Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 4, No. 4, p. 218-232, 2014
http://www.innspub.net

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RESEARCH PAPER **OPEN ACCESS**

Analysis of trophic gradient through environ-mental filter influencing fish assemblage structure of the river Teesta in Eastern Himalayas

Munmun Chakrabarty, Sumit Homechaudhuri*

Aquatic Bioresource Research Laboratory, Department of Zoology, University of Calcutta, 35, Ballygunge Circular Road, Kolkata-700019, India

Article published on April 18, 2014

Key words: Hill-stream, ichthyofauna, dietary composition, feeding guild, niche filter.

Abstract

Factors controlling biodiversity and co-existence of species need immediate attention to maintain biodiversity. Co-existence between interacting species is based on their ecological niches or functional roles and can be assessed by niche assembly theory and construction of trophic guild. *In the present study,* the diet composition of fishes have been analyzed both qualitatively and quantitatively to describe feeding patterns along environmental gradient towards linking biodiversity with functional diversity patterns to shape species assemblage. We evaluated the trophic guild structure of 92 fish species *of the large, torrential river Teesta (within West Bengal) having its origin in eastern Himalayas.* Stomach contents of 1515 fish specimens have been analyzed and fishes were ascertained 14 different trophic guilds. Canonical correspondence analysis was performed to study species associations with environmental parameters. *Preliminary analysis showed a dietary shift of the respective fish assemblages from high to low altitude from specified feeders (aquatic insectivores) to omnivorous respectively.* Aquatic insect larvae formed the most important prey in general, especially in high altitude zone followed by algae. The dietary preferences indicate that fish assemblage pattern seems to be guided by niche breadth and environment acting as the main filtering agent towards species sorting and survival. This study is an important step in structuring fish community of the River Teesta and to lay the foundation for subsequent future efforts on the conservation of aquatic communities and their feeding habitats.

***Corresponding Author:** Sumit Homechaudhuri ✉ sumithomechaudhuri@gmail.com

Introduction

The Eastern Himalayan Biodiversity Hotspot region and its foothills are very rich; especially the piscine diversity and their populations inhabiting these areas are numerous in variety and taxonomically interesting. As such, the northern districts of West Bengal, India especially the districts of Darjeeling and Jalpaiguri, lying within the Eastern Himalayan biodiversity hotspot range, hold a great importance faunistically. The chief rivers are Mahananda and Teesta with many tributaries like Murti, Atrai, Jaldhaka, Karala, Karotoyar, etc. The Himalaya is the source of all major river systems in India. Like other Himalayan rivers, Teesta river and its tributaries provide a fair ecological niche for many indigenous and a few exotic fish species. However, there is a lack of baseline information on freshwater fish species distributions and their ecological requirements throughout the Eastern Himalayas. It was found that 31.3% of the 1,073 freshwater species of fishes, molluscs, dragonflies and damselflies currently known in the Eastern Himalaya region are assessed as Data Deficient, emphasizing the urgent need for new research in the region (Allen *et al.,* 2010). These augmented research of freshwater fish species in this region and their various ecological implementations towards evaluating their functional traits leading towards assessment of aquatic environment health.

Alterations in water quality or habitat conditions usually lead to variations in the availability of food resources. Fish generally display high diet flexibility and both temporal and spatial variations in their diets (Abelha *et al.*, 2001; Dekar *et al.*, 2009). However, in highly specific and also in disturbed environments, experiencing alterations of water flow and available substrates, these patterns can be altered, and changes like increase in generalist species and reduced numbers of trophic guilds can occur (Casatti *et al.*, 2006; Casatti *et al.*, 2009).

In recent years, rapid radial expansion of urban habitats and increased human interferences in the natural environmental conditions of River Teesta might lead to its obvious degradation in near future. Moreover, hydropower dams construction at various levels of the river could potentially decrease its faunal composition. Till date scanty work has been undertaken to study the fish assemblage of River Teesta and their various ecological implications. In context, evaluation in variations in the trophic organization of ichthyofaunal assemblages can be considered to be indicators of changes in the quality and complexity of a habitat (Karr, 1981). Considering niche filtering hypothesis, which assumes that at local scale species assemblages can be regulated both by abiotic and biotic interactions acting simultaneously with environmental conditions (abiotic properties of the habitat) acting as a filter causing only a bottle neck population to survive (Zobel, 1997; Mouillot, 2006), we propose to evaluate how the origin and use of food resources varied spatially across the riverine stretch. Therefore, we aimed to describe the diet of the fish assemblages in a hill stream river, Teesta in West Bengal (originating in the Eastern Himalayan biodiversity hotspot region) to evaluate the use of food resources of the resident fish species and whether and how they varied across different environmental gradient and to seek assembly rules based on functional traits.

Material & methods

Study area

River Teesta, originating from north Sikkim and carving out verdant Himalayan temperate and tropical river valleys, traverses the Indian states of Sikkim and West Bengal and finally descends to Brahmaputra in Bangladesh. The total length of the river is 309 km (192 mi), draining an area of 12,540 Km^2. The present study area includes the course of the River Teesta in West Bengal (Fig. 1) divided into ecological zones based on elevation gradient and habitat types. The river stretch was divided in four zones (Table. 1) viz. the upper stretch (Rishi khola and Rungpo) where elevations is higher with low temperatures; middle stretch (Teesta Bazaar) with low elevation; at Sevoke the river hits the plains; lastly the river plains (Gojoldoba, Domohoni and Haldibari). Fish sampling was performed at regular intervals at seven sites along the longitudinal stretch of the river in West Bengal covering a distance of 99.28 km.

Table 1 Habitat types of the sampling zones along longitudinal gradient of River Teesta in West Bengal.

