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Establishment and impact of exotic *Cyprinus carpio* (Common Carp) on native fish diversity in Buxar stretch of River Ganga, India

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The catch pattern of the exotic Common Carp (Cyprinus carpio) *and their relationship with water quality along with maturity status of fishes were assessed during 2017-2019 to understand overall establishment and impact of the species in Buxar stretch of River Ganga in West Bihar, India. A total of 64 fish species were recorded including two exotic fishes* (C. carpio and Oreochromis niloticus) *from the river stretch during the study period. The annual production data depicted* Cyprinus carpio *to be the most dominating fish species encountered from the study area sharing 57.07% (by weight) during the period 2017-19. Calculated average 'Invasion coefficient index (I_x)'of 0.25 in entire three-year study period revealed that the invasion has moderately impacted the indigenous fish diversity. Landing of Indian Major Carp (IMC) indicated severe decline (76.4 - 95.6%) in comparison to the catch data recorded earlier from Buxar. Data generated on sex structure of Common Carp indicated that the overall sex ratio showed positive recruitment within the smaller size range of 282-307 mm and thus avails a competitive breeding advantage over other carp fishes. Gut content of Common Carp from the stretch observed major share of phytoplankton (81.04%) and zooplankton (17.18%) and thus there are significant dietary overlap of Common Carp with other valuable species. The stretch has been impacted with anthropogenic loading as identified through significantly higher water specific conductivity (580 μScm^{-1}), Biochemical Oxygen Demand (3 mgl^{-1}), etc. in drastically reduced water discharge regime. Among different water parameters, river flow, Biochemical Oxygen Demand and Total Phosphate showed positive whereas specific conductivity showed negative correlation with Common Carp seasonal abundance. Future conservation management measures may be formulated keeping in view of the identified factors through the present study for reducing the impending risks of the invasive fish species in Buxar stretch of River Ganga.*

Keywords: fish biodiversity, riverine health, invasive fish

Introduction

River Ganga, sustains rich fish biodiversity of more than 266 fish species (Vass et al., 2010) contributing a substantial percentage of important ecological services to the society. Riverine fisheries contribute significantly to the livelihood as well as act as a key source of protein for the riparian community (Pathak et al., 2013). However, in recent years, alterations in river water quality (physico-

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chemical characteristics) and several other factors have resulted in decreased native fish yield (Sinha and Khan, 2001) affecting the fish community as a whole (Khanna et al*.,* 2007). Ecological integrity of River Ganga is at stake owing to severe anthropogenic interventions such as construction of dams and barrages, invasion of exotic fish species, etc. (Lakra et al., 2008). The induction of exotic fishes in a natural ecosystem ramifies constant threats on native biodiversity (Singh and Lakra, 2006). Freshwater ecosystems are highly susceptible to exotic species invasions leading to huge biodiversity loss (Dudgeon et al., 2006). Introduction of exotic fishes in natural aquatic systems around the world have resulted in various threats to the trophic structure finally misbalancing the sustainable biological veracity (Casal, 2006). The outcome of exotic invasions leads to the decline of native species through hybridization, predation, competition etc. (Blackburn et al., 2014). The species *Cyprinus carpio* (Common Carp) has been reported to evolve from Caspian Sea and is now established in 91 out of 210 countries in the world (Casal, 2006). This highly invasive species is the most detrimental among all freshwater invasive fishes (Crivelli, 1983) and long being observed having a deleterious effect on indigenous fish species worldwide (Vilizzi et al., 2015).

This exotic carp has paved its way in several inland water bodies of India including the mighty River Ganga. The exotic Common Carp (*Cyprinus carpio communis*) was introduced in India way back in 1959 from Bangkok for propagating aquaculture practices in the country (Pathak et al., 2011). Dominance of Common Carp in middle stretch of River Ganga is well documented by several workers in recent years (Sarkar et al., 2012; Singh et al., 2013; Jha et al., 2016). Increased abundance of Common Carp strongly impacted native fish diversity including Indian Major Carps which has showed a drastic declining trend as compared to the past (Singh et al., 2010). However, long-term systematic studies on occurrence and establishment of exotic species like *C. carpio* in different stretches of Ganga is still to be addressed on a large scale. The profound impact of invasive fish species in coordination with environmental factors towards the resident fish species requires a clear understanding. This in turn could help in creation of specific management measures. In this background, a study was undertaken to assess the dominance and impact of the invasive Common Carp on indigenous fish diversity in Buxar stretch of River Ganga over a time period of three years. The factors identified in the present investigation might help to formulate a possible framework towards examining the effects of Common Carp over other endemic Gangetic fish fauna.

