Fish guild structure along a longitudinally–determined ecological zonation of Teesta, an eastern Himalayan river in West Bengal, India

M. Chakrabarty & S. Homechaudhuri

Abstract

Fish guild structure along a longitudinally–determined ecological zonation of Teesta, an eastern Himalayan river in West Bengal, India.— The Eastern Himalaya Biodiversity Hotspot contains exceptional freshwater biodiversity and ecosystems that are of vital importance to local and regional livelihoods, but these are under threat from the developmental and anthropogenic pressures arising from the 62 million people living in the area. Therefore, monitoring the riverine health and considering future conservation approach, the study of fish biodiversity plays a significant role in this region. The River Teesta in the Brahmaputra basin in India forms one of the major rivers in the Eastern Himalayas. In the present investigation, we studied ecological fish guilds as they can enhance the usefulness of fish zonation concepts and serve as tools to assess and manage the ecological integrity of large rivers. We classified fish species according to their water flow preference and spawning substrate preference. Ten spawning habitats were identified, occurring in three water flow guilds. The most widely preferred habitat in upstream zones was lithophils while in lower stretches it was lithopleagophils. On applying predictions of the *River Continuum Concept*, our results indicated the presence of a zonation pattern based on fish species assemblage and their ecological attributes along the longitudinal stretch of the Teesta River in west Bengal. Along the longitudinal stretch of the river, species richness increased downstream, with maximum richness in the mid–reaches. However, species richness decreased further downstream. The number of ecological guilds also increased downstream, and there were clear shifts in the structure of the guilds.

Key words: Eastern Himalayas, Teesta, lotic water, biodiversity, flow–preference guild, altitudinal gradient.

Resumen

Estructura de un gremio de peces a lo largo de una zonación ecológica definida longitudinalmente en el río Teesta del Himalaya Oriental (Bengala Occidental, India).— El ecosistema de gran riqueza de biodiversidad (*hotspot*) del Himalaya Oriental contiene una biodiversidad excepcional en agua dulce y unos ecosistemas de vital importancia para la subsistencia de las comunidades locales y regionales, pero todo ello está amenazado por la presión antropogénica y de desarrollo provocada por la existencia de una población de 62 millones de personas

en la zona. Por consiguiente, el estudio de la biodiversidad piscícola desempeña un papel fundamental en esta región como forma de supervisión de la salud fluvial y de evaluación de políticas de conservación futuras. El río Teesta, en la cuenca india del Brahmaputra, es uno de los mayores ríos del Himalaya Oriental. En el estudio actual hemos analizado los gremios ecológicos de peces ya que ello puede contribuir a mejorar la utilidad de los conceptos de zonación de los mismos y servir como herramienta para evaluar y gestionar la integridad ecológica de los grandes ríos. Hemos clasificado las especies de peces en función de su preferencia por un segmento determinado del curso fluvial y por un substrato de desove. Se han identificado diez hábitats de desove, que se dan en tres gremios de cursos fluviales. El hábitat preferido en mayor medida en el curso superior es el litófilo, mientras que en el curso inferior es el litopleagófilo. Al aplicar predicciones basadas en el concepto de *Continuum Fluvial*, nuestros resultados indican la presencia de patrones de zonación basados en el ensamblaje de especies de peces y sus atributos ecológicos a lo largo de un tramo longitudinal del río Teesta en Bengala Occidental. A lo largo del tramo longitudinal del río, la riqueza de especies aumenta aguas abajo, con valores máximos en el curso medio, pero la riqueza de especies se reduce en el curso inferior. El número de gremios ecológicos también aumenta aguas abajo, produciéndose claras alteraciones en la estructura de las comunidades.

