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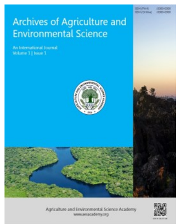

ORIGINAL RESEARCH ARTICLE

Fish productivity: Assessing sustainability in a tropical oxbow lake of Nadia district, West Bengal, India

Dipankar Ghosh and Jayanta Kumar Biswas*

Department of Ecological Studies, University of Kalyani, Kalyani-741235, (West Bengal), INDIA
*Corresponding author's E-mail: biswajoy2000@yahoo.com

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ABSTRACT

Fish productivity in oxbow lake is impacted severely due to varied unsustainable anthropogenic practices like over exploitation, indiscriminate use of fine meshed fishing gears, jute retting etc. This particular study was conducted in a semi closed oxbow lake ecosystem in eastern India to assess both the present and sustainable fish productivity based on the data collected through direct catch assessment survey, fishing effort survey and catch per unit effort calculation. Hike in relative abundance values like numbers of fish catch (>3.78 times), catch per gear effort (>2.6 times), fish density (>2.65 times) and fall in relative biomass values like catch per gear effort, catch per unit effort and fish standing biomass (>41%) were observed during monsoon compared to premonsoon due to flooded turbid water from the river Ganga and jute retting processes during monsoon. Jute retting and indiscriminate over fishing of the monsoon made fish production reduced by >50% during post monsoon. The current fish productivity was estimated at 1146.64kg/ha/year supporting only 23.33% livelihoods of enlisted fishers and about 97.67% of fish production remains unreported every year in the official records of the cooperative society based on the oxbow lake ecosystem indicating inefficient management. Total sustainable production of 285MT (@5MT/ha/year) with total operating capital need of INR 1.00 crore (@INR 0.01716 crore/ha/year) with benefit cost ratio of 4.28 was estimated as the sustainable and replicable basis for promotion of organic aquaculture supporting 100% livelihoods of all fishers and rejuvenating the management of the present oxbow lake ecosystem.

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INTRODUCTION

West Bengal, an eastern state of India is blessed with so much potential of oxbow lake ecosystem but oxbow lake fishery is still underutilized and there remains an urgent need to manage them properly to meet the maximum or optimum sustainable yield (MSY/OSY), improve living standards, bridge the gap between supply and demand for cheap protein security and reduce the unemployment without harming oxbow lake ecosystems in the state. But fish productivity in oxbow lake is impacted severely due to varied unsustainable anthropogenic practices like over exploitation, indiscriminate use of fine meshed fishing gears, jute retting etc. Limited studies have been conducted on fish productivity in the past. The higher fish production is associated with higher species richness (Azher *et al.*, 2007). Fish productivity values varied from 0.028 to 0.281gC/m^2/day in simply stocked pond to stocked, inorganic fertilized and supplementary fed ponds (Olah *et al.*, 1986). Varied fish productivity values have also been r ported in other types of aquatic production systems: 242.47 kg/ha in Saldu oxbow lake in Bangladesh (Saha and Hossain, 2002); 300.6-459.6 kg/ha in "Kua" fisheries in Bangladesh (Dewan *et al.*, 2002); 476-2,324 kg/ha/yr in Assam oxbow lakes (Dehadrai, 2006); 68-108.5kg/ha/yr in unmanaged ox-bow lakes of Assam (Das *et al.*, 2011); 600 kg/ha in flood plains of the Ganga river system in West Bengal (Bhaumik *et al.*, 2006); and 281.86 kg/ ha/yr in oxbow lakes in Bangladesh (Sayeed *et al*., 2014).

It is quite obvious that information available on quantitative bio-assessment on the status of fish community biomass structure with potential impacts of anthropogenic activities including jute retting and indiscriminate use of fishing gears of different mesh sizes on the fish productivity and estimation of sustainable fish productivity (MSY/OSY) in a tropical oxbow ecosystem in Ganga river basin in Nadia district in particular is either insufficient and lacking which remains to be addressed immediately to recommend sustainable conservation and management measures. This particular study was conducted in a semi closed oxbow lake ecosystem in eastern India obviously to assess both the present and sustainable fish productivity. The findings of this unique study will benefit the planning and management of sustainable fisheries and conservation of these natural resources at the national level. Keeping such perspective in view this investigation was carried out to study the fish productivity and its sustainability in a tropical oxbow lake of Nadia district, West Bengal, India.

MATERIALS AND METHODS

Study area: The Chhariganga oxbow lake, an abandoned, fractioned derived from the river Ganga is selected at random and it is located in Nakashipara development block of Nadia district, West Bengal, India. It is situated at 23.5800°N, 88.3500°E, about 90 Km away from the Kalyani University campus, Nadia and nearly 40 km away from the line of tropic of cancer towards the north. It is fresh water and semi-closed type oxbow lake and receives water from the river Ganga during monsoon through a narrow channel at the north east corner of a loop of the river. The oxbow lake is spread over an area of 58.28 ha with an annual average depth of 2.6m. It also stores rain water. The catchments area of the oxbow lake is nearly 600 ha (Figure 1**)**. There are three distinct annual seasons observed in changed climate of this region: the monsoon or rainy season generally from July to October when jute retting period lies normally during August- September**,** post monsoon or winter from November to February and the pre monsoon or dry season from March to June. There was an occasional inundation of the surrounding banks during the monsoon. The oxbow lake is subjected to all forms of human activities including jute retting during monsoon, agriculture and fishing. It is the only source of irrigation water to the immediate agriculture communities.

Fish yield data collection: The study was conducted based on the data collected through direct Catch Assessment Survey (CAS), Fishing Effort Survey (FES), direct interviews and Focus Group Discussions (FGDs) with different stakeholders with sufficient replicates from in and around the oxbow lake (Nelson, 1991; Chambers, 1994; Pretty *et al.,* 1995; Grenier, 1998; Angrosino, 2002; Morgan *et al.,* 2008). FES and CAS were conducted using a boat starting from 6 am to 6 pm twice in a month over 12 months for three seasons in two years. Sampling of catches and their assessment were done twice per month during the study period. The fishermen were selected on the basis of types representative samples were taken with the help of hand without repetition of the net in each sampling day. The FGDs were conducted with a pre-structured and pre-tested questionnaire involving people from all sections.

Fish sampling and analysis: Sample fishing was carried out by using the expertise of local fisher folk using 8 different types of gears (Table 1a) on several occasions at random allowing us to sample a range of fish sizes and minimize the bias due to specific gears. Each gear was operated for hours ranging from 4 to 24 in different sites of the oxbow lake bringing the total mean efforts per day (65, 44, 77 and 95) with gear density (2565, 5161, 2957 and 10683); and total Sampling Gear Efforts (3648, 5200, 3411 and 12259), respectively during pre monsoon, monsoon, post monsoon and the year for all the gears used in the sampling. The catch per unit of fishing effort (CPUE) is a much used ecological measure for the density of stock. In our study, gear wise CPUE in fish caught in per unit hour of operation was calculated by dividing total sampling gear catch in number, which is observed value of fish catch by a particular gear, by the total sampling effort hours (product of average sampling effort hour of operation of a particular gear per day and total numbers of such gear used i.e. gear density in the sampling) put in sampling. Similarly, gear wise catch per gear effort (CPGE) as fish caught in per unit effort or attempt or operation was calculated by dividing total sampling gear catch by the total sampling gear effort (product of putting average sampling effort of a particular gear per day and total numbers of such gear used i.e. gear density in the sampling) put in sampling. The overall catch per unit or gear effort (CPUE or CPGE), a measure of relative abundance (n/h and n/e), was calculated by dividing total catch in number (n) from gear (s) by total hours (h) or efforts (e) of operations off gear(s) used during those three seasons and the year. Average mean fish density (n/m^3) was calculated by dividing total number (n) of fish encountered in area (m^3) operated by gear (s) for each season. Local fish markets associated with the oxbow lake system were also visited to monitor and look for the presence of any species which were not available during our sample fishing. The relative abundance equaling to percentage of catch biomass of fish across lake was worked out for those three seasons by dividing the product of number of samples of particular species and 100 by total number of samples.

