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Niche Heterogeneity in Vulnerable Habitat Conditions Maintains and Amplifies Fish Diversity in Rivers of South Bengal, India

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ABSTRACT

One hundred and thirty seven fish species belonging to 12 orders, 39 families and 91 genera have been sampled from non-saline portions of 13 different rivers and associated lentic bodies. Order Cypriniformes contributes 28.467% of total species. Orders Perciformes and Siluriformes contribute to 26.277% and 24.087% respectively. Other orders contribute less than 10% of the total fish species. Beloniformes has contributed to 0.729 % only. Out of 137 species, 36 species, i.e. more than 26% have maximum niche expansion as they are common to all rivers. Altogether 17 alien fish species have established across the rivers. Per cent indices of Diversity, Equitability, Richness and Concentration of Dominance ranged from 26.31 to 54.54, 7.05 to 10.69, 10.39 to 23.86 and 5.12 to 10.53 respectively. Increase in diversity has been ensured by the increase in species richness only, without any significant change in species equitability. This suggests for vulnerable communities with spontaneous adaptive changes plus survival of existing species through heterogeneous niche spaces in face of habitat fragility, as evidenced by many co-existing genera with multiple species, subspecies, varieties, ecotypes etc.

Key words : *Alien species, Adaptation, Dominance diversity Curve, Habitat fragility, Migration, Speciation.*

Introduction

Rivers rich in fish diversity undergo rapid bio-diversification induced by recurring niche amplification and contraction mediated through inter-riverine migration in South Bengal (Rakshit and Roy, 2021). Again, spatially and temporally dynamic strategies for efficient use of detritus (nutrients) have been revealed in the lower end of these same rivers that attract marine biota including ichthyofauna to bio-diversify these lotic systems close to the sea (Roy, 2011). Fish of all kinds are among most favoured food of Bengali population. Human population density is however, high in this part of India where many rivers have turned from perennial to seasonal and even have ceased to flow during dry seasons (Arthington, 2012). This is primarily due to anthropogenic exploitation through dams, barrages, canal diversifications, industrial refuge plus solid waste deposition, encroachment, unethical fishing and siltation. Fish diversity in rivers is manifested as species clustering in selected stretches of river continuum (Lasne *et al.*, 2007), depending on local habitat variations creating heterogeneity (Johnson *et al.*, 2012). Perturbed river habitats are bound to be highly heterogeneous. This study is a review supported repeated spot investigations to examine the hypothesis that constrained river ecosystem's instability

and fragility have both positive and negative influences on present state of ichthyofaunal diversity.

Materials and Methods

Study Area

The study sites (Fig. 1) are within geographical coordinates of 22°18´ to 24°10´N latitude and 86°32´ to 89°09´E longitude, in the lower Ganga Delta of West Bengal in India, supporting a large tract of deciduous Sal (*Shorea robusta*) dominating forests, habitations, industries, mines and agricultural lands on a mixed terrain. Land is lateritic in western part of the delta and alluvial in the eastern part. Climate is dry tropical with seasonality such as rainy, winter and summer with three transition periods in between. Annually seven to eight months remain dry continuously with occasional localized showers and storms. Remaining months are wet due to South West monsoonal rainfall. Rainy season encounters about 76 per cent of total annual precipitation creating recurring flood. The average annual rainfall is around 1400 to 1500 mm. The highest temperature may reach up to 40°C to 43°C in May, and the lowest temperature may go down below 10°C in late December and early January nights.

Riverine system of lower Ganga delta

Thirteen principal rivers included in the lower Ganga river basin (23371 sq km) in the state of West Bengal (Fig. 1) have been investigated within freshwater zone characterized by less than 0.05 % of dissolved salts. Bhagirathi (R1) (called Hooghly from the lower end at the meeting point of river Jalangi), is the central river originating from the Ganga and