Fish Zones	Sites	Elevation	Riparian vegetation	Predominant substrate
High-Mid altitude zone	Rishi Khola	Moderate to high elevation watersheds dominated by side slopes with gentle slopes and steep slopes.	Primary forest; hilly terrain.	Rocky
	Rungpo		Secondary forest.	Predominantly rocky along with sandy stretches
Mid altitude zone	Teesta Bazaar	Moderate to high elevation watersheds dominated by side slopes and gentle slopes.	Secondary forest; ongoing construction work of Teesta Barrage project.	Sandy stretches with pebbles, partly rocky
Low altitude-plain zone	Sevoke	Moderate to low elevation watersheds dominated by gentle slopes with substantial areas of flats and sideslopes; river hits the plain at this site.	Secondary forest	Sandy with pebbles and stones
River plains	Gojoldoba	Low elevation dominated by flats, pastured land and urban inhabitation.	Secondary forest; Urban area; presence of Teesta Barrage	Few stretches with pebbles, mostly muddy
	Domohoni		Agriculture land; Urban area	
	Haldibari		Agriculture land; Urban area	

Fig. 1 River Teesta Catchment area in West Bengal.

Sampling

Fish sampling was carried out from December 2010 to March 2013 at 7 sites under 4 environmental zones following a transverse transect intended to give a representative sample of all mesohabitat types along the longitudinal gradient of River Teesta at Darjeeling and Jalpaiguri districts in West Bengal. All the important freshwater aquatic microhabitats (riffles, pools, cascade, falls, etc.) were sampled using gill nets, cast nets, dragnets, and hooks and lines of varying dimensions. Captured fish specimens were fixed in 10% formalin solution and, after 48 h, transferred to a 70% Ethyl alcohol solution. Fishes were identified to the lowest taxonomic level (Shaw and Shebbeare, 1937; Day, 1889; Talwar and Jhingran, 1991; Jayaram, 2006, 2010; Menon, 1987). All specimens have been deposited in the fish collection repertoire at the Zoological Survey of India, Kolkata.

Food and Intestine length analysis

For 92 of the identified species, sub-samples were used for diet analysis. Stomach contents of two to ten fish specimens were examined in each species (1515 specimens). After drying the fish between two pieces of tissue paper the body mass and standard length of each preserved specimen was measured to the nearest 0.01 g using an electronic balance. Guts were dissected under a binocular microscope and then preserved in 70% ethanol. In species, mostly cyprinids, which do not have a discrete stomach, the anterior third of the intestine was dissected. Specimens in which the stomach (anterior third of intestine in cyprinids) contained no food items were categorized as empty. The contents of each gut were examined under a dissecting microscope using reflected light and each item identified and assigned to broader taxonomic groups (Merona *et al.*, 2005). Each prey item was then allocated to one of a number of taxonomic groups, subsequently referred to as dietary categories. The frequency of occurrence of each dietary category in the gut of each fish (%F) was recorded (Lima-Junior and Goitein, 2001).

Dietary analysis

To analyze how the diets of the fishes are related to temporal variations in habitats, we used the statistical package PRIMER-E v 6.0 (Clarke and Gorley, 2001). Similarity matrices between samples were constructed using the Bray-Curtis index (Legendre and Legendre, 1998) and data were standardized (as percentage) to minimize discrepancy between samples. To examine the relative extents to which the dietary compositions of fish were influenced overall by differences among species and habitat type, the percentage frequency and volumetric contributions of the various dietary categories in the guts of each species in each habitat type were first allocated into groups of ten. The mean percentage frequency contributions of the various dietary categories in each group (¼ dietary sample) were then calculated and square-root transformed. These values were used to construct a Bray-Curtis similarity matrix, which was subjected to non-metric multidimensional scaling (MDS) ordination and one-way analyses of similarities (ANOSIM) (Clarke and Gorley 2001; Hourston et al. 2004) to evaluate whether habitat type significantly influence dietary regime and resource optimization and if so which is the most favourable condition for optimum resource utilization/partitioning. The magnitudes of the global R-statistic values in the ANOSIM test (which typically range from 1 when the composition of all samples within each group are more similar to each other than to any of the samples from any other group, downwards to 0 if the average similarities between and within groups are the same), were used to ascertain the relative extent to which the dietary compositions differed among species in respective habitat types (Clarke, 1993). The significance level (P) was recorded only for the most influential of those factors and where that value was less than 5%. SIMPROF ('similarity profile') test was performed, in which the biotic similarities from a group of a priori unstructured samples are ordered from smallest to largest, plotted against their rank (the similarity profile), and this profile compared with that expected under a simple null hypothesis of no meaningful structure within that group (Clarke *et al.*, 2008).

Environmental data analysis

At each site, the following physical parameters of the stream were measured at 2-3 points each 1feet apart- a) stream depth, b) stream width, stream velocity, d) air and water temperature, e) water pH, f) water conductivity and g) Turbidity. CCA was conducted using CANOCO (version 4.5) software packages where the relative contribution of the ordination axes was evaluated by the canonical coefficients between the environmental variable and the fish assemblage pattern based on their feeding habits. The species–environment correlation is a measure of the association between species and the environmental variable (Ter Braak and Verdonschot, 1995).

