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An Appraisal of Introduced African Catfish *Clarias gariepinus* (Burchell 1822) in India: Invasion and Risks

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Production trend, food and feeding, reproduction and distribution of clandestinely introduced African catfish *Clarias gariepinus* was studied in 419 grow out ponds. Hybrid African catfish was found more popular owing to its fast growth and because of recycling it with chicken and slaughterhouse wastes. The growth, survival and production of the fish was found to vary largely due to variations in stocking density, pond sizes, feeding types, level of cannibalism, predation, genetic lineage. The calculated growth of the fish ranged 23.52±2.8 g $month^{-1}$ (minimum) in some grow-out farms while it was 223.14±18.8 g $month^{-1}$ (maximum) in others. The computation of the grow-out farms as per the feed types revealed that 7% grow-out farms subsisted on naturally available pond food; while 29% farms, the fish was fed with slaughterhouse waste; in 32% farms, chicken waste was used as feed while in 11% cases fish waste material was provided and 21% ponds, the farmers used improvised convention feed or commercial pellet feed. The fish was found to possess human health risk as assessed for heavy metal contamination of lead (Pb) in chicken waste fed cultures. *C. gariepinus* was assessed as generalised piscivore, and invasive species therefore, we have attempted to

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understand the impacts associated with unauthorised introduction and spread of the fish in India. The highly carnivorous habit, tolerance to wide habitat and harsh environment and natural breeding of the fish warranted for its invasiveness which were attributable to the biodiversity loss. The issues associated with the culture and spread of the fish is discussed in this paper.

Keywords: Clarias gariepinus; grow-out ponds; feed types; culture; biodiversity; disease; health risks.

1. INTRODUCTION

The development of aquaculture in India has been associated with an increasing interest in translocation of fishes outside their native range [1-3]. In India, African catfish and its hybrid entered clandestinely into culture system via Bangladesh through private fish traders without prior official sanction and rapidly spread into whole of the country [3]. High growth rate, efficient utilization of variety of cheap feeds including wastes and low management practice were some of the reasons, which encouraged its unauthorised culture in larger areas. Farmers and consumers in India usually get confused to discriminate *Clarias gariepinus* from local species *C. batrachus* at early age. It is to mention that the Asian catfish, *Clarias batrachus* and the peninsular catfish *C. dussumieri* are regarded as prized food fish in India.

In developing countries, the risk of biological invasions within freshwater ecosystems was perceived after species introductions (Sena De Silva et al. Singh and Lakra [2,3]). While impacts of introduced African catfish is poorly understood [2,4]. African sharptooth catfish *Clarias gariepinus* is arguably the most latitudinally distributed introduced freshwater fish that naturally occur in many aquatic bodies [3,5-8]. Catfish introductions are increasing worldwide primarily due to their popularity in aquaculture [4,6-10]. In many parts of the world, it has successfully established within freshwater ecosystems as escapee fish from aquaculture facilities and through deliberate angler introductions [4,10,11]. Although the impact of the fish in India is yet to be known, concern has been raised over its predation and competition with local biota [3,12], and genetic impact through introgression with native catfishes [5,13]. Widespread culture of *Clarias gariepinus* and its hybrid into India prompted us to assess its performance and impacts. In this paper, the culture, diet, growth, reproduction, diseases, genetics, certain aspects of marketing and socio-economics as well as biodiversity issues have been addressed.

2. MATERIALS AND METHODS

2.1 Field Data Collection

Extensive survey was conducted on culture, food and feeding, reproduction as well as diseases in *Clarias gariepinus* in the States of West Bengal, Andhra Pradesh and Uttar Pradesh in India (Fig. 1) and random data was collected through our field study and also with the help of state fisheries extension workers. The specimens collected were subjected to the species identification [14]. The information on ponds area (ha) with stocking details (number of fish and mean weight (g± SD), harvest details (number of fish and mean weight (g± SD), diet given to the fish, period of culture, age and weight at maturity, breeding and diseases were collected through extensive surveys. Collected field data from 419 monoculture culture ponds during the year from 1997 to 2012 was pooled and arranged. The average survival rate (%) was calculated as:

$$\text{Survival rate (\%)} = \frac{\text{No. of fish stocked} - \text{No. of fish harvested} \times 100}{\text{Number of fish stocked}}$$

2.2 Grow-out Production

The production levels for different pond size groups were calculated as production kg ha^{-1} yr^{-1}. Further, production data from a group of three identical cement cisterns (9×3×1 m) was also collected where the farmer was raising African catfish. The production data from these cement cisterns was treated as controlled culture production since data from the grow out farms were not in uniform conditions. These cement cisterns were stocked with 500 fingerlings of African catfish having means weight of 40±2.5 g and fed with conventional feed (rice polish and mustard oil cake) mixed with 20% fishmeal up to satiation.

Water temperature, dissolved oxygen and pH were monitored every third week using a portable water analysis kit (WTW multi340i/Set, made in Germany) throughout the study period of 180 days. Observation on the gain in wet weight (g),

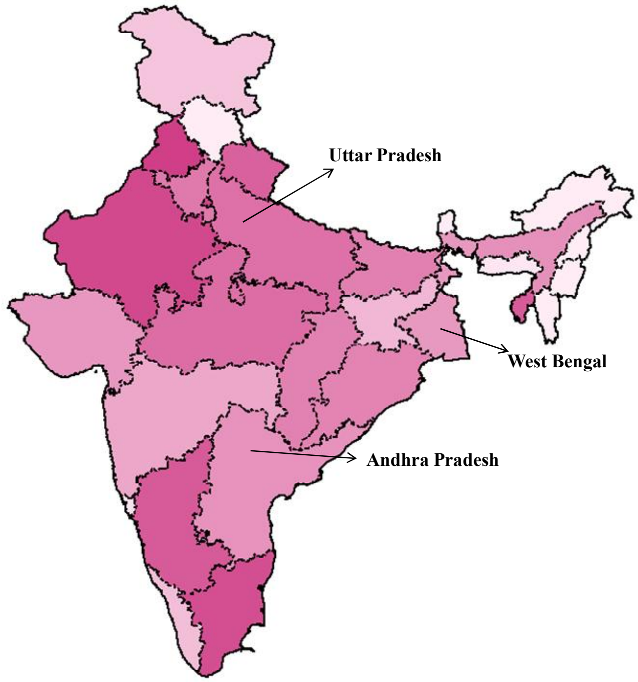

Fig. 1. Map showing survey areas covered in the study

number of surviving fish was taken every third week and the biomass of the cistern was calculated.

2.3 Food and Feeding

The farmers were using different feed types in grow out farms so the production level under different feeding types was calculated separately for each feed type. Further, gut contents of 131 African catfish specimens captured from river stretches was also examined. The guts of the captured specimens were removed and fixed in 5% formalin, rinsed into a Petridish for examination of the contents with the help of a binocular microscope. The quantitative occurrence of each food item was estimated and expressed as percentage of the total number of contents in the gut [15].