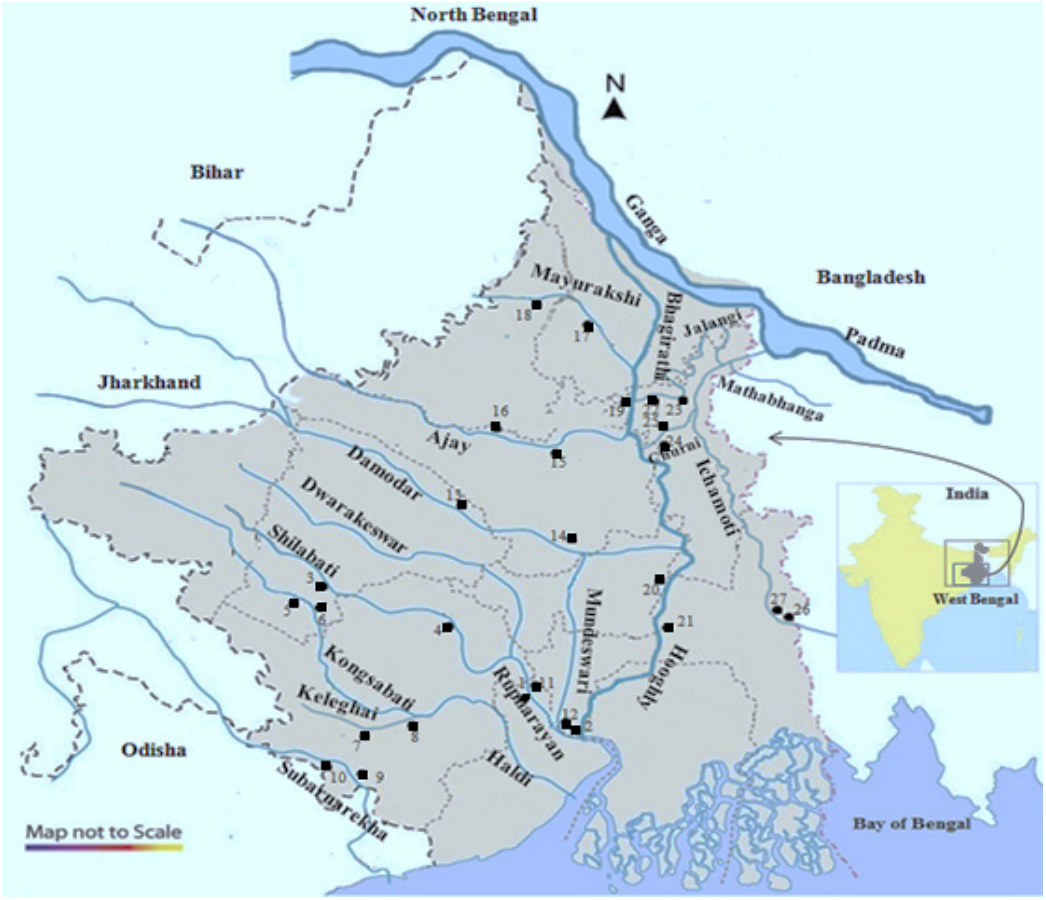

Fig. 1. Study sites on lower Gangetic Bengal delta. Ghatal (1), Gadiara (2), Mukutmanipur (3), Khirpai (4), Ranibandh (5), Khatra (6), Dudhkundi (7), Mahisadal (8), Shyamsundarpur (9), Gopiballavpur (10), Kolaghat (11), Deulti (12), Birbhanpur (13), Amta (14), Ketugram (15), Kenduli (16), Suri (17), Sundarpur (18), Nabadwip (19), Bandel (20), Panihati (21),Krishnanagar (22), Tehatta (23), Ranaghat (24), Birnagar (25), Hasnabad (26), Basirhat (27).

flows southward for 260 km to the Bay of Bengal. Mayurakshi (R3, 118 km), Ajay (R2, 109 km) Damodar (R7, 134 km), Rupnarayan (R10, 87 km) [formed by joining of Darakeswar (R8, 69 km) and Shilabati (R9, 46 km)], Kongsabati (R11, 89 km) and Keleghai (R12, 57 km) [last two later join to form Haldi river (45 km)] have been studied. Mundeswari (76 km) remains mostly dry during summer and connects Damodar with Rupnarayan. These rivers meet Hooghly on west bank. Subarnarekha (R13) originates from Orissa state and passes through Bengal for about 79 Km and re-enters Orissa to meet the sea. On Eastern bank, Jalangi (R4, 74 km) flows from Padma into Bhagirathi. Churni (R5, 56 km) and Ichhamoti (R6, 98 km) are two diversions of common water of Mathabhanga (19.5 Km, originating from Padma) and Bhairab (32 Km, originating from Jalangi). Churni flows into Hooghly and Ichhamoti flows to Bangladesh and occasionally manifests mild salinity during up tide in dry seasons.

Literature Survey

An extensive literature survey for listing the previously available taxa (Mishra *et al.,* 2003; Jayaram, 2010; Mahapatra *et al.,* 2014; Lakra *et al.,* 2010; Sarkar *et al.*, 2012; Roy *et al.,* 2013; Kar *et al.,* 2017; Das *et al.,* 2013) preceded a total of ten years of data accumulation through direct fish catches coordinated methodically following Rakshit and Roy (2021). Existing literature was also cross checked through spot sampling from fishermen along with local fish market survey, and rural appraisals from villagers involved in fish catch and fishing business. However, only sampled species have been listed.

Sampling

Each river has been sampled seasonally from two locations i.e., one at the upstream and the other at the downstream. Bhagirathi (Hooghly) has been sampled from three locations for being the most important river of this region. Altogether there were 27 study sites. Samples were also taken from marsh lands, paddy fields, and lentic bodies associated with rivers whenever there was intermixing of water, primarily during post monsoon period. Twenty seven fish landing regions (two landing regions per river), (Fig. 1) were selected one each by and large at upstream and downstream; except Hooghly/ Bhagirathi where three landing regions were sampled for being the central and largest river. 100 m by 30 m rectangular quadrats were hypothetically placed for sampling. Accuracy of sampling was difficult due to vastness, openness and depth of all rivers particularly in Bhagirathi/ Hooghly during monsoon.

Diversity analysis

All diversity indices were calculated consulting Roy (2003), Fedor and Zvarikova (2019). Standard indices such as Equitability Index, Concentration of Dominance, Index of Diversity and Species Richness Index were calculated.

Indices have been represented as relative (among rivers) per cent values for easy comparison among rivers. Models have also been obtained by fitting these indices into polynomial equations. Dominance Diversity Curves (DD curve) have been represented as log values of annual average fish count of each species (Total average fish count plotted separately for each river per 30×100 m^2 quadrat) on Y axis of a semi logarithmic scale with each species arranged on X axis in an order of most to least abundance

Statistical analysis

Polynomial modelling and Gaussian species packing were conducted using Past 3.14 statistical software, Graph Pad Prism 5 Statistical Software and Microsoft Excel 7.

Results and Discussion

Ichthyofaunal diversity

Altogether 137 sampled fish species are distributed in 91 genera and 40 families belonging to 12 orders (Appendix 1 and Fig 2). Order Cypriniformes is the most diverse with only 2 families but with a maximum number of 39 species (28.467%). Perciformes has the maximum (15) number of families containing 36 species (26.277%) followed by Siluriformes with 11 families and 33 species (24.087%). Ceupeformes has 9 species in 2 families (6.967%); Syntranchioformes has 5 species (3.649%) under 2 families; Mugiliformes has 4 species (2.919%) in 1 family; Anguliformes has 2 species (1.459%) in 2 families; Cyprinodontiformes, Pleuronectiformes, Tetradontiformes and Osteoglossiformes all have 2 species (1.459%) in 1 family; Beloniformes is least diverse with 1 species (0.729%) in 1 family only (Appendix 1). 17 alien species have permanently established in these rivers (Perceformes 6, Cypriniformes

Appendix 1: List of sampled Ichthyofauna. [PM: Pre Monsoon, M: Monsoon; PoM: Post Monsoon; TY= Throughout the year; MO= March to October; MA= May to August. **Feeding Habit**: Om= Omnivorous; C= Carnivorous; H= Herbivorous; D = Detritivorous; L= Larvivorous. **Economic value**: F = Food fish; O = Ornamental. **Optimum Habitat**: P = Pelagic; BP = Bentho Pelagic; Dm = Demersal; E: Estuarine; B = Benthic; CP = Coastal Pelagic. **Migration:** Ca = Catadromous; Po = Potamodromous; A = Amphidromous, An = Anadromous; Oc = Oceanodromous. **Alien species:** Bold**. Species appeared in samples from all rivers for at least one time: ***. **IUCN status**: According to The IUCN Red List of Threatened Species 2020: NT: Near Threatened, LC: Least Concern, DD: Data Deficient, V: Vulnerable, NE: Not Evaluated, CE: Critically Endangered].

