Case Study 2

Impacts of Flow Alteration on Benthic Biota and Fish Fauna

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INTRODUCTION

Hydraulic parameters are considered to influence micro-distribution of the benthic organisms (Gore 1978, Statzner 1981a, b). In-stream hydraulics affects the benthos at different scales (Statzner and Higler 1986, Corkum 1992, Carter et al. 1996). Five major hydraulic conditions most affect the distribution and ecological success of lotic biota: suspended load, bed-load movement, and water column effects, such as turbulence, velocity and substratum interactions (near-bed hydraulics) (Gore et al. 2001). Leopold et al. (1964) noted that in-stream hydraulic parameters such as velocity and depth relate to the dimensions of the stream channel. Reduced flows can affect population densities and community compositions of many aquatic organisms including mussels, shrimps, fishes and macro-invertebrates (Boulton 2003, Covich et al. 2003, Lake 2003). Dewson et al. (2007) also observed that decreases in discharge usually cause lower water velocity, water depth, and wetted channel width; increased sedimentation; and changes in thermal regime and water chemistry. Invertebrate abundance increases or decreases in response to decreased flow, whereas invertebrate richness commonly decreases because habitat diversity decreases. Invertebrates differ in their environmental tolerances and requirements, and any loss of habitat area or alteration of food resources from decreased flow can influence organism behavior and biotic interactions. Invertebrate drift often increases immediately after flow reduction, although some taxa are more responsive to changes in flow than others. Stevenson (1983) noted that community growth form determines periphytal responses to spatial variations in velocity within stream reaches. Studies have shown major differences in the way biomass of stream periphyton is controlled by spatial variations in velocity. Biomass was moderate at low velocities, peaked at near-bed velocities from 0.18 to 0.2 $m \cdot s^{-1}$ (~ 0.40–0.45 $m \cdot s^{-1}$ mean column velocity), and then decreased at higher velocities in both of the stalked/ short filament communities of diatoms analyzed (Biggs et al. 1998).

Thus, flow is a major determinant of physical habitat in rivers. The complex interaction between flow and the physical habitat governs the distribution, abundance and diversity of the stream and river organisms (Schlosser 1982, Poff and Allan 1995, Ward et al. 1999, Nilsson and Svedmark 2002). It flushes and replenishes the sediments. Flow regime changes lead to habitat alterations, changes in species distribution and abundance and loss of native biodiversity. The biological communities of fluvial ecosystems are assembled from the organisms that are adapted to regional conditions, including the physical environment and food resources, and are further refined through interactions with other species (Allan and Castillo 2007). Biological assemblages with a mix of diverse species are expected to carry out various ecosystem functions.

Human alteration of flows is now contributing globally to biodiversity loss in freshwater ecosystems and to the degradation of many of the natural goods and services that these ecosystems provide to human communities (Postel and Richter 2003, Dudgeon et al. 2006, Poff et al. 2007). In India, though the need for minimum flows in rivers is recognised as a part of the National Water Policy (2012) which states that "minimum flow should be ensured in the perennial streams for maintaining ecology and social conditions", there has been practically no effort until recently to assess environmental flows requirements. There is near total lack of knowledge of the responses of biota to the changes in flow regimes and the flow requirements of various organisms at different stages of life-history.

The first significant study on the assessment of environmental flows has been made in the upper reaches (ca. 800 km in length) of River Ganga, under the WWF's Living Ganga programme, following the Building Block Methodology (for a summary, see Kaushal and Babu 2013). This paper provides a detailed account of benthic algae and invertebrates, and the fish fauna in the upper reaches of River Ganga and an assessment of their requirements of flow regimes. Major changes in the composition of these biotic communities in recent years recorded on the basis previously published information in summarised in Appendix I. This study also projects the flows recommended for the biodiversity requirements of the E-Flows assessment.

River Ganga has an extensive north basin spreading in the Indian and Nepal Himalaya and a relatively smaller south basin in central and eastern Peninsular India. The river Ganga has its source in glaciers of Indian Himalaya and the river course consists of a short mountain section which spans 283.8 km from the source to Hardwar (Mathur 1991) and a 2000 km long stretch in the Plains. The mountain section lies in the West Himalayan biogeographic region and the rest in Upper and Lower Gangetic Plains (Rodgers et al. 2002). The stretch from Devprayag in the Lesser Himalaya to Kanpur in the middle of the Gangetic Plain was considered as Upper Ganga and divided into several zones for the assessment of environmental flows (Kaushal and Babu 2013). However, for analyzing the effects of flow alterations on benthos and fish, only three sections were investigated: (a) from Tehri Dam to Bheemgoda barrage near Haridwar representing the Lower Mountain Zone (LMZ; 70 km), (b) from Bheemgoda to Narora barrage in the Upper Ganga Plain Zone I (UGPZ I; 305 km) and (c) from the Narora barrage to Bithoor in the Upper Ganga Plain Zone II (UGPZ II; 330 km). Details of the sampling locations in these three stretches are presented in Table 1.

The LMZ of River Ganga is characterized by a narrow channel with low to moderately steep slopes along the banks littered with rocks and prismatic boulders of varying size

Table 1. Site variables at sampling stations in LMZ, UGPZ I and UGPZ II of Upper Ganga

Parameters	Kaudiyala (LMZ)	Narora		UGPZ I	Bithoor UGPZ II
		U/s	D/s	Kachla Ghat	
Latitude, N	30° 04'34	28° 16'130"	28° 10'879"	27° 55'44"	26°36'09"
Longitude, E	78 ° 29'56	78° 19'204"	78° 24'002"	78° 51'38"	80° 16'48"
Altitude (m above sea level)	424	165	164	145	114
Air temperature (°C)	21.5 -27.5	10.4	19.5	19-34.5	12.6- 33.5
Water temperature (°C)	11.8-21	13.6	15	15-31.5	15.2-32
Depth range (cm)	30-60		27	30-60	30-60-75
Current velocity (cm s^{-1})	21-94	29-32	2-15	9-75	9-65
Transparency (cm)	30	270	25	12-30	6-30
pH	8.1-8.4	8.6	9.1	8.4-10.2	8.3-9.7
Conductivity (µS)	140-320	270	25	25 (Narora) 220-270	270-440
D.O. (mg L^{-1})	8.6-10	6.4		4.8-7.8	6.4-8.6
Alkalinity (mg L^{-1})	44-68	60	-	60-100	50-128
Hardness (mg L^{-1})	72-135	128		96-104	120-188.4
Chloride (mg L^{-1})	5.2-12	38.34		12-28.4	14-31.24
Fluoride (mg L^{-1})	<1.0			<1.0->10	<1.0->10
Nitrate (µg L^{-1})	0.00046 - <0.001			<0.001-0.88	<0.001-2.07
Phosphate(µg L^{-1})	0.00003-0.112-			<0.001-0.6	<0.003-0.66
Iron (mg L^{-1})	<1.0->1.0-<3.0			<0.01-<3.0	<3.0->3.0
Silicate (mg L^{-1})	10-10.8	0.168		12-0.156	16-0.176
TOC (mg L^{-1})	11.94			20.8	26.56
Substratum type	Boulder>Cobble >Pebble	Sand>Silt >clay	Sand>Silt >clay	Sand>Silt >clay	Sand>Silt >clay

or less frequent sandy banks. The habitats in LMZ occur in the form as longer pools, short runs and riffles, which also extend into the UGPZ. In the UGPZ, the river channel is much wider and meandering with extensive flood plains. The river bed in this zone consists mostly of soft sediments and fewer small gravel or pebbles in varied proportions. The vegetation consists of sub-tropical forest in the LMZ and extensive cultivation in the floodplain (UGPZ).