Resum

Estructura d'un gremi de peixos al llarg d'una zonació ecològica definida longitudinalment al riu Teesta de l'Himàlaia Oriental (Bengala Occidental, Índia).— L'ecosistema de gran riquesa de biodiversitat (*hotspot*) de l'Himàlaia Oriental conté una biodiversitat excepcional en aigua dolça i uns ecosistemes d'importància vital per a la subsistència de les comunitats locals i regionals, però tot això està amenaçat per la pressió antropogènica i de desenvolupament causada per l'existència d'una població de 62 milions de persones a la zona. Per tant, l'estudi de la biodiversitat piscícola exerceix un paper fonamental en aquesta regió com a forma de supervisió de la salut fluvial i d'avaluació de polítiques de conservació futures. El riu Teesta, a la conca índia del Brahmaputra, és un dels més importants de l'Himàlaia Oriental. En aquest estudi hem analitzat els gremis ecològics de peixos perquè això pot contribuir a millorar la utilitat dels conceptes de zonació i servir com a eina per avaluar i gestionar la integritat ecològica dels grans rius. Hem classificat les espècies de peixos en funció de la preferència que mostren per un segment determinat del curs fluvial i per un substrat de fresa. S'han identificat deu hàbitats de fresa que es donen en tres gremis de cursos fluvials. L'hàbitat preferit principalment al curs superior és el litòfil, mentre que al curs inferior és el litopleagòfil. Els resultats de l'aplicació de prediccions basades en el concepte de *Contínuum Fluvial* indiquen la presència de patrons de zonació basats en l'assemblatge d'espècies de peixos i els seus atributs ecològics al llarg d'un tram longitudinal del riu Teesta a Bengala Occidental. Al llarg del tram longitudinal del riu, la riquesa d'espècies augmenta aigua avall, amb valors màxims al curs mitjà. Però la riquesa d'espècies es redueix al curs inferior. El nombre de gremis ecològics també augmenta aigua avall i es produeixen alteracions evidents en l'estructura d'aquestes comunitats.

Munmun Chakrabarty & Sumit Homechaudhuri, Aquatic Bioresource Research Lab., Dept. of Zoology, Univ. of Calcutta, 35 Ballygunge Circular Road, Kolkata–700019, West Bengal, India.

E–mail: sumithomechaudhuri@gmail.com; sumithomec@yahoo.com

Introduction

Analysis of the quality of aquatic environments should ideally incorporate attributes that are able to integrate the behavior of elements and biological processes at various levels of organization expressing multiple scale interferences with aquatic communities. The most recent approaches to assess the integrity of environments are multimetric, aiming to combine attributes that represent the broad existing ecological diversity at different levels of biological organization (Casatti et al., 2009). There is a lack of baseline information on freshwater fish species distributions and their ecological requirements throughout the Eastern Himalayas. It has been 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). Based on these findings, the study of freshwater fish species holds immense importance. Moreover, analysis of their various ecological aspects can adequately assess the ecological integrity of the aquatic ecosystem. Ecological integrity for streams implies the presence of an adaptive assemblage of organisms having a species composition, species richness, and functional organization comparable to that of natural habitat in the region (Karr, 1995).

The Eastern Himalayan Biodiversity Hotspot region and its foothills are rich in both floral and faunal diversity. Fish diversity, in particular, is very rich because the region is home to many large torrential rivers. Fish populations inhabiting these areas are numerous in variety and taxonomically interesting (Abell et al., 2008). As such, the northern districts of West Bengal, specially the districts of Darjeeling and Jalpaiguri, lying within the Eastern Himalayan biodiversity hotspot range, hold a great faunistic importance. The chief rivers are Mahananda and Teesta, with many tributaries such as Murti, Atrai, Jaldhaka, Karala, and Karotoyar. The Himalayas are the source of all major river systems in India. Like other Himalayan rivers, the Teesta River and its tributaries provide a fair ecological niche for many indigenous, and a few exotic, fish species.