Order	Family	Scientific name	Local name	Feeding habit	Economic value	Optimum habitat & migration pattern	Breeding time	IUCN status
Anguilliformes	Anguillidae	*Anguilla bengalensis bengalensis*	Bam / Eel/ Mottled or Long finned eel	Om	O	Dm, Ca	M	NT
	Ophichthidae	***Pisodonophis boro***	Rice / Paddy Eel / Bangla kharu	Om	F,O	E, BP, A	M	LC
Beloniformes	Belonidae	*Xenentodon cancila**	Kankila / Kakila / Freshwater Garfish / Needle fish	C	F,O	P, A	TY	LC
Clupeiformes	Clupeidae	*Corica soborna*	Ganges river sprat / Kechki	C	F	E, P	TY	LC
		Escualosa thoracata	White Sardine / Samudra maurala	Om	F	CP, A	PM	LC
		Gonialosa manmina	Gizzard Shad / Chaapila	Om	F,O	Dm, Po	PM	LC
		Gudusia chapra	Khaira / Indian river shad	H,D	F	P, Po	MO	LC
		Tenulosa ilisha	Ilish / Hilsha	H	F	P, An	PM	LC
	Engraulididae	*Coilia ramcarati*	Ramcarti / Anchovy	Om	F	B,A	PM	DD
		Setipinna phasa	Phasa / Gangetic hairfin anchovy	Om	F	CP, A	PM	LC
		Setipinna taty	Scaly hairpin anchovy	Om	F	CP, Oc	PM	LC
		Thryssa hamiltonii	Ray finned fish variety	Om	F	CP	PM	LC
Cyprinodontiformes	Aplocheilidae	*Aplocheilus panchax**	Kampona / Panchoke / Blue Panchax	C&L	F,O	Dm	M	LC
		Gambusia affinis	Western mosquito controlling fish	L	F	Dm	TY	V
Cypriniformes	Cobitidae	*Botia birdi*	Gunpho / Indian loch / Gurdol	Om	F,O	P	TY	NE
		Botia lohachata	Loach	Om	F,O	P	M	NE
		Lepidocephalichthys guntea	Guntey / Guntea loach	Om	F,O	Dm	TY	LC
	Cyprinidae	*Amblypharyngodon mola **	Mourala / Pale carplet	Om	F	BP	TY	LC
		Barbonymus gonionotus	Java/ Thai Punti / Sarpunti/ Japani punti	Om	F,O	Dm	TY	LC
		Barilius barila	Koksa / Barred baril	C	F,O	BP	TY	LC
		*Barilius barna**	Ghol/ Bhola	C	F	P	TY	LC
		Barilius bendelisis	Joia	C	F,O	P, Po	TY	LC
		*Catla catla**	Katla	H	F	P	TY	LC
		Chagunius chagunio	Lal punti / chaguni	C	F	CP	M	LC
		*Cirrhinus mrigala**	Mrigel	Om	F	P	TY	LC
		Cirrhinus reba	Raik bata / Tatkini	H&D	F	P, A	TY	LC

Appendix 1. *Continued*

Order	Family	Scientific name	Local name	Feeding habit	Economic value	Optimum habitat & migration pattern	Breeding time	IUCN status
		Crossocheilus latius latius	Kala Bata / Pahari bata	H	F	BP	M	LC (but less population in South Bengal)
		Ctenopharyngodon idella	Grass Carp/White amur	H	F	B, A	TY	NE
		Cyprinus carpio*	Common Carp	H	F	BP, A	TY	CE
		Danio rerio	Danra / Anju / Zebra Fish	H	O	B	PM,M	LC
		Devario devario	Techokha / Bengal Danio	H	O	P	PM,M	NE
Cypriniformes	Cyprinidae	*Devario aequipinnatus*	Chebli / Giant danio	H	O	CP	PM,M	DD
		Esomus danricus	Darke/Indian flying barb	Om	F,O	BP	TY	LC
		Garra mullya	Mottu	Om	F,O	P	TY	LC
		Hypophthalmichthys molitrix*	Silver carp	H	F	BP	TY	LC
		Labeo angra	Angrot / Kharsa	H	F,O	BP, Po	TY	LC
		*Labeo bata**	Bata	H	F	BP, Po	TY	LC
		Labeo boga	Kursha, Kulka Bata	H	F	P	TY	LC
		*Labeo calbasu**	Kalbose/ Kalbaush/ Orange finned labeo	H	F	Dm, A	TY	LC
		Labeo dero	Khursha / Kathalkushi	H	F	P	TY	LC
		*Labeo rohita**	Rui / Rohu	H	F	P	TY	LC
		Chela (Laubuca) laubuca	Chela / Indian grass barb	Om	F,O	BP	TY	LC
		Osteobrama cotio	Ray finned fish variety	H	F,O	BP,A	TY	LC
		*Pethia ticto**	Tit punti / Ticto barb	Om	F	BP, A	TY	LC
		*Puntius chola**	Kerrundi / Swap barb	Om	F	B, A	TY	LC
		Puntius conchonius	Punti / Rosy barb	Om	F,O	P, A	TY	LC
		Puntius phutunio	Punti / Dwarf barb	Om	F,O	P, A	TY	LC
		Puntius sarana sarana	Swarna punti / Olive barb	Om	F	BP, A	M	LC
		*Puntius sophore**	Sar punti/ Pool barb	Om	F,O	BP, Po	TY	NT
		Salmostoma bacaila	Chela / Large Razor belly minnow	H	O	BP, Po	TY	LC
		Salmostoma phulo phalo	Phul chela / Fine scale Razor belly minnow	Om	F	P, A	TY	LC
		Securicula gora	Gora chela	C&L	O	P, A	M	LC