Results

Composition and % occurrence of different dietary components

The gut contents of individual fish species showed that they mainly consumed 10 types of food items. On analysis of cumulative frequency of the food categories (Table. 2) obtained from gut analysis of the individual fish species expressed as percentage at respective altitude zones it was observed that majority of the fish species consumes aquatic invertebrates. The most consumed types of items were aquatic insect larvae (36% of the total resources consumed) in the high-mid altitude zones followed by algae (23% of the total resources consumed) which was consumed by 40% and 20% of species respectively. Whereas, in the river plains various food resources were optimally consumed resulting in the majority of omnivorous forms which was consumed by 29 % of the species and detritivores (23% of the total resources consumed). Feeding guilds were developed based on the major diet constituent of individual species and each species were ascertained to 14 dietary categories recognized in this study: Aquatic invertevore that comprised mainly of Ephemeropteran, Chironomidae and Hemipteran larvae, annelid and arachnid remains; Algivore comprising filamentous algae and vascular plant material; Detritivore that includes unidentified material and also mineral material including sand and gravel; Herbivore; Insectivore; Macro-carnivore; Micro-carnivore; Omnivore; Planktivore with high proportions of zoo/phyto planktons and five rest mixed groups that shared different food habits, viz., Micro-carnivore/Insectivore, Planktivore/ Aquatic Invertevore, Herbivore/ Detritivore, Insectivore/ Algaevore and Insectivore/ Detritivore (Fig. 2).

Table 2. Frequency (%F) of occurrence of recognized dietary categories of the gut of each species at respective habitat zones

Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
High-Mid altitude zone	*Psilorhynchus sucatio* (*Psu*) (Hamilton 1822)	0	0	0	80.5	0	0	0	5.5	0	14
	Psilorhynchus balitora (Pb) (Hamilton, 1822)	0	0	0	75.5	0	0	0	7.5	0	17
	Puntius terio (Pt) (Hamilton, 1822)	0	0	0	75.5	0	0	0	7.5	0	17
	Devario aequipinnatus (Da) (McClelland, 1839)	0	0	0	0	15.2	0	17.5	59.2	0	8.1
	Schistura devdevi (Sd) Hora, 1935	0	0	0	10.2	20.2	0	1.6	60.2	0	7.8
	Schistura savona (Ss) (Hamilton, 1822)	0	0	0	9.5	16	0	2.1	61.2	0	11.2
	Danio rerio (Dr) (Hamilton, 1822)	0	0	0	0	10.6	0	15.2	63.5	0	10.8
	Amblyceps mangois (Amg) (Hamilton, 1822)	0	0	0	0	0	0	19.8	58.5	0	21.7
	Channa marulius (Cm) (Hamilton, 1822)	0	0	0	0	25.2	0	0	45.2	0	29.6
	Macrognathus pancalus (Mp) Hamilton 1822.	0	0	0	15.3	0	0	0	45.2	0	39.5
	Tor tor (Tt) (Hamilton 1822)	12.3	0	9.5	40.3	0	0	0	0	0	37.9
	Schizothorax richardsonii (*Sr*) (Gray 1832)	0	0	0	0	0	39.5	0	45.3	0	15.2
	Neolissochilus hexagonolepis (Nh) (McClelland, 1839)	0	0	0	60.2	7.5	0	0	15.3	0	17
	Barilius barila (Bba) (Hamilton, 1822)	17.2	0	19.5	0	0	13.9	0	29.1	0	20.3
	Olyra kempi (Ok) Chaudhuri, 1912	0	0	0	5.2	39.8	0	0	40.2	0	14.8
	Badis badis (Bd) (Hamilton, 1822)	0	0	10	0	0	0	29.5	31.6	0	28.9