Material and Methods

Study area

River Ganga after passing through Varanasi in Uttar Pradesh traverses about 130 km before reaching Buxar in West Bihar. Here, the river cut across two common banks bordering Uttar Pradesh (Balia District) and Bihar. As per 2011 census, the region hosts 1002 people per sq.km. Agriculture is the main occupation of the region and forms the mainstay of the livelihood. Rivers like Son and Ganga are the two perennial sources for irrigation. The study area receives moderate tropical climatic regime with annual mean air temperature of 35°C and peak monsoon period from June to September. Organic load originating from surrounding villages and towns are the major sources of river pollution.

Data collection

Field survey was conducted during 2017-2019 on quarterly basis to investigate the present catch trend of native fishes and exotic Common Carp (*Cyprinus carpio*) in Buxar (Bihar) stretch of River Ganga. Overall, three sampling sites covering upstream and downstream of the river were sampled for the study. The sampling stations are Bharauli pool (S1) (25º33’50’’N, 83º56’28’’E), Nasirpur math (S2) (25º34’51’’N, 83º58’13’’E) and Kotwa narayanpur (S3) (25º35’25’’N, 83º59’28’’E) (Fig. 1). The sampling points were selected on the basis of varied catch composition and exotic abundance, thus representing the entire fish species spectrum of the area. Samples of Common Carp and other indigenous fishes were collected directly from the local and commercial catch of the fishers who were using multiple fishing gears like drag nets, hook and lines and multi meshed gill nets (10-90 mm). Fish species collected were identified using taxonomical

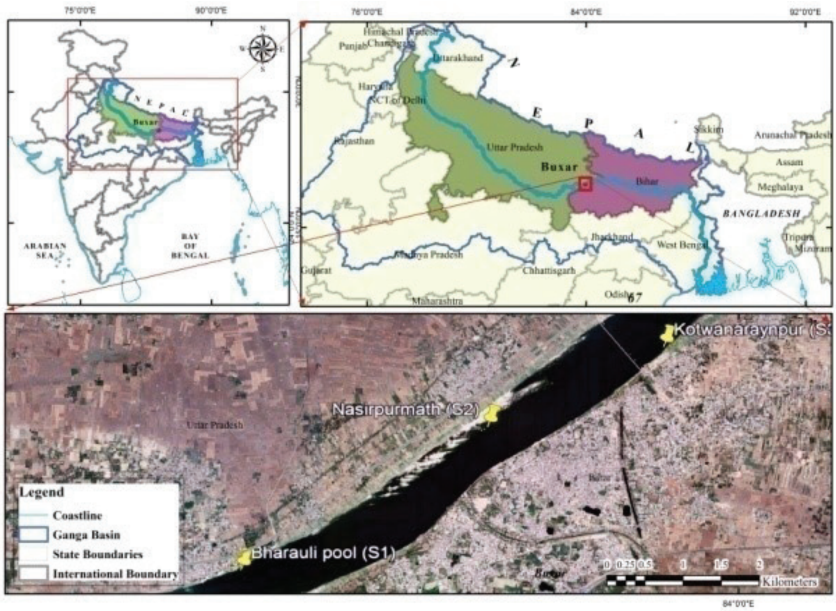

Figure 1. Sampling locations in river Ganga at Buxar, Bihar, India.

keys (Talwar and Jhingran, 1991) and were further categorized under respective threatened category following IUCN (2020). Length of the fishes was measured using Vernier calipers (nearest 0.01 mm), counted and weighed using portable digital balance. Each individual was also dissected for determining sex. For studying fish feeding behaviour, gut content of the fish species was randomly collected and preserved in 5% neutral buffer formaldehyde solution and brought to the laboratory for further analysis. The stomach contents were examined under microscope and identified up to the genus level. Catch data of both resident and exotic were estimated by calculating the total quantified weight of the fish species available in a landing centre on particular day to reveal the pattern of landing. Physico-chemical parameters of river water were assessed following standard methods (APHA, 2017) at the sampling stations.

Data analysis

Abundance (%) values of native fishes were calculated by dividing its number by the total available individuals collected through a representative random sampling from all different fishing gears presently being operated in the river stretch. Invasion index (Ix) was computed to assess the rate of impact. Application of the index helps in determining the rate up to which a particular alien species has invaded in a particular system and was calculated on the basis of exotic abundance (En) with respect to other native riverine fish species (N) (Singh et al., 2013). Value near 0 depicts lesser loss of native fish diversity, whereas value near 1 result in higher rate of loss. The relationship between length–weight (LWR) of Common Carp was calculated by the method of linear regression analysis using the formulae: Log W = Log a + b Log L (Where: W =Body weight (gm), L =Total length (cm) and 'a' is the intercept and 'b' is the slope of the linear regression on the logarithmic value of weight and length). Principal Component Analysis (PCA) was employed using R software (R core Team 2015) to analyze and detect the major parameters which act as driving forces for water quality variations and eventually influencing *C. carpio* productions. A total of 16 water quality parameters were taken into consideration for PCA analysis. Further, based on principal component loadings, total number of parameters was reduced to few important parameters which significantly contributing to the total variance. Finally, correlation coefficients were calculated between the selected significant parameters with the *C. carpio* production to determine the major influencing parameters.