Appendix 1. *Continued*

Order	Family	Scientific name	Local name	Feeding habit	Economic value	Optimum habitat & migration pattern	Breeding time	IUCN status
Mugiliformes	Mugilidae	*Liza tade*	Bhanga / Tade mullet	Om	F	E, BP, Ca	TY	LC
		Liza parsia	Parshey / Gold spot mullet	Om	F	E, BP, Ca	TY	LC
		Mugil cephalus	Parshey /Parsia / Flathead grey mullet	Om	F	E, P, Ca	TY	LC
		Rhinomugil corsula	Konia / Kannua	C	F	E, NP	TY	NT
Osteoglossiformes	Notopteridae	*Notopterus chitala**	Chital / Humped feather-back / Clown feather-back	Om	F	Dm	TY	LD
		Notopterus notopterus * (A species complex with taxonomic disputes)	Pholui / Bronze featherback	Om	F	Dm, Po	M	DD
Perciformes	Ambassidae	*Chanda nama*	Chanda / Elongate Glassy perchlet	Om	F,O	BP	TY	LC
		Chanda (*Psedoambassis /Parambassis*) *ranga*	Chanda / Indian glass perch	Om	F,O	Dm, Po	M	LC
		Parambassis lala	Highfin glassy perchlet	Om	F,O	E, BP	TY	DD
	Anabantidae	*Anabus cobojius**	Gangetic koi / Vietnam koi	Om	F	BP	TY	LC
		*Anabus testudineus**	Koi machh / Climbing perch	Om	F	Dm	TY	LC
	Badidae	*Badis badis*	Botkoi, Dwarf chameleon fish	Om	F,O	BP	M	LC
	Belonidae	*Polycanthus fasciata*	Khalisha, Kholsa / Banded gourami	C	F,O	B	PM, M	LC
	Centropomidae	*Lates calcarifer*	Vetki / Asian sea bass	Om	F	E, Ca, Dm	TY	LC
Perciformes	Channidae	*Channa gachua*	Gachhua/Brown dwarf snakehead	C	F	BP,A	PM,M	LC
		Channa marulius	Gajal / Giant snakehead	C	F	BP,A	TY	LC
		*Channa orientalis**	Chang / Asiatic Snakehead	C	F	BP,A	TY	LC
		*Channa punctatus**	Lata / Spotted snakehead	C	F	BP,A	TY	LC
		*Channa stewartii**	Tel-chang	C	F	B,A	TY	DD
		*Channa striata**	Shol / Striped snakehead	C	F	B,A	TY	LC
	Cichlidae	***Oreochromis mossambicus****	Tilapia	Om	F,O	B	TY	LC
		Oreochromis niloticus*	Nylontica /Nilotica	Om	F	B	TY	LC
	Eleotridae	*Prionobutis (Butis) koilomatodon*	Mud Sleeper / Crested gudgeon	C	F,O	BP	TY	NT
		Eleotris fusca	Dusky Sleeper / Brown spine cheek gudgeon	C	F	Dm,A	TY	V
	Gobiidae	*Apocryptes cantoris*	Dakur machh	Om	F	Dm	M	CE
		Apocryptes macrolepis	Goby	Om	F	CP,E,A	M	LC
		*Glossogobius giuris**	Bele / Tank goby	C	F	B,E	TY	LC

Appendix 1. *Continued*

Order	Family	Scientific name	Local name	Feeding habit	Economic value	Optimum habitat & migration pattern	Breeding time	IUCN status
		Pseudapocryptes elongatus	Chema	Om	F	CP,A	M	CE
		Odontamblyopus rubicundus	Eel goby	C	F,O	BP,E,A	TY	LC
	Nandidae	*Nandus nandus*	Nadosh / Gangetic leaf fish	C	F,O	BP	TY	LC
	Osphronemidae	*Colisa fasciata*	Khalisa / Banded gourami	Om	F,O	BP	MO	LC
		Colisa lalia	Khalisa / Dwarf gourami	Om	F,O	BP	MO	LC
		Trichogaster fasciata	Kholse / Giant gourami	Om	F,O	P	M	LC
		Trichogaster labiosa	Kholse / Thick-lipped gourami	Om	F,O	P,A	M	V
Perciformes	Polynemidae	*Eleutheronema tetradactylum*	Guchhia, Sahal / Four finger threadfin	C	F	P, A	PM, M	LC
		Polynemus paradiseus	Topshe / Paradise threadfin	C	F	E, Dm, A	PM, M	LC
		Nibea soldado	Soldier croaker	C	F	Dm, A	TY	CE
		Otolithoides biauritus	Bronze croaker	Om	F	E, Dm, A	TY	CE
	Sciaenidae	***Pama pama***	Pama	H	F	BP, A	M	LC
		Panna microdon	Pama / Croaker	H	F	Dm, A	M	LC
	Sillaginidae	*Sillaginopsis panijus*	Tool- Belle / Gangetic whiting	C	F	Dm, A	TY	LC
	Teraponidae	*Terapon jarbua*	Teerpye / Crescent grunter / Crescent perch	Om	F	Dm, Ca	M	LC
Pleuronectiformes	Cynoglossidae	*Cynoglossus lingua*	Jivakritir maachh	C	F	E, A	PM	CE
		Cynoglossus puncticeps	Jiv Maachh/ Spiny Tongue Eel	C	F	E, A, Dm	PM	CE
Siluriformes	Ariidae	***Arius gagora****	Gagora catfish	C	F	E	TY	NE
		Arius platystomus	Flat mouth sea catfish	C	F	E, A	TY	LC
		*Aorichthys aor**	Aar / Long-whiskered catfish / Bagrid type	C	F	Dm, Po	M	LC
		Aorichthys seenghala	Aar / Giant-whiskered catfish	C	F	Dm, A	M	LC
	Bagridae	*Batasio batasio**	Batashi / Tista batasio	C	F,O	Dm	TY	LC
		*Mystus bleekeri**	Nodi tangram / Day's mystus	C	F	Dm	TY	NE
		Mystus cavasius	Kabasi tangra/ Gangetic mystus	C	F, O	Dm, A	TY	LC
		Mystus gulio	NunaTangra / Long whiskered catfish	C	F,O	Dm, Ca	TY	LC
		*Mystus tengara**	Tangra	C	F	Dm	TY	LC
Siluriformes	Bagridae	*Mystus vittatus**	Dorakata Tangra/ Striped dwarf catfish	Om	F,O	Dm	TY	NE
		Rita rita	Rita/ Ritha	Om	O	Dm	M	LC
	Clariidae	*Clarias batrachus**	Magur/ Walking catfish	Om	F	Dm, A	TY	LC