Scientific documentation of the Ichthyofaunal diversity of the River Teesta drainage basin is poor and there is no documentation on its stretch within West Bengal. However, as a whole there are several studies on the fish diversity of all along North Bengal. The most comprehensive account of the fish fauna of North Bengal was published by Shaw & Shebbeare (1937) and Hora & Gupta (1941). Apart, Menon (1962) published a distributional list of the fishes of the Himalayas, followed by Jayaram (1977). Subsequent to these there seems to be no report of any fish biodiversity from North Bengal. Allen et al. (2010) reported work on the IUCN status of the freshwater biodiversity in the Eastern Himalayas but there remains an extensive gap in the study of aquatic ecosystem and fish ecology. Analysis of the integrity of riverine environments using a multimetric approach is therefore needed in this region. This approach should include study of the ecological fish guild because knowledge of fish zonation can be used to assess and manage the ecological integrity of large rivers. Grouping fish species into ecological guilds can be a useful method to assess ecological integrity and functioning of large river systems (Aarts & Nienhuis, 2003). Shifts in the structure of functional groups as a result of environmental degradation can be explained by general theories of river ecology, geomorphology and chemistry that can also set guidelines for ecological restoration of degraded river systems, by elucidating the natural configuration of riverine habitats and processes (Vandewalle et al., 2010). The guild and river continuum concept has been largely applied to European rivers (Noble et al., 2007; Fausch et al., 2002), but such information is lacking in Indian rivers. In the present study, the fish guild approach was incorporated to ascertain fish assemblage patterns along the longitudinal gradient of River Teesta in West Bengal, India.

Materials and methods

Study area

The 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, draining an area of 12,540 km^2. The present study area includes the course of the River Teesta in West Bengal divided into ecological zones based on elevation gradient and habitat types (table 1, fig. 1). The river stretch was divided into four zones *viz.* the upper stretch (Rishi khola and Rungpo) where elevations is higher with low temperatures; the middle stretch (Teesta Bazaar) with low elevation; a lower stretch at Sevoke, where the river hits the plains; and lastly, the river plains (Gojoldoba, Domohoni and Haldibari). Along the longitudinal stretch of the river in West Bengal, covering a distance of 142 km, each site was sampled at regular intervals (bi–annually with pre–monsoon and post–monsoon visits) when flow conditions were the most stable and similar among sites. Local habitat attributes were recorded to find any associations with the variation in fish assemblages. Habitat variables for each sampling sites at each sampling operation were recorded in the field. Stream width was measured along three transects regularly spaced across the stream channel. Water depth, current velocity and temperatures were measured at the mid–point of each transect.

Ichthyologic biodiversity in perspective of longitudinal zonation concepts of River Teesta

Fish sampling was carried out from December 2010 to March 2013 every alternate six months at seven sampling areas (approximately 20–30 km apart) in the four zones covering the longitudinal gradient of the River Teesta at Darjeeling and Jalpaiguri districts in West Bengal. After an initial pilot survey of the entire riverine stretch, these seven areas were chosen based on different habitat patches, high fishing activity, accessibility and availability of local fish markets nearby (for gathering secondary data). Each sampling area was further divided into
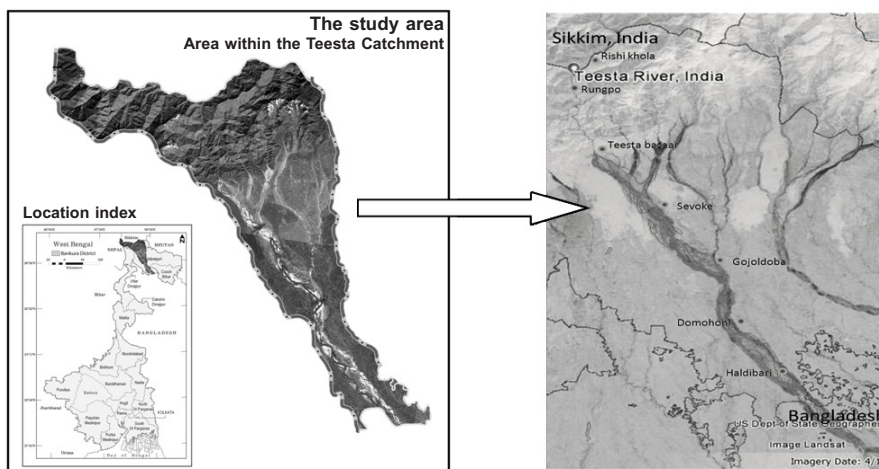

Fig. 1. Teesta River in West Bengal.
Fig. 1. Río Teesta en Bengala Occidental.