Fishes were subsequently identified as per standard literature (Jayaram, 1981, 1999; Talwar and Jhingran, 1991; Dutta Munshi and Shrivastava, 1988; Froese and Pauly, 2015; Vidthayanon, 2012; IUCN, 2015). The threat status of the fishes of Chhariganga oxbow lake was divided into nine categories as adapted from Lakra and Sarkar (2007), Lakra *et al.* (2010), IUCN (2011), Vidthayanon (2012), IUCN (2015): LRnt: low risk near threatened, Lrlc: low risk least concern, LC: Least Concern, NE: Not Evaluated, DD: Data Deficient, EN: Endangered, NT: Near Threatened. VU: Vulnerable, NA: Not Assessed for the IUCN Red List. Fishes were sorted out by their numbers and weighed. Fish species compositions during pre monsoon, monsoon and post monsoon were calculated.

Fish yield calculations: Season wise 8 different gears with their densities (AGD=Average Gear Density), days of operation (DOP), Average efforts per day per gear (AEPD), Average Efforts Hrs per Day per gear (AEHPD), Total Gear Efforts (TGE), Total Gear Efforts Hrs (TGEH) and Gear catch (GC) are calculated in details. Total Gear Efforts (TGE), Total Gear Effort hours (TGEH) and Gear catch (GC) were calculated for total fish production of the oxbow lake during a year by the following formulas (Where, g = gram, n = number, e = effort, h = hour): Total Gear Efforts (TGE) in (e) =AGD (n) X DOP (n) X AEPD (e), Total Gear Effort hours (TGEH) in (h) = AGD (n) X DOP (n) X AEHPD (h) Gear catch (GC) (in g or n) =TGE (e) X CPGE (g or n per e) and Gear catch (GC) (in g or n) =TGEH (h) X CPUE (g or n per h).

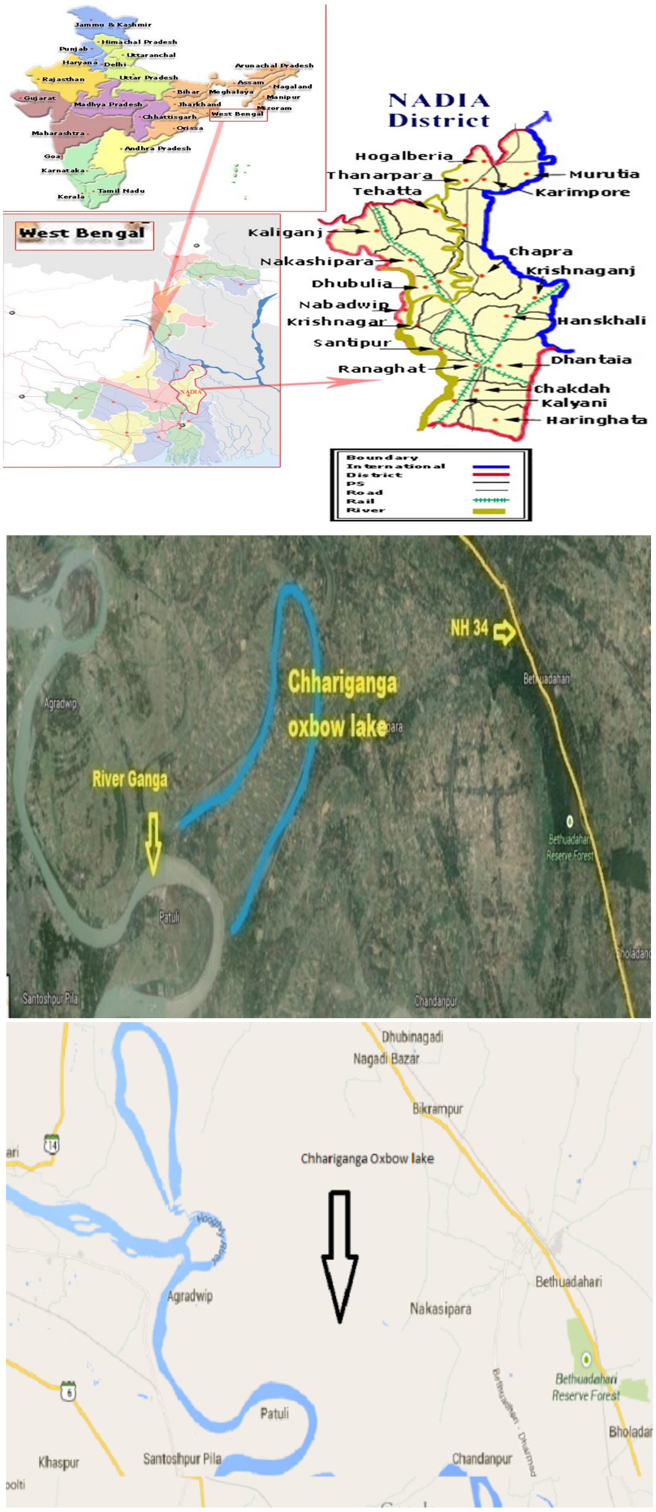

Figure 1. *Map showing study area of Oxbow lake.*

Statistical analysis: Statistical analyses including mean, standard deviation and the degree of relationships were determined with the help of MS-Excel and then presented in textual, tabular and graphical forms. The level of statistical significance was accepted at $P<0.05$.

RESULTS AND DISCUSSION

Annual fish production based on CPUE: As calculated by CPGE and CPUE through the sample survey by random sampling, PRA and catch analysis, it was found that annual average and total values of Gear Catch (8687818 and 8458926, 14481232 & 14692344, 4361484 and 4736220, 550001 each, 2199999 each, 22769454 and 22308372, 7568025 and 8390716 and 5489771 each and 66107784 and 66826349 gram of fish) and GC (1040760 and 1085280, 1611500 and 1654950, 18000 and 22860, 57780 each, 83600 each, 4280472 and 4211592, 8614 and 9326, 47280 each and 7148006 and 7172668 numbers of fish), respectively in Triangular Push nets, Gill nets, Long lines, Seine net, Drag net, Stationary Dip net, Cone framed cast net, Line & Hook and the year. Estimated total average fish production both in biomass and number from the lake was around 21.21 ton (1.02 lakh), 30.47 ton (3.87 lakh), 15.14 ton (2.28 lakh), 66.11 ton (7.15 lakh), and 66.83 ton (7.17 lakh) in the pre monsoon, monsoon, post monsoon, year average and year total (Table 1).

The average body weight values (which were calculated by dividing the total catch by numbers) were observed at 20.78g, 7.88g, 6.63g, 9.25g and 9.32g respectively during pre monsoon, monsoon, post monsoon, year average and year total. Stationary Dip net followed by Gill nets contributed the most of the total annual catch both in biomass (33.38%, 21.98%) and numbers (58.74%, 23.08%). The least contributions were made by Seine net (0.82%, in *Komor,* a FAD) and Cone framed cast net (0.13%) in the total fish catch in biomass and numbers, respectively.

Verification of the estimated total fish yield calculated based on CPUE: Total fish productions data obtained from local whole sale fish market survey through the participatory rural appraisal (PRA), sale analysis of fishers survey through PRA, catch analysis by survey through PRA and sample, catch analysis of gears by survey through PRA and sample, catch analysis of gears operators through survey in PRA and sample, corroborate the fish production analysis results as calculated by CPGE and CPUE through the sample survey by random sampling, PRA and catch analysis (Tables 2-7).