River Regulation

Agriculture is the major landuse in vast stretches of land around the rivers Ganga and Yamuna, and hence, a network of barrages and canals has been developed for irrigation. The barrage at Chilla, Bhimgoda, Bijnor and Narora on River Ganga were commissioned prior to 1980. The details of abstractions and flow augmentation between Haridwar and Kanpur are available at http://www.rid.go.th/thaicid/6_ activity/Technical-Session/SubTheme2/2.15Ravindra_K. pdf (accessed, 27 July 2012). Besides the municipal wastes from the towns and cities of varying magnitude, industrial effluents are also discharged into the river between Narora and Kanpur.

Flow Characteristics of River Ganga

The rivers Bhagirathi and Alaknanda which join unite to form River Ganga are discharge-starved for long distances below the Maneri, Tehri and Vishnuprayag dams (Singh 1988, Gaur 2007, Rajvanshi et al. 2012). Since the Ganga has a glacier at source, the water is ice-cold in headwaters (4.3°C), cold in the unregulated section in LMZ (<21°C) and moderately cool even in UGPZ (13.6 to 32 °C). The temperature rises by10°C in the upper temperature limit from LMZ to UGPZ, while lower limit differs marginally. The current velocity regime differs in the mountain and plains. The water current velocity is higher (21 to 94 cm s^{-1}) in the LMZ compared with the UGPZ where it ranges from <9 cm s^{-1} to <75 cm s^{-1}) except upstream of Narora where the velocity range deviates depending upon the river regulation (Table 1). Exceptionally, low velocities (both lower and upper limits of the range) are observed downstream of Narora (immediately below the barrage).

Along with the flow velocity, the DO declines from LMZ to UGPZ. Loss of torrential flows and ice-cold water are the major threats to the specialised biota of the riverine network in the mountains. This can be gauged by comparing its peninsular tributaries with the Ganga. The maximum turbidity is high (about 1500 NTU) in the LMZ and declines to <300 NTU in the UGPZ. The pH, conductivity, alkalinity, hardness and nutrients increase gradually from LMZ to UGPZ.

PRODUCER COMMUNITIES (Benthic and Planktonic Algae)[1]

Composition

The benthic algae consist of diatoms, green (GA) and blue-green algae (BGA) at all depths

[1]*Detailed data on the biota are available as supplementary files online at the publisher's website (www.nieindia.org) or from the author.*

in the LMZ. At UGPZ I, the benthic algae occurs only at 15 cm depth. A dominance of GA and BGA over diatoms had been reported earlier at Devprayag (Anon. 2002-2003). Phytoplankton constitutes a large part of plankton community. The diatoms dominate phytoplankton at all depths, especially at 30 cm depth in UGPZ I and 60 cm depth in UGPZ II (Table 2). Vass et al. (2010) noted that the phytoplankton accounted for a very large share of the total plankton and that diatoms (Bacillariophyceae) accounted for 83.4% of phytoplankton between Tehri and Kannauj.

The species-rich benthic genera differ between LMZ and UGPZ I (Table 3). Among other algae Euglenophyceae, Dinophyceae, Chrysophyceae and Xanthophyceae were present in UGPZ only.

Table 2. Planktonic and benthic algal communities: Species richness and density at different depths in the three zones of Upper Ganga during winter

	Benthic algae									Plankton								
Stations	LMZ			UGPZ I			UGPZ II			LMZ			UGPZ I			UGPZ II		
Depths	15	30	60	15	30	60	15	30	60	15	30	60	15	30	60	15	30	60
Total Density (units l^{-1})	498	601	502	523	N	N	N	N	N	498	400		547	297	364	361	339	278
Total Species Richness	42	71	32	36	N	N	N	N	N	18	11		36	52	37	24	24	30
Diatoms	36	59	28	26	N	N	N	N	N	16	11		30	46	30	21	21	28
Blue green algae	4	8	3	6	N	N	N	N	N	2	8		1	2	2	2	2	2
Green algae	2	4	1	1	N	N	N	N	N	0	0		2	2	3	1	1	3
Zooplankton	0	0	0	0	N	N	N	N	N	0	0		4	3	2	0	0	0

Table 3. Species rich genera of benthic and plankton community during winter

	Benthic algae		Plankton		
Taxa	LMZ	UGPZ I	LMZ	UGPZ I	UGPZ II
Nitzschia	7		2	9	8
Navicula	11		3	8	5
Cymbella	8	4	3	7	1
Gomphonema	10		1	4	1
Amphora	4			5	3
Synedra	3	3	2	5	4
Oscillatoria	5			2	3

Species Richness

The species richness of benthic algae in LMZ increased with increase in depth from 15 cm to 30 cm but decreased at 60 cm depth. In UGPZ I, benthic algae occurred only at 15 cm depth. The plankton richness too declined with depth in LMZ but was higher at 30 cm depth in UGPZ I. In UGPZ II, the richness increased up to 60 cm depth. The benthic algae occur as epilithon in LMZ (79 taxa), episammon in UGPZ I (36 taxa) and is absent in UGPZ II. In contrast, the plankton increases from 24 taxa in LMZ to 70 taxa and 50 taxa in UGPZ I and II, respectively.

It augurs that 30 cm depth with optimum velocities, support higher density and richness of benthic algae in LMZ. The benthic algae become scarce and plankton increases in density and richness as the substrate changes from hard to soft substrate from mountain to the Plains (UGPZ I, II) and gradient decreases from 5 m km^{-1} because to 0.5 m km^{-1}

Density

The density of benthic algal community also increased from 15 to 30 cm depth but decreased at 60 cm depth (Table 2). In UGPZ I and II, benthic algae occurred as episammon at 15 cm depth only. The plankton density decreased with depth and was not found beyond 15 cm depth in all three regulated zones. Among these zones, the density of plankton increased from LMZ to UGPZ I only (Table 2).

