ for forecasting temporal biomass from 2019 to 2028 as year t_{final}:

$$\Delta Y_{MAW} (\Delta t / t_{final}) = Y (t_{final} + \Delta t) - Y (t_{final})$$

Where $\Delta t \in \{2019\text{-}28\}$, the change in centroid was $\Delta Y(\Delta t/t_{\text{final}})$ over Δt and the forecasting year for calculating data through years 2019 to 2028 was t_{final}. The forecasted centroid as Y_{CE} (t_{forecast}/ t_{final}) in year t_{forecast} was done using data through t_{final} and the growth model:

$$\Delta Y_{CE}\ (\Delta t/t_{\text{fina}})\ l = Y_{CE}\,(t_{\text{final}} + \Delta t/t_{\text{final}}) - Y_{CE}\ (t_{\text{final}}/\ t_{\text{final}})$$

The variance are explained as $R^2(\Delta t) = 1 - V(\Delta t)$, a model performing as well as the persistence forecast which had $V(\Delta t) = 1$ and $R^2(\Delta t) = 0$, while a model with $R^2(\Delta t) > 0$ outperforms the persistence forecast while a model with $R^2(\Delta t) < 0$ had degraded performance relative to a persistence forecast (Draper and Smith, 1998).

Water quality monitoring

Indicator water quality consisting of pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD) and alkalinity was determined on quarterly and on annual basis for the period from 2009 to 2018 using standard methods of APHA (2012) so as to capture the changes/ modifications/ transformations in the water quality.

Statistics

All data were presented as mean ± SE. Field data obtained from different study locations were subjected to one-way analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS), version 8.1. The correlation coefficients between the water quality parameters from different locations were calculated by Pearson's correlation analysis. Parameters were further analyzed statistically at 5% significance level.

RESULTS AND DISCUSSION

The observed water quality (temperature 16±3.2 to 30±0.9°C; pH 6.9 ± 0.4 to 7.8 ± 0.6; DO 5.1 ± 1.1 to 8.1 ± 1.0 mg L^{-1}; BOD 1.4 ± 1.8 to 4.8 ± 1.1 mg L^{-1}; COD 8.1 ± 1.6 to 40.8 ± 1.2 mg L^{-1}) during monitoring of the physicochemical values of the Ganga water were significantly ($p < 0.05$) higher than the optimal required values reported for tilapia (FAO, 2012). The comparative assessment of water quality with predefined criteria or standards set for determining like habitat of tilapia revealed the existence of habitat plasticity and endurance for harsh aquatic environment. Interestingly the tilapia biomass-dependent populations behaved differently as the fish catch data was more abundant in the degraded water quality. These findings confirmed a positive correlation of abundance even in degraded water quality (Dwivedi *et al.,* 2017) over the years for adapting deteriorated habitat for invasion and expansion. The biomass of tilapia was observed high in degraded water quality as confirmed by correlating the exponential and logistic growth with COD and BOD. The spread of tilapia in the Ganga river has been found closely related to the adversities of the aquatic environment while there was a decline in the abundance of local fish (Singh *et al.,* 2013; Sarkar *et al.,* 2017; Pathak, 2018).

The life cycle of *O. niloticus* is short (3-6 months) and the spawning frequency is generally three to four times (Singh *et al*., 2013; Ishikawa *et al*., 2013). The inter-annual analysis of tilapia abundance showed a gradual upward trend for the period from 2009 to 2018 (10 year). However, the increase was much pronounced between 2015 to 2018 in all studied locations (Fig. 2). The correlation coefficient generally showed an increasing trend for tilapia abundance from 2009 to 2018 at different locations (Fig. 3). The abundance of *O. niloticus* ranged from 3.07 to 15.05% during 2009 to 2018 which was observed to continually increase at different locations during study period, except at Kanpur and Kannauj where the presence of tilapia was hardly observed. However, it was most abundant at Prayagraj followed by Varanasi, Ghazipur, Mirzapur and Ballia, respectively. The absence or stray occurrence of tilapia at Kanpur or Kannauj could be possibly due to the fact that it