2.4 Environmental Monitoring

A cluster of over 100 monoculture ponds of African catfish in Amrahi village of Lucknow district in Uttar Pradesh (N 26° 51' ; E 80º 51.12') having approximately 5 km^2 culture water area was chosen for monitoring the water parameters and heavy metals. Metal contaminants in randomly selected ponds' water (n=27) and fish tissues (n=324) from the culture ponds using commercially available pellet feed, slaughter house waste and chicken waste as feed. Water samples were collected from ponds with different feed types and subjected to analysis of water temperature, pH, free CO_2, dissolved oxygen (DO), total hardness, ammonia, chlorides and alkalinity either *in situ* or in the laboratory following the standard methods of [16]. Water quality rating for physico-chemical parameters was done by calculating the water quality index (WQI) which was divided into four stages viz. permissible, slight, moderate and severe and was rated on a scale of 0 to 100. Selected parameters were calculated with the help of a software (BIOPATRA) water quality calculator (www.textbookx.com).

2.5 Estimation of Heavy Metals

For estimation of metals, water samples were collected in sterilised polyethylene bottles, brought to the laboratory and kept in refrigerator until analysis. Similarly, tissues (muscles, gills, gonad and liver) of *C. gariepinus* were collected and washed with double-distilled water and put in Petri dishes to dry at 120°C until reaching a constant weight. One gram of dried tissue (in three replicates) was then digested with di-acid (HNO3 and $HClO_4$ in 2:1 ratio on a hot plate set at 80°C (gradually increased) until all materials were dissolved. Stored water samples and digested tissue samples were subjected to heavy metals estimations using a UNICAM- flame atomic absorption spectrophotometer (AAS, Agilent) using the methods of APHA (2005). Analysis of sample was done according to standard, reagent blank and sample replicate randomly inserted in the analysis process to assess contamination and precision. The transportation error contamination was 0.0207 to 0.0857. Recovery studies of metals determination were conducted to demonstrate the efficiency of the method. The recovery rates ranged from 83.3% to 92.2%.

2.6 Health Risk Assessment

Calculated total heavy metal exposure levels were compared with the tolerable daily intake (TDI) which refers to the reference dose of a substance that can be taken in daily without identifiable risk at lifetime exposure. Additionally, the hazard index was calculated as the ratio of the calculated lifetime daily exposure divided by the reference dose (TDI) [17,18]. Daily exposure (mg kg^{-1} day^{-1}) averaged over a lifetime of 70 years was calculated as HQ= TDI/ RfD where HQ was hazard quotient, TDI was tolerable daily intake and RfD was reference dose. The Health index was calculated as:

$$HI = HQ_{1+} HQ_{2+} \ldots\ldots\ldots\ldots HQ_n$$

If the hazard index was below 1, no health risk may occur.

2.7 Socio-Economic Study and Spread

For studying the socio-economic aspects, a benchmark survey of fish markets in different places was conducted to generate data/ information on the size and bulk of the fish available. Further, occurrences of the fish in wild was ascertained by sampling at few landing sites along the Ganga and the Yamuna River stretches where fishermen captured the fish using dragnet and gill net. The latitude and longitude of these fishing sites were also recorded.

2.8 Diseases

The pathological problems from monoculture ponds were recorded during survey tours and diseased live specimens were brought to the laboratory to examine the disease based on the symptoms [19]. Information on the therapeutical measures resorted by farmers for treatment of different types of pathology was registered on site. 60 diseased African catfish measuring 18- 42 cm length and weighing 40-430 g were collected from grow out farms from Lucknow and Bareilly districts of Uttar Pradesh state during 2011-2012. Inocula of tissue of these diseased specimens were taken from infected region (body surface) and internal organs (gill, liver, kidney, etc.) of diseased or moribund fishes exhibiting symptoms of columnaris disease and collected samples were kept in saline solution (0.3 % NaCl) at sampling site and then transported in ice pack condition up to the lab [36]. The tissue samples and body swab was used for bacterial culture on selected medium (Anacker & Ordal, 1959). Different isolates of *Flavobacterium columnare* (FC) were isolated from diseased or moribund or alive symptomatic *Clarias gariepinus* exhibiting clear clinical symptoms of columnaris disease ("saddle back" lesion, ulcerations on the body surface, lethargic behavior). All samples were streaked and spread on selective medium cytophaga agar medium [20] and plates were incubated at 25°C for 24 to 48h. After incubation period, isolated colonies were checked on the basis of colour, adherence to the agar and rhizoid edges. The colony of *F. columnare* was identified and characterized by whitish/creamish pigmentation, flat with irregular rhizoidal edges which were tightly adhered to medium [36].

2.9 Reproduction

The sex of the fish was determined by examining the genital organs and belly of the fish and also by examining the gonads. The maturity of captured fish from river stretches was ascertained by macroscopic and microscopic examination of gonads. The length and weight of 173 mature fishes were registered for each sex. The seed production method was collected through interaction with the hatchery managers who were breeding the fish. The inducing agents and the doses used by the farmers were noted. In addition to induced breeding at hatcheries, the natural breeding of the fish was also observed by examining the presence of fry and fingerlings in grow out ponds even after one year post harvest.

2.10 Statistical Analysis

The growth of the fish $month^{-1}$ was calculated as mean wet weight gained at harvest (g) divided by period of culture (months). The standard deviation (SD) for growth $month^{-1}$ for each group of pond size was calculated. All values from chemical analyses were presented as mean±SD. Data obtained from the experiment were subjected to one way analysis of variance (ANOVA) test using the Statistical Package for the Social Sciences (SPSS). The correlation coefficients between the quality parameter pairs of the water samples were calculated by the application of Pearson correlation analysis. Parameters were analysed statistically (at 5%) and significance was calculated by student's 't' test with the use of computer programmed statistical tool SPSS.

3. RESULTS

The African catfish and its hybrid was found under culture in earthen ponds and tanks, shallow seasonal water area, cement cisterns, homestead ponds and even government leased water bodies. Culture in shallow seasonal waters was usually found to have less than 0.7 m deep water indicating that the water requirement for the fish was less than what was required for carp culture. In monoculture grow-out ponds, the stocking density varied largely from farm to farm which was up to 40,000 ha^{-1}. The fingerling size varied from 2-6 inches and the culture period was 4-6 months which sometimes extended to one year. The calculated growth of the fish was 23.52±2.8 g month^{-1} (minimum) in some grow-out farms while it was 223.14±18.8 g month^{-1} (maximum) in other ponds. The variation in growth was large and the survival ranged from stray to 60 % in grow-out farms in different size groups. The calculated production level was as low as 200.9±18.6 kg ha^{-1} yr^{-1} while in others it ranged from 18593.8±96.8 to 29880.0±56.4 kg ha^{-1} yr^{-1} (Table 1). There was high variability in stocking density, survival rate and production levels amongst different grow-out farms sizes. Increased stockings did not enhance production, however, in some grow-out farms stockings @ 25,000 to 40,000 fingerlings ha^{-1} fetched productions of 18593.8±96.8 to 29880.0±56.4 kg ha^{-1} yr^{-1} (Table 1). The husbandry conditions were poor in general at most of the grow-out farms. Culture of *C. gariepinus* in polyculture along with carps gave losses to the carps and consequently farmers suffered. The losses to carp were in the range of 44.3 to 55.8% (Fig. 2).