Table 1. Abundance, habitat and conservation status of fish species recorded at surveyed stretch in River Ganga

Sl.	Fish species	Family	Order	Abundance % by no.	Abundance % by wt.	Size range (mm)	Habitat	IUCN status
1.	*Notopterus notopterus*	Notopteridae	Osteoglossiformes	1.9	0.02	181-210	DM	LC
2.	*Chitala chitala*			0.4	0.01	210-315	DM	NT
3.	*Corica soborna*	Clupeidae	Clupeiformes	N/A	0.01	23-35	PG	LC
4.	*Gonialosa manmina*			1.2	0.91	71-126	PG	LC
5.	*Gudusia chapra*			2.1	1.30	88-175	PG	LC
6.	*Setipinna phasa*	Engraulidae		1.3	1.66	61-192	PG	LC
7.	*Botia dario*	Botiidae	Cypriniformes	N/A	0.05	66-116	DM	LC
8.	*Botia lohachata*			0.6	0.05	36-84	DM	NE
9.	*Lepidocephalicthys guntea*	Cobitidae		N/A	0.40	54-74	DM	LC
10.	*Chagunius chagunio*	Cyprinidae		1.9	0.24	97-116	DM	LC
11.	*Cirrhinus mrigala*			0.6	0.05	102-280	DM	LC
12.	*Cirrhinus reba*			0.9	2.79	112-153	BP	LC
13.	*Cyprinus carpio**			16.9	33.85	91-430	BP	LC
14.	*Tariqilabeo latius*			N/A	0.13	85-112	BP	LC
15.	*Labeo rohita*			2.4	0.07	175-415	BP	LC
16.	*Labeo calbasu*			4.8	0.17	125-483	DM	LC
17.	*Catla catla*			3.4	0.04	200-540	BP	LC
18.	*Labeo bata*			0.4	1.97	90-136	BP	LC
19.	*Labeo boga*			0.9	1.38	98-113	BP	LC
20.	*Pethia gelius*			N/A	0.04	30-42	BP	LC
21.	*Pethia ticto*			N/A	0.14	43-69	BP	LC
22.	*Pethia conchonius*			1.0	0.68	42-64	BP	LC
23.	*Puntius sophore*			1.2	0.90	73-102	BP	LC
24.	*Osteobrama cotio*			3.1	0.91	83-96	BP	LC
25.	*Systomus sarana*			0.6	0.61	71-135	BP	LC
26.	*Esomus danrica*	Danionidae		0.8	0.09	N/A	BP	LC
27.	*Cabdio morar*			3.7	1.05	58-99	BP	LC
28.	*Devario devario*			N/A	0.02	43-74	BP	LC
29.	*Rasbora daniconius*			N/A	0.01	56-79	BP	LC
30.	*Salmostoma bacaila*			2.1	0.17	26-68	BP	LC
31.	*Ailia coila*	Aillidae		3.8	0.98	85-157	PG	NT
32.	*Aillicthys punctata*			0.9	0.25	74-127	PG	NT
33.	*Clupisoma garua*			2.3	0.31	108-269	DM	LC
34.	*Eutropiichthys murius*			1.2	0.15	109-248	DM	LC
35.	*Eutropiichthys vacha*			3.3	0.64	110-250	DM	LC
36.	*Silonia silondia*			0.6	0.20	138-389	DM	LC
37.	*Pachypterus atherinoides*	Horabagridae		1.1	0.47	66-95	DM	LC
38.	*Mystus cavasius*		Siluriformes	2.8	2.25	77-156	DM	LC
39.	*Mystus vittatus*			0.5	0.21	60-112	DM	LC