Whole sale fish market survey: Market survey through PRA reveals that on an average 8 whole sellers (*Aratdar*) of nearby markets around the Chhariganga oxbow lake sale around 25 kg of fish daily and the markets opens for nearly 300 days of a year, selling total of about 60 ton, with 6.89 tons of fish catch directly consumed by fisher's households, and thus whole sellers' sales plus fishers' own consumption/sale as surveyed through the PRA, totaling total fish catch of 66.89 (ton/yr), which is much closer to present results calculated CPGE and CPUE through sample survey by Random Sampling, PRA and catch analysis (Table 2).

Fisher's catch sale analysis: Fisher's catch sales analysis by survey through PRA reveals that on an average 105, 120, 85 and 103 numbers of fisher's catch sale daily in the lake during pre-monsoon, monsoon, post monsoon and year, respectively with the average daily individual catch sale of 2.13kg, 2.30kg, 1.93kg and 2.12kg for 95 days, 110 days, 93 days and 298 days of operation together with total fish catch sales of 21197kg 30360kg,15217, and 65179kg (year total being 66774kg) during those three season and the year respectively (Table 3).

Both gears and their operators' catch analysis: Considering both gears and their operators' catch analysis made by survey through PRA and sampling, we found year mean total AGOD (average gear operators density) of 257 numbers, ADGOC (average daily a gear operator's catch)

Table 1. Estimation of annual fish production based on CPUE and CPGE

Season	Gear	Triangular Push nets	Gill nets	Long lines	Seine net	Drag net	Stationary Dip net	Cone framed cast net	Line & Hook	Total
PRM	AGD	21	940	14	10	-	-	33	2500	3518
MON		-	1160	55	-	1	21	-	5125	6362
POM		28	830	21	10	-	21	33	2875	3818
YR		25	977	30	10	1	21	33	3500	4596
PRM	DOP	120	120	120	2	-	-	90	120	572
MON		-	120	120	-	80	110	-	120	550
POM		120	120	120	2	-	118	50	120	650
YR		240	360	360	4	80	228	140	360	1772
PRM	AEPD	28	1	1	1	-	-	33	1	65
MON		-	1	1	-	6	35	-	1	44
POM		37	1	1	1	-	23	13	1	77
YR		33	1	1	1	6	29	23	1	95
PRM	AEHPD	5	10	11	24	-	-	7	10	67
MON		-	10	11	-	7	22	-	10	60
POM		4	10	11	24	-	18	7	10	84
YR		4.5	10	11	24	7	20	7	10	70
PRM	TGE (e)	70560	112800	1680	20	-	-	98010	300000	583070
MON		-	139200	6600	-	480	80850	-	615000	842130
POM		124320	99600	2520	20	-	56994	21125	345000	649579
Year Average		191100	351600	10800	40	480	138852	105455	1260000	2058327
PRM	TGEH (h)	12600	1128000	18480	480	-	-	20790	3000000	4180350
MON		-	1392000	72600	-	560	50820	-	6150000	7665980
POM		13440	996000	27720	480	-	44604	11375	3450000	4543619
Year Average		26460	3516000	118800	960	560	95760	32095	12600000	16390635
PRM	GC (g)	4410025	6222048	2049607	275001	-	-	6682498	1570801	21209980
MON		-	5826912	2046026	-	2199999	17325139	-	3075007	30473083
POM		4048901	2643384	640586	275000	-	4983233	1708218	843962	15143285
Year Average		8687818	14481232	4361484	550001	2199999	22769454	7568025	5489771	66107784
Year Total		8458926	14692344	4736220	550001	2199999	22308372	8390716	5489771	66826349
PRM	GC (n)	312480	662700	6720	18760	-	-	7110	12960	1020730
MON		-	730800	13860	-	83600	3012240	-	27600	3868100
POM		772800	261450	2280	39020	-	1199352	2216	6720	2283838
Year Average		1040760	1611500	18000	57780	83600	4280472	8614	47280	7148006
Year Total		1085280	1654950	22860	57780	83600	4211592	9326	47280	7172668

AGD=Average Gear Density, DOP=Days of operation, AEPD=Average efforts per day per gear, AEHPD= Average Efforts Hrs per Day per gear, TGE=Total Gear Efforts=AGD X DOP X AEPD, TGEH=Total Gear Efforts Hrs= AGD X DOP X AEHPD, GC=Gear catch (g or n)=TGE X CPGE=TGEH X CPUE, g=gram, n=number, e=effort, h=hour, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-)=No operation

Table 1a. Different gears used in sample fishing

Common name	Vernacular name	Dimensions and attributes	Mesh size	EGA	Area of operation (AOP) in (sqm)			
Gear			(mm)	(sqm)	PRM	MON	POM	YR
Triangular Push net	Thela Jaal	(1sqm=0.5X1mX2m), operated mainly under water hyacinth covered area	5.0-15.0	1	16620	-	22710	19665
Gill nets	Fansh Jaal	(45m X 0.75m), Made of Monofilament, 10-12 no net each for 70-110 fishers	≥ 22.0	33.75	183380	455050	277290	305240
Long lines	Daun	With 80-100 baits, mainly carnivores caught, operates in coverage area (200sqm=200mX1m)	-	200	183380	455050	277290	305240
Seine net	Komor	Fish caught from a type of Micro Sanctuary or FAD created by tree branches	3.0-10.0	333	200000	-	300000	250000
Drag net	Ber Jaal	(50m X 6m)	10.0-12.0	300	-	500000	-	500000
Stationary Dip net	Bashaal Jaal, Dhenki Jaal	(72sqm=0.5 X 12m X 12m)	≥ 5.0	72	-	455050	277290	366170
Cone framed cast net	Chaabi Jaal	(7 sqm= 3.14X 1.5m X 1.5m)	≥10.0	7	200000	-	300000	250000
Line and Hook	Nal Borshi	Area (1200sqm=1000 m X 1.2m) operates in a line of with 200-250 baits, mainly carnivores caught	-	5.33	183380	455050	277290	305240
Total mean	8				966760	2320200	1731870	2301555

EGA=Effective Gear Area, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-) =No Operation

of 1.3624kg, for DOP (days of operation) of 298 days, SGOC (season's gear operators catch) of 66826kg; and AGD (average gear density) of 4566, ADGC (average daily a gear catch) of 4.2858kg, AEPD (average effort per day per gear) of 10, CPGE (catch per gear effort) of 0.4447kg and SGC (season's gear catch) of 66825kg (Tables 4 and 5).

Gear's catch analysis: Gear's catch analysis through PRA and sampling reveals an annual fish production of 68089kg in the year with 8 different gears. Gear wise AGD (Average gear density in numbers), annual ADGC (Average daily a gear catch in kg), operated for DOP (Days of operations) and resulting GC (Gear catch in kg) were surveyed and estimated for Triangular Push nets (25, 1.4775, 240 and 8865); Gill nets (977, 0.0412, 360 and 14481); Long lines (30, 0.5947, 360 and 6387); Seine net (10, 13.75, 4 and 550) in *Komor*; Drag net (1, 27.50, 80 and 2200); Stationary Dip net (21,4.7555, 228 and 22769); Cone framed cast net (33, 1.6506, 140 and 7510) and Line & Hook (3500, 0.0042, 360 and 5327), respectively (Table 6).

Gear's operators catch analysis: Gear's operators catch analysis was carried out through PRA and sampling and a fish catch of 65953kg was estimated. Annual AGOD (average gear operators density), ADGOC (average daily a gear operator's catch in kg) and GOC (gear operators catch in kg) were estimated for Triangular Push nets (25, 1.4775 and 8688); Gill nets (88, 0.4554 and 14481); Long lines (30, 0.5947 and 6423); Seine net in *Komor* (90, 1.5469 and 557); Drag net (10, 2.750 and 2200); Stationary Dip net (32, 2.8805 and 20688); Cone framed cast net (33, 1.6506 and 7568) and Line & Hook (16, 0.9484 and 5349), respectively (Table 7).