Table 1. Longitudinal zonation concepts, the sampling areas and their hydrological and ecological characteristics. Fish zones: HmAz. High–mid altitude zone (moderate to high, 1,093–1,000 ft, elevation watersheds dominated by side slopes with gentle slopes and steep slopes); MAz. Mid–altitude zone (moderate, 628 ft, elevation watersheds dominated by side slopes and gentle slopes); LAz. Low altitude–plain zone (moderate to low elevation, 500 ft, watersheds dominated by gentle slopes with substantial areas of flats and side slopes; the river meets the plain at this site); RPz. River plains (low elevation, 380–187 ft, dominated by flats, pastured land and urban inhabitation). Sampling areas: RK. Rishi Khola; RP. Runhpo (26°10' 21.94" N, 88° 31' 46.73" E); TB. Teesta Bazaar (26° 00' 03.97" N, 88° 26' 31.80" E); S. Sevoke (26° 53' 25.37" N, 88° 28' 22.97" E); G. Gojoldoba (26° 45' 08.55" N, 88° 35' 05.04" E); D. Domohoni (26° 33' 47.11" N, 88° 45' 39.34" E); H. Haldibari (26° 20' 52.00" N, 88° 54' 16.76" E).

Tabla 1. Conceptos de zonación longitudinal, áreas de muestreo y sus características hidrológicas y ecológicas. Zonas piscícolas: HmAz. Zona de altitud media–alta (elevación entre moderada y alta, de 1.093–1.000 pies, con cuencas de captación dominadas por taludes y pendientes suaves y fuertes); MAz. Zona de alltitud media, 628 pies, con cuencas de captación dominadas por taludes y pendientes suaves); LAz. Zona de baja altura y llanos (elevación moderada, de 500 pies, con cuencas de captación dominadas por pendientes suaves y zonas de llanuras y laderas considerables; el río alcanza la llanura en este punto); RPz. Llanuras fluviales (elevación reducida, de 380–187 pies, dominada por llanuras de pastoreo y asentamientos humanos). Para las abreviaturas de las áreas de muestreo, ver arriba.)

Fish zones	Sampling areas	Temperature (°C)		Water velocity (m/sec)	Stream (ft)		Habitat guilds	Preferred spawning habitat
		AT	WT		with	depth		
HmAz	RK	21–23.7	18.5–21	2.1–2.9	1	1	Primary forest; hilly terrain	Lithophils / lithopelagophils
	RP	21.1–24.5	19.5–21	1.9–2.2	15	31–32.5	Secondary forest	
MAz	TB	24–27	20.7–24.9	1.6–1.9	20	23–25	Secondary forest; ongoing construction work of Teesta Barrage Porject	Lithoplegophils / Speleophils
LAz	S	18.5–25.2	15.4–18.5	1.3–1.6	7.4–21	24–25	Secondary forest	Lithoplegophils / Psammophils
RPz	G	30.1–35.5	28.2–31	0.9–1.4	40	25–27	Secondary forest; urban area presence of Teesta Barrage	Phytophils / Phytolothophils
	D	34–35.7	30.1–31	0.45–0.9	38	20–22	Agriculture land; urban area	
	H	33.7–37.2	29.9–31.1	0.45–0.55	35	20–21	Agriculture land; urban area	Phytophils / polyphils

4 sampling sites (approx. 1–2 km apart) totaling 28 sites altogether. It was observed that 4 sampling sites per area were sufficient to represent the fish assemblage of the respective area. All the important freshwater aquatic microhabitats (riffles, pools, cascades, falls, etc.) were sampled using gill nets, cast nets, dragnets, and hooks and lines of varying dimensions. A sample reach of 50 m were fished for 2 hours at every site using the above–mentioned fish nets as well as the electro–fishing method using a single anode electro–fisher (300V, 3–4A, DC) operated by the same person. Captured fish specimens were counted and fixed in 10% formalin solution and, after 48 h, transferred to a 70% ethyl alcohol solution. Fishes were identified to the lowest taxonomic level using Shaw & Shebbeare (1937), Day (1889), Talwar & Jhingran (1991), Jayaram (2006, 2010), and Menon (1987). All fish specimens were deposited in the fish collection repertoire at the Zoological Survey of India, Kolkata. The status of the species on the IUCN Red List of Threatened Species was incorporated. The divisions (table 1) of the zones is based on Aarts & Nienhuis (2003) and Aquatic Ecological System (AES) classification (Maxwell, 1995) and also adds some later subdivisions based on the present occurrence of the zones.