Culture production of *C. gariepinus* in cement cisterns showed pH value of 7.4 to 7.6, dissolved oxygen 2 to 3 mg l^{-1} and the temperature 28 to 30ºC (mean 28±1.5ºC). The survival of the fish in these cisterns gradually declined and at harvest (180 days) it was 50%. The declining survival rate was observed to be due to mortality and also cannibalism exhibited by the fish. The mean wet weight of the fish was 425±85.5 g at the end of 180 days of rearing period. The growth rate in length showed an increase of 1.55±0.26 mm day^{-1}. The production calculated from the biomass was 10,870.37±112.8 kg ha^{-1} yr^{-1} (Fig. 3).

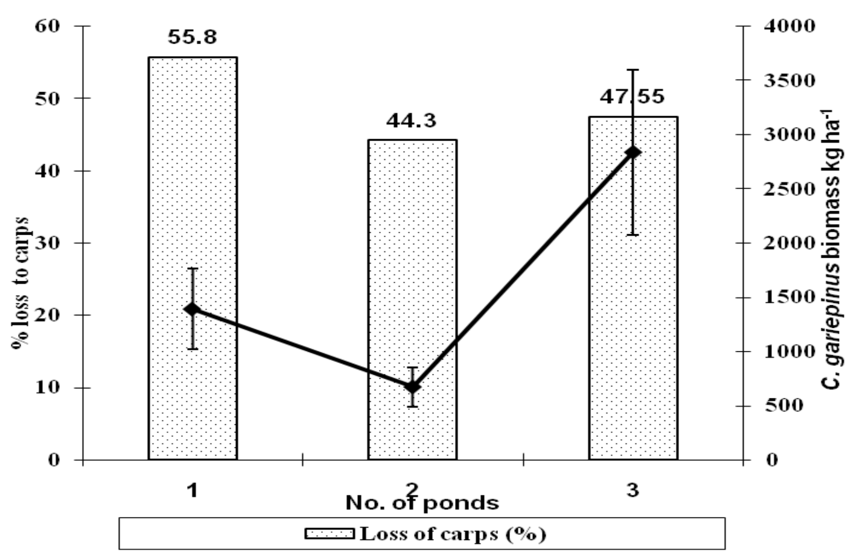

Fig. 2. Loss to the carp in polyculture of African catfish with Indian major carp

Table 1. Growth and survival of African catfish in grow- out ponds (the values given in parentheses are average weight (g) (±SD)

Grow-out ponds area (ha) and No. (n)	Average no. of stocking	Average no. of harvested fish	Rearing period (month)	Growth $month^{-1}$ (Mean ±SD)	Average survival rate (%)	Production (kg ha^{-1} yr^{1})
0.02 (n=7)	25 (25±2.5)	13 (212±12.8)	4	53.00± 3.2	52.0	413.4±4.2
0.10 (n=19)	200 (65±11.2)	80 (285±8.4)	6	47.00±5.6	40.0	451.2±12.4
0.16 (n=29)	5000 (40±4.6)	500 (450±4.8)	7	64.28±16.2	10.0	200.9±18.6
0.23 (n=65)	800 (110±12.2)	200 (350±21.4)	6	58.32±17.4	25.0	608.6±16.4
0.25 (n=32)	5000 (60±5.2)	3000 (830±32.2)	4	207.50±18.8	60.0	29880.0±56.4
O.28 (n=21)	7000 (30±2.4)	2000 (655±52.6)	6	109.16±17.8	33.3	9356.6±102.8
0.24 (n=06)	10,000 (25±3.2)	3500 (850±112.4)	8	106.25±13.5	35.0	18593.8±96.8
0.30 (n=71)	500 (70±5.6)	65 (650±42.4)	5	130.00±12.8	13.0	338.0±23.2
0.37 (n=11)	10,000 (40±6.4)	4100 (1230±42.8)	10	123.00±6.5	41.0	16355.6±103.2
0.40 (n=23)	2,000 (30±4.2)	280 (965±66.2)	7	137.85±15.2	14.0	1157.94±32.6
1.20 (n=40)	1000 (150±15.2)	237 (1562±122.6)	7	223.14±18.6	23.7	528.8±18.5
1.50 (n=36)	1500 (110±12.4)	NIL	6	--	NIL	--
7.00 (n=59)	65,000 (10±3.2)	17,000 (235±14.8)	10	23.5±2.8	20.0	684.9±28.2

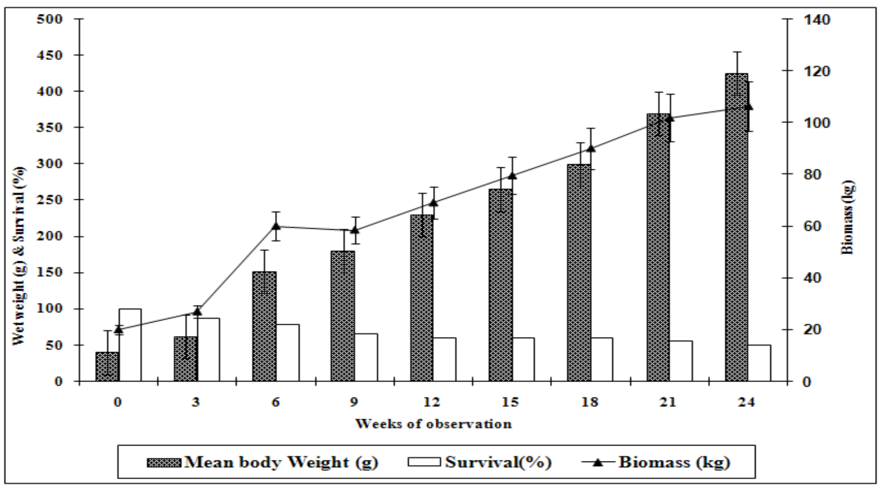

Fig. 3. Growth and survival of African catfish in cement cisterns

Information collected on different feed types used by farmers revealed that most of the culture depended on slaughterhouse and chicken wastes as feed. The conventional diet (rice bran and mustard oil cake) mixed with fishmeal and/or boiled eggs and commercial pellet feed was also used at few farms. The computation of the grow-out farms as per the feed types revealed that 7% grow-out farms subsisted on naturally available pond food; while 29% farms, the fish was fed with slaughterhouse waste consisting of the whole blood and flesh contents. In 32% farms, chopped head and gut contents of chicken waste was used as feed while in 11% cases fish waste material was provided. In 21% ponds, the farmers used improvised convention feed having rice bran and mustard oil cake mixed with fishmeal and/or boiled eggs or commercial pellet feed. Farmers generally applied higher feeding level during the first three months of culture in order to acclimatize the fish to the feed and feeding place, while lower feeding level was applied during later period of culture. Growth response to different feed types showed highest weight gain in slaughter house waste feeding followed by natural pond feeding to the fishes. However weight gain with chicken feeding was generally impressive (Fig. 4). Observations made on the gut contents of wild caught *C. gariepinus* revealed the presence of mainly fish remains, aquatic insects and its larvae, crustaceans, higher plant matter, detritus and mud (Fig. 5).

The water analysis of African catfish monoculture ponds fed with different feed types showed varied values for pH, dissolved oxygen, ammonia, total dissolved solid, total hardness, free CO_2, alkalinity, chlorides and conductivity which were significantly different in ponds using different feed types and the water quality was miserably poor in most of the ponds (Table 2). The poor environmental condition in all the African catfish culture ponds showed that the *C. gariepinus* was a hardy fish and tolerated harsh environments.