Appendix 1. *Continued*

Order	Family	Scientific name	Local name	Feeding habit	Economic value	Optimum habitat & migration pattern	Breeding time	IUCN status
		***Clarias gariepinus** **	Rakkhuse Magur / Thai magur / African catfish	Om	F	Dm	TY	LC
	Cyprinodontidae	*Oryzias melastigma*	Dheno chuna	C	F	E	PM	CE
	Erithistidae	*Erethistes pusillus*	Tinkantia / Giant moth catfish	C	F	B	TY	CE
		Hara hara	Kata kunti / Kosi hara	Om	F	B	TY	CE
	Heteropneusti-dae	*Heteropneustes fossilis**	Singhi / Stinging catfish	Om	F	Dm, Po	TY	LC
	Pangasidae	***Pangasius pangasius***	Pangus / Yellow tail catfish	Om	F,O	BP	TY	LC
	Plotosidae	*Plotosus canius*	Kanmagur / Gangmagur / Gangetic eel cat fish	C	F	E, Dm, A	PM,M	LC
	Schilbeidae	*Ailia coila*	Kojoli / Gangetic ailia	C	F,O	P	TY	LC
		Clupisoma garua	Garua, Puttoshi, ghero	C	F,O	Dm, A	TY	LC
		Eutropiichthys vacha	Bacha / Tunti / Batchwa / Vacha	Om	F,O	P	TY	NE
		Neotropius atherinoides	Batasi/ Indian potasi	C	F,O	P, Po	M	LC
		Pseudeutropiu-satherinoides	Doya, Potasi	C	F,O	P	TY	LC
	Sisoridae	*Gogangra viridescens*	Sisorid catfish	Om	F	B, A	TY	LC
		Bagarius yarrelli	Giant devil catfish	H	F,O	P, A	TY	NE
		Bagarius bagarius	Baghari / Garua / Gangetic goonch	C	F	BP	TY	NE
		Gagata cenia	Jungla / Indian gagata	C	F	B, A	TY	LC
Siluriformes	Siluridae	*Ompok bimaculatus*	Puffta / Indian butter catfish	C	F,O	Dm, A	TY	LC
		Ompok pabda	Pabdah / Catfish	C	F,O	Dm, A	TY	LC
		Ompok pabo	Pabo / Pabo catfish	C	F,O	Dm, A	TY	LC
		*Wallago attu**	Boal / Freshwater shark	C	F,O	Dm, Po	TY	LC
Synbranchio-formes	Mastace-mbelidae	*Macrognathus aculeatus*	Baan	C	F,O	E,A	M	LC
		Macrognathus aral	Golchi / One stripe spiny eel	Om	F	BP, Po	TY	LC
		Macrognathus armatus	Baan / Zigzag eel	C	F,O	Dm, A	TY	LC
		*Macrognathus pancalus**	Pankal / Gangetic eel	Om	F	BP, A	TY	LC
	Synbranchidae	*Monopterus cuchia*	Cuche / Gangetic mud eel	C	F	Dm	M	LC
Tetraodontiformes	Tetradontidae	*Tetraodon cutcutia*	Tepa / Ocellated pufferfish	C/ Om	O	P	PM,M	NE
		Tetraodon fluviatilis	Potoka / Green puffer fish	C/ Om	O	P	PM, M	DD

5, Siluriformes 4, Cyprinodontiformes 1, and Anguliformes 1).

Out of 137 sampled species, 36 species are common to all rivers (marked *, Appendix1) remaining 101 species are uncommon to at least one or more rivers. River Subarnarekha revealed maximum number of 125 species followed by Keleghai (124), Kongsabati (117), Rupnarayan (112), Bhagirathi (107), Shilabati (92), Churni (91), Jalangi (90), Dwarakeswar (82), Damodar (79), Ichhamoti (67), Mayurakshi (67). River Ajay had the minimum number of 64 species. Bhagirathi (Hooghly), with 107 species is a conservative estimate as precision of sampling is restricted due to vastness and depth. Further, the list prepared from 27 locations should never be conclusive as well, due to habitat adaptation of extreme heterogeneous local clustering of Fish fauna and inaccessibility in a lotic continuum. Jalangi, Churni and Ichhamoti have been sampled from Indian side only.

Diversity indices

Fish diversity indices for 13 rivers are given in Table 1 and concurrently Fig. 3 represents dominance diversity curve. Equitability index is highest in the river Churni, and lowest in the river Darakeswar. Diversity index is highest in the river Subarnarekha and apparently lowest in the Ajay and again Richness index is highest in Subarnarekha and lowest in the river Ajay. Hooghly although is the largest river receiving all other rivers, has the moderate index of diversity and richness index because of vastness that allows big separation among species as well as individuals, resulting in fair index values mostly represented as bits per individual (Roy, 2003). Indices of diversity, equitability, richness and concentration of dominance in relative per cent values were 26.31 to 54.54, 7.05 to 10.69, 10.39 to 23.86 and 5.12 to 10.53 respectively across all rivers (Table 1).