Abundance

The abundance of benthic taxa *A. biasolettianum* and *A. minutissimum* increased marginally with depth at station LMZ (Table 4). Plankton was similar to benthic algae because scouring effect dislodges the attached algae from hard substrates. Their abundance variesd marginally

Table 4. Benthic algae and plankton taxa at depths in LMZ and UGPZ during winter

	Benthic algae				Plankton								
River sections	LMZ			UGPZ I	LMZ			UGPZ I			UGPZ II		
Taxa	15	30	60	15	15	30	60	15	30	60	15	30	60
Cyclotella glomerata				11				9.4	6.9	8.6	13	21	29
Nitzschia palea											9.8	15	21
Cyclotella menenghiana				9				5.6	8.2	7.2	9.9	15	12
A. biasolettianum	13	14	16	12	11	13	11	11	12	10	9.5	14	0
A. minutissimum	10	10	11	15	9	10	12	13	9.5	7.8			
Nitzschia acicularis											11	0	0
Aulacoseira granulata				10				10	7.7	9.1	10	0	0
Diatoma mesodon								8.6	9.8	10			
Gyrosigma scalproides								4.1	8.4	2.6			
Synedra ulna	3.5	5.3	7.1		5	5.3	9						

in plankton community at all stations and thus, were ‘indifferent” to both depth and velocity. *A. minutissimum* is a cosmopolitan and ubiquitous diatom and abundant taxon, common in well-oxygenated, circumneutral or alkaline lakes and streams with low or moderate concentrations of nutrients and organic pollution. It is usually tolerant to various types of stressors (hydrologic disturbance, low pH, heavy metals, low nutrient and ionic content; Ponder and Potopova 2007).

Except for the two diatoms, *A. biasolettianum* and *A. minutissimum* (dominants of the episammic community also in UGPZ I), other taxa differed in their abundance between zones. In LMZ, *S. ulna* had a tendency to increase in abundance with increasing depth and velocity, both in benthic algae and plankton community. Among plankton, abundant taxa at in the two zones were different (Table 4): *D. mesodon exibited* increasing abundance with increase in depth in UGPZ I, *A. granulata* declined with increasing depth both in UGPZ I and UGPZ II while *Nitzschia acicularis* declined in UGPZ II only. *C. glomerata, Nitzschia palea* and *C. menenghiana* exhibit highest abundance at greater depths in UGPZ II. *C. glomerata* and *C. menenghiana* were abundant in the benthic algae community also.

Evidently, different depths provide high variability and higher species diversity for both communities. The abundance of taxa varies among the banks also. This demonstrates the importance of natural flows in a river. Reduced flows and river regulation cause homogenization of substrate (prevalence of soft sediments) that affects the abundance patterns. Since abundance patterns in pre-regulation period are not known, the observed pattern can be treated as a feature of present river regulation and specifies the prevailing assemblages.

CONSUMER COMMUNITIES
(Benthic Macroinvertebrates)

Density

The density of benthic macroinvertebrates was higher at 30 cm depth. In LMZ, density increased with increase in current velocity and from 15 cm to 30 cm depths. In UGPZ I, density decreased with increase of current velocity and depth from 15 cm to 30 cm and increased from 30 cm to 60 cm along with increase of current velocity at right bank (downstream of Narora barrage the density decreased compared with upstream barrage). In UGPZ II, density decreased with increase of current velocity from low to high depth at left bank. The densities were low and differed barely among the sections (Table 5).

Table 5. Density and richness of macroinvertebrate fauna in regulated sections. In UGPZ II fauna absent on RB and observed on LB only. The LB had low richness and densities in all sections

River sections	LMZ			NB U/s			NB D/s			UGPZ I			UGP II (LB)		
Depth	15	30	60	15	30	60	15	30	60	15	30	60	15	30	60
Density	22	550	NS	231	99	220	154	154	99	220	99	330	305	55	22
Taxon richness	3	4		4	2	3	5	4	5	4	3	1	1	4	1

Species Richness

In LMZ, the number of taxa varied slightly - from 3 at 15 cm and 60 cm depths to 4 at 30 cm depth. Earlier studies reported 20 families from 8 orders from Devprayag to Rishikesh, 9 families at Devprayag and 17 at Rishikesh (Singh et al 1994, Joshi 2005). Ten taxa were reciorded from Devprayag to Kanpur in other reports (Anonymous 2001-2006). The number of taxa remains constant from 15 cm to 60 cm depth; 7 taxa in UGPZ I and one in UGPZ II (Table 5). However, at 30 cm depth it decreased in UGPZ I. In UGPZ II, there were no benthic macroinvertebrates along the right bank. On the left bank also only one taxon was found at 15 and 30 cm depths. Four taxa were present at 60 cm depth. The richness was low and did not differ among the three zones.

Composition

In the LMZ, the most speciose Orders were Ephemeroptera, Diptera and Trichoptera, as noted earlier also (Singh et al 1994). Water-mites are known from LMZ only (Singh et al loc.cit.), while Ostracoda (Crustacea), Hymenoptera (Insecta) and Annelida were present only in UGPZ. The LMZ benthic fauna differs sufficiently from the whole UGPZ where Gastropoda, Diptera, Odonata and Pelecypoda occur in higher relative abundance. Baetidae (mayfly), Hydropsychidae (caddisfly) and most of the Diptera excluding Chironomidae did not extend beyond LMZ.

Relative Abundance (%)

The benthic macroinvertebrate abundance varied with river depth and current velocity (Table 6). In LMZ, the abundance of Hydropsychidae and Baetidae decreased with increase of current velocity from 15 to 30 cm depth, while the chironomids and tipulids occurred only

Table 6. Variation in macroinvertebrate abundance at different depths in the three zones of River Ganga. **Ba**-Baetidae, **Hy**-Hydropsychidae, **Ch-**Chironomidae, **Ti-**Tipulid, **Hl**-Helidae, **Gp**-Gastropoda, **Pp**-Pelecyepoda

River sections	Family	LMZ			UGPZ I			UGPZII(RB)			UGPZ II (LB)		
Depth (cm)		15	30	60	15	30	60	15	30	60	15	30	60
Ephemeroptera	Ba	50	8										
Trichoptera	Hy	50	2										
Diptera	Ch		64		15	22	100						
	Ti		24										
	Hl											40	
Mollusca	Gp											20	
	Pp1/2				10						100	20/20	100
Hemiptera			2		45	22							
Unidentified					30	56							

at 30 cm depth. In UGPZ I, the chironomid abundance increased from 30 cm to 60 cm depth and was positively related with current velocity. Hemiptera (at 15-30 cm depth) extended from LMZ to UGPZ I. The chironomid ceased to exist in UGPZ II, while Helidae (Diptera) continued from LMZ to UGPZ II at 30 to 60 cm depths. The gastropod also continued from UGPZ I to II at 15 cm depth (Table 6). In UGPZ II, Pelecypoda found up to 60 cm depth were the major component among the molluscs, probably due to mainly clay substrate along the banks (Table 7).