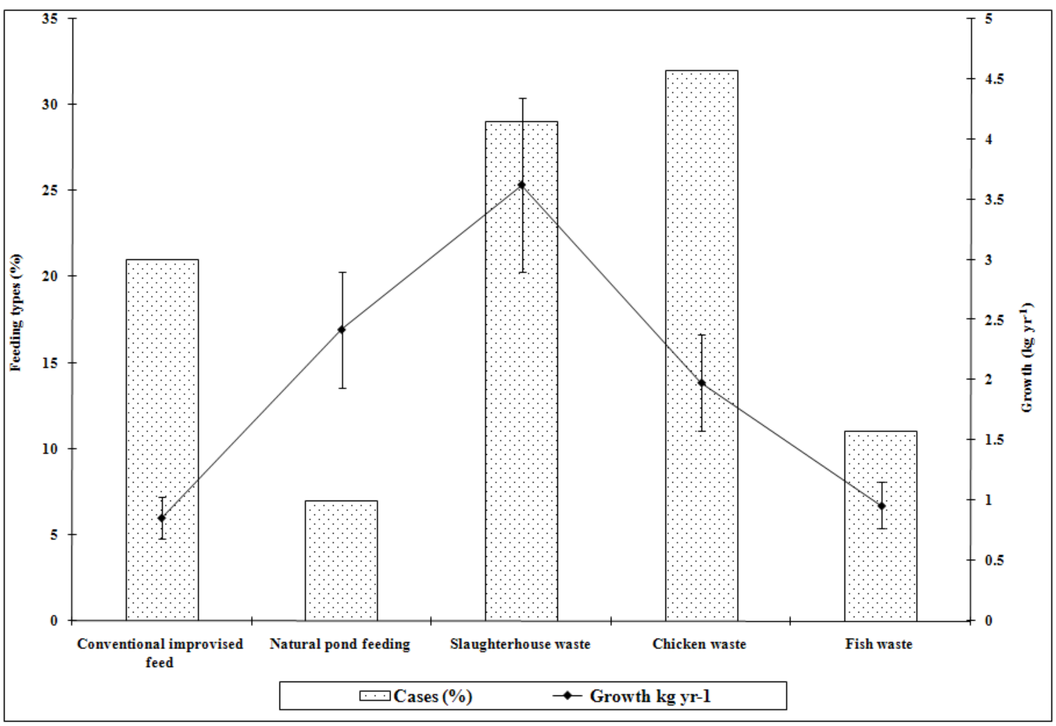

Fig. 4. Growth performance in African catfish with different diet types

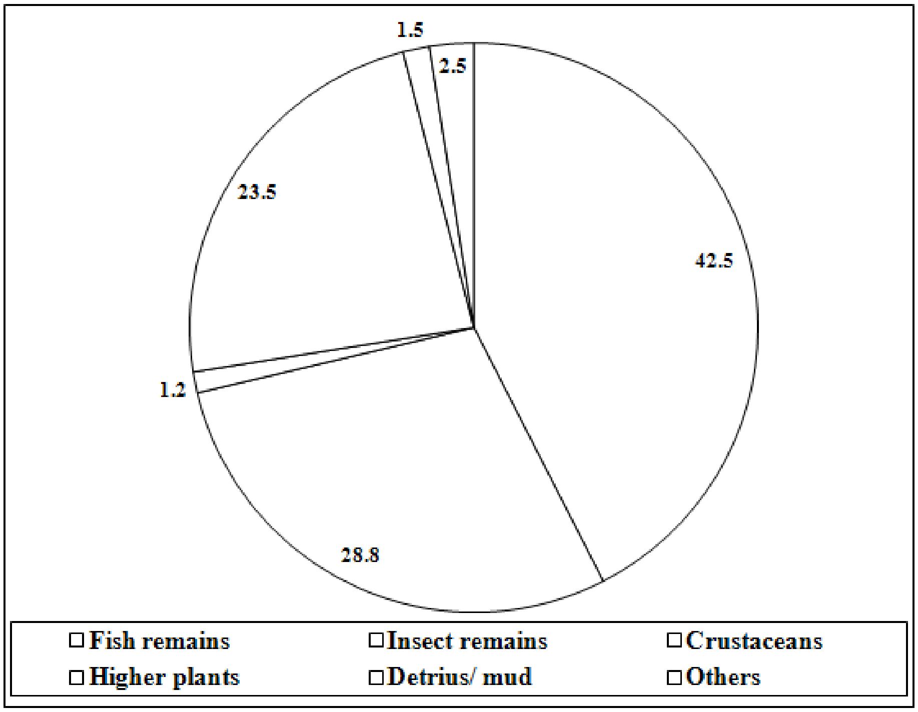

Fig. 5. Diet composition observed in feral African catfish

Table 2. Physico-chemical parameters of the water samples collected from African catfish monoculture ponds fed with different feed types (Mean±SD)

Parameters	CoF	SH	CW	Permissible Limit#
pH	8.98±0.043	8.42±0.12	8.71±0.15	7-8.5
Temperature (ºC)	29.5±0.64	29.7±0.32	28.5±0.43	Over 5°C
Conductivity (µs/cm)	473.3±60.41	789.3±61.66	684±60.71	----
Total dissolved solid (mg/L)	157.6±7.21	94.6±12.0**	138.3±14.83*	500
Total hardness (mg/L)	345.3±14.49	336.7±6.32	346.7±13.03	200
DO (mg/L)	5.0±0.12	5.1±0.39	4.9±0.14	3.00
Free CO_2 (mg/L)	7.33±0.048	7.11±0.18	6.9±0.1	5-10
Ammonia (mg/L)	0.18±0.049	0.56± 0.17*	2.67±0.074**	0.50
Alkalinity (mg/L)	62±2.00	58.3±7.91	61.6±2.23	200
Chlorides (mg/L)	73.74±1.19	71.40±2.10	73.09±2.31	251
Lead (mg/L)	0.007±0.002	0.005±0.003	0.014±0.012	0.05
Cadmium (mg/L)	0.004±0.004	0.003±0.001	0.003±0.001	0.01
Aluminum (mg/L)	0.951±0.103	0.972±0.391*	0.964±0.748**	0.03
Cupper (mg/L)	0.005±0.001	0.004±0.001	0.004±0.001	0.05
Chromium (mg/L)	0.011±0.007	0.011±0.004	0.013±0.011	0.05
Iron (mg/L)	0.815±0.464	0.966±0.417*	0.887±0.827	0.01
Manganese (mg/L)	0.027±0.012	0.045±0.002	0.042±0.018	0.05
Zinc (mg/L)	0.063±0.002	0.069±0.043	0.083±0.012	5.00
Molybdenum (mg/L)	0.002±0.001	0.002±0.001	0.003±0.001	0.025
Nickel (mg/L)	0.002±0.001	0.001±0.001	0.004±0.001	0.01
Cobalt (mg/L)	0.004±0.004	0.003±0.001	0.003±0.001	0.0002