Average total annual fish yield: Data on total fish p roduction obtained from fishers' sales surveyed through PRA and sale analysis showed an annual total fish yield of 66.77 ton with an annual mean of 65.98 ton. The yield was calculated as 65.95 ton when considered the gear operators' catch only as surveyed by PRA and sample catch analysis, which also revealed total annual gears catch of 68.09 ton and both the gears and their operators' catch of 66.83 ton. The mean fish production of the Chhariganga oxbow lake was estimated to be 66.70±0.82 ton which also corroborates the result obtained from calculation by CPGE and CPUE (Table 8).

Relative fish production analysis: Relative fish production analysis is furnished in the synopsis in the Table 9. CPUE (g/h) of 5.07, 3.98, 3.33, 4.03 and 4.08 and CPUE (n/h) of 0.24, 0.50, 0.50, 0.44 and 0.44 were observed

Table 2. Whole sale fish market survey through PRA

Whole sale fish market (also called 'Arat' in vernacular language)	No.	Daily sale	Days of operation	Yr Average
Fish sale proceeds in 'Arat' (kg/yr)	8	25	300	60000
Fish directly consumed by fishers (kg/yr)				6891
Total fish catch from the market survey (kg/yr)				66891

Table 3. Fishers catch sale analysis made through PRA based survey

Attribute	PRM	MON	POM	Yr Average	Yr Total
Fishers daily density (no.)	100	100	80	93	93
	110	140	90	113	113
Average of fisher's daily density (no.)	105	120	85	103	103
Individual catch (kg) per fisher	2.00	2.10	1.75	1.95	1.95
	2.25	2.50	2.10	2.28	2.28
Average individual catch (kg) per fisher	2.13	2.30	1.93	2.12	2.12
Average value of days of operation	95	110	93	298	298
Total catch (kg)	21197	30360	15217	65179	66774

PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon

Table 4. Both gears and their operators' catch analysis made by survey through PRA and sampling

Season	Gears	Triangular Push nets	Gill nets	Long lines	Seine net	Drag net	Stationary Dip net	Cone framed cast net	Line & Hook	Mean
PRM	AGOD	21	85	14	100	-	-	33	11	264
	AGD	21	940	14	10	-	-	33	2500	3518
	ADGOC	1.750	0.610	1.220	1.375	-	-	2.250	1.190	1.399
	ADGC	1.750	0.055	1.220	13.750	-	-	2.250	0.005	3.172
	AEPD	28	1	1	1	-	-	33	1	11
	CPGE	0.063	0.055	1.220	13.750	-	-	0.068	0.005	0.293
	DOP	120	120	120	2	-	-	90	120	95
	SGC	4410	6222	2050	275	-	-	6683	1571	21209
	SGOC	4410	6221	2050	275	-	-	6683	1571	21209
MON	AGOD	-	105	55	-	10	42	-	23	235
	AGD	-	1160	55	-	1	21	-	5125	6362
	ADGOC	-	0.462	0.310	-	2.750	3.750	-	1.114	1.677
	ADGC	-	0.042	0.310	-	27.500	7.500	-	0.005	7.071
	AEPD	-	1	1	-	6	35	-	1	9
	CPGE	-	0.042	0.310	-	4.583	0.214	-	0.005	0.804
	DOP	-	120	120	-	80	110	-	120	110
	SGC	-	5827	2046	-	2200	17325	-	3075	30473
	SGOC	-	5827	2046	-	2200	17325	-	3075	30473
POM	AGOD	28	75	21	80	-	21	33	13	271
	AGD	28	830	21	10	-	21	33	2875	3818
	ADGOC	1.21	0.294	0.254	1.719	-	2.011	1.051	0.541	1.011
	ADGC	1.21	0.027	0.254	13.750	-	2.011	1.051	0.002	2.614
	AEPD	37	1	1	1	-	23	13	1	11
	CPGE	0.033	0.027	0.254	13.750	-	0.087	0.081	0.002	0.238
	DOP	120	120	120	2	-	118	50	120	93
	SGC	4049	2643	641	275	-	4983	1708	844	15143
	SGOC	4049	2643	640	275	-	4983	1708	844	15143

AGOD=Average gear operator's density, AGD=Average gear density, ADGOC= Average daily a gear operator's catch, ADGC=Average daily a gear's catch, AEPD= Average effort per day per gear, CPGE= catch per gear effort, DOP= Days of operations, SGC=Seasonal gear catch, SGOC= Season gear operator's catch, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-) =No operation respectively during premonsoon, monsoon, postmonsoon, year average and year total. RAW (recorded water area) standing biomass of the oxbow lake showed values of 17.33, 17.43, 10.19, 44.48 and 44.97 g/m^3 during those corresponding period and RAW standing biomass values during all seasons of course showed higher values when calculated in the EWSA (effective water spread area) of the lake. Considerable increase in the fish catch in numbers (n >3.78 times), CPGE (n/e >2.6 times) and RAW fish density (no /m$^{3)}$ (>2.65 times) were observed during the monsoon over the premonsoon period. The premonsoon relative abundance in biomass values like catch per gear effort (CPGE in g/e), catch per unit effort (CPUE in g/h) and EWSA standing fish biomass (g/m^3) get reduced during monsoon and postmonsoon period and consequently significant fall was noticed in fish production (>50%) and RAW fish standing biomass (>41%) during postmonsoon from the previous season (monsoon).

Fish catch biomass composition analysis: As many as 33 native fish species (31.68% by biomass and 33% by number as vulnerable or endangered) belonging to 8 orders and 17 families was recorded. The season wise catch composition of all the 33 species have been shown in Table 10. It is evident from the table that the order of dominant fish orders in terms of catch biomass composition was as follows: Cypriniformes > Perciformes > Siluriformes > Osteoglossiformes. *Labeo rohita* dominated in terms of catch biomass during all seasons and throughout the year (nearly one fourth of the total annual fish catch). Others species under Cypriniformes contributing in present study were *Catla catla* (8.37%) and *Pethia ticto* (7.15%) during monsoon; and *Amblypharyngodon mola* (6.84%) during postmonsoon. *Channa marulius* (3rd highest among all in the year) followed by *Channa striatus* (4th highest among all in the year) topped the order Perciformes throughout the year. A near threatened species *Wallago attu,* was found to be the most dominating among the Siluriformes and secured in 2nd topmost position in the year in terms of total catch composition after *L. rohita*. *Heteropneustes fossilis* and *Clarias batrachus* are other Siluriformes dominating in terms of catch biomass. While *Chitala chitala/ornata*, an endangered species (EN) stood 5th position in the year composition, *N. notopterus*, another endangered species was observed to be 3rd highest catch in the monsoon both belonging to the order Osteoglossiformes.