Gore (1978) noted that the conditions for highest faunal diversity were 75-125 cm s^{-1} at 20-40 cm depth. The optimum condition appeared to be 76 cm s^{-1} at a depth of 28 cm over medium cobble substrate. Further, Degani et al. (1993) based on the relationship between current velocity, depth and invertebrate community in a river system, noted that a reduction in discharge would directly affect the species dependent on slow current velocity (0-20 cm s^{-1}) habitats and high current velocity (> 140 cm s^{-1}) habitats. Evidently, hydraulic and substrate conditions are physical variables that strongly affect community composition, abundance, and distribution of macroinvertebrates. The interaction of depth and velocity with the substrate profile is of critical importance to the range of potential microhabitats available to benthic macroinvertebrates (Statzner and Higler 1986, Statzner et al.1988).

Table 7. Distribution of macroinvertebrates in different zones of River Ganga (+ = pool, * = riffle)

Orders	Families / Depth (cm)	LMZ			UGPZ I			UGPZ II		
		15	30	60	15	30	60	15	30	60
Diptera	Chironomidae		+*	+	+	+	+			
	Tipulide		+*							
	Tabanidae		+							
	Helidae		+*				+		+	+
Coleoptera	Elmidae		+			+	+			
	Dytiscidae				+		+			
Odonata	Agrionidae						+			
	Gomphidae				+	+	+			
Ephemeroptera	Baetidae	*	*							
Trichoptera	Hydropsychidae	*	*							
Hemiptera			+		+	+				
Nematoda		+*	+							
Gastropoda					+				+	
Pelecypoda sp 1/2					+	+	+	+	+*	
Unidentified insect			+		+	+				
Total		3	8	3	7	6	7	1	4	1

CONSUMER COMMUNITIES (FISH)

Catch

There are no density estimates for fish community in the Upper Ganga and it is a practice in India to quantify fish as catch and its composition. However, there are no estimates for the study period. Proper catch records are available for the Ganga from Allahabad onwards to Farakka. Earlier, Nautiyal (1998) recorded catch per day from the Ganga at Ajeetpur D/s Hardwar from roughly 2-3 km stretch of the river. During the lean months it varied from 15-62 kg in November, 12-122 kg in December, 28-150 kg in January and 31-108 kg in February. The catch is comparable during minor flooding caused by snow-melt (March 7-109 kg, April; 13-170 kg, May 5-178 kg; June 4-72 kg). No catch during monsoon floods (July to September) and low catch during October (12-26 kg). The catch increases to 955 kg km-1 at Kanpur. Unlike the macroinvertebrates that begin to emerge into adults with flooding of the river causing a decline in the community density, the populations of various fish species remain constant except for fresh recruits every spawning season.

Species Richness

There is distinct fish fauna in each zone, being least in the LMZ and higher in UGPZ I than in UGPZ II. The fish fauna consisted of 149 fish species from 25 families along the study stretch of the river Ganga (Nautiyal et al. 2013). Fifty eight species are present in LMZ and 122 species in UGPZ (both I, II). Most fish species common to LMZ, and UGPZ I and II belong to Order Cypriniformes and Siluriformes.

During this study 26 fish species from 14 families and 7 orders were recorded in the Upper Ganga of which 20, 6 and 22 fish species were recorded from the respective zones.

Community Composition

The fish fauna in LMZ is typical mountainous in character with the dominance of snow trout followed by mahseer. There is a considerable decline in mahseer population in recent years (Nautiyal 2013). The most typical fish in LMZ are Cyprinidae; snow trouts (*Schizothorax*sp, *Schizothoraichthys* sp.) Sisoridae (*Pseudecheneis* sp., *Glyptothorax* sp.) and Balitoridae (*Schistura* sp.). In UGPZ I besides *Schistura* and *Glyptothorax* sp., a wide variety of other genera of these families are exclusive. Presence of four silurid (four) families is the unique feature of this zone. In UGPZ II, cyprinid elements become few and besides few Bagridae, Siluridae and Schilbidae, there is greater representation of Sisoridae as in the MZ, but the genera are different. Some unique elements appear in UGPZ II, especially clupids, mugil and perch. Fish belonging to Tetradontiformes, Osteoglossiformes and Clupeiformes were restricted to UGPZ only (Nautiyal et al. 2014). Probably mobility and physiological requirements in respect of tolerance for temperature and adaptation for habitats restrict the faunal elements. Extreme habitats such as torrential ice-cold waters are inhabited by adapted fish species only.

FACTORS AFFECTNG THE BENTHIC COMMUNITIES
(Ecological preferences)

Producer Communities

The examination of common and rare taxa in LMZ revealed that the ecological preferences vary during high and low flows (Appendices Ai-iii, Bi-iii). During lean flows, *Meridion circulare* and *Nitzschia sigmoideae* (benthic algae) occur on the cobbles in riffles at 15 to 30 cm depth and current velocities of 36 cm s^{-1}. During high flows no rare taxa were observed and the common taxa *Nitzschia frustulum* and *Reimeria sinuata* prefer velocities nearing 100 cm s^{-1} on the cobble substrate submerged by flooding of banks. In UGPZ I A sub was a rare (sensitive) plankton taxon during lean flows which occurred at 60 cm depth and CV 31 cm s^{-1}. The commonly occurring *Aulacoseira granulata* and *Gomphonema minutum* as plankton prefer CV 18-21 cm s^{-1} but latter was limited to 30 cm depth while *Gomphonema minutum* was tolerant to depth variation. During high flows *Nitzschia palea* and *Nitzschia frustulum* respectively occurred at 15 and 30 cm depths, and CV 36 and 45 cm s^{-1},. *Nitzschia palea* an indicator of organic pollution, was present as benthic algae while *Nitzschia frustulum*, a moderately tolerant taxon was present as plankton. *Diatoma mesodon* though present as a common plankton taxa was found to be a rare benthic taxa with preference for 15 cm depth and 14 cm s^{-1} CV. In UGPZ II, the examination of preferences during lean flows shows that *Nitzschia acicularis*-as common plankton occurred at 15 cm depth and 13 cm s^{-1} CV. In these flows a rare taxon *Diatoma mesodon* occurred as plankton at 60 cm depth and 58 cm s^{-1} CV. During high flows in both communities *Nitzschia palea* is tolerant to variation in depth and flows while *Nitzschia frustulum* occurred as benthic algae and plankton as well at 29 cm s^{-1}. *Craticula citrus*, as rare benthic algae and *Epithemia sorex* , *Gomphonema sphareophorum* as plankton preferred 29 cm s^{-1}. Ghosh and Gaur (1998) determined preferences of some common diatom species for current regimes: pool for *Gomphonema parvulum* and *Gomphonema lanceolatum*; 10–14 cm s^{-1} for *Navicula cryptocephala*; and 18–21 cm s^{-1} for *Gomphonema olivaceum*, *Caloneis bacillum* and *Pinnularia gibba*.