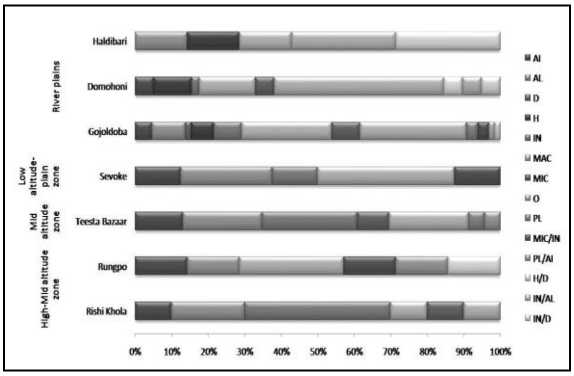
Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
Mid altitude zone	*Barilius barila (Bba)* (Hamilton, 1822)	17.2	0	19.5	0	0	13.9	0	29.1	0	20.3
	Barilius barna (Bbr) (Hamilton 1822)	0	0	0	0	0	0	0	79.2	0	20.8
	Barilius bendelisis (Bbe) (Hamilton, 1807)	19.2	0	17.5	0	0	15.6	0	24.5	0	23.2
	Barilius shacra (Bs) (Hamilton 1822)	11.5	0	18.2	0	0	14.3	0	26.4	0	29.6
	Barilius vagra (Bv) (Hamilton, 1822)	13.5	0	19.2	0	0	16.1		25.6	0	25.6
	Crossocheilus latius latius (Cl) (Hamilton, 1822)	2.5	5.6	0	10.2	0	61.8	0	0	0	19.9
	Danio dangila (Dd) (Hamilton, 1822)	0	0	0	10.2	0	0	0	70.2	0	19.6
	Danio rerio (Dr) (Hamilton, 1822)	0	0	0	0	10.6	0	15.2	63.5	0	10.8
	Garra annandalei (Ga) (Hora, 1921)	0	0	0	87.6	0	0	0	0	0	12.4
	Garra gotyla gotyla (Ggg) (Gray, 1830)	0	0	0	79.5	0	0	0	0	0	20.5
	Garra lamta (Hl) (Hamilton, 1822)	0	0	0	81.2	0	0	0	0	0	18.8
	Neolissochilus hexagonolepis (Nhg) (McClelland, 1839)	0	0	0	60.2	7.5	0	0	15.3	0	17
	Neolissochilus hexastichus (Nhx) (McClelland 1839)	0	0	0	65.2	9.5	0	0	10.3	0	15
	Schizothorax richardsonii (Sr) (Gray 1832)	0	0	0	0	0	39.5	0	45.3	0	15.2
	Acanthocobitis botia (Ab) (Hamilton, 1822)	0	0	0	12.5	0	0	10.5	60.6	0	16.4
	Schistura corica (Sc) (Hamilton, 1822)	0	0	0	15.5	19.5	0	3.2	55.5	0	6.3
	Schistura devdevi (Sd) Hora, 1935	0	0	0	10.2	20.2	0	1.6	60.2	0	7.8
	Schistura savona (Ssa) (Hamilton, 1822)	0	0	0	9.5	16	0	2.1	61.2	0	11.2
	Schistura scaturigina (Ssc) McClelland, 1839	0	0	0	8.6	12.5	0	5.2	55.9	0	17.8
	Botia lohachata (Bl) Chaudhuri, 1912	0	0	0	0	29.2	0	0	61.8	0	9
	Botia rostrata (Br) Günther, 1868	0	0	0	0	24.5	0	0	55.6	0	19.9
	Lepidocephalichthys guntea (Lg) (Hamilton, 1822)	0	0	1.3	30.1	0	29.4	0	20.4	0	18.8
	Pseudecheneis sulcata (Ps) (McClelland, 1842)	0	0	0	0	10.2	15.2	0	52.2	0	22.4
Low altitude-plain zone	*Barilius barila (Bba)* (Hamilton, 1822)	17.2	0	19.5	0	0	13.9	0	29.1	0	20.3
	Barilius bendelisis (Bbe) (Hamilton, 1807)	19.2	0	17.5	0	0	15.6	0	24.5	0	23.2
	Garra gotyla gotyla (Ggg) (Gray, 1830)	0	0	0	79.5	0	0	0	0	0	20.5
	Garra lamta (Gl) (Hamilton, 1822)	0	0	0	81.2	0	0	0	0	0	18.8
	Schistura corica (Sc) (Hamilton, 1822)	0	0	0	15.5	19.5	0	3.2	55.5	0	6.3
	Amblyceps mangois (Amg) (Hamilton, 1822)	0	0	0	0	0	0	19.8	58.5	0	21.7
	Olyra kempi (Ok) Chaudhuri, 1912	0	0	0	5.2	39.8	0	0	40.2	0	14.8
	Badis badis (Bb) (Hamilton, 1822)	0	0	10	0	0	0	29.5	31.6	0	28.9

Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
	Amblypharyngodon mola (Amo) (Hamilton, 1822)	5.2	7.4	0	59.5	0	10.2	0	0	0	17.7
	Aspidoparia morar (Am) (Hamilton, 1822)	2.5	3.8	0	59.6	0	10.1	0	0	0	24
	Bangana dero (Bd) (Hamilton, 1822)	0	0	0	75.2	0	15.2	0	0	0	9.6
	Barilius barila (Bba) (Hamilton, 1822)	17.2	0	19.5	0	0	13.9	0	29.1	0	20.3
	Barilius barna (Bbr) (Hamilton 1822)	0	0	0	0	0	0	0	79.2	0	20.8
	Barilius bendelisis (Bbe) (Hamilton, 1807)	19.2	0	17.5	0	0	15.6	0	24.5	0	23.2
	Barilius vagra (Bv) (Hamilton, 1822)	13.5	0	19.2	0	0	16.1		25.6	0	25.6
	Crossocheilus latius latius (Cl) (Hamilton, 1822)	2.5	5.6	0	10.2	0	61.8	0	0	0	19.9
	Danio rerio (Dr) (Hamilton, 1822)	0	0	0	0	10.6	0	15.2	63.5	0	10.8
	Devario devario (Dd) (Hamilton 1822)	0	0	0	31.5	0	0	0	45.6	0	22.9
	Devario acuticephala (Da) (Hora, 1921)	0	0	0	12.5	0	0	0	79.5	0	8
	Esomus danricus (Ed) (Hamilton 1822)	0	0	0	0	15.2	0	0	38.5	0	46.3
	Garra annandalei (Ga) (Hora, 1921)	0	0	0	87.6	0	0	0	0	0	12.4
	Garra lamta (Gl) (Hamilton, 1822)	0	0	0	81.2	0	0	0	0	0	18.8
	Labeo pangusia) (Lp) (Hamilton 1822)	0	0	0	7.5	0	84.2	0	0	0	8.3
River plains	*Neolissochilus hexagonolepis (Nhx)* (McClelland, 1839)	0	0	0	60.2	7.5	0	0	15.3	0	17
	Pethia ticto (Pt) (Hamilton, 1822)	0	1.2	6.8	38.3	0	0	0	20.5	0	33.2
	Psilorhynchus sucatio (Ps) (Hamilton 1822)	0	0	0	80.5	0	0	0	5.5	0	14
	Puntius conchonius (Pc) (Hamilton, 1822)	0	1.2	3.5	35.5	0	0	0	33.5	0	26.3
	Pethia phutunio (Pp) (Hamilton, 1822)	0	0	0	29.5	0	1.2	4.5	31.2	0	33.6
	Puntius sarana (Ps) (Hamilton, 1822)	0	2.5	4.5	39.2	0	0	0	30.5	0	23.3
	Puntius sophore (Ps) (Hamilton 1822)	0	0	12.5	49.5	0	0	0	7.5	0	30.5
	Puntius terio (Pt) (Hamilton, 1822)	0	0	0	75.5	0	0	0	7.5	0	17
	Rasbora rasbora (Rr) (Hamilton 1822)	5.2	1.2	9.5	35.6	0	0	1.3	30.2	0	17
	Salmophasia bacaila (Sb) (Hamilton, 1822)	1.2	3.9	1.3	39.6	0	0	0	30.9	0	23.1
	Salmophasia phulo (Sp) (Hamilton 1822)	0	0	0	30.5	0	0	15.2	40.2	0	14.1
	Acanthocobitis botia (Ab) (Hamilton, 1822)	0	0	0	12.5	0	0	10.5	60.6	0	16.4
	Schistura corica (Sc) (Hamilton, 1822)	0	0	0	15.5	19.5	0	3.2	55.5	0	6.3
	Schistura savona (Ss) (Hamilton, 1822)	0	0	0	9.5	16	0	2.1	61.2	0	11.2
	Schistura scaturigina (Ssc) McClelland, 1839	0	0	0	8.6	12.5	0	5.2	55.9	0	17.8
	Botia lohachata (Bl) Chaudhuri, 1912	0	0	0	0	29.2	0	0	61.8	0	9
	Canthophrys gongota (Cg) (Hamilton, 1822)	0	0	0	0	21.2	0	19.5	48.5	0	10.8

Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
	Lepidocephalichthys berdmorei (Lb) (Blyth, 1860)	0	0	0	25.6	0	15.2	0	26.1	0	33.1
	Lepidocephalichthys guntea (Lg) (Hamilton, 1822)	0	0	1.3	30.1	0	29.4	0	20.4	0	18.8
	Amblyceps mangois (Am) (Hamilton, 1822)	0	0	0	0	0	0	19.8	58.5	0	21.7
	Batasio tengana (Bt) (Hamilton, 1822)	0	0	20	30	0	0	0	40	0	10
	Mystus bleekeri (Mb) (Day 1877)	0	0	0	0	31.2	0	19.2	36.5	0	13.1
	Mystus tengara (Mt) (Hamilton, 1822)	0	0	0	0	29.8	0	21	35	0	14.2
	Chaca chaca (Cc) (Hamilton 1822)	0	0	0	0	0	0	0	12.5	51.2	36.3
	Hara horai (Hh) Misra 1976	1.2	0	0	30	0	0	0	39.8	0	30.2
	Pseudolaguvia ribeiroi (Pr) (Hora 1921)	0	0	0	0	31.2	0	0	36.7	3.2	28.9
	Pseudolaguvia foveolata (Pf) Ng, 2005	0	0	0	0	35.2	0	0	39.2	5.1	20.5
	Olyra kempi (Ok) Chaudhuri, 1912	0	0	0	5.2	39.8	0	0	40.2	0	14.8
	Olyra longicaudata (Ol) McClelland, 1842	0	0	0	4.8	38.4	0	0	41	0	15.8
	Ompok pabda (Op) (Hamilton, 1822)	0	0	0	3.2	40.2	0	0	39	0	17.6
	Bagarius yarrelli (By) (Sykes 1839)	0	0	0	0	45.2	0	0	35.6	10.2	9
	Glyptothorax indicus (Gi) Talwar, 1991	0	0	0	0	41.6	0	0	39.5	0	18.9
	Glyptothorax telchitta (Gt) (Hamilton 1822)	0	0	0	0	45.5	0	0	39.2	0	15.3
	Glyptothorax cavia (Gc) (Hamilton, 1822)	0	0	0	0	38.9	0	0	42.1	0	19
	Glyptothorax conirostris (Gc) (Steindachner, 1867)	0	0	0	0	35.2	0	0	39.5	0	25.3
	Gogangra viridescens (Gv) (Hamilton, 1822)	0	0	0	45.8	0	20.1	0	0	0	34.1
	Chanda nama (Cn) Hamilton, 1822	0	0	0	61.5	0	15.9	0	0	0	22.6
	Parambassis lala (Pl) (Hamilton, 1822)	0	0	0	10.2	0	0	0	71.2	0	18.6
	Badis badis (Bd) (Hamilton, 1822)	0	0	10	0	0	0	29.5	31.6	0	28.9
	Channa gachua (Cg) (Hamilton, 1822)	0	0	0	0	0	28.5	0	0	0	71.5
	Channa marulius (Cm) (Hamilton, 1822)	0	0	0	0	25.2	0	0	45.2	0	29.6
	Channa punctata (Cp) (Bloch, 1793)	0	0	0	0	39.5	0	0	35.6	0	24.9
	Channa stewartii (Cs) (Playfair, 1867)	0	0	0	0	36.2	0	0	31.5	5.9	26.4
	Glossogobius giuris (Gg) (Hamilton 1822)	0	0	5.2	32.5	2.5	0	10.2	35.2	0	14.4
	Trichogaster fasciata (Tf) Bloch & Schneider, 1801	0	0	5.3	31.5	0	2.9	11.2	36.8	0	12.3
	Trichogaster lalius (Tl) (Hamilton, 1822)	0	0	0	15.2	39.1	0	10.2	35.1	0	0.4
	Macrognathus pancalus (Mp) Hamilton 1822.	0	0	0	15.3	0	0	0	45.2	0	39.5
	Mastacembelus armatus (Ma) (Lacepède, 1800)	0	0	0	0	0	0	0	8.5	0	91.5
	Monopterus hodgarti (Mh) (Chaudhuri, 1913)	0	0	0	10.3	31.2	0	0	30.2	0	28.3

Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
	Xenentodon cancila (Xc) (Hamilton, 1822)	0	0	0	35.5	0	15.2	0	32.5	0	16.8
	Barilius tileo (Bt) (Hamilton, 1822)	12.5	0	15.5	0	0	18.9	0	21.6	0	31.5
	Labeo angra (La) (Hamilton, 1822)	5.2	0	4.5	45.5	0	0	0	0	0	44.8
	Puntius ticto (Pt) (Hamilton, 1822)	0	1.2	6.8	38.3	0	0	0	20.5	0	33.2
	Raiamas bola (Rb) (Hamilton, 1822)	0	10.2	12.5	20.5	0	0	0	29.8	0	27
	Lepidocephalichthys annandalei (La) (Chaudhuri, 1912)	0	0	0	29.8	0	18.2	0	27.5	0	24.5
	Parambassis ranga (Pr) (Hamilton, 1822)	0	0	0	5.2	0	0	0	75.5	0	19.3
	Macrognathus aral (Ma) (Bloch & Schneider, 1801)	0	0	0	0	0	0	0	55.2	0	44.8
	Aspidoparia jaya) (Aj) (Hamilton, 1822)	1.2	5.9	0	61.5	0	9.2	0	0	0	22.2

LV: leaves; FR: fruits; HR: higher plants; AL: Algae; TI: Terretrial insects; PL: Planktons; CR: crusteceans; AI: aquatic insects; FI: Fish; DU: detritus and unidentified food materials.



IN: Insectivore; AL: Algaevore; H: Herbivore; PL: Planktivore; MIC: Micro-Carnivore; MAC: Macro-Carnivore; O: Omnivore; D: Detritivore

Fig. 2 Proportional composition (by frequency) of major prey items (feeding guilds) of species at respective altitudinal zones.

Environmental stimulants in functional group structure

Environmental characteristics (Table. 3) were measured for Dissolve Oxygen (DO), Temperature (WT & AT), pH, Conductivity (CON), Turbidity (TUR) and Water current (WC). The positions of the environmental vectors indicate their correlation to the axes as well as to each other. Canonical component analysis (CCA) ordination graph (Fig. 3) showed that the major fish assemblage groups based on their feeding habits along longitudinal gradient of River Teesta in West Bengal are positively correlated air and water temperatures. As temperature is one of the main deterministic factors for altitudinal variations of fish communities based on their functional traits, we have analyzed as to whether altitude has any role/effect in composing fish trophic groups along different habitat types. The canonical axes 1 and 2 (Eigenvalues = 0.62 and 0.35) explained 70.1% of the cumulative variance of the species data, while they explained 70.6% of the cumulative variance of the species–environment relation. Out of the seven variables used in the model, air and water temperature were found to be most significant ($p < 0.05$).

Table 3. Environmental Parameters of River Teesta.

		pH	Air temp. (°C)	Water Temp. (°C)	DO (mg/lt)	Turbidity (ppm)	Conductivity (µS/cm)	Water velocity (m/sec)
Rishi Khola	Avg±SE	7.38 ±0.16	22.25±1.14	19.52±0.92	7.94±0.10	43.02±1.78	99.35±0.34	1.16±0.13
	range	7.2-7.6	21-23.7	18.5-21	7.9-8.1	41.2-45.4	99-99.9	1.1-1.4
Rungpo	Avg±SE	7.13±0.09	22.98±1.06	20.10±0.51	7.69±0.07	43.93±1.24	98.23±1.12	1.07±0.10
	range	7.02-7.3	21.1-24.5	19.5-21	7.6-7.8	42.7-45.8	96.8-99.6	0.9-1.2
Teesta Bazar	Avg±SE	7.07±0.07	25.72±1.13	22.53±1.92	7.56±0.10	43.14±1.52	107.10±3.21	1.14±0.15
	range	7.01-7.2	24-27	20.7-24.9	7.4-7.7	41-45.1	100.7-109.3	0.9-1.4
Sevoke	Avg±SE	7.19±0.09	22.57±2.60	17.03±0.99	7.28±0.11	76.78±1.24	110.93±0.78	1.40±0.11
	range	7.1-7.3	18.5-25.2	15.4-18.5	7.1-7.4	75.3-78.9	110-112.3	1.3-1.6
Gojoldoba	Avg±SE	7.28±0.17	32.82±2.04	29.52±1.01	7.09±0.07	73.28±1.68	110.85±0.81	1.71±0.10
	range	7.14-7.5	30.1-35.5	28.2-31	7.01-7.2	70.6-75.1	109.6-112.1	1.6-1.9
Domohoni	Avg±SE	7.72±0.43	35.02±0.57	30.47±0.31	6.99±0.12	71.18±0.90	114.73±1.20	2.16±0.21
	range	7.3-8.5	34-35.7	30.1-31	6.8-7.1	70.2-72.5	113.7-117	1.9-2.2
Haldibari	Avg±SE	7.56±0.11	35.38±1.32	30.53±0.53	6.95±0.11	76.32±1.34	117.20±2.21	2.40±0.36
	range	7.4-7.7	33.7-37.2	29.9-31.1	6.8-7.1	74.8-78	113-119	2.1-2.9

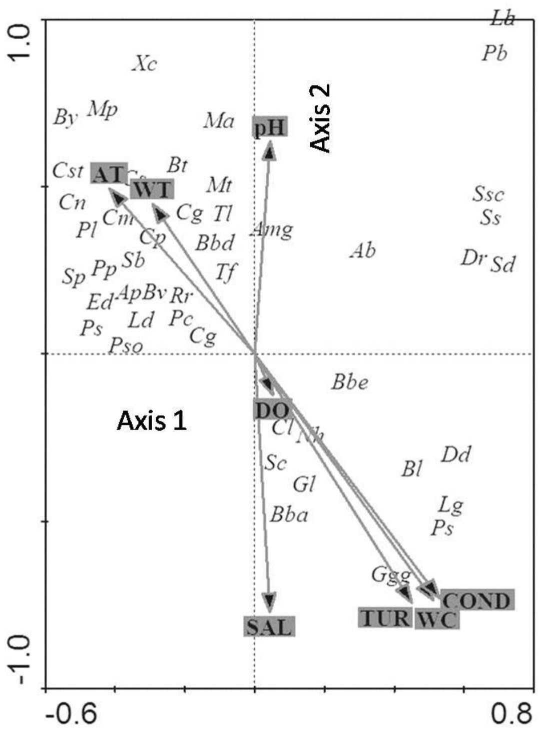


Fig. 3 CCA plot showing species scores along environmental vectors.