*Feed types: CoF - Conventional Feed, SH - Slaughter House Waste, CW - Chicken Waste Significance level: *P <0.05, **<0.01 (in comparison to CoF); #WHO (2006) Guidelines for drinking water quality third edition.*

Among metals detected in ponds water were lead (Pb), cadmium (Cd), aluminium(Al), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), zinc (Zn), molybdenum (Mo), nickel (Ni) and cobalt (Co). However, the levels of most of these detected heavy metals were much below the permissible levels (WHO, 2011) except for Al and Fe (Table 3). Further examination of metals in the tissues (gonad, liver, gills and muscles) of *C. gariepinus* cultured with different feed types revealed the presence of Al, Cd, Co, Cu, Cr, Fe, Mn, Mo, Ni, Pb and Zn (Table 3). However, Al level was found high in most of the tissues but highest (5.230±0.547 mg kg^{-1}) in gonads of the fish followed by liver, particularly in chicken waste fed fishes (CW) where Al level was 4.006±0.356 mg kg^{-1}. Co was detected significantly ($P < 0.05$) high in liver of *C. gariepinus* collected from ponds fed with slaughter house waste (SH). Cr was found significantly ($P < 0.001$) high in gonads of the fish collected from all the three feed types. Cu was detected as 0.126±0.011 mg kg^{-1} in muscle of *C. gariepinus* collected from pond fed with CW diet. Fe was detected high (9.238±0.413, 11.70±0.548 and 18.777±0.598 mg kg^{-1}) in fish muscles collected from all the three feed types as compared to other tissues. Mg was detected 1.681±0.49 mg kg^{-1} in liver and in muscle it was 1.069±0.714 mg kg^{-1}in fish collected from SH and CW feeds. Mo was detected 0.139±0.065 mg kg^{-1} in muscle of *C. gariepinus* collected from ponds fed with CW and SH. Ni was 0.327±0.006 mg kg^{-1} and 0.468±0.016 mg kg^{-1} in muscles in *C. gariepinus* collected from pond fed with CW and SH respectively. Pb was detected significantly ($P < 0.05$) high in the muscle tissues of *C. gariepinus* raised particularly with chicken waste (CW) amongst all the three feed types where it was 1.053±0.067 mg kg^{-1}. Zn was observed 4.076 ± 1.23 mg kg^{-1} in of *C. gariepinus* fed with all the three feed types (Table 3). Ingestion of fish for Pb was found 1.7×10^{-2} in case of conventional feed, 2.1×10^{-2} in slaughter house waste and 4.1×10^{-2} in chicken waste fed African catfish in grow-out farms. Our results revealed that the metals contaminant in fish tissues was mainly from animal waste and not from ponds water since the levels of metals in the water were very low. The combined HI value for all metals ranged from 0.001 to 0.108 for 95% UCL concentrations. The individual HQ for all metals was less than 1 under exposure routes. These results indicated that there might not be any concern for the potential adverse health effects on human in general for all studied metals except for lead for which the health risk was high especially in fish raised with chicken waste.

The African catfish was found to breed throughout year except December to February when fully mature eggs or sperms were not found. The male and female were easily distinguished from one another. The males had distinct sexual papillae located just behind the anus, which was absent in females. The female African catfish had a fully developed ovary, which contained ripe eggs during the most part of the year except November to February. The eggs of ripe females made up 15-20% of the body weight i.e., a ripe female of one kg was found to possess about 150-200 g of ripe eggs. In general the testes of the male were fully developed at an age of about eight months when they reached a weight of approximately 450 g. Sperms could be obtained whole year round. Females weighing 350-450 g were found with swollen belly and mature eggs only at 5-6 months of age while males were observed to mature a bit later.

We identified 6 reproductive phases of *C. gariepinus* and the gonadosomatic index (Ig) of different reproductive stages was observed in specimens obtained from culture ponds. The details on the gonadal structure, their morphology and gonado somatic indexes (Ig) are given in Table 4. However, wild caught *C. gariepinus* did not show all six reproductive stages except few stretches along the Yamuna River indicating that natural breeding of the fish in river stretches was in the process of establishing. Farmers breeding African catfish at farms used pituitary extract or ovaprim. The fishes were either injected with carp pituitary (0.4 mg kg^{-1} body weight) or ovaprim (0.2 ml kg^{-1} body weight). The females were stripped whereas males were cut open and their testes were macerated and mixed with the stripped ova for fertilization. Breeding this fish artificially or under simulated condition was quite easy. However, farmers found heavy mortality during early period of fry rearing. Natural pond breeding was also recorded in some of the grow-out ponds at different places in Uttar Pradesh. The natural spawning was triggered by rise or fall in water level particularly in monsoon when temperature was 27±2°C. Paddy field was found fantastic grounds for natural breeding. The African catfish or its hybrid was not sterile and it bred at maturity.

Table 3. Level of heavy metals (mg/Kg) in different tissues of *Clarias gariepinus* raised with different feed types (Mean±SD)

Parameters	Organs	CoF	SH	CW
Aluminum	Liver	0.289±0.074	2.672±0.461**	4.006±0.356*
	Gills	2.02 ±0.043	2.87±0.023	3.18±0.072
	Muscles	0.676±0.015	0.982±0.011	1.034±0.058
	Gonads	3.774±0.118	3.870±0.356*	5.230±0.547**
Cadmium	Liver	0.010±0.002	0.172±0.011	0.254±0.022
	Gills	0.004±0.001	0.011±0.001	0.093±0.007
	Muscles	0.034±0.007	0.036±0.006	0.056±0.035
	Gonads	0.028±0.004	0.065±0.002	0.307±0.019
Cobalt	Liver	0.010±0.003	0.099±0.217*	0.254±0.029
	Gills	0.004±0.001	0.111±0.074*	0.089±0.0548
	Muscles	0.034±0.005	0.036±0.003	0.056±0.001
	Gonads	0.028±0.006	0.065±0.003	0.307±0.054
Chromium	Liver	0.416±0.066	0.689±0.037	1.146±0.658
	Gills	0.015±0.0036	0.016±0.005	0.025±0.009
	Muscles	0.152±0.0145	0.196±0.007	0.216±0.003
	Gonads	0.013±0.007	0.035±0.007	0.061±0.092*
Copper	Liver	0.00±0.00	0.00±0.00	0.00±0.00
	Gills	0.008±0.004	0.011±0.006	0.016±0.008
	Muscles	0.00±0.00	0.141±0.007	0.126±0.011
	Gonads	0.00±0.00	0.00±0.00	0.38±0.002
Iron	Liver	1.656±0.86	2.637±0.56**	7.859±0.924*
	Gills	3.110±0.334	3.258±0.239*	3.532±0.289
	Muscles	9.238±0.413	11.700±0.548*	18.777±0.598*
	Gonads	3.472±0.51	3.665±0.12**	10.592±0.760**
Magnesium	Liver	0.664±0.039	0.955±0.042	1.681±0.490
	Gills	0.080±0.0153	0.810±0.355**	0.105±0.048
	Muscles	0.110±0.005	0.702±0.003	1.069±0.714**
	Gonads	0.124±0.016	0.177±0.011	0.284±0.031
Molybdenum	Liver	0.086±0.085	0.271±0.064	0.864±0.026*
	Gills	0.008±0.009	0.011±0.001	0.023±0.001
	Muscles	0.109±0.004	0.117±0.008	0.139±0.065*
	Gonads	0.056±0.004	0.076±0.005	0.077±0.003
Nickel	Liver	0.129±0.081	0.243±0.023	0.318±0.067
	Gills	0.00±0.00	0.001±0.001*	0.023±0.003
	Muscles	0.279±0.009	0.327±0.006	0.468±0.016
	Gonads	0.024±0.002	0.076±0.003	0.076±0.006
Lead	Liver	0.063±0.052	0.110±0.062	0.344±0.843*
	Gills	0.011±0.001	0.011±0.005	0.017±0.006
	Muscles	0.436±0.003	0.559±0.007	1.053±0.067*
	Gonads	0.030±0.006	0.058±0.008	0.192±0.072*
Zinc	Liver	1.336±0.892	2.435±0.546**	4.076±1.230**
	Gills	0.068±0.005	0.178±0.038	0.093±0.061
	Muscles	0.622±0.032	0.629±0.044	0.796±0.074
	Gonads	0.472±0.018	0.70±0.005	0.829±0.028