Consumer Communities (Macroinvertebrates and Fish)

In LMZ, BA, HY and NE at 15 cm depth and TB at 30 cm depth, while TI tolerates to flow and depth variation in lean flow. HP, PE and LM prefer for 15 cm depth at high flows (58 cm s^{-1} CV). In UGPZ I, during lean flows at 15 cm and 30 cm depth: PO, HE, PL1 and at 60 cm depth PL1. During high flows at 15 and 30 cm depth: GT2, GT2, PL2, PL3 and PL4. In UGPZ II during lean flows at 30 cm depth: PL2, HL, while during high flows at 15 cm depths; GT1, CH.

The preferences of fish fauna in LMZ are well explained by Menon (1954) who related the distribution of Himalayan fish to morphological characteristics which enable them to inhabit the torrential streams. He identified six major groups:

(a) fish dwelling in shallow, clear cold water in the foothills without any striking modification to current: *Tor*

(b) fish inhabiting the bottom water layers in deep fast current, with powerful muscular cylindrical bodies: schizothoracines and the introduced trout;

(c) fish sheltering among pebbles and stones to ward off the strong current: *Crossocheilus*

(d) fish sheltering among pebbles and shingles in shallows, with special attachment devices: the loaches*, Botia*

(e) fish which cling to exposed surfaces of bare rocks in lower current, with adhesive organs on their ventral surface for attachment to rocks: *Garra, Glyptothorax* and *Glyptosternum*, and

(f) fish which cling to the exposed surfaces of bare rocks in fast current, with limpet-shaped bodies and mouth, gills and fins highly modified to suit the habitat: *Balitora*.

The preferences are not very well defined in the UGPZ, but it can be tentatively said that *Chela atpar, Mystus tengra, Rita rita* prefer habitats in UGPZ I, while *Labeo calbasu* in UGPZ II.

The presence or abundance of sensitive diatom and even macroinvertebrate taxa at specific depths demonstrates the fragility of river ecosystems and underlines the importance of small habitats and refuges provided by substrate heterogeneity. Their loss often leads to loss or disruption of key links of the food-web thus affecting the consumer trophic levels, leading to loss of the ecological integrity of the ecosystem. Such ecosystems have dominance of one or two species in contrast to greater number of dominants or even better with high evenness, and many species with similar levels of abundance (no dominance).

RESPONSE OF COMMUNITIES TO FLOW TIMINGS

The life-histories of river biota in the mountain and upper Ganga plains are synchronized with the flow pulses round the year. As the monsoon and floods subside, flows return to normal and as temperatures fall in winter and fresh snow is added to the glaciers, the flows from glaciers decline resulting in lean flows and this affect is visible from source to Allahabad. The period generally extends from October to February, and is characterised by highest transparency, lowest temperature and current velocities. During February - March, temperature starts rising as spring gradually gives way to summer; flows are augmented as fresh snow in the lower reaches of glaciers melts, and soon flood the channel. The river flow is characterised by increasing turbidity, peak water temperature and increased current velocities. In recent years, the timing for the beginning of summer floods seems to have been delayed. Increased flooding of the middle mountain stretches and turbidity in March-April have been influenced by the barrages and dams on the rivers Alaknanda and Bhagirathi. The flooding is steady during May and June. The commencement of monsoon[2] increases flooding, turbidity, current velocities but water temperatures decline. However, water temperatures are steady until September. The monsoon flooding occurs rapidly but the highest flows

[2] In 2013, monsoon set in during the middle of June and unprecedented heavy rain at places (Badrinath, Kedarnath, Gangotri and Yamnotri) caused severe floods on 16–17 June that spelt disaster mainly through landslides and the failure of river banks. The loss of aquatic life was evident from the fishes that were littered far away from the banks.

may not occur in mid-monsoon (August) in the Himalayan catchment of the Ganga, as in 2013 highest floods happened in the beginning of monsoon itself. Floods are moderate disturbances (except for extreme flooding that devastates the channel) very important for higher levels of biodiversity (Krebs 1994). In brief, the flow pulses are governed by large volumes of surface run-off from catchments. Monsoon is the sole source for major part of high floods whereas the variations in glacier melting contribute moderately. The response of major communities in these different flows is described below.

Benthic Algae

In LMZ, density and richness of benthic algae were relatively high during lean flows (winter), and declined with increase in summer flooding. In UGPZ I and UGPZ II density and richness were higher in receding floods of post monsoon months (September-October) than during lean flow, but declined or were absent with increased flows during summer and even during lean flows (winter) in latter zone. In LMZ and UGPZ I, the diatom communities were dominated by *Achnanthidium biasolettianum* while *Cymbella* and *Navicula* were speciose genera irrespective of increase or decrease in the flows. In UGPZ II *Nitzschia* and *Scenedesmus* were speciose genera. *Achnanthidium minutissimum* - *Cymbella excisa* assemblage occurred during summer snow-melt flooding, while *Aulacosiera granulata* and *Achnanthidium biasolettianum* during receding floods (post monsoon).

Plankton

In LMZ, the plankton occured only during the lean flows. In UGPZ I and II the plankton density and richness were higher during receding floods of post monsoon and lean flows during winters and declined during summer flooding. In UGPZ I *Cymbella* and *Navicula* were mostly speciose genera except for *Achnanthidium* and *Cymbella* during receding floods of post monsoon. The assemblages were highly variable during winter lean flows at all depths compared with *A. minutissimum* - *A. biasolettianum* during summer snow-melt flooding. In UGPZ II, *Scenedesmus* and *Nitzschia* were speciose during summer snow-melt flooding, *Cymbella* and *Synedra* during receding floods of post monsoon while *Nitzschia* during winter lean flow, which may vary with depth. *A. biasolettianum* or *A. minutissimum* dominate the assemblages during lean flows. The post monsoon assemblage of receding floods was similar to benthic algae; *A. granulata* and *A. biasolettianum*. The winter lean flow assemblages were unique *Cyclotella menenghiana* - *Nitzschia palea* – *C. glomerata*.