We observed that *Mastcembelus armatus*, a vulnerable

Table 5. Synopsis of both gears and their operators' catch analysis

Season	AGOD	AGD	ADGOC (kg)	ADGC (kg)	AEPD	CPGE (kg)	DOP	SGC (kg)	SGOC (kg)
PRM Mean	264	3518	1.3992	3.1717	11	0.29278	95	21209	21209
MON Mean	235	6362	1.6773	7.0714	9	0.80357	110	30473	30473
POM Mean	271	3818	1.0107	2.6143	11	0.23767	93	15143	15143
Year mean Total	257	4566	1.3624	4.2858	10	0.4447	298	66826	66825

AGOD=Average gear operator's density, AGD=Average gear density, ADGOC= Average daily a gear operator's catch, ADGC=Average daily a gear catch, AEPD= Average effort per day per gear, CPGE= catch per gear effort, DOP= Days of operations, SGC=Seasonal gear catch, SGOC= Seasonal gear operator's catch, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon

Table 6. Gears's catch analysis through PRA and sampling

Gear		Yr	PRM	MON	POM	Yr	PRM	MON	POM	Yr	Yr
Common name	Vernacular name	AGD	ADGC (kg)				DOP				GC (kg)
Triangular Push nets	*Thela Jaal*	25	1.7500	-	1.2050	1.4775	120	-	120	240	8865
Gill nets	*Fansh Jaal*	977	0.0552	0.0419	0.0265	0.0412	120	120	120	360	14481
Long lines	*Daun*	30	1.2200	0.3100	0.2542	0.5947	120	120	120	360	6387
Seine net	*Komor*	10	13.7500	-	13.750	13.750	2	-	2	4	550
Drag net	*Ber Jaal*	1	-	27.5000	-	27.500	-	80	-	80	2200
Stationary Dip net	*Bashaal Jaal*	21	-	7.5000	2.0110	4.7555	-	110	118	228	22769
Cone framed cast net	*Chaabi Jaal*	33	2.2500	-	1.0512	1.6506	90	-	50	140	7510
Line & Hook	*Nal Borshi*	3500	0.0052	0.0050	0.0024	0.0042	120	120	120	360	5327
Total		4596	3.1717	7.0714	2.6143	4.2858	95	110	93	298	68089

AGD=Average gear density, ADGC=Average daily a gear catch, DOP= Days of operations, GC=Gear catch, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-) =No operation

Table 7. Gear operator's catch analysis through PRA and sampling

Gears	PRM	MON	POM	Yr	PRM	MON	POM	Yr	PRM	MON	POM	Yr	Yr
	AGOD				ADGOC				DOP				GOC
Triangular Push nets	21	-	28	25	1.7500	-	1.2050	1.4775	120	-	120	240	8688
Gill nets	85	105	75	88	0.6100	0.4625	0.2937	0.4554	120	120	120	360	14481
Long lines	14	55	21	30	1.2200	0.3100	0.2541	0.5947	120	120	120	360	6423
Seine net	100	-	80	90	1.3750	-	1.7188	1.5469	2	-	2	4	557
Drag net	-	10	-	10	-	2.7500	-	2.7500	-	80	-	80	2200
Stationary Dip net	-	42	21	32	-	3.7500	2.0110	2.8805	-	110	118	228	20688
Cone framed cast net	33	-	33	33	2.2500	-	1.0512	1.6506	90	-	50	140	7568
Line & Hook	11	23	13	16	1.1900	1.1141	0.5410	0.9484	120	120	120	360	5349
Total	264	235	271	257	1.3992	1.6773	1.0107	1.3624	95	110	93	298	65953

AGOD=Average gear operator's density, ADGOC= Average daily a gear operator's catch, DOP= Days of operations, GOC= Gear operator's catch, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon, (-) =No operation

Table 8. Estimation and analysis of fish yield (in ton) following different methods

S. N.	Survey	Method	Yr Average	Yr Total	Mean	SD
1	CPGE and CPUE	Random Sampling, PRA & catch analysis	66.11	66.83	66.47	0.51
2	Whole sellers' sales plus fishers' own consumption/sale	PRA, Sale & consumption analysis	66.89	66.89	66.89	-
3	Fishers' catch sales	PRA & catch Sale analysis	65.18	66.77	65.98	1.12
4	Gear operators' catch only	PRA & sample catch analysis	65.95	65.95	65.95	
5	Gears' catch only	PRA & sample catch analysis	68.09	68.09	68.09	-
6	Both gears & their operators' catch	PRA & sample catch analysis	66.83	66.83	66.83	-
Average fish yield/yr		Mean	66.51	66.89	66.70	0.82
		SD	1.00	0.68	0.79	0.44

CPGE=Catch per gear effort, CPUE= Catch per unit effort, SD=Standard deviation

species (VU), among the members belonging to the order Synbranchiformes contributed 6.95% of the total catch during the monsoon. As *Gudusia chapra*, a (VU) belonging to the order Clupeiformes contributed (0.35%), a near threatened species (NT) *Tetradon cutcutia* belonging to the order Tetraodontiformes shared 0.12% of the total catch of the year.

In the present study it was noted that overall 47.80% reduction in total fish catch biomass occurred during monsoon compared to that in premonsoon for the Perciformes (79.41%), Cypriniformes (41.93%), Osteoglossiformes (39.12%) and Siluriformes (25.41%). When compared to the catch composition from premonsoon to monsoon, following species showed remarkable reduction during the monsoon: *Xenentodon cancila, Salmophasia bacaila, Anabus testudineus, Glossogobius giuris, Ompok pabda* (EN or VU), *Monopterus cuchia and Tetradon cutcutia* (NT) (all reduced by100%); *Labeo calbasu* (33.56%), *Labeo rohita* (75.35%), *Chitala chitala/ornata* (EN) (80.04%), *Chanda nama* (78.54%), *Channa marulius* (VU) (91.36%), *Channa striatus* (89.92%) and Wallago attu (NT) (59.91%). By contrast the following species were found more frequently among the fish caught during the monsoon with a remarkable increase: *Gudusia chapra* (VU) (28 times), *Amblypharyngodon mola* (57.21%), *Aspidoparia morar* (31.89%), *Pethia ticto* (81.36%), *Notopterus notopterus* (EN) (2 times), *Colisa fasciata* (6 times), *Channa punctatus* (3 times), *Nandus nandus* (42.54%), *Sperata aor* (VU) (80.83%), *Mystus vittatus* (VU) (97.63%), *Heter pneustes fossilis* (4 times), *Mastcembelus armatus* (VU) (64.67%) and Synbranchiformes (43.91%). We also observed overall 4 times increase in total fish catch biomass during postmonsoon over monsoon with Perciformes by 9 times, Cypriniformes and Osteoglossiformes by 4 times each, Siluriformes by 3 times and Synbranchiformes by 2 times, *Channa marulius* by 21 times, *Channa striatus* by 16 times, *Chitala chitala/ornata* by 10 times, *Chanda nama* and *L. rohita* by 7 times each, *Wallago attu* by 6 times, *A blypharyngodon mola* by 5 times in the present study (Table 10).

The mean production of all the gears was comparatively higher

Table 9. Relative fish production analysis through sampling

S. N.		PRM	MON	POM	Yr Average	Yr Total
1	RAW (ha)	58.28	58.28	58.28	58.28	58.28
2	EWSA (ha)	20.00	50.00	30.00	33.33	33.33
3	RAW Volume (m^3)	1223880	1748400	1486140	1486140	1486140
4	EWSA Volume (m^3)	420000	1500000	765000	850000	895000
5	Total estimated catch (kg)	21210	30473	15143	66108	66826
6	Total estimated catch (g)	21209980	30473083	15143285	66107784	66826349
7	RAW CPUA (kg/ha)	363.93	522.87	259.84	1134.31	1146.64
8	RAW standing biomass (g/m^3)	17.33	17.43	10.19	44.48	44.97
9	RAW fish productivity (kg/ha/yr)	1091.80	1568.62	779.51	1140.48	1146.64
10	RAW fish productivity ($g/m^2/d$)	0.36	0.52	0.26	0.38	0.38
11	RAW fish productivity ($g/m^3/d$)	0.18	0.16	0.11	0.15	0.15
12	EWSA CPUA (kg/ha)	1060.50	609.46	504.78	1983.23	2004.99
13	EWSA standing biomass (g/m^3)	50.50	20.32	19.80	77.77	74.67
14	EWSA fish productivity (kg/ha/yr)	3181.50	1828.39	1514.33	2114.53	2174.74
15	EWSA fish productivity ($g/m^2/d$)	1.06	0.61	0.50	0.70	0.72
16	EWSA fish productivity ($g/m^3/d$)	0.53	0.18	0.21	0.26	0.25
17	Average body weight (g) caught	20.78	7.88	6.63	9.25	9.32
18	Total estimated catch (no)	1020730	3868100	2283838	7148006	7172668
19	RAW fish density (n/m^3)	0.83	2.21	1.54	4.81	4.83
20	EWSA fish density (n/m^3)	2.43	2.58	2.99	8.41	8.01
21	Total gear efforts	583070	842130	649579	2058327	2074779
22	Total gear efforts hrs	4180350	7665980	4543619	16390635	16389949
23	CPGE (g/e)	36.38	36.19	23.31	32.12	32.21
24	CPGE (n/e)	1.75	4.59	3.52	3.47	3.46
25	CPUE (g/h)	5.07	3.98	3.33	4.03	4.08
26	CPUE (n/h)	0.24	0.50	0.50	0.44	0.44