Feed types: CoF- Commercial Feed, SH- Slaughter House Waste, CW- Chicken Waste,
*Significance level: *P<0.05, **P<0.01(in comparison to CoF)*

Table 4. Maturity scale to classify reproductive stages of *C. gariepinus*

Maturity Stages	Males	Females	Gonado-somatic Index (I_g)
I	A pair of thin thread like gonads, transparent sacs running along the dorsal wall of the body cavity	Sexes at early stage were indistinguishable macroscopically	< 2.5 (n=11)
II	Testes semitransparent and flattened	Ovary reddish, smooth, small ova were hardly visible in transparent matrix of follicular cells. Ova volumes were smaller than matrix and exuded when lobes were cut and squeezed.	2.0 - 7.5 (n=19)
III	Testes whitish, wider late and more or less flattened. No milt exudes when cut or squeezed	Ovary was opaque and yellowish. Small ova were visible in transparent matrix of follicular cells.	8.0 -15 (n=23)
IV	Testes with firm clear lobes less flattened. small amount of milt present	Ovary yellowish, fully swollen with translucent yellow ova. Pre-mature ova volume was larger than matrix.	15.0 - 32.0 (n=32)
V	Testes with fully developed lobes. Readily produces milt when lobes are cut and squeezed.	Ovary yellowish very soft and swollen. Greenish yellow ova were visible through superficial membranes and ova were tightly packed. Little follicular matrix was present	5.0 - 8.0 (n=32)
VI	Testes flattened having thin lobes but milt extrudes when cut and squeezed	Ova extruded from vent when pressure was applied from pectoral fin to vent.	3.0 - 10.0 (n= 14)

Note: The maturity stages shown in bold letter were found in the river collected specimens (n=131)

In general, diseases were not found to be a serious problem under culture operations of African catfish. However, some symptoms of disease were observed in grow-out ponds raising this fish in higher densities. Five types of pathology, the slimy disease, dropsy, anorexic disease, gastro-intestinal blockages were identified which had distinct clinical symptoms. The dumping of nitrogenous wastes (slaughterhouse waste, chicken wastes or other wastes) in culture ponds caused deterioration in water quality and fowling smell was a usual problem for the local inhabitants in the vicinity. The farmers resorted to the treat the ponds with either lime @250-300 kg ha^{-1} or potash @5 ppm or salt solution @ 0.3-0.5% irrespective of the diagnosis and type of diseases. In few cases the fish culturists used antibiotic (Oxytetracycline) when the mortality in fish was beyond control even after application of earlier mentioned therapeutics. We recorded the presence of columnaris disease at some grow out farms in Lucknow and Bareilly districts of the Uttar Pradesh. Some fungal, parasitic and bacterial diseases were also found to occur. The dumping of nitrogenous wastes (slaughterhouse waste, chicken wastes or other wastes) irrationally in culture ponds caused deterioration in water quality and this creates high chances of disease. Further, the use of animal wastes as feed was prone to gave rise to the possibility of zonotic disease problems.

African catfish had easy catchability unlike local magur *Clarias batrachus* and were transported live for long distances for marketing. The difference in harvest size of this fish revealed their growth up to 1.1-kg in 280 days whereas some remained as small as 0.1 kg. Selling of magur over 1.0 kg was really a problem as the consumers were familiar to maximum of 0.2 kg size magur, which corresponded with that of local magur (*Clarias batrachus*). Consumers did not prefer the taste of African catfish as compared to the traditional recipes liked for local magur. The preference is for 0.09-0.33 g, although 0.09-0.2 kg is easier to sell. Consumers did not prefer the taste, as the traditional recipes used for indigenous magur (*C. batrachus*) did not suite this exotic variety.

Availability of *C. gariepinus* was high in most of the fish markets in many states of the country in general. However, the bench mark survey conducted in the state of Uttar Pradesh revealed its predominance in most of the fish markets spread over different districts. The bulk of African catfish available in different fish markets in Uttar Pradesh has been presented (Fig. 6). The data recorded on the occurrences of the fish in river stretches revealed that the fish escaped and spread in several river stretches. The collected data from the Ganga and the Yamuna river stretches have been synthesised for the size range, GPS positions and the abundance (Table 5).