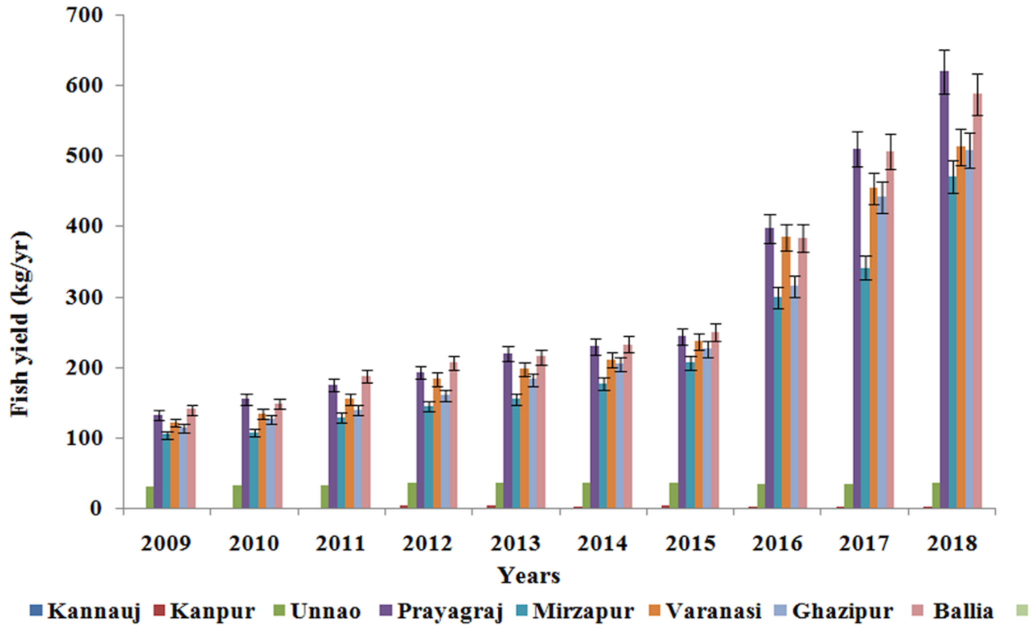

Fig. 2: Fish yield rate (mean ± SE) at study locations in mid-stream of the Ganga river

does not prefer ascending upstream rather moving downstream of the river. Nevertheless, tilapia in the Yamuna river was abundantly present in Kanpur but outside the Ganga river (Singh *et al.*, 2013).

While calculating the abundance over the graphical perspective, it was observed that growth rate of tilapia was according to the biomass at different studied locations. For tilapia biomass-independent populations at Kannauj and Kanpur, there was hardly any growth while for tilapia biomass-dependent populations at other locations, growth increased over the base year 2009. Consequent upon the population mass increase, population growth increase represented straight line year after year (Fig. 4). The time series catch data, statistical significance value was $p < 0.05$ for the

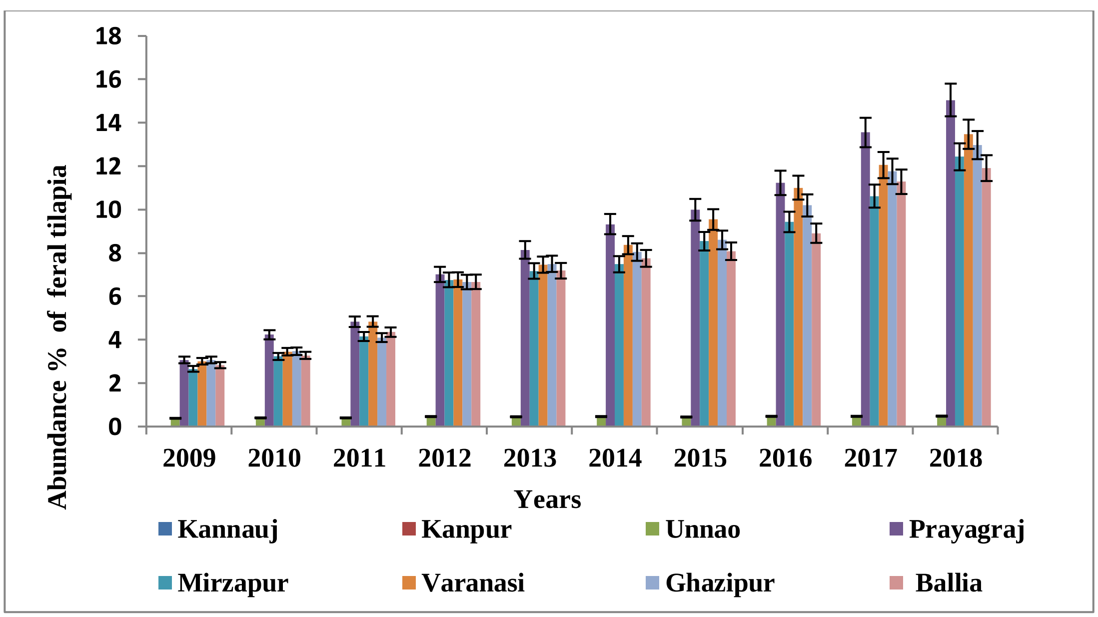

Fig. 3: Year-wise abundance % (mean ± SE) of non-native tilapia in mid-stream of the Ganga river