Table 1. *Continued.*

				Abundance				
Sl.	**Fish species**	**Family**	**Order**	**% by no.**	**% by wt.**	**Size range (mm)**	**Habitat**	**IUCN status**
40.	*Mystus tengara*	Bagridae		0.5	0.35	93-118	DM	LC
41.	*Rita rita*			3.9	5.22	98-455	DM	LC
42.	*Sperata aor*			2.2	1.55	88-465	DM	LC
43.	*Sperata seenghala*			1.8	1.97	72-464	DM	LC
44.	*Bagarius bagarius*	Sisoridae		1.5	1.01	162-470	BP	NT
45.	*Gagata cenia*			1.0	0.14	54-95	DM	LC
46.	*Sisor rabdophorus*			0.9	0.02	N/A	DM	LC
47.	*Ompok bimaculatus*	Siluridae		0.7	0.04	94-147	DM	NT
48.	*Wallago attu*			1.9	0.25	234-498	DM	VU
49.	*Heteropneustes fossilis*	Heteropneustidae		0.4	0.02	68-180	DM	LC
50.	*Glossogobius giuris*	Gobiidae	Gobiiformes	1.3	0.12	88-132	BP	LC
51.	*Macrognathus pancalus*	Mastacembelidae	Synbranchiformes	1.0	0.22	97-309	DM	LC
52.	*Mastacembelus armatus*			1.4	0.98	178-442	DM	LC
53.	*Ophichthys cuchia*	Synbranchidae		N/A	0.01	344-517	DM	LC
54.	*Channa marulius*	Channidae	Anabantiformes	0.3	0.44	124-319	BP	LC
55.	*Channa punctata*			1.4	0.28	106-183	BP	LC
56.	*Trichogaster fasciata*	Osphronemidae		0.2	0.02	48-64	BP	LC
57.	*Oreochromis niloticus**	Cichlidae	Cichliformes	3.1	30.52	93-436	BP	LC
58.	*Xenentodon cancila*	Belonidae	Beloniformes	N/A	0.02	189-248	PG	LC
59.	*Hyphorhamphus limbatus*	Hemiramphidae		N/A	0.01	63-108	PG	LC
60.	*Rhinomugil corsula*	Mugilidae	Mugiliformes	0.5	0.13	49-149	PG	LC
61.	*Leiodon cutcutia*	Tetraodontidae	Tetraodontiformes	0.1	N/A	36-59	DM	LC
62.	*Chanda nama*	Ambassidae	Perciformes	1.6	0.06	26-72	BP	LC
63.	*Parambassis ranga*			1.8	0.38	44-59	BP	LC
64.	*Johnius coitor*	Sciaenidae		2.4	0.96	72-135	DM	LC

*exotics; NT- Near threatened, LC- Least Concern, NE- Not Evaluated, VU- Vulnerable, DM- Demarsal, BP- Benthopelagic, PL- Pelagic

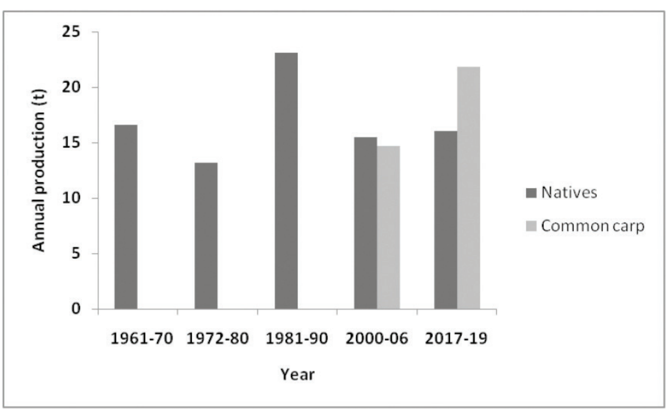

Figure 2. Annual landing data of native fishes and exotic *C. carpio* from Buxar stretch of River Ganga.

Results and discussion

Present status of native fish contribution in Buxar stretch

A total number of 64 native fish taxa were recorded from Buxar stretch of River Ganga belonging to 25 families and 12 different orders along with two exotic species (*Cyprinus carpio communis* and *Oreochromis niloticus*) (Table 1). The conservation status assessment of the native fish species revealed10% of the population is under threatened category (5 Near Threatened and 1 Vulnerable) as per IUCN red list (2020). Among major carps, *Labeo calbasu* contributed maximum (0.17%) with mean catch per day of 1.0 kg day^{-1} (avg.) in the stretch. Contribution of *Cirrhinus mrigala* was estimated to be 0.05% with size range of 175-415 mm. Reduced share of carps like *Labeo rohita* (0.07%) and *Catla catla* (0.04%) was also observed during the study period. Minor carp species having reasonable demand contributed to the tune of 6.14%, comparatively higher than IMCs. Among the commercially important catfishes, *Rita rita* shared maximum (5.22%) followed by *Mystus cavasius* (2.25%), *Sperata aor* (1.55%) and *S. seenghala* (1.97%). Relative abundance of clupeids like *Gudusia chapra* and *Gonialosa manmina* were estimated to be 1.30% and 0.91% respectively covering all three tropical seasons. Likewise, Spiny Eels (*Mastacembelus armatus* and *Macrognathus pancalus*) and featherbacks (*Chitala chitala* and *Notopterus notopterus*) contributed merely to the range between 0.20-1.00 % and 0.01-0.02 % respectively. In case of small indigenous fishes (SIFs), species like *Cabdio morar* (1.05%), *Johnius coitor* (0.96%) and *Osteobrama cotio* (0.91%) were found to be more abundant species contributing significantly to the total catch.

Present status of Common Carp contribution in Buxar

The quantitative picture of annual fish production (t) of both Common Carp and native fishes from 1960's to 2019 has been shown in Figure 2. The results showed that average annual catch of Common Carp increased from 14.65 t during 2000-06 to 21.86 tonnes during 2017-2019 in Buxar stretch. Jha et al., (2016) made similar observations from Allahabad stretch of Ganga, where Common Carp production increased from 20.81 to 60.29 tonnes during the period of 2002 to 2015. This certainly depicts its remarkable growth rate, good adaptability in a suitable hydroecological condition.