Altitudinal comparisons of dietary compositions

Distinct differences in dietery regime in relation to habitat use were detected. At the habitat level, four major zones were separated according to their altitude and water temperature regime. Cluster analysis was attempted to group various zones along the longitudinal gradient of River Teesta in West Bengal based on the dietary regime of the available species in respective zones. Fig. 4 shows the results of a hierarchial clustering using individual species linking on data sampled during December 2010 to March 2013 in 7 sites representing the longitudinal gradient of River Teesta at Darjeeling and Jalpaiguri districts in West Bengal. The raw data were expressed as % frequency of availability of prey items of 92 fish species at respective sites, and Bray-Curtis similarities calculated on √√-tranformed frequencies. The dendogram provides a sequence of fairly convincing groups; two groups (determined at 50 % similarity level) have been obtained. One group forms the high-mid altitude zones viz. Rishi Khola, Rungpo, Teesta bazaar and Sevoke while the other group segregated as the river plain one viz. Gojoldoba, Domohoni and Haldibari. Hence, it is observed that altitudinal variations influence the resource availability and dietary composition of species obtained at each sites. However, a cluster analysis is not adequate enough to give a complete and jointed picture of the trophic group pattern. It is not clear from the dendogram alone whether there is any natural sequence of community change across the two main clusters. In fact, there is a strong dietary shift across the region, associated with changing altitude and habitat conditions. This is best seen in an ordination of the diets of the 92 fish species at respective sites (Fig. 5). There is a greater degree of variability of the feeding habit nature and hence the changing community composition with altitude and temperature. Evident is a marked change in composition between Rungpo (high altitude) and Gojoldoba (plains). One-way ANOSIM demonstrated the influence of the factor "altitude". The overall dietary compositions differed to a greater extent among species at respective zones with $P<0.001$ in most of the cases. Similarity profile (SIMPROF) test have been carried out on the MDS ordination of the altitudinal zones, based on the diet regime of the fish communities (Fig. 6). The dendrogram displays one group (dashed lines) structure for which there is no evidence from a SIMPROF test, and the other group (continuous lines) being used for divisions for which SIMPROF rejects the null hypothesis (that samples in that group have no relation to habitat types). Dashed lines indicate groups of samples not separated (at $P<0.05$) by SIMPROF. The dashed line groups forms the species that belong to a single altitudinal zone viz. mostly the river plains, whereas the continuous lines forms the species that belong to different zones indicative of distinct groups of species filtered through feeding habits in perspective of altitudinal variation.

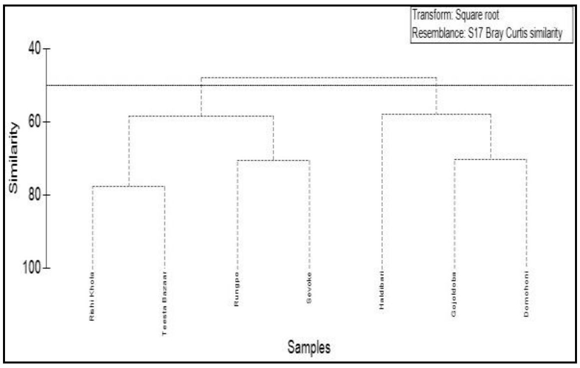


Fig. 4 Similarity dendogram for hierarchial clustering of sites constitutive of respective altitudinal zones showing linking of Bray-Curtis similarities calculated on obtained feeding groups at each site.

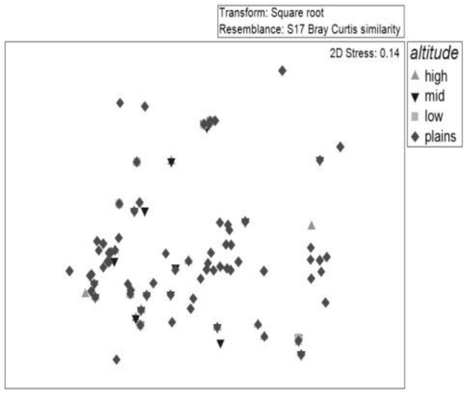


Fig. 5 Two-dimensional MDS ordination plot of the volumetric dietary data for respective fish species coded for habitat/altitudinal gradient.

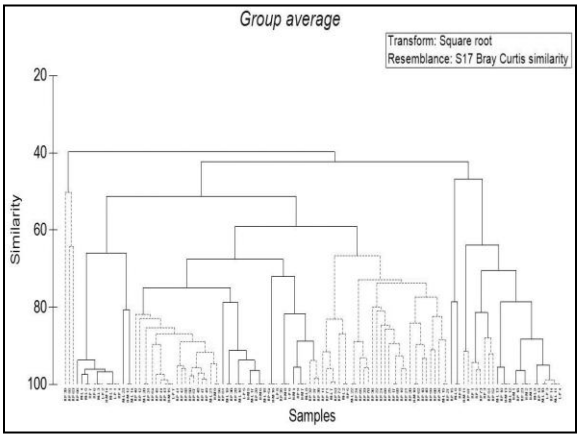


Fig. 6 Sequence of SIMPROF tests on dendrogram from standard hierarchical clustering based on the diet composition fish species.