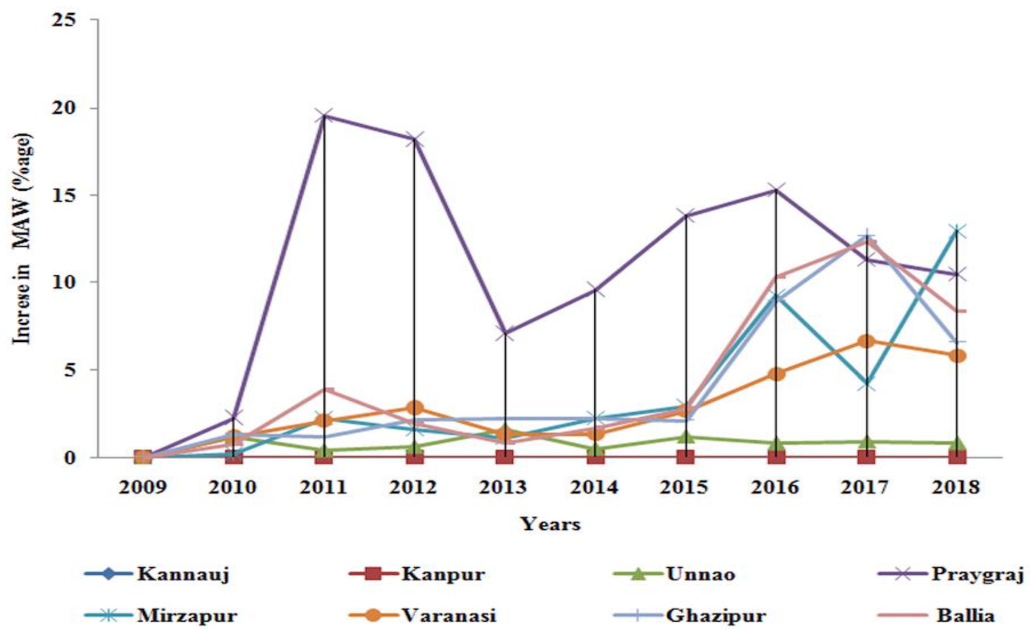

Fig. 4: Exponential and logistic growth of non-native tilapia in the mid-stream during 2009-2018

year 2012-2013 and $p < 0.001$ for the year 2017-2018 validating the observed catch data series. The fish yield rate kg km^{-1} of local fish species declined from 128.91 to 38.58 kg km^{-1} while there was a sharp increase in the catches of non-native invasive tilapia (Singh *et al.*, 2013; Laxmappa *et al.*, 2015; Bucol *et al.*, 2017).

The calculated exponential and logistic growth for the study period of 2009 to 2018 was found to depict 'J' shape at all study locations which was highly pronounced during 2011-2012 and 2015-2016 (Fig. 4). The exponential growth was 19.55% during 2011 and 18.19% during 2012 which followed an increase of 11.3% during the years 2017 and 10.5% during 2018 depicting similar trend (Fig. 4). The logistic growth showed maximum population growth rate depicting nearly J-shaped curve particularly at Prayagraj and Varanasi over time scale (Fig. 4). However, at other locations downstream Varanasi to Ballia, the curve of logistic growth was although not exactly 'J-shaped' but it tended to pick-up J-shape. This indicated that the invaded population of tilapia at Prayagraj and Varanasi were well established from 2009 onwards whereas at other studied locations it was following similar trend particularly during 2015 onwards. Average per day biomass data in the mid-stream of the Ganga river was further observed to consistently increase significantly ($p < 0.05$) over the years starting from 2009 till 2018 and the recorded values were 53.44, 58.43, 67.91, 70.12, 84.45, 90.9, 100.4, 132.37, 148.7 and 151.08 kg day^{-1} km^{-1} month^{-1}, respectively. However, the increase in MAW of tilapia was very conspicuous and highly significant ($p < 0.001$) during the period from 2016 to 2018 as compared to the base year value in 2009. The evaluated temporal predictive values for forecasting years (2019 to 2028) based on MAW values were fitted on Shewhart chart and the observations are presented (Fig. 5). The calculation for MAW based concrete value showed that the average biomass was 51.95 kg day^{-1} km^{-1} during 2009 which increased to 151 ± 3 kg day^{-1} km^{-1} in 2018 showing 292% rise in a decade time. However, the stablished population of tilapia showed predicted value of 170 ± 6 kg day^{-1} km^{-1} in 2028. The concrete and forecast values were calculated considering 95% lower and upper level of confidence, which was significant ($p < 0.05$) and the annual-regression was found $p < 0.419$. The confidence limit of 95% for the forecasted variance in distribution had little correlation with observed distribution. The median variance was low but it was positive for the annual-regression (0.02–0.3) for concrete value. However, it was higher (0.06–0.39)