Cyprinus carpio was recorded to be the most dominating fish species encountered from the study area sharing 57.07% (by weight) during the period 2017-19. The annual average yield per day was estimated 19.17 kg day^{-1} between sites S1 and S3 during the present study, which was almost at par with the yield observed from Allahabad stretch of River Ganga (Tripathi et al., 2017). The species was confronted in all three seasons with its peak extending from August to November during which the percentage catch may even rise up to 43.67%. The population of the catch was chiefly dominated by the size ranging from 201-324 mm. In analogy with the native fishes, almost proportionate contribution of Common Carp was noticed in the year 2017 (30.07%) and 2018 (29.06%), while sharp increase in Common Carp abundance (42.44%) was recorded in 2019. The average value of Invasion coefficient index (Ix) resulted 0.25 during the course of study indicating that the invasion has exerted moderate impacts on the native riverine fish biodiversity (Table 2).

Table 2. Results of Invasion Index over three years of study.

Year	Invasion coefficient index (Ix)
2017	0.31
2018	0.24
2019	0.21
Average	0.25

Impacts of Common Carp invasion on native fishes of River Ganga

The present study clearly indicated the superiority of *Cyprinus carpio* in Buxar stretch of River Ganga over other native fishes with proportionate contribution of 29.06% to 42.44% (by number). Considerable decline of major carp landings was also noticed in the region from 3.26 tonnes to 0.33 tonnes reflecting an average decline of 88.57% during the period of 1984-85 to 2017-

19 (Table 3). Studies suggest that Common Carp is a year-round spawner exhibiting high breeding frequency and asynchronous spawning behaviour (Gupta, 1975) under controlled conditions. Presence of breeding population of Common Carp in the river stretch as identified in the present study confirmed its local spawning, similar to observation of Singh et al., (2010) from Kanpur to Varanasi stretch of the river. The reproductive potentialities found from the samples of early life stages (282-307 mm) of the species specify its capability for establishment in the stretch as the species is known to display early sexual maturity, wide environmental tolerance and rapid expansion (Singh and Lakra, 2006). Moreover, there are evidences that Common Carp invades on breeding grounds of other fish species (Taylor et al., 1984), thereby, reducing their population cycle. Consequently, the species while feeding from the substratum often disturbs the bottom sediments resulting in an increase in turbidity (Cahoon, 1953) which can generate serious problems for native species to dwell. Gut content analysis of adult Common Carps (more than 100 mm) captured from the studied river stretch revealed a significant portion of plant material (Bacillariophyceae 46.84%, Myxophyceae 24.96%, Chlorophyceae 9.08%, Desmids 0.17%), animal material (Zooplankton 17.18%) and decay matter (1.78%) respectively. However, previous observations on other native fishes like *Labeo rohita*, *L. calbasu* and *L. bata* depicts similar feeding preferences indicating possible chances of dietary overlapping (Mookerjee, 1945; Tripathi et al., 2013). Therefore, increased appearances of an alien population may lead to long term changes in resource competition and finally may pave way for community displacement.

Table 3. Estimated Annual fish landing (t) at Buxar in River Ganga.

Major species	1984-85*	2017-19	% Decrease
Labeo rohita	0.53	0.07	86.8
Catla catla	0.88	0.04	95.5
Cirrhinus mrigala	1.13	0.05	95.6
Labeo calbasu	0.72	0.17	76.4
Sperata aor	2.22	1.55	30.2
Wallago attu	1.87	0.35	81.3
Miscellaneous	15.48	13.79	10.9

* CIFRI Annual Report (Anonymous, 1985)

Biological factors behind establishment of Common Carps

The constant rise of several impending factors is the major reason behind successful establishment of invasive fish species thereby disturbing the ecological integrity of River Ganga (Singh and Lakra, 2011). Observations on the mature size composition of *C. carpio* revealed a range between 204-386 mm in total length and 277-610 gm in weight (Fig. 3). In case of mature stock, size group of female fishes were found to be dominant compared to the male in 282-307 mm, 308-333 mm, 334-359 mm and 360-386 mm. In our study, about 30 % of the gravid female stock was recorded in the size class of 308-333 mm. In contrast, male proportion was listed higher than female in 204-229, 230-255 and 256-281 mm (TL) size groups. Fully mature females were observed in the size groups of 282-307, 308-333 and 334-359 mm with sex ratio 3:4, 6:17 and 1:5 respectively indicating its late maturity in the Ganga river system. This shows that the overall sex ratio depicted positive recruitment within the smaller size range of 282-307 mm in the Buxar stretch of River Ganga and thus availing a competitive breeding advantage over other carp fishes. Maximum value of Gonadosomatic index (*IG*) of *C. carpio* have been observed in the period from February-March and July-August from the river (Singh et al., 2010) which signifies two peak breeding seasons in a year. In addition to this, maturation of Common Carp is rapid in tropical countries and varies substantially with climatic condition (specifically temperature) in Indian plains (18-35˚C) (Sharma and Rathi, 1974); however, the present findings are in agreement as similar temperature variation (20.5-35.4°C) was recorded from the study site (Table 4).