Benthic Macroinvertebrates

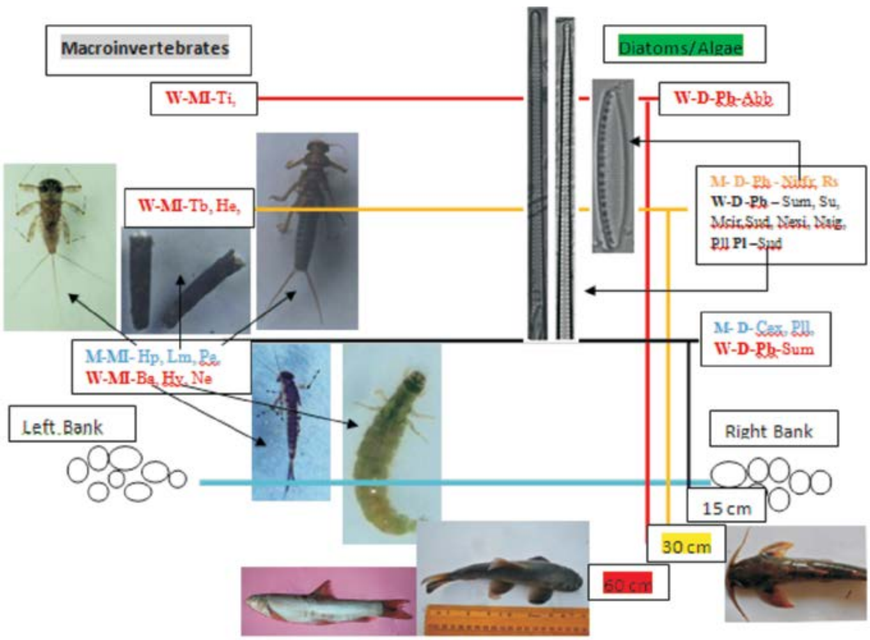
In LMZ, the macroinvertebrate density and richness were highest during winter lean flows, that declined with increasing flows during summer flooding and were washed away during monsoon high floods. Chironomid-dominated assemblages prevailed at all flows. In UGPZ I, densities and richness did not vary substantially among the flows: chironomids dominated assemblages during summer snow-melt flooding, gastropods during post-monsoon receding floods while Pelecypoda and Hemiptera during winter lean flows. In UGPZ II, densities declined slightly through summer snow-melt flooding in relation to receding floods (post monsoon) and lean flows (winter). The assemblages were largely dominated by Pelecypoda.

Fish Fauna

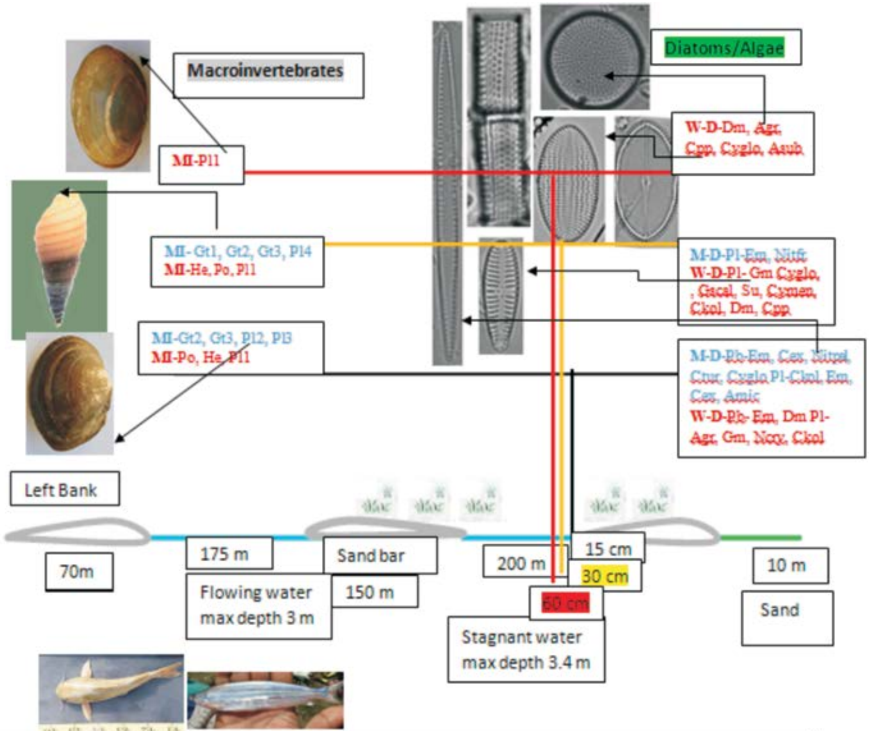
Fish assemblages changed much in response to the flow regimes in the three zones. In all zones the fish species feed to generate energy reserves during winter lean flows. As flows increase during floods of summer and/or monsoon, some fish move into tributaries for breeding while some move away (local migration) from the zone of residence to the breeding zones, especially in the flood plains. Most of the fish move for short distances that provide optimum temperature requirements and suitable breeding substrate, except the Himalayan mahseer in LMZ. The increased volume of water provides fish with the access to the breeding areas in the Ganga river or provides lateral connectivity with its tributaries.

LINKAGES BETWEEN BIODIVERSITY AND FLOW ALTERATION

The aquatic biodiversity in LMZ consists of highly specialized communities that are restricted to the habitats in which they are well suited. If the flows of the river are modified, loss of highly specialized elements may occur, especially in LMZ part of the Ganga. Some components of the biotic communities are adaptive. There is evidence of shift in feeding



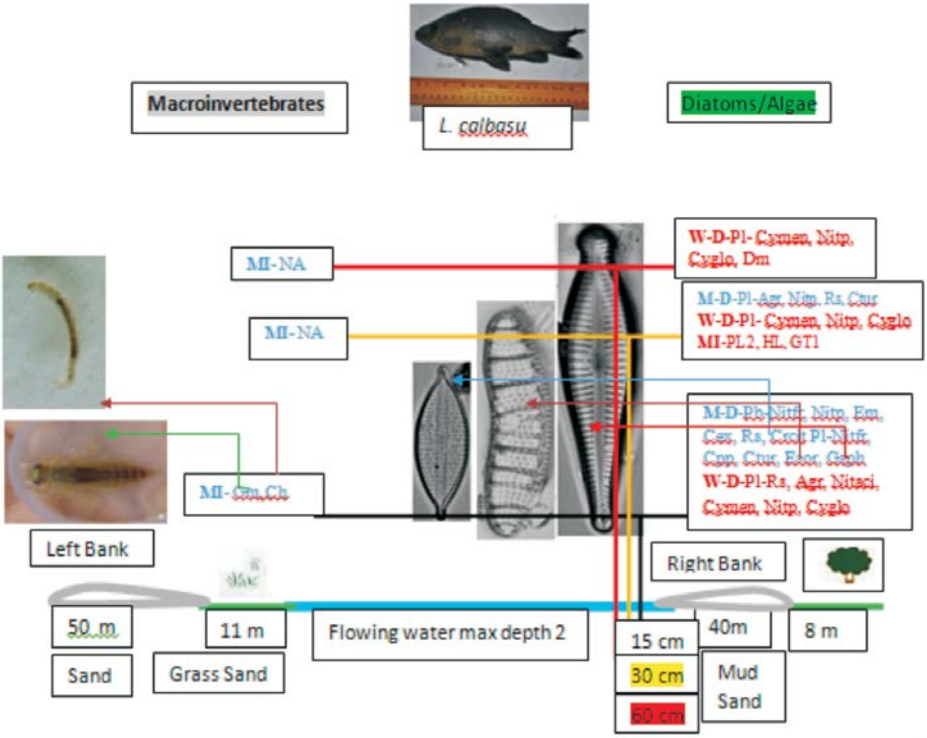
LMZ: DISTRIBUTION OF FLOW INDICATOR TAXA AT SPECIFIC DEPTHS
(Acronyms: M- Monsoon, W- Winter, D-Diatom, Pb- Phytobenthos, MI- Macroinvertebrate, Nitfr-*Nitzschia frustulum*, Rs- *Reimeria sinuata*, Cex-*Cymbella excisa*, Pll-*Planothidium lanceolatum*, Ba- Baetidae, He - Hemiptera, Hp- Heptageniidae, Hy-Hydropsychidae, Lm-Limnephilidae, Ne-Nematoda, Pe- Perlidae, Ti - Tipulidae, Tb - Tabanidae) . Fish fauna: Snow trout (left below), *Garra* (right below) and *Glyptothorax* spp (extreme right).