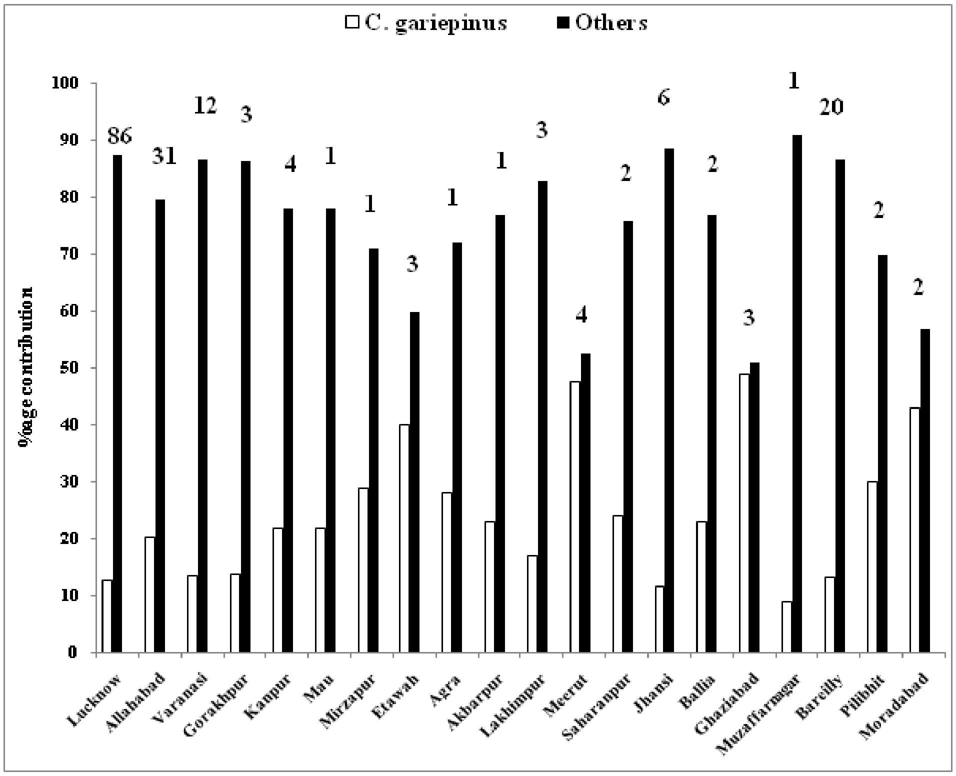

Fig. 6. Distrution of African catfish in different fish markets

Table 5. Occurrences of *Clarias gariepinus* in the Ganga River, Uttar Pradesh

Sampling site	Presence of *C. gariepinus*	Weight range (kg)	GPS position	
Allahabad	+			
(a) Phaphamau		0.5-1.5	25° 30.485'N	081° 51.985'E
(b) Sangum		0.1-2.5	25°25.696'N	081° 52.674'E
Kanpur				
(a) Mishra Ghat	+	0.3-1.2	26°28.501' N	080° 22.486'E
(b) Parmath	+	0.2-1.3	26° 29.217' N	080° 20.704'E
(c) Bhairov Ghat	+	0.2-2.4	26° 29.717' N	080° 19.602'E
Kannouj	+	0.2-0.9	27° 00.704' N	079° 59.109' E
Meerut	+	0.1-2.0		
Varanasi				
(a) Sarai Mohan	+++	0.2-2.5	25° 19.744'N	083° 02.641'E
(b) Ram nagar	++	0.2-3.5	25°16.259'N	083° 01.406'E
(c) Dashashwamed	++	0.1-2.7	25°18.399'N	083° 00.631'E
Balia	+	0.1-2.5	25°43.776'N	084° 09.842'E
Mirzapur	+	0.2-3.0	25°09.087'N	082° 33.346'E

+Occasionally captured; ++regularly captured (<20kg/day); +++regularly captured (>20kg/day).

4. DISCUSSION

The African catfish (*C. gariepinus*) was clandestinely introduced into the state of West Bengal possibly during 1994 and quickly spread throughout the country, including coldwater regions as well as coastal areas. It is largely cultured in the states of West Bengal and Andhra Pradesh. However, seed production is mainly practiced in the state of West Bengal. Although its culture is unauthorized, the fish has become popular among aquaculturists in the country on the grounds that it easily accepts animal waste as feed and serves as very good scavenger. The diagnostic characters of *C. gariepinus* identified were heads somewhat between rectangular and pointed in dorsal outline, frontal fontanelle long and narrow (knife shaped), sides of head behind eye bony, suprabranchial organ completely filled the suprabranchial chamber, dorsal fin almost reached the caudal fin. However, the hybrid African catfish was also similar except a bit of change in pigmentation and colouration on the dorsal side of the body. The hybrid catfish (*C. gariepinus x C. macrocephalus*), a fast growing variety is being produced in hatcheries in Bangladesh [21,22] and smuggled into the bordering north-eastern States, Assam and West Bengal and as far as Bihar, forming the basis of a flourishing trade in India. Hybrid catfish is more popular owing to its fast growth and is very inexpensive to feed because recycled chicken and slaughterhouse wastes are generally used [3,22].

In India, monoculture of African catfish or its hybrid was observed to fetch varied level of production. In monoculture studies, the growth, survival and production of the fish did not show any consistency. This could be due to varied stocking densities, poor management, irregular feeding, cannibalism and diseases [3,22]. However, its polyculture with carps was not compatible severely caused losses to carp production because the fish was found highly carnivorous [3,20]. The highly varied production and survival could be attributable to the fact that stocked fish could be of different genetic lineage [5] or hybrid of African catfish. It is to mention that fish farmers procure the fingerlings from private fish seed traders usually from West Bengal which is a hub of African catfish seed production. Wide variability in growth, survival and production could be attributable to the hybrid catfish (*C. gariepinus x C. macrocephalus*) [19,23] or the segregated stock of the hybrid catfish since the hybrid was not sterile and it bred at farms. The varied growth and production could also be due to varied nature of feed given to the fish, different stocking densities, stocking size variations and varied culture periods. Whatsoever might be the reason for varied growth and production, the popularity of culture stems from several characteristics of the fish that it withstands harsh environments and readily accepts cheap feed [3,24].

Our findings on the compatibility of the fish with Indian major carps also corroborate with the report from Nigeria where a poor growth performance of Indian major carps has been shown [25]. From Thailand the fish was introduced to Bangladesh where estimated net production of *Clarias gariepinus* in Bangladesh is reported 10-12 $tha^{-1}yr^{-1}$, 7.3-15 $tha^{-1}yr^{-1}$ and 14.2-14.3 $tha^{-1}yr^{-1}$ under magur dominated polyculture, magur polyculture integrated with chicken and magur monoculture systems respectively and it has been suggested that its production on a per unit area basis could be increased further with stocking of surface feeder species such as silver carp (*Hypophthalmichthys molitrix*) and catla (*Catla catla)* without affecting the growth rate of magur [26]. However, the fish did not perform well in polyculture in our findings which is supported by earlier reports [21,25].

This species was found to possess a highly carnivorous feeding habit feeding on live fish, frogs, insects, snails, earthworms, plankton, plants and fruits and also rotting flesh (Fish Base 2012). It exhibits a lethargic behaviour when raised under optimal husbandry conditions, which results in low maintenance requirements [27]. However, it is necessary to feed the fish with good quality of feed having high protein to achieve good growth of fish, [28]. Being tolerant to harsh environment, it is identified as top predator fish [3,29]. The biological attributes of the African catfish related to its culture, generalised feeding habits, high mobility and ability to survive in a wide range of habitat raises concern over its impact as an invasive species [10,30]

Since *C. gariepinus* was cultivated in very unhygienic conditions, monitoring of the heavy metals in grow-out ponds was done to find out bioaccumulation of heavy metals and the results revealed that risks in the range of 1E - 06 to 1E - 04 was prevailing which was typically adjudged to be acceptable. The potential ingestion risk of exposure to Al, Fe and Pb was 6.3E-03 to 9.6 E–03, 3E-03 to 9.7 E–03 and 1.15E-05 to 9.3 E–06 respectively in our findings and the risk for Pb was assessed high in this study [18]. Calculated value of HI through the ingestion of fish was less than the acceptable limit but value of HI was high when considered through all routes (i.e. ingestion of sediment, ingestion of surface water, ingestion of suspended matter, dermal contact with sediment, dermal contact with surface water) and thus was more than the acceptable limit that can cause risk for human health [18,31]

In India, the fish has been found to mature at an early age where females weighing 250-450g were found with swollen belly and mature eggs only at 5-7 months of age while males were observed to mature a bit later. Breeding of the fish is carried out at farms either injecting with carp pituitary (0.4mg kg^{-1} body weight) or ovaprim (0.2 ml kg^{-1} body weight). The females are stripped whereas males were cut open and their testes are macerated and mixed with the stripped ova for fertilization. Breeding this catfish artificially or under simulated condition is quite easy [32]. The African catfish matures easily in pond conditions having mature eggs and sperms throughout the year except for November to February [33] and natural pond breeding has also been observed indicating its capability to establish in wild [18].