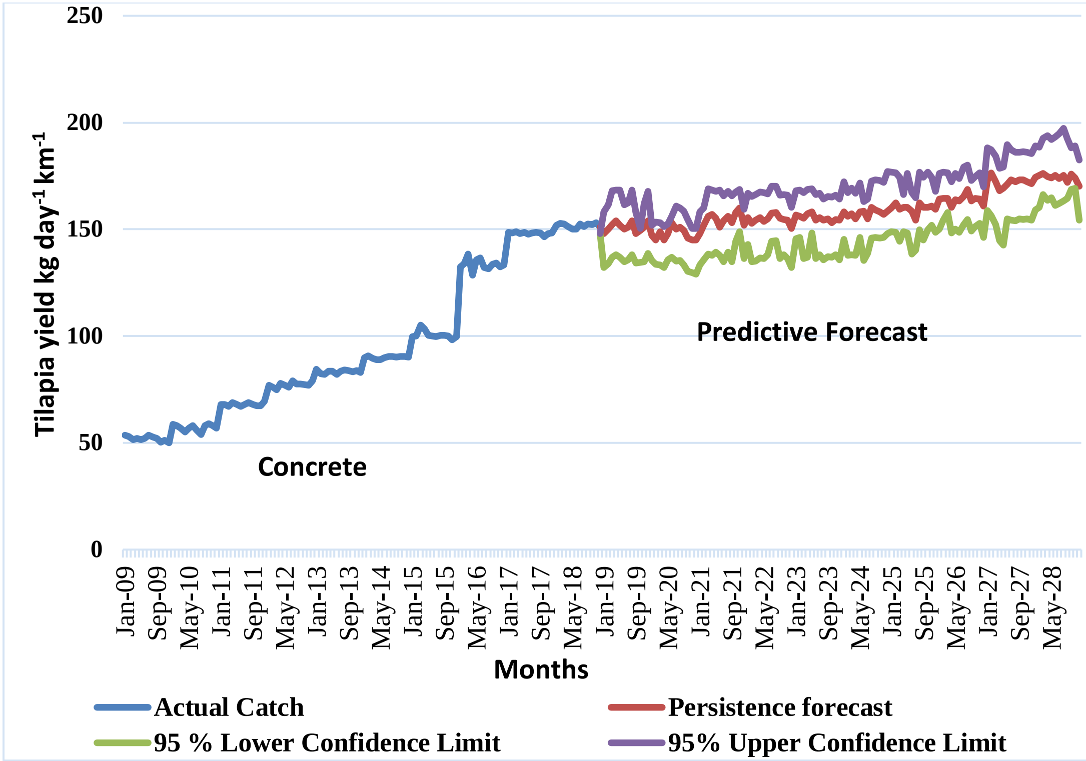

Fig. 5: Shewhart chart for spatial and temporal concrete tilapia yield for the period (2009-2018) and predictive forecasting for the period (2019 to 2028) in the Ganga river

for forecasted values showing that the general variance for next 10 year of forecast increased faster. Hypothetically, obtained value for variance of R^2 (Δt) was 0.326 which explained that 15.05% of the variance may occur in future. The observed MAW based forecast of non-native tilapia catch for the period of 2018 to 2028 at 95% confidence limit suggests a stable tilapia production in the river (Schnute, 1981; Lugert *et al.*, 2019). Similar predictive models have been used by other workers supporting our findings (Budy and Gaeta, 2017; Lugert *et al.*, 2017; Esther *et al.*, 2019) using incremental exponential and logistic growth functions. *O niloticus* has been observed to establish a sizable population contributing substantially to the fishery of mid-stream of the Ganga river. At the same time, Common carp *Cyprinus carpio* has already invaded on the same locations indicating that the trophic conditions created by these two worst invasive species are suitably supporting each other (Singh *et al.*, 2010; Singh *et al.*, 2013) and the entire invasion process shows a clear invasion meltdown (Simberloff, 2006).

Conclusion: It is expected that trophic changes in the Ganga water owing to fast invasion of tilapia would affect the survival of the fry and fingerlings of local fishes while non-native tilapia would survive better in the changing conditions. It is thus, non-native tilapia has the capacity to exhibit substantial growth in the Ganga river even in adversely changing environmental conditions. There is every possibility that tilapia will spread even in other areas of the Ganga river basin due to its high adaptability and better survival. Predictive logistic growth and biomass of the invaded tilapia warrant fishery managers to develop regulatory framework to contain it.

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Conflict of interest: The authors declare that they have equally contributed towards conceptualizing and data analysis work, while preparing the manuscript. We also declare that there is no conflict of interest.

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