UGPZ I: DISTRIBUTION OF FLOW INDICATOR TAXA AT SPECIFIC DEPTHS (Acronyms: M- Monsoon, W- Winter, D-Diatom, MI-Macroinvertebrate, Dm-*Diatoma mesodon*, Cyglo-*Cyclotella glomerata*, Agr-*Aulacoseira granulata*, Cpp-*Cocconeis placentula* v. *placentula*, Asub-*Achnanthidium subhudsonis*, Em-*Encyonema minutum*, Gm-*Gomphonema minutum*, Gscal-*Gyrosigma scalproides*, Su-*Synedra ulna*, Cymen-*Cyclotella meneghiana*, Ckol-*Cymbella kolbei*, Cex-*Cymbella excisa*, Amic-*Achnanthidium microcephala*, Ncry-*Navicula cryptotenella*, Gt 1-Gastropoda sp.1, Gt 2- Gastropoda sp.2, Gt 3- Gastropoda sp.3, He - Hemiptera, Po-Potamanthidae, Pl1-Pelecypoda sp.1, Pl2 - Pelecypoda sp.2, Pl3 - Pelecypoda sp.3, Pl4-Pelecypoda sp.4. FISH Images; ***Rita rita*** **(left),** ***Ailia colia*** **(right).**

strategies. Wantzen and Wagner (2006) suggested that shredders (a functional feeding group among benthic macroinvertebrates), might be either facultative specialists due to the low and sporadic input of coarse organic matter which switch to shredding when the resource becomes abundant, or localized specialists which are restricted to only a few sites that provide a permanent food resource.

Existing information on feeding behabiour of fishes in the region is mostly generalized type and only for species of economic importance. Fore example, herbivores (LMZ; *Schizothorax Garra, Crossocheilus* spp.; UGPZ *Labeo, Cirrhinus* spp.), omnivores LMZ; mahseer, UGPZ *Barilius* spp.), carnivores (*M. tengra*, *B. bagarius E. vacha* and other cat fish species in respective zones). *T. putitora* stock revealed preference for all insect groups. This preference was similar in the larval, juvenile, adolescent and adult stages in all the



UGPZ II DISTRIBUTION OF FLOW INDICATOR TAXA AT SPECIFIC DEPTHS
(**Acronyms:** M- Monsoon, W- Winter, D-Diatom, MI -Macroinvertebrate, Cymen-*Cyclotella menenghiana*, Nitp-*Nitzschia palea*, Cyglo-*Cyclotella glomerata*, Dm-*Diatoma mesodon*, Agr-*Aulacoseira granulata*, Rs- *Reimeria sinuata*, Ctur-*Cymbella turgidula*, Em-*Encyonema minutum*, Cex- *Cymbella excisa*, Crcit-*Craticula citrus*, Cpp-*Cocconeis placentula* v. *placentula*, Nitfr-*Nitzschia frustulum*, Esor-*Epithemia sorex*, Gsph-*Gomphonema spheophorum*, Ch- Chironomidae, Gm- Gomphidae)

streams and rivers. Overlap in diet was high among <10 and 19 cm size in the Saung and Nayar. The <19 and <52 cm size exhibited more overlap in the Ganga. Among dietary components, the overlap was highest for insects in all streams. There is no information on the feeding preferencesof macroinvertebrates. It is therefore difficult to gauge breaches in the food chains due to the loss of sensitive components of the community wirh flow changes. Flow affects the distribution of case building caddisflies that use these sediments to spin the nets to trap the food particles. Hydropsychids are known to prefer large stable substrate and high current velocities and their larvae select microhabitats with high flow rates which allow them to maximize their filter feeding rate (Georgian and Thorp 1992). In absence of appropriate flows the populations of such important links with detritus or grazing will fail, subsequently affecting the populations of higher trophic levels (consumers).

CONCLUSIONS

In order to sustain biodiversity the flows in a river must be such that the functions of each trophic level are not inhibited. One time releases and releases during peaking hours related only to volume and not the symphony of habitat complexity, discharge, current velocity, constant supply of sediments, nutrients and Particulate Organic Matter (POM) that makes even the headwaters inhabitable by a diverse assemblages. Flows need to be consistent below the dams and barrages and must vary with seasonal hydrology.

The depth was used as surrogate for measuring the impact of flow alterations on the ecosystem functions in the regulated sections of the river Ganga. Study demonstrated that moderate depths (30 to 60 cm) were important for high richness, diversity and abundance of tolerant species and depths of 15 cm were low in species richness, density etc. It augurs from study, that 30 cm depth with optimum velocities, support higher density and richness in the benthic community in LMZ. The plankton density and richness is higher at 15 cm depths in LMZ while at 30 to 60 cm depths in UGPZ, demonstrating that producer and hence consumer communities had higher densities, richness and abundant at 30cm in LMZ and 30 to 60 cm depths in UGPZ I and II. It was also noted that a very few benthic taxa were specific at 15 and 60 cm depths but many were present only at 30 cm depth. The planktonic diatoms also exhibited depth specificity of which a considerable number occurred at 30 cm and quite a few at 15 and 60 cm depths in UGPZ I. The plankton diatoms at UGPZ II exhibited a linear increase in the number of species with increasing depth. Further in contrast to upstream locations there were fewer diatom taxa that were specific to each depth. Thus, each community with common and rare taxa had specific ecological preferences. The variability of depth and current velocities in different flows create habitat heterogeneity and act as key drivers of biodiversity.

Impoundments impair the natural flow of a river, and therefore disrupt the daily and seasonal flow pulses that are a source of stimulus not only for the major events of life-history but also for the maintenance of the unique, endemic elements of the biodiversity. The regulatory structures modify and regulate the flow to suit the needs of power generation, which is detrimental to the biota adapted to highly oxygenated waters, by virtue of the gushing flows, torrents and turbulence. Moreover, the flora and fauna in the Himalayan streams and rivers is highly specialized and has evolved over years of evolutionary processes. Loss of these elements is imminent if the flows of the river are modified.