Discussion

This study demonstrated the overall dietary compositions of the ninety-two species collected and identified along the longitudinal stretch of River Teesta. Aquatic insects are being consumed as the main dietary constituent as has been observed from the dietary composition of the species. This pattern has been observed in hilly streams by many other authors outside India (Motta and Uieda, 2004; Uieda and Motta, 2007; Winemiller *et al.,* 2008; Vidotto-magnoni and Carvalho, 2009; Ferreira and Casatti, 2006; Rocha *et al.*, 2009). However, any such documentation in Teesta River, India is lacking. Detritus was also a large part of the diet of the fish assemblages, which generally occurs in higher in impacted streams. The specific diets of each species were related to their distinct feeding habits and use of stringent habitats. The effects of shared resource used and competition that might occur in locations where the food supply is limited to a few sources is intensified by this factor. Therefore, the patterns of use of a specific range of food resources by the high altitude species is probably not related to food overlap or competition, but to the abundance of specific aquatic invertebrates limited to this specific zone. Hence we observed that the high-mid altitude zones were mainly dominated by the loaches (*Danio rerio*, *Schistura devdevi* and *Schistura savona)* and cold water carps (*Schizothorax richardsonii* and *Tor tor*) having specific diet requirements. Further downstream, where the river hits the plain, both the availability and respective abundance of food resources increased (in view of higher water temperature, lesser water current and muddy river beds, providing a favorable and productive habitat for a variety of organisms) resulting in the dominance of omnivores species (*Rasbora rasbora*, *Salmophasia phulo*, etc). As such, analysis of the food composition in perspective of the main habitat occupation and activity patterns of some species, suggested ecological segregation existed among species within the community. Further the field observations indicated habitat segregations among overlapping species, suggesting that food partitioning mechanisms may occur at different levels with environment being a major filtering agent. Our result support that habitat segregation explained the observed co-existing pattern with environmental factors determining the occurrence of specialized species such as loaches (*Schistura* spp.) at certain stations; as has been observed by other authors (Costa de Azevedo *et al.*, 2006; Mouillot *et al.*, 2006).

Apart, as observed in a Panamanian stream (Zaret and Rand, 1971), the results show that despite hydrological variation produced year round in the form of spates, habitat modifications do not seem to be sufficient to produce drastic changes in food niches. However, in the present study, habitat modification somewhat seems to effect the pattern of resources utilization and the occurrence of resident fish community. This was seen in the increase of omnivorous species at both somewhat anthropogenic disturbed sites (Teesta bazaar and Sevoke). Although these sites form the high-mid altitude zones of the River Teesta, here omnivorous species seems to be equally abundant as insectivores. This may be due to the fact that disturbances (dam construction and movement of heavy vehicle over the river bed) at these sites have led to lesser availability of the specific aquatic insect prey items. As such species might have shifted to higher variety of resource utilization. This flexibility accounts for the ability of these species (*Barilius* spp. and *Lepidocephalichthys* spp.) when in altered habitats, to feed on suites of prey that vary significantly in their compositions and to flourish in those habitats. Studies (Hourston *et al.*, 2004) have shown that differences in the diets of *Atherinomorus ogilbyi, S. schomburgkii* and *L. platycephala* among the different habitat types, which differed in the extent to which they were exposed to wave action, could be related to differences in the relative abundances of their different potential prey. This is in consistent to the present study which accounts for the differences and or specificity of the potential prey, owing to temperature, water velocity and substrate variations at respective zones which intensifies altitude as one of the main factor in determining species assemblage pattern and resource utilization. In context, habitat segregation, however was observed among most of the species, suggesting some degree of food partitioning exists in hill-stream species.

Beside, other authors have found that most of the food resources consumed by stream fish are of allochthonous origin (Castro, 1999; Esteves and Aranha, 1999; Lowe-mcconnell, 1999; Alvin and Peret, 2004). In the present study, although both allochthonous and autochthonous resources were used by fish assemblages, autochthonous resources dominated the diet of most species. This was also observed in studies performed by Rondineli *et al.* (2011) and Bonato *et al.* (2012). This may be in view of the fact that terrestrial insects and vegetal fragments were only consumed during the rainy season which consisted of a large area within riparian vegetation. Therefore, low contribution of allochthonous items can be explained by the disruption of riparian vegetation in the studied areas. As opined by many authors (Angermeier and Karr, 1983; Rezende and Mazzoni, 2005; Tófoli *et al.*, 2010) normally, the input of allochthonous material from both plants and animals in aquatic environments is greater in the rainy season, mainly because of the displacement of these organisms to the aquatic environment by rain and wind and the leaching of adjacent areas. The fish fauna of River Teesta is thus mantained by a few resources, of which those of autochthonous origin are fundamental for the maintenance of the greatest part of fish biomass. The small size of most of the species populations, the high number of habitat-specific species and the direct and indirect dependence of food sources that derive from the forest, suggest that the fish populations of this clear water river of the eastern Himalayan biodiversity hotspot region might be very sensitive to habitat alteration. Hence, future studies which will aim to assess anthropogenic impacts and prioritize conservation efforts are strongly recommended.

Acknowledgements

The authors are highly grateful Shri K.C.Gopi, Scientist-E, Zoological Survey of India, Kolkata for guidance, support and research facilities in the taxonomic study. We are also indebted to the local fishermen of Jalpaiguri and Darjeeling districts of West Bengal for assistance in experimental fishing and providing necessary amenities. Financial assistance provided by Council of Scientific and Industrial Research (CSIR) to Munmun Chakrabarty is gratefully acknowledged.

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