Length weight relationship

A total of 121 representative samples of Common Carp were collected from the study site to determine LWR. The total length and total weight of the species varied from 91-430 mm (avg. 24.10 ±7.01) and 9.69- 578.0 g (avg. 280.99 ± 176.03) respectively. The estimated parameters of the length weight relationship are found to be $W = 0.010\, L^{2.92}$ (R^2=0.960) (Fig. 4). All the regression values were highly significant (p <0.001) in the

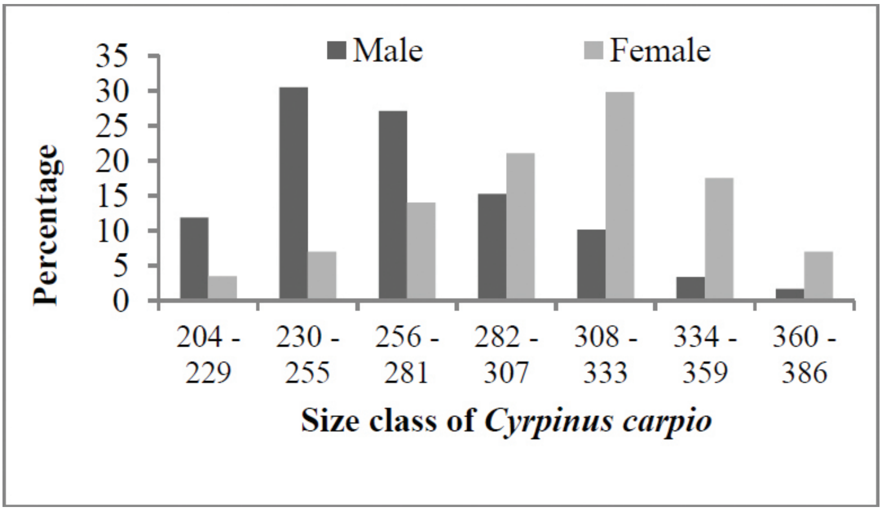

Figure 3. Size class of *C. carpio* in Buxar stretch of River Ganga (N=116; Male=59; Female=57).

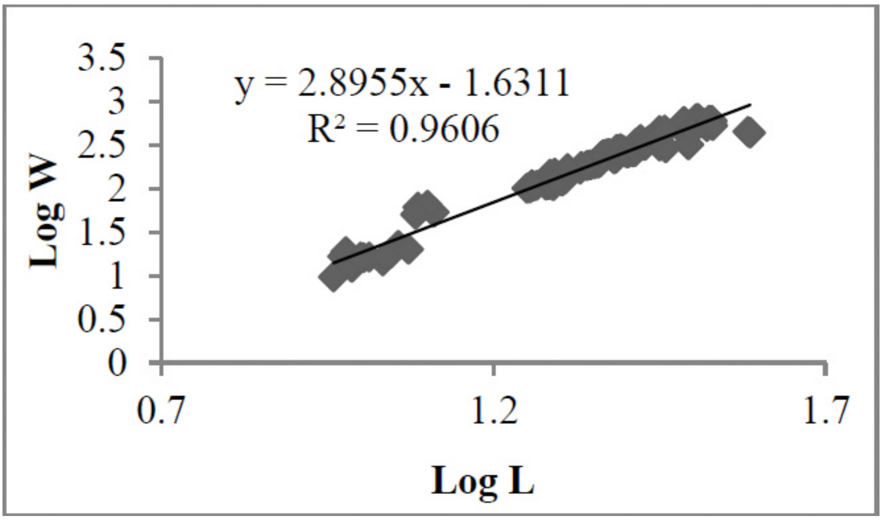

Figure 4. Length-weight relationship of *C. carpio* (pooled).

present estimation. The estimated exponent 'b' value was within the expected range (3.0) for the species (Froese, 2006) indicating isometric growth pattern.

Environmental factors behind establishment of Common Carp

The important physical characteristics and water quality parameters in three phases 2017, 2018 and 2019 are represented in Table 4. The contribution of environmental variables towards fish assemblage in the riverine ecosystem has been reported to establish direct impact on fish structure (May and Brown, 2002). Hydrological degradations like reduced flow rate and water volume, large scale discharge of industrial and domestic effluents has created better chances of survival of exotic Common Carp in the middle stretch of River Ganga (Rao, 2001; Vass et al., 2008). Data of average annual flow analyzed from previous reports at Allahabad (upstream of Buxar) depicted a reduction of 50.69% from 1970's to 2003, thus, suggesting a compatible environment for the proliferation of Common Carp. Discharge of domestic sewage in the studied stretch can easily be observed through significantly higher levels of water sp. conductivity (580 μScm^{-1})

Table 4. Annual variation in physico-chemical parameters at Buxar of River Ganga.