CPUA=catch per unit area=fish yield per unit area for a particular season, EWSA=Effective water spread area, RAW=Recorded area of water body, g=gram, n=number, e=effort, h=hour, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon

during monsoon and it might be due to the species richness and closeness and connection with the mighty Ganga River corroborating other finding on higher fish production associated with higher species richness (Azher *et al*., 2007; Siddiq *et al.*, 2013). Seasonal fish production showed significant differences ($p<0.05$). The highest fish production was observed in monsoon followed by premonsoon which was in partial compliment with the findings (FAP-17, 1995; Sayeed *et al.*, 2014). The average production of the Chhariganga oxbow lake in the present study was estimated as high as 1146.64kg/ha/year against the district range of 300-500kg/ha/year (ADF Nadia, 2014). Annual production as reported by several studies varied from 68-2,324kg/ha (Dewan *et al.*, 2002; Saha and Hossain, 2002; Bhaumik *et al.*, 2006; Dehadrai, 2006; Das *et al.*, 2011; Sayeed *et al.*, 2014). The difference in fish productivity in the present oxbow lake ecosystems may be due to variation in pulse effect of flood and species richness. The abundance and production of fish species were tightly linked with the flooding pattern during the monsoon season as like other study (Ahmed, 1991). The annual inundation connects all the aquatic areas into one large production system for up to four to five months (July to October). Fishes enter to the Chhariganga oxbow lake by up-stream migration from the Ganga River when inundation commences in the monsoon. The Chhariganga oxbow lake then serves as an excellent feeding and nursing ground for many important indigenous fish species. Over fishing of brood fish within the river, however, restricts migration to the Chhariganga oxbow lake area under study. In addition, during the late monsoon when the flood waters recede, fishermen indiscriminately harvest fish of all sizes using gears of various sizes thereby reducing returns to the Ganga River. Other anthropological effects, including construction of roads, dams, embankments and human settlements, also obstruct migratory routes, causing adverse affects on the aquatic ecosystems.

Considerable hike in the fish catch in numbers (>3.78 times), catch per gear effort (CPGE) (n/e >2.6 times) and recorded water area's fish density ($no/m^{3)}$ (>2.65 times) were observed during the monsoon over the premonsoon period which might be attributed to the influx of fishes from the Ganga river and new recruitment due to breeding during the monsoon. The premonsoon relative abundance and biomass values like catch per gear effort (CPGE in g/e), catch per unit effort (CPUE in g/h) and effective water spread area's standing fish biomass (g/m^3) reduced during monsoon and postmonsoon period resulting in significant fall in fish production (>50%) and fish standing biomass (>41%) in recorded water area during postmonsoon. The reductions were obviously due to anthropogenic activities including jute retting and indiscriminate over fishing during the monsoon. Observations pertaining to fish catch biomass composition are not in conformity with other studies (Dewan *et al.*, 2002; Ahmed *et al.*, 2005; Siddiq *et al.,* 2013; Ghosh and Biswas, 2015c) with some devia-

Table 10. Seasonal variations in fish catch biomass composition

S. N.	Taxonomy				Threat status			PRM	MON	POM	Year total
	Vernacular name	**Order**	**Family**	**Scientific name**	**NBFGR ^**	**IUCN#**	**IUCN ****	**Catch %**			
1	Kankle	Beloniformes	Belonidae	*Xenentodon cancila*	LRnt	LC	LC	0.03	0.00	-	0.01
2	Khoira	Clupeiformes	Clupeidae	*Gudusia chapra*	VU	LC	NA	0.02	1.20	0.16	0.35
3	Bengal Loach	Cypriniformes	Cobitidae	*Botia dario*	VU*		LC	-	-	0.02	0.01
4	Mourala/ Moya		Cyprinidae	*Amblypharyngodon mola*		LC	LC	0.80	2.42	6.84	2.96
5	Morar			*Aspidoparia morar*	LRnt		NA	0.11	0.29	-	0.12
6	Catla			*Catla catla*	VU	NE	NA	-	8.37	-	2.03
7	Chela			*Salmophasia bacaila*		LC	LC	0.03	-	-	0.02
8	Mrigal			*Cirrhinus mrigala*	LRnt	LC	LC	-	-	0.79	0.23
9	Bata			*Labeo bata*	LRnt	LC	LC	-	5.65	-	1.37
10	Calbaus			*Labeo calbasu*	LRnt	LC	LC	2.04	2.60	0.18	1.63
11	Rohu			*Labeo rohita*	LRlc	LC	LC	32.57	15.38	22.07	25.32
12	Punti			*Pethia ticto*	LRnt	LC	LC	2.06	7.15	4.22	3.93
	Sub Total			Cypriniformes				37.61	41.85	34.11	37.61
13	Chital	Osteoglossiformes	Notopteridae	*Chitala chitala/ ornata****	EN	EN	LC	7.60	2.91	8.94	6.86
14	Folui			*Notopterus notopterus*	EN	LC	LC	2.13	8.44	1.88	3.59
	Sub Total			Osteoglossiformes				9.73	11.35	10.82	10.44
15	Chanda	Perciformes	Ambassidae	*Chanda nama*	LRlc	LC	LC	2.48	1.02	1.33	1.79
16	Koi		Anabantidae	*Anabus testudineus*	DD		NA	1.28	-	0.16	0.64
17	Khalse			*Colisa fasciata*	LC	LC	NA	0.10	1.16	0.54	0.48
18	Shaal/ Gazar		Channidae	*Channa marulius*	VU	LC	LC	13.82	2.29	16.56	11.83
19	Lyata			*Channa punctatus*	LRnt	LC	NA	0.69	4.01	0.71	1.50
20	Shol			*Channa striatus*	LRnt	NE	NA	12.82	2.48	11.36	9.89
21	Bele		Gobiidae	*Glossogobius giuris*	LRnt	LC	LC	0.02	-	-	0.01
22	Nados/ Nona/ Bheda		Nandidae	*Nandus nandus*	LRnt	LC	LC	0.58	1.59	0.61	0.83

Table 10. *Contd.*

	Sub Total		Perciformes					31.78	12.54	31.26	26.97
23	Aar	Siluri-formes	Bagridae	*Sperata aor*	VU*	VU	LC	0.08	0.29	-	0.11
24	Tangra			*Mystus vittatus*	VU	LC	LC	0.58	2.21	0.62	0.99
25	Magur		Clariidae	*Clarias batrachus*	LC	LC	LC	2.07	5.87	1.69	2.88
26	Singhi		Hetero-pneustidae	*Heteropneustes fossilis*	VU*	LC	LC	1.25	6.78	1.11	2.55
27	Pabda		Siluridae	*Ompok pabda*	EN/ VU*		NA	0.30	-	0.16	0.19
28	Boal			*Wallago attu*	LRnt	NT	NT	13.67	10.50	17.43	14.00
	Sub To-tal		Siluriformes					17.95	25.65	21.01	20.71
29	Tora Ban	Syn-branchifor mes	Masta-cembelidae	*Macrognathus aculeatus*		LC	NA	-	-	0.25	0.07
30	Pankal/ Guchi Ban			*Mastacembelus pancalus*	LRnt	NT	NA	0.24	0.46	0.38	0.33
31	Ban			*Mastcembelus armatus*	VU	LC	NA	2.20	6.95	1.66	3.19
32	Kuche		Synbranchi-dae	*Monopterus cu-chia*	DD		LC	0.24	-	0.23	0.18
	Sub To-tal		Synbranchiformes					2.68	7.40	2.52	3.78
33	Potka/ Tyapa	Tetraodon-tiformes	Tetraodonti-dae	*Tetradon cutcutia*	LRnt	NT	NA	0.18	-	0.11	0.12