Variations in species packing

Gaussian species packing within ichthyofaunal population (Fig. 4) across all rivers in five high (above 1450 mm) and five low (below 1450 mm) precipitation years indicate more elaborate and amplified species abundance in high rainfall years compared to that of low rainfall years. Curves indicate that in these rivers fish species abundance gets lim-

Table 1. Diversity Indices represented as relative percent values sampled from thirteen rivers.

Diversity Indices	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
Equitability index (Es):	7.05	8.39	8.46	6.68	10.69	7.2	7.5	6.01	6.9	7.94	8.01	7.05	7.35
Concentration of Dominance (Cd):	10.53	7.9	7.9	10.53	7.9	10.53	7.9	5.12	7.9	7.9	5.12	5.12	5.12
Index of Diversity (D):	37.46	26.31	29.75	28.44	35.23	32.63	27.59	32.14	35.85	39.48	42.55	44.03	54.54
Species richness index (d):	16.50	10.39	11.42	11.42	14.69	12.90	12.79	12.63	15.11	17.58	19.27	20.86	23.86

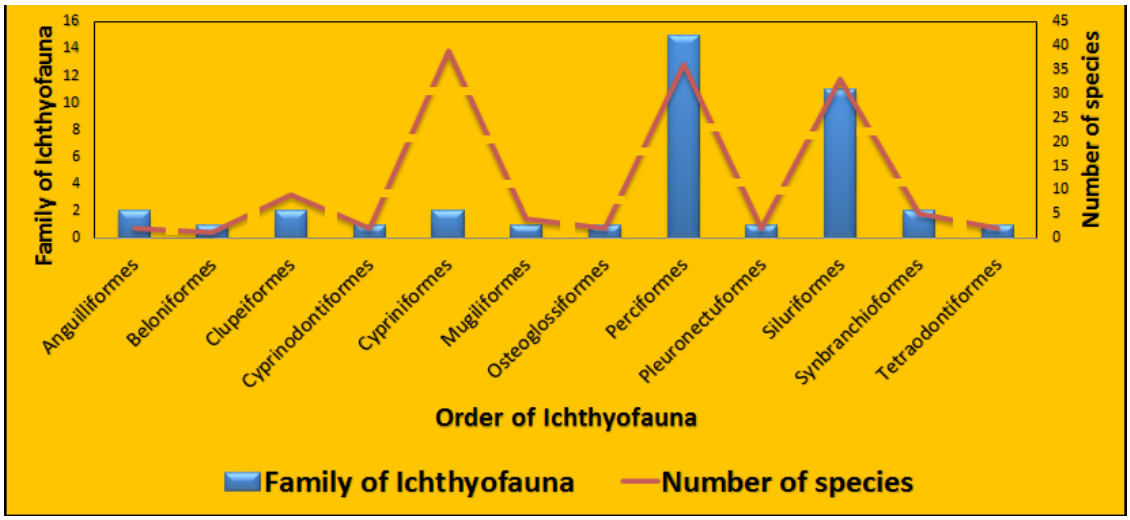

Fig. 2. Distribution of Fish species and families in different orders

ited within imploded population under water constraints. Diagrams of Gaussian species packing models are also supported by the fact that the rainfall accounts for 88 per cent variability in fish populations across these rivers (Rakshit and Roy, 2021).

Alien species

Out of total number of 137 sampled species some

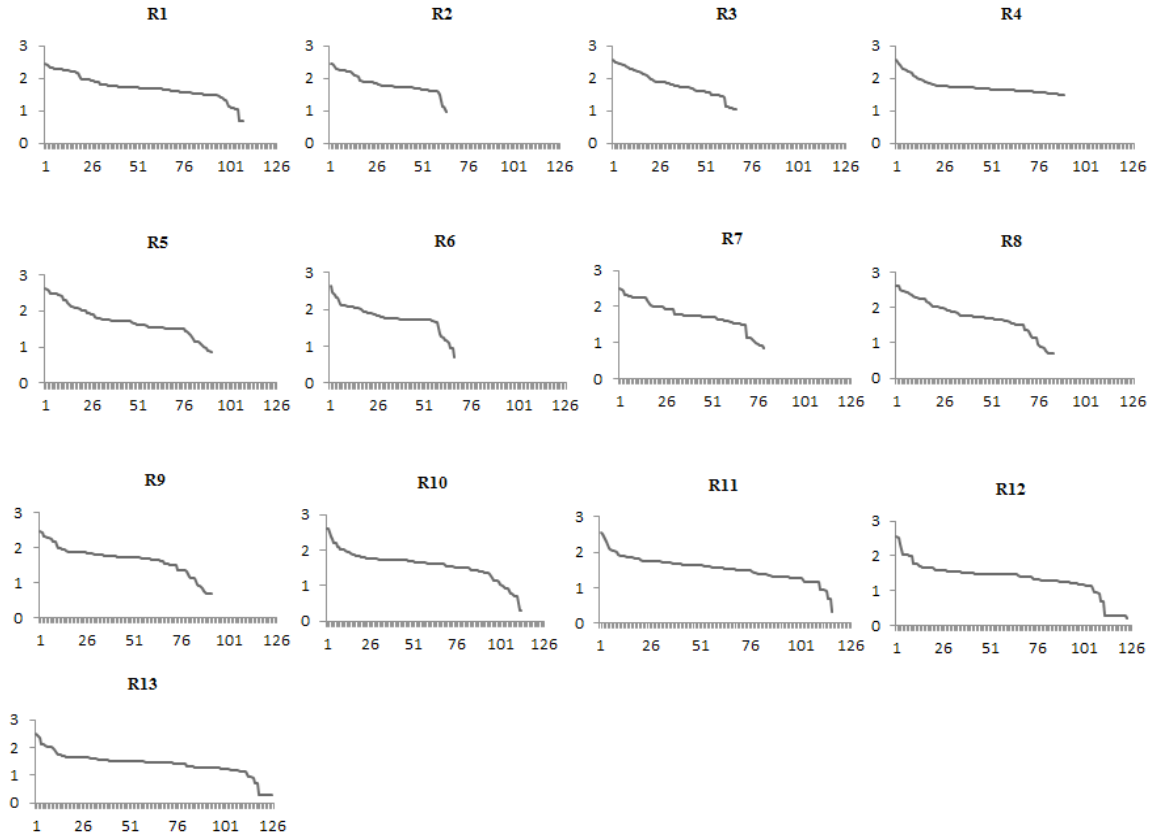

Fig. 3. Dominance Diversity Curve of all rivers. X : Species sequence in order of most to least abundance; Y: Log number of individuals in each species (Log of total annual population represented as an average fish count within 30 X 100 $m^2 y^{-1}$).