Parameters (unit)	Year (mean value)					
	2017	Range	2018	Range	2019	Range
Water temperature (˚C)	25.7	20.5-28.7	28.13	22.0-31.9	29.9	26.0-35.4
Depth (m)	8.89	7.0-11.50	7.63	6.00-9.28	6.93	5.70-8.85
Water velocity (m s^{-1})	0.23	0.10-0.40	0.30	0.20-0.40	0.42	0.07-0.90
Water turbidity (NTU)	66.02	5.67-174.0	18.36	12.60-29.20	59.95	8.55-143.0
Water pH	7.70	7.40-7.90	8.30	7.90-8.60	8.16	7.46-8.30
Dissolved oxygen (mgl^{-1})	6.46	6.00-7.20	7.10	6.30-8.40	6.86	5.80-8.40
Water sp. cond. ($mScm^{-1}$)	0.35	0.27-0.52	0.51	0.38-0.58	0.45	0.32-0.56
Total hardness (mgl^{-1})	136.6	116.0-160.0	143.3	80.0-194.0	131.3	128.0-136.0
Total alkalinity (mgl^{-1})	144.6	114.0-168.0	210.0	196.0-234.0	159.1	101.1-210.0
BOD (mgl^{-1})	0.86	0.00-1.80	1.21	1.10-1.33	2.03	1.50-3.00
Water total P (mgl^{-1})	0.03	0.01-0.05	0.24	0.14-0.44	1.22	0.28-2.75
Water total N (mgl^{-1})	0.80	0.50-0.80	0.64	0.46-0.85	0.92	0.11-1.60
Salinity (chloride) (ppt)	0.09	0.06-0.12	0.10	0.10-0.11	0.02	0.01-0.05
Silicate (mgl^{-1})	4.86	0.71-8.99	4.59	3.97-5.52	9.08	7.53-11.58
Sediment org. carbon (%)	0.45	0.15-0.67	0.61	0.52-0.72	0.49	0.06-0.75
Soil sp. cond. (mS cm^{-1})	0.61	0.23-0.98	0.31	0.17-0.54	0.13	0.10-0.17

and BOD (3 mgl^{-1}) values. Sluggish water flow has also facilitated the growth of *Microcystis* sp. as evidenced by its presence (24.79%) in the gut content of Common Carp, thus indicating partial eutrophic condition of water (Al-Tebrineh et al., 2012). Among different water quality parameters, river flow, Biochemical Oxygen Demand (BOD) and Total Phosphate (TP) showed positive whereas specific conductivity showed negative correlation with Common Carp seasonal abundance. Increased concentration of water and soil specific conductivity (0.98 mS cm^{-1}), higher water total phosphate (2.75 mgl^{-1}) compounded with low volume discharge and reduced water flow (0.10-0.90 m sec^{-1}) might have helped in establishment of Common Carp in this stretch of the river.

Principal Component Analysis between environmental parameters and Common Carp abundance

The first three Principal Components (PCs) have eigenvalues more than unity explaining a total of 73.56% variance to the total variance of information contained in the original data and hence, the first three PCs were used for further analysis. It is observed that PC 1 with 34.82% variance is positively and largely influenced by total alkalinity and salinity (depicting chlorinity being freshwater stretch of the river) whereas biochemical oxygen demand (BOD) and water turbidity are negatively affecting the component. Similarly, second principal component is largely and positively influenced by water total nitrogen (TN) and water temperature (W. Temp) whereas negatively and strongly influenced by river depth (Dept). PC3 with 13.79% variance is strongly and negatively loaded with dissolved oxygen (DO) concentration and positively loaded with total hardness (TH) (Figure 5).

Correlation between selected parameters and *C. carpio* production

After considering the first 3 PCs, the parameters which are loaded with maximum score to these 3 PCs (> 0.75 positive or negative) were selected to reduce the number of parameters to ascertain the significant contributors to the water quality variations (Tripathi and Singal, 2019). Consequently, 9 variables viz. water temperature, depth, flow, turbidity, dissolved oxygen, biochemical oxygen