Threat status adapted from ^Lakra and Sarkar (2007), *Lakra *et al.* (2010), #IUCN (2011), **IUCN (2015), *** Vidthayanon (2012), LRnt: low risk near threatened, Lrlc: low risk least concern, LC: Least Concern, NE: Not Evaluated, DD: Data Deficient, EN: Endangered, NT: Near Threatened. VU: Vulnerable, NA: Not Assessed for the IUCN Red List, PRM=Premonsoon, MON=Monsoon, POM=Postmonsoon

Table 11. Fish production data of the management board of the KPFCS Ltd

S. N.	FY	Fish (kg)	Sale (Rs.)	Average market price (Rs/kg)	KPFCS's productivity (kg/ha/yr) calculated
1	2008-09	2514.00	125706	50	43.14
2	2009-10	2093.00	115137	55	35.91
3	2010-11	529.00	31784	60	9.08
4	2011-12	1700.00	110550	65	29.17
5	2012-13	860.00	55937	65	14.76
6	2013-14	2075.00	186805	90	35.60
7	2014-15	1105.00	104536	95	18.96
	Total	10876.00	730455	67	186.62
	Yr mean	1553.71	104351	69	26.66
	SD	734.70	50032	17	12.61

KPFCS=Kutirpara Primary Fishermen's Cooperative Society Limited, FY=Financial year, SD=Standard deviation

Table 12. Comparison of fish productivity, production of cooperative management with the present findings

Source	Oxbow lake	Value	WSA	Productivity	Total Production	Being Reflected in official record	Being Un reflected in official record
			(Ha)	(Kg/ha/yr)	(Kg/yr)	%	%
District fisheries depart-ment, Nadia	Nadia district	Min	2383.60	300.00	715080	-	-
		Max	2383.60	500.00	1191800	-	-
		Mean	2383.60	400.00	953440	-	-
	Chhariganga	Min	58.28	300.00	17484	26.21	73.79
		Max	58.28	500.00	29140	43.69	56.31
		Mean	58.28	400.00	23312	34.95	65.05
KPFCS record		RAW	58.28	26.66	1554	2.33	97.67
Present findings		RAW	58.28	1146.64	66701	-	-
		EWSA	33.33	2001.23	66701	-	-

RAW=Recorded area of water body, EWSA=Effective water spread area

Table 13. Estimation of sustainable fish production and cost of operation

S.N.	Estimation	Unit	Households	Population
1	Total fishers as per PRA	No.	270	1240
2	Total existing fish production as per present findings	kg/yr	66701	66701
3	Existing fish productivity in recorded area {[2] ÷ 58.28}	kg/ha/yr	1146.64	1146.64
4	Existing per capita production {[2] ÷[1]}	kg/yr	247.04	53.79
5	Existing per capita production during average fishing operation days {[4]÷300}	kg/day	0.82	0.18
6	Per capita sustenance demand (assuming Rs 400/family, average market price of fish Rs. 150/kg) for livelihood	kg/day	2.667	0.580
7	Per capita own consumption need (50g fish/day for a person as per WHO's recommendation)	kg/day	0.230	0.050
8	Average per capita sustainable production need {[6]+[7]}	kg/day	2.897	0.630
9	Average per capita sustainable production need {[8] X 365}	kg/yr	1057.28	229.84
10	Average fishers' livelihood supported by the existing fish production { [2] ÷ [9]}	No./yr	63	290
11	Average fishers' livelihood unsupported by the existing fish production {[1]-[10]}	No./yr	207	950
12	Total sustainable production need {[8] X [1]}	kg/day	782.10	780.84
13	Total sustainable production need {[12] X 365}	kg/yr	285467	285007
14	Total sustainable production needed during average fishing operation days {[13] ÷ 300}	kg/day	951.56	950.02
15	Sustainable productivity needed in recorded area {[13] ÷ 58.28}	kg/ha/yr	4898.19	4890.30
16	Productivity gap {[15]-[3]}	kg/ha/yr	3753.71	3745.83
17	Production gap {[13]-[2]}	kg/yr	218766	218306
18	Fish feed need (assuming feed conversion ratio, FCR of 1.75:1) to bridge the fish production gap {[17] X 1.75}	kg/yr	382840	382035
19	Feed cost (assuming traditional feed of rice bran and mustard oil cake mix @INR15/kg) {[18] X 15}	INR/yr	5742594	5730528
20	Operating cost needed (Feed cost is usually 60% of production cost) {[19] ÷ 0.6}	INR	9570991	9550879
21	Total operating cost (rounded after adding misc cost) needed once as finance	INR in Crore	1.00	1.00
22	Average operating capital needed once as finance	INR in Lakh/ha	1.716	1.716

tions which may be attributed to the differences in size, type, location, fishing intensity and pollution status of water body under study.

Comparison of fish productivity, production of cooperative management with present findings: The comparison of fish productivity, production of cooperative management is furnished with present study findings **(**Table 12) which revealed that the fish production data of 6 years mean (from 2008-09 to 2014-15) on Chhariganga oxbow lake collected from the Kutirpara Primary Fishermen's Cooperative Society Limited (KPFCS Ltd.) to be 1554kg against the present findings of 66701kg and extrapolated data (Table 11) collected fishery department, Nadia district, Government of West Bengal to be ranging from 17484 kg to 29140 kg (mean 23312 kg). Therefore, we found fish production of the oxbow lake is under reported which is only 2.33% of the present finding being reported or reflected in the catch/cash book of the KPFCS.

Estimation of sustainable fish production and cost of operation: The estimation of sustainable fish production and demand of operating cost is detailed (Table 13**)** to sustain the fish production of the Chhariganga oxbow lake ecosystem. Existing per capita production during average fishing operation days (300) was estimated to be 0.82 and 0.18 kg/year for fishers' households and fishers' population respectively. The per capita sustenance demand (assuming INR 400/family, average market price of fish INR 150/kg) for livelihood for households and population was estimated through the PRA to be 2.667 and 0.58 kg/day with the per capita own consumption need of 0.23 and 0.05 kg/day (assuming 50g fish/day needed by a person as per WHO's recommendation). In the present study, the daily average per capita sustainable production need of 2.897 and 0.63kg with the annual average per capita sustainable production need of 1057.28 and 229.84 kg were estimated for households and population, respectively. Thus the average fishers' livelihood supported by the existing fish production was estimated for households of 63 and population of 290, which, in other words, hinted that the livelihood of nearly 76.67% of the fishers were not supported by the existing fish production and making most of them non fishers by profession and forcing them to shift outside the locality/district/state/country. Therefore, an estimation of fish productivity for the Chhariganga oxbow lake ecosystem was sustainable in nature where all the KPFCS members (same as households' numbers) get their livelihood and fish consumption secured. Total sustainable production need was estimated around 285MT with productivity of near 5MT/ha/year and with the average estimated existing production and productivity gaps of about 218MT/year and 3.75 MT/ha/year respectively when compared with the existing production.