Recommended Critical Flows

The E-Flows to meet biodiversity requirements during January and August in the regulated zones of the river were determined for the maintenance and drought years (Table 8) based on preferred depth and current velocities of benthic biota and ichthyofauna. The flows corresponding to required depths for all components of the biodiversity were then read from the stage-discharge curves for the specific sites in each zone (Kaushal and Babu 2013).

In the final assessment of E-Flows, many estimates were based on biodiversity requirements in these zones, the others being geomorphological and cultural aspirations from the river.

Table 8. Recommended critical flows for biodiversity requirements in different zones

Location	Time/Month	Discharge (cumecs)	Depth (m)	Average Velocity (m/s)
Kaudiyala	January - Maintenance	265	8/9	0.5/0.55
	August - Maintenance	1840	17.45	0.97
	January - Drought	206	7.27	0.5
	August - Drought	1469	16.28	0.91
Kachla Ghat	January - Maintenance	300	3.49	0.38
	August - Maintenance	551	4.49	0.33
	January - Drought	161.5	2.99	0.33
	August - Drought	300	3.49	0.38
Bithur	January - Maintenance	330	3.5	1.03
	August - Maintenance	1986	6.69	1.67
	January - Drought	193.8	3.08	0.88
	August - Drought	498	4.09	1.16

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APPENDIX I

CHANGES IN ECOLOGICAL STATE (WITH RESPECT TO PAST)

LMZ-Lower Mountain Zone: Presently, this zone falls in Category B[3] with respect to benthic algae, plankton and benthic macroinvertebrate community.

Benthic algae and plankton community: The share of BGA increased, while GA has declined.

Benthic macroinvertebrate community: There is change in the number of taxa and their abundance. In past studies, Ephemeroptera (represented by Baetidae – Heptageniidae), and Diptera (chironomidae) were abundant taxa that are functionally scrapers and collectors[4], respectively. However, presently collectors primarily Diptera comprising Chironomidae, Tabanidae, Helidae and Tipulidae are abundant, pointing towards shift to solely heterotrophic condition, instead of predominantly autotrophic system, especially in the LMZ. Trichoptera also functions as collector and are present in small numbers. The abundance of chironomids is related to abundance of silt compared to other substrate and is therefore abundant taxa. Thus presently, macroinvertebrate community belongs predominantly to detritus chain. The presence of Plecoptera during monsoon shows that their range is extended from middle to lower stretches of the Ganga in this season.

Fish fauna: A marginal decline in number of species is evident; 30 in past compared to 21 in present. The proportion of CP: CT: O is in tune with the ecological state. The integrity of fish habitat is intact, especially the breeding and feeding niches.

UGPZ I-Upper Ganga Plain Zone I: At Narora the river was assessed as Category D, Largely modified owing to a large loss of natural habitat due to Narora barrage as it impairs transport functions (nutrient, detritus, material or sediment transport material). River is regulated so it experiences floods and deficient discharge of water. Consequently, biota and basic ecosystem functions have changed. The changes in the biota were ;

Benthic algae and plankton community Notable decline in the share of GA and BGA, which increased the share of D.

Benthic macroinvertebrate community With respect to habitat lack of clay/ silt at Z II results in slight changes in the number of taxa and their abundance. In the past gastropoda consists of 6 species. Their diversity has reduced to 3 types. Chironomids (collectors FPOM) have gained abundance along with GT (scrapers) suggesting increase in

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[3] *Ecological Management Class (EMC) gives 6 classes of river condition or health. Class A: close to natural condition; Class B: largely natural with few modifications;Class C: moderately modified;Class D: largely modified;Class E: seriously modified; no longer providing sustainable services; Class F: critically modified; no longer providing sustainable services.*

[4] *Collectors prefer fine particulate organic matter (FPOM) which is derived from coarse particulate organic matter (CPOM). In the upper section of the river hydroelectric projects (HEP) are functional, which regulate water flow and movement of POM (particulate organic matter). Thus the concentration of different types of POM has declined in this section. However, FPOM and CPOM is also coming from the riparian vegetation along the river bank at Zone I.*

detritus. CH is indicator taxa in summer, while GT, CH at 15 to 30 cm depth and Hemiptera in monsoon. In winter, at the right bank CH at 15 to 30 cm depth and PL at 60 cm depth are indicator taxa, while only PL is indicator at the left bank**.**

Fish fauna: More species in past. Marginal decline in the number of fish species. Carp: Catfish: Other in past 45:17:20 compared with 13:6:3 in present. Carp contribution still high, indicating natural fish assemblage and autotrophic river ecosystem. The abundant taxa include *Mystus* sp. *Chela* sp., while the rare ones were *O. cotio*, *N. chitala*, *M. armatus*, *C. garua*

The conditions at Kacchla Ghat were similar to those at Narora.

Benthic algae and plankton community Notable decline in the share of GA and BGA. Thus share of D appears to have increased.

Benthic macroinvertebrate community In the past GT were represented by 6 species at Narora. Their diversity has reduced to 2 types. CH (collectors FPOM) have gained abundance and GT (scrapers) has reduced while PL has appeared, the abundance level varying from low to similar to GT, suggesting increase in detritus and change in substrate conditions.

Fish fauna: Of the fish fauna recorded from here, two species are common to both past and present study. Rest species are new to this zone. Carp: Catfish: Other = 8:7:14 is different from Narora as carp contribution is low which a deviation from expected domination of carps.

UGPZ II-Upper Ganga Plain Zone II: At Bithoor, the river is presently in Category D Largely modified. A large loss of natural habitat as clay has been substituted by silt and sand in the river bed (possible role of current intensive agro practices), change in biota & basic ecosystem functions have occurred.

Benthic algae and plankton community Notable decline in the share of GA and BGA. Thus share of D appears to have increased.

Benthic macroinvertebrate community: There is general decrease in density. The Pelecypoda (filterer UFPOM) and Chironomids (collector FPOM) have replaced GT (scrapers), possibly due to more detritus (POM) and changes in particle and substrate type. Abundance of silt and sand substratum at left bank suits PL abundance. Annelids have been replaced by CH, while TI and GM have appeared (summer).

Fish fauna: Of the 31 species, 24 species are common to past as well as present study, while 7 species appear in the present study only (*Aspidoparia jaya*, *C. carpio*, *P. muzaffarpurensis, Sicamugil cascasia, Securicula gora, Rhinomugil* sp. Udwar). However, these are known from lower Himalaya. Thus, reasons for change in fauna are not clear. Carp: Catfish: Other 12:07:12. Fisheries **in past** Carp: Catfish: Other. The abundant taxa include *Mystus* sp. *Chela* sp., while the rare ones were *M. bleekeri*, *M. vittatus*, *C. atpar*, *L. bata*.