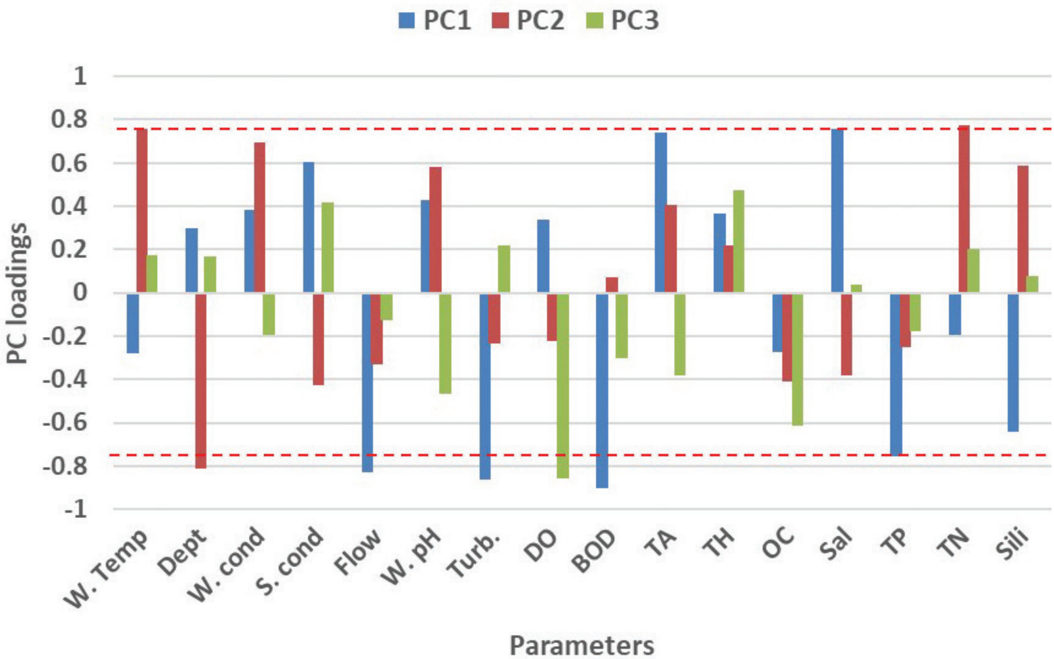

Figure 5. Factor loadings of three principal components with major contributing factors (Red dotted line denotes the 0.75 score positive and negative).

demand, salinity (chloride), total phosphate and total nitrogen were selected which are considered key parameters for water quality variations in the studied area. Now, correlation coefficients were calculated to measure the correlations between these 9 selected parameters and Common Carp production. Table 5 depicts four parameters viz. river flow, BOD, salinity (chloride) and total phosphate are the major influencing factors behind seasonal catch variations of *C. carpio*. Positive correlation with BOD and TP is a clear sign of anthropogenic pollution behind Common Carp abundance. Besides tolerating to low oxygen (less than 2 ppm) level, the species can also adjust to any significant fluctuations in the ecosystem (Chondar, 1999). Adaptation in river might be due to its quick movement as much as 25 km day^{-1}in free-flowing waters (Steffens, 1958). Influence of river depth also plays significant role towards its higher frequency in deeper waters. Higher abundance of Common Carp during monsoon may be attributed due to its frequent bottom dwelling habit less impacted by increased flow in monsoon. Subsequently, negative correlation with salinity (chloride content) might have influenced higher abundance of *C. carpio* in monsoon months when chloride content reduces due to large volume of water discharge.

Conclusions

Increasing abundance of invasive *Cyprinus carpio* has created a wide spectrum of variations in the sustenance of indigenous fish species in River Ganga. In our study, considerable emergence of Common Carp and other exotics over native ones are clear indication of their increasing population.

Table 5. Major influencing factors for *C. carpio* seasonal catch variations.

	Water Temp	Depth	Flow	Turbidity	Dissolved Oxygen	BOD	Salinity (Chloride)	Total Phosphate	Total Nitrogen
C. carpio	0.49	-0.29	0.67*	0.33	-0.31	0.73*	-0.78*	0.82*	0.09

* Marked correlations are significant at $p<0.05$

The increased availability of the exotic carp may be attributed to biological as well as environmental factors which have created an added advantage for their propagation over the years compared to the native species. Reduced annual average water discharge contributes to the loading of anthropogenic organic matters resulting in elevated BOD and total phosphate concentration. This may lead to a favourable ecosystem for the multiplication of Common Carp population in comparison to the native fishes which prefers suitable riverine habitat. Therefore, maintenance of a minimum water flow throughout the year can be an important factor for minimizing its propagation. Moreover, availability of significant proportion of mature stock of Common Carp in smaller size group from Buxar stretch also supplements its advantage over other native fishes. Although *C. carpio* are one of the most common detri-omnivore species, gut content analysis of the species confirmed its dietary preference towards riverine plankton. This might create an intricate relationship resulting in slow competition for food particularly with the native carp population. Overall, the impacts of *C. carpio* in the Buxar of River Ganga have been observed to be at moderate risk at present. However, this might alter the entire trophic structure in coming years. As there seems no possible way for eradicating this species from the river system, further studies are required to elucidate species interactions (native–exotic relationship), habitat degradation, genetic deterioration, etc. The impending risks thus affect the biodiversity as a whole including hampering the socio-cultural attributes along the fisher community who depends on the capture fisheries from such aquatic ecosystem for their livelihood and nutrition. The consequences of increased Common Carp abundance may undoubtedly create severe repercussions over sustainable ecological balance of mighty River Ganga.

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