Based on the results of analysis of different physicochemical, biological and socioeconomical parameters, the Chhariganga oxbow lake ecosystem fall under oligotrophic to mesotrophic category with moderate to poor pollution status (Ghosh and Biswas, 2014; 2015a; 2015b; 2015d; 2015e; 2016a; 2016b). Mere capture fisheries from the Chhariganga oxbow lake ecosystem would not sustain the fish production and livelihood of the fishers. Therefore that aquaculture promotion is the only way out for sustainable fish production of the Chhariganga oxbow lake ecosystem. And for the culture fisheries it was tried to quantify the operating capital finance as required for once to sustain the above production, productivity and livelihoods on the Chhariganga oxbow lake ecosystem. The total fish feed amount required to bridge the fish production gap to be around 382 MT/year assuming the fish feed conversion ratio (FCR, which is the quantity of feed needed to produce a unit quantum of fish) of 1.75 and estimated feed cost to be around INR 57 lakh/year assuming traditional feed of rice bran and mustard oil cake mix @INR15/kg. Thereby estimated the operating cost was needed to be of about INR 95.50 lakh as feed cost is usually 60% of total production cost (Kumar, 1992). Total operating cost (rounded after adding miscellaneous cost) needed as financial support has been estimated to be INR 1.00 crore (INR 1.716 lakh/ha). Providing one time assistance of the amount needs to be considered for promotion of organic and integrated aquaculture in the Chhariganga oxbow lake ecosystem for its sustainable management.

It might not be possible to achieve equitable and sustainable socioeconomic development for the people of the Gangetic basin in West Bengal without improving the sustainability of the ecosystem through responsible utilization of water resources by the people (Bhaumik *et al.*, 2006). Although based on problems and key issues thus identified for mitigation and management actions suggested by fisher community from a randomly selected single oxbow lake in the district, discussions are to be on how best possible a holistic management solution suiting local condition for the oxbow lake and its stake holders as token in a sustained, economical, eco-friendly and climate resilient way which can be replicable in all the oxbow lakes in the Nadia district and other regions. In-situ and ex-situ management strategies must be adopted on the level of mass awareness among fisher/non fisher community about policies, rules, regulations, government and NGOs' role, restoration/reclamation of the oxbow lake environment, observing fishing close season, rehabilitation of endangered species through ranching, macrophyte management and proper utilization, cryopreservation/natural collection, germplasm for breeding, maintenance of genetic resources in nature, standardizing breeding techniques for indigenous fish, ecological farming, integrated and/or organic aquaculture promotion, etc. besides culture based fisheries (Biswasroy *et al*., 2011) involving both stocking and autostocking of fish, desilting of connecting channels with the operation of sluice gates to facilitate entry of brood fish and juveniles and construction of perimeter dykes, intensive aquaculture practices with an emphasis on adoption of integrated fish farming rather than composite fish culture alone, a multicommodity farming system for higher returns, suitable legislation to overcome the conflict between agriculture and fisheries and participation and proper training of each and every stakeholder utilizing the water resource benefiting the economy. Certain amount of fish can be conserved in dry season in the deeper pools of oxbow lake ecosystem with the installation of Brush Park (FAD) to ensure next year's successful breeding and recruitment to the population. Fishing regulation on such destructive fishing gears are to be imposed properly to prevent indiscriminate killing of juveniles of different fishes during post-spawning season. Conducting awareness program for the fishers can reduce indiscriminate killing of juveniles.

Management becomes problematic especially for large oxbow lakes, which cross several block boundaries and falls within the responsibility of a number of local and zonal authorities. The effectiveness of the authoritarian management system may be enhanced by participatory management and input from fisher communities (Susan *et al.,* 2016). There is an urgent need for integrated action and legislation to ensure that endangered species are legally protected in the entire district within its jurisdiction. Of course stakeholder participation and political will are also needed. However, the failure of the Ganga Action Plan in India and the collapse of river fisheries throughout Asia demonstrated that it will be unwise for scientists to assume that governments and policy makers will institute requirements and practices to protect freshwater biodiversity without societal pressures which often appear as stumbling blocks. Scientists must communicate the fact that freshwater biodiversity is in crisis and indicate what can be done to ameliorate the state of affairs. Successful communication of this message will be an essential first step in halting further impoverishment of biodiversity.

Based on level of physicochemical, biological and socioeconomical degradations and fish demand calculated for the fishers' sustenance as major source of income, maximum or optimum sustainable fish productivity for the oxbow lake is estimated that would support cheap protein security, income and employment generation in a sustained manner. Based on the results of analysis of different physicochemical, biological and socioeconomical parameters, we observed the Chhariganga oxbow lake ecosystem fall under oligotrophic to mesotrophic category with moderate to poor pollution status and estimated the current fish catch yield of 66.70MT/year and its annual average market value of nearly about INR 1.00 crore, which currently supports only 23.33% of enlisted fishers of the society, mere capture fisheries would not sustain the fish production and livelihood of majority of the fishers. Again 97.67% of present finding on fish production remains unreported every year in the catch/cash book of the KPFCS. That indicates its inefficiency in management of the KPFCS based on the Chhariganga oxbow lake ecosystem. There arises an urgent need of public private partnership for proper management of the Chhariganga oxbow lake ecosystem.

Therefore, we recommend that organic aquaculture promotion with integrated farming and pen culture are the only way out for sustainable fish production. Total sustainable production need of 285MT (market value of nearly INR 4.28 crore annually) with average fish productivity of about 5MT/ha/year supporting 100% livelihoods of all fisher members of the cooperative society with the average estimated additional production and productivity gaps of about 218MT/year and 3.75 MT/ha/year respectively compared with the existing production and with total operating cost need of INR 1.00 crore (INR 0.01716 crore/ha) was estimated for promotion of organic aquaculture for rejuvenating the sustainable and replicable management of the present oxbow lake ecosystem. The estimate hints that if financial aid is provided the returns would be 4.28 times (i.e. Benefit-Cost ratio) annually both in terms of fish and its value. The sustainable fish production through aquaculture and different management practices in oxbow lake ecosystem is however subject to the varying degrees of danger of the massive use of mosquito nets; jute retting, agriculture crop irrigation with oxbow lake water and fishing by complete dewatering in the dry season; converting oxbow lake into crop lands; intensive fish culture practices; indiscriminate and over fishing; application and entry of fertilizers, soap oil emulsions and pesticides; and making dykes around oxbow lake. The application of soap oil mixture to kill different aquatic macro invertebrates including insects before fish stocking is quite common practices in Nadia district. Such killing of aquatic insects may lead to poor aquatic diversity and health status of the oxbow lake. The present oxbow lake under study, however, had no aquaculture practices except its entire reliance on fish production based on autostocking and capture fishery. The proposed management of oxbow lake ecosystem would satisfy triple bottom line of sustainability in maintaining ecology in natural ways, supporting economy through economic (profit) security and sustaining local society through livelihood and nutritional (cheap protein) security.

Conclusions

The present study concluded that hike in relative abundance values like numbers of fish catch (>3.78 times), catch per gear effort (>2.6 times), fish density (>2.65 times) and fall in relative biomass values like catch per gear effort, catch per unit effort and fish standing biomass (>41%) were observed during monsoon compared to premonsoon due to flooded turbid water from the river Ganga and jute retting processes during monsoon. Jute retting and indiscriminate over fishing of the monsoon made fish production reduced by >50% during post monsoon. The current fish productivity was estimated at 1146.64kg/ha/year supporting only 23.33% livelihoods of enlisted fishers and about 97.67% of fish production remains unreported every year in the official records of the cooperative society based on the oxbow lake ecosystem indicating inefficient management. Total sustainable production of 285MT (@5MT/ha/year) with total operating capital need of INR 1.00 crore (@INR 0.01716 crore/ha/year) with benefit cost ratio of 4.28 was estimated as the sustainable and replicable basis for promotion of organic aquaculture supporting 100% livelihoods of all fishers and rejuvenating the management of the present oxbow lake ecosystem.

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