Clarias gariepinus is resistant to disease [23], usually becoming infected in poorly maintained aquaculture situations [34]. In most of the culture, the fish was fed with slaughterhouse and chicken waste, which caused deteriorated water to produce offensive fowling smell which was conducive for infections. Some diseases like ruptured intestinal syndrome (RISue) and epizootic ulcerative syndrome (EUS) of which aetiology is not exactly known and are of concern today since there exists much of literature documenting the diseases of concern [35,36].

The Asian catfish, *Clarias batrachus* and the peninsular catfish *C. dussumieri* are regarded as good food fish in India. However, *C. gariepinus* has now substituted these fishes because it can easily be cultivated in ponds and tanks, homestead ponds, cement cisterns using wastes as feed. African catfish, *C. gariepinus* does not taste like local catfish but it grows faster. The local catfish, *C. batracuhs* is considered as a highly prized fish in India because it has fewer inter-muscular bones, good taste, flavour and more recuperative and medicinal qualities [37]. However, low fecundity and slow growth rate of the species [37] do not attract farmers for its culture when compared to African catfish.

The commercially important catfish which contribute substantially to the total inland fish production in India are *Aorichthys aor, A. singhala, Mystus cavasius, M.gulio, Rita rita, Wallago attu, Ompok bimaculatus, Heteropneustes fossilis, Clarias batrachus, Silonia silondia, Pangasius pangasius*. African catfish *C. gariepinus* has been introduced in India in a big way but growing interest in its culture was assessed as a serious concern rather than benefits. The results on the biological information generated from India constructed popular belief that African catfish is a ferocious predator capable of even eating away large variety of natural aquatic organisms. Thus, African catfish was found to have strong potential to wipe out the local aquatic diversity provided it establishes in wild [3]. The introduction of *C. gariepinus* has not been a success in India as several socio-economic aspects and ethical issues are now emerging. Many of the consumers refused to buy *C. gariepinus* even at reasonable price because of its taste, relatively large head (which cannot be consumed) and also because of the religious sentiments that this fish consumes slaughterhouse waste.

The results of this study revealed that the fish escaped in several river stretches where its propagation through natural reproduction is quite likely. Our findings on the biological aspects including food and feeding and reproduction focus on its invasive potential seriously views its spreading into natural aquatic drainages [3,38]. The fish was found to tolerate harsh environmental conditions and was distributed over a wide range of temperatures (12–36±1ºC) and salinities (<14 ppt). Its presence was recorded from coastal areas, freshwater ponds, tanks, lakes, reservoirs, aquatic bodies of foot-hills in cool environments and even in some rivers, such as the Godavari, Yamuna, Gomti and the Ganga Rivers, with different pristine diversity is assessed detrimental [3,39]. Introduced African catfish may interact adversely with native species through predation, competition or hybridization [13]. African catfish is an omnivorous fish feeding on insects, crabs, plankton, snails and fish and can also eat live birds, rotting flesh, plants and fruits and is a voracious predator [3,29]. A critically declining bird, the Moorhen *Gallinula chloropus*, was recently found in the gut of a 67-cm-long fish caught from the Bharatpur bird sanctuary in

Rajasthan [40]. The gut content analysis in this study delineated that fish and aquatic insects constituted major food of the fish. African catfish has been assessed to be associated with top-down effects and tropic cascading through eliminating certain prey groups or through competition with sympatric native predators [41], [42]. This study focuses on the impact of an introduced African catfish from a food web perspective due to its generalist predatory feeding habits. It poses a potential threat to the depauperate native ichthyofauna. The impact of the catfish may also be related to variation in its food sources. A generalised consumer could have a high probability of invasion success because food availability is unlikely to be limiting.

This spreading of the fish in wild is of high risk to the fish biodiversity in general (Vitule *et al.,* 2006) and *Clarias batrachus* in particular which has declined notably in recent years [43]. The introduction of *C. gariepinus* in South Africa has been reported to exterminate some native fishes and crabs [3]. African catfish culture has been found to occur in all areas where local *C. batrachus* naturally exist. *Clarias gariepinus* has the potential to hybridize with local *C. batrachus* [43,44], suggesting the possibility of genetic pollution when escapee fish breed in the wild. Gene introgression has already been reported in the local species *C. macrocephalus* in Thailand as a result of escapee *C. gariepinus* [13]. In Western Ghat, a biodiversity rich hotspot, farmers culture *C. gariepinus* over the endemic yellow catfish (*Horabagrus brachysoma*), which is now critically declined [45]. The threat of *C. gariepinus* and its invasion into a river in South Brazil have also been reported [8]. Considering the threats posed by African catfish, the Ministry of Agriculture, Government of India, ordered destroying of the stock and imposed a ban on its culture. However, it is still bred and cultured even today in different parts of the country.

Quantitative knowledge about food web structure of the fish has important practical applications in the assessment of the impact of introduced species. Freshwater catfish *C. gariepinus* in the tropics are obligatory air-breathers having carnivorous behaviour that metabolize more protein in its food and consequently more ammonia is released in water as an end product of metabolism [46,47]. Thus accumulating ammonia can cause a wide range of ecological impacts including loss of native biodiversity, altered habitats, changes in water chemistry, altered biogeochemical processes, hydrological modifications, and altered food webs [48,49,50,51]. Invasion success of an introduced species has been reported to be variable with some invasion events having adverse negative impacts [52] whereas other invasive species appear to integrate well into their recipient systems with little or no impact [53]. In aquatic ecosystems, the major concern is the invasion by introduced fish that have many negative impacts ranging from local extirpation of native species to the alteration of ecosystem processes [4,54]. On the other hand, impacts are likely to be influence the use of local resource particularly native *C. batrachus* that would disappear from different localities [3] and between agro-climatic environments (Coastal, plains and hilly areas). A common feature for invasive generalist predators appears to be their broad trophic niche with potential to affect a large number of species in the invaded community [55]. The results of this study on sharptooth catfish introduced illegally in India indicated that it is an indiscriminate and competitive predator that can alter the food webs of the invaded community [7,12].

5. CONCLUSION

Various factors such easy to transport, culture, acceptance of various types of feed and habitata, air-breathing nature, ability to walk on land, burrowing capabilities and ability to hide in vegetation make this species easy to spread. There is no legislation or law to control such ferocious fish in India. The department of Animal Husbandry, Dairying and Fisheries (DAHD&F), Ministry of Agriculture, Government of India banned culture of African catfish vide office letter number 31016/1/96-FY dated 19-12-97. There are State Fishery Acts and Fishery Policy in different states but most of the Fishery Acts are very old and not effective to contain illegal culture of introduced fish species. However, a few states have so far come out with amendments in Fishery Acts and new fishery policies e.g., Gujarat Fishery Act- 2003 (G/PF/11/2003/FDX/1268/5152/Part-VI/T) has made some amendments in the Act. It is thus, there is an urgent need to develop regulatory policy and guidelines at the central as well as state levels to manage the menace of the introduced obnoxious fish species. Article 8(h) of the Convention on Biological Diversity (CBD) calls on member governments to "as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystem, habitats or species". However, national responses to the

Invasive Alien Species (IAS) problem have so far been insufficient to counter the increasing toll of invasive species on natural resources and society.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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