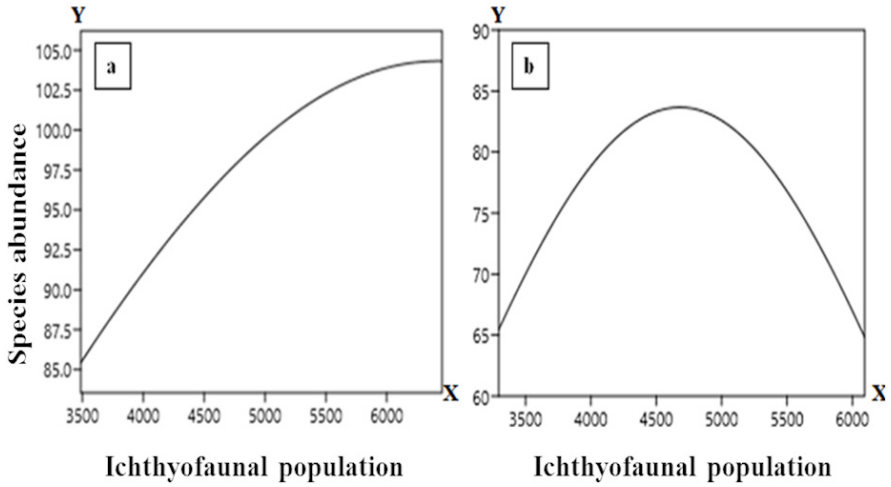

Fig. 4. Gaussian species packing within total fish population across all rivers during post monsoon **(a)** and summer drought **(b)** periods of the years. *X* axis represents population values. *Y* axis is species abundance represented by the number of species corresponding to a limit of population.

alien species probably under captive breeding have invaded the rivers and 17 of them have established permanently. A system of spatially and temporally co-ordinated supply of conserved nutrients (detritus) has evolved harmoniously with the events of recurring alien species migration in the Ganga delta river mouth (Roy, 2011). Further, many native biotas throughout the world are represented by invaded species of the past (Mc Donald and Hershey 1989). Although regions with the history of alternate and repeated inundations due to recurring floods and failed monsoon induced droughts can seldom provide any reliable data of ichthyofaunal alien nature, yet in South Bengal it appears that most of the alien species have come through anthropogenic input in the past. Three more alien species available in aquaculture farms have also been sampled from nature but not included as they failed to reappear in samples of the subsequent years.

IUCN Red Data List species

Available data (Fig 5, Appendix 1) suggests (IUCN 2020) that 11 %, 4 % and 3% of the fish species of this region belong to 'Critically Endangered', 'Near Threatened', and 'Vulnerable' groups respectively.17 % of species are either 'Data Deficient' or are not yet properly evaluated for population status. However 65% of the existing species are in 'List concern' group. So existence of by and large 35% of species in either fragility or information deficiency is no doubt a matter of concern and demands holistic habitat improvement. This deserves mention that present authors have opinion that IUCN list needs to be freshly reviewed depending upon detail down to earth samplings in future.

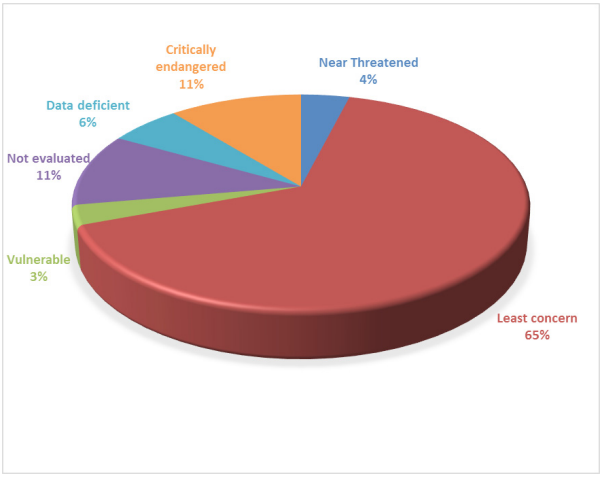

Fig. 5. Species distribution in accordance with 'IUCN Red Data List of Threatened Species' in all rivers.

Indices relationship indicates ecosystem's fragility and niche diversification

Species richness increases to increase the overall diversity without any influence on species equitability across the rivers, as the index of diversity explains 82% variability (r = 0.919, p<0.01) in the ichthyofaunal species richness (Figure 6). However, the same relationship is insignificant between the index of equitability and the index of diversity. This insignificance indicates towards fragility and instability of these fish community as the increase in diversity rise is only through species richness rise but not the equitability. Habitat vulnerability induces spontaneous diversification and gradual speciation through heterogeneous niche spaces to combat stresses. This is evidenced through a coexisting multiple genus with a number of species, subspecies and varieties of Ichthyofauna (Appendix 1). Phenotypic plasticity, standing genetic variations and newly derived mutations have been the prime adaptive potentials of freshwater fish with limited dispersal abilities to avoid extinction due to natural stresses (Smith *et al.*, 2013).

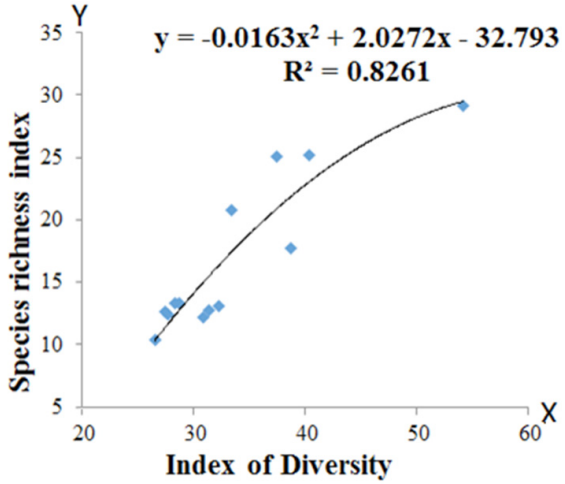

Fig. 6. Polynomial relationship between the index of diversity (*X*) and species richness index (*Y*), across the rivers; both the relationships are significant at r = 0.919, p < 0.01 at 11 *df*.

Conclusion

Vulnerable rivers have manifested high species richness with 137 ichthyofaunal species, 91 genera and multiple varieties within same taxa. Fish diversity

increase is ensured only through increase in species richness, without confirming any stability to the population as species equitability fails to rise significantly. Highly heterogeneous habitats that always exist in lotic continuums have facilitated survival, spontaneous adaptation, ecotype formation and gradual speciation in multiple alternate niche spaces. Once established, these species may have also flourished elsewhere during monsoonal increase in habitat homogeneity to facilitate migration. The process is repeated continuously with recurrence of dry and wet seasons. This observation also indicates that many species exist through very less number of populations. IUCN red data book supports this fact that conservation of at least 35% of species needs priority. Holistic habitat improvements should be the prime target for conservation.

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References

Arthington, A.H. 2012. Environmental flows: Saving rivers in the third millennium. University of California Press. Berkley, C.A.

Das, M. K., Sharma, A. P., Vass, K. K., Tyagi, R. K., Suresh, V. R., Naskar, M. and Akolkar, A. B. 2013. Fish diversity, community structure and ecological integrity of the Tropical River Ganges, India. *Aquatic Ecosystem Health & Management*. 16: 395-407.

Fedor, P. and Zvarikova, M. 2019. Conservation ecology: Biodiversity Indices, pp 337-46. In: B. Faith edited. *Encyclopedia of Ecology*, Elsevier, Oxford.

IUCN. 2020. IUCN Red List for Threatened Species. International Union for the Conservation of Nature and Natural Resources. www.iucnredlist.org.

Jayaram, K.C.2010.The Freshwater Fishes of the Indian Region. Second Edition. Narendra Publishing House, Delhi, India, 616.

Johnson, J.A., Parmer, R., Ramesh, K., Sen, S. and Murthy, R. S. 2012. Fish diversity and assemblage structure in Ken River of Panna landscape, central India. *Journal of Threatened Taxa.* 4 (13) : 3161–3172.

Kar, A., Bhattacharya, M., Ghorai, M., Patra, S. and Patra, B. C. 2017. Ichthyofaunal Diversity of Kangsabati River at Paschim Medinipur District, West Bengal, India. *Proceedings of the Zoological Society*. 70 (2): 165-173.

Lakra, W. S., Sarkar, U. K., Gopalakrishnan, A. and Kathirvelpandian, A. 2010. *Threatened Freshwater Fishes of India*. National Bureau of Fish Genetic Resources Publication, Lucknow (ICAR).

Lasne, E., Bergerot, B., Lek, S. and Laffaille, P. 2007. Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire basin (France). *River Research and Applications.* 23(8): 877-890.

Mahapatra, B. K., Sarkar, U. K. and Lakra, W. S. 2014. A Review on Status, Potentials, Threats and Challenges of the Fish Biodiversity of West Bengal. *Journal of Biodiversity, Bioprospecting and Development.* 2(1): 140.

Mc Donald, M. E., Hershey, A. E. 1989. Size structure of a lake trout (*Salvelinus namaycush*) population in an arctic lake: Influence of angling and implications for fish community structure. *Canadian Journal of Fisheries and Aquatic Sciences* 46: 2153-2156.

Mishra, S.S., Pradhan, P., Kar, S., Chakraborty, S.K. 2003. Ichthyofaunal diversity of Midnapore, Bankura and Hooghly districts of South West Bengal. *Rec ZSI Occasional paper* 220: 1- 65 (Published by the Director, Zoological Survey of India, Kolkata).

Rakshit, A. and Roy, S. 2021. Ichthyofaunal Migration Causes Realized Niche Amplification Leading to Habitat Adaptation and Speciation in Rivers of Bengal Delta. *Indian Journal of Ecology* 48 (4): 1155 – 1164.

Roy, C., Vass, K. K., Patra, B. C. and Sanyal, A. K. 2013.Fish Diversity in Two South-Western Districts of West Bengal- Bankura and Purulia. *Records of Zoological Survey of India* 113 (4): 167 - 179.

Roy, S. 2003. *Environmental Science: A Comprehensive treatise on Ecology and Environment,* pp 624. Publishing Syndicate, Kolkata. ISBN: 31-87704-00-4.

Roy, S. 2011. Seasonally and Spatially Coordinated Strategy of Detritus Conservation and Use in the World's Largest Mangrove Ecosystem. *Proceedings of the Zoological Society*. 64(2) : 63-71.

Sarkar, U. K., Pathak, A. K., Sinha, R. K., Sivakumar, K., Pandian, A. K., Panday, A., Dubey, V. K. and Lakra, W.S. 2012. Freshwater Fish Biodiversity in the River Ganga (India): changing pattern, threats and conservation perspectives. *Reviews in Fish Biology and Fisheries.* 22 : 251-272.

Smith, S., Bernatchez, L. and Beheregaray, L. B. 2013. RNA – Sequence analysis reveals extensive transcriptional plasticity to temperature stress in a fresh water fish species. *BMC Genomics* 14(1): 1-12.