Ecological fish guilds

Fish data should be interpreted ecologically to yield information about riverine habitats and processes. In ecological studies, fish species sharing more or less the same niche are often grouped into guilds (functional groups) of species that exploit a resource (food or habitat) in a similar fashion (Bain et al., 1988; Bergers, 1991). Distributions of guilds were studied in space to give distinctly different information in prospect of the River Continuum Concept (Vannote et al., 1980). Identified fish species were grouped into guilds on the basis of classification related to river water flow regime, habitat use (Aarts & Nienhuis, 2003) and spawning habitat (Balon, 1975a, 1975b, 1981) to assess the underlying causes and ecological mechanisms of the present state of ichthyofauna of River Teesta in West Bengal (table 2). Balon (1975a, 1975b, 1981) classified fishes according to their spawning habitats and habits. His system is now used worldwide, with only minor adjustments, using ethological types (guarders and nonguarders), ecological groups (describing parental investment type), and substrate types as criteria.

Data analyses

Analysis focused on quantifying spatial variation in fish assemblages and identifying habitat variables explaining this variation. Because sampling effort (*i.e.*, sample time, length and procedures) was similar among sites and years of sampling, counts of individual fish species at each sample site were directly used in the analyses. A number of diversity indices of the fish community structure in River Teesta were calculated using PRIMER (Plymouth Routines In Multivariate Ecological Research) v6 software package (Clarke & Gorley, 2006). Diversity indices included species richness (d), Pielou's evenness (J') (Pielou, 1969), and Shannon–Weaver (1949) index.

Results

A total number of 16,703 fish specimens were collected. We recorded 92 species belonging to 50 genera and 19 families from the longitudinal stretch River Teesta in West Bengal. Overall, the fish species with highest abundances were *Barilius bendelisis, Puntius sophore, Schistura corica, Lepidocephalichthys guntea*. Ichthyological biodiversity exhibited maximum value in the middle reaches of the river *viz.* Gojoldoba and Domohoni domimated by Cypriniformes (*Aspidoparia morar*, *Barilius bendelisis*, *Devario devario*, *Puntius sophore*, *Esomus danricus*, *Lepidocephalichthys guntea*) and Siluriformes (*Mystus bleekeri*, *Bagarius yarrelli*, *Glyptothorax telchitta*, *Glyptothorax striatus*, *Glyptothorax indicus, Glyptothorax cavia*) fishes.

Table 2. Flow preference guild (Aarts & Nienhuis, 2003) and reproductive guild, based on spawning habitat/substrate (Balon, 1975) applied to the fish species of River Teesta in West Bengal).

Tabla 2. Gremios según preferencia del curso fluvial (Aarts & Nienhuis, 2003) y gremios reproductivos basados en hábitat/sustrato de desove (Balon, 1975) aplicado a las especies de peces del río Teesta, Bengala Occidental.

Guilds	Definition	Probable reactions to environmental changes/disturbance
Reproductive guild		
Lithophils	Eggs deposited in clean gravels, rocks, stones, rubble or pebbles	Choking, desiccation or overly deep submergence of gravel substrates may render them unusable to the fish
Phytophils	Eggs deposited in plants, leaf and/or roots of live or dead vegetation	Generally resistant but can be affected by changes that affect distribution and abundance of submerged and emergent plants
Phytolithiphils	Eggs deposited in submerged plants, if available, or on other submerged items	Resistant to most environmental changes
Psammophils	Eggs deposited in roots or grass above a sandy bottom or on sand itself	Generally resistant but susceptible to excessive sedimentation
Lithopelagophils	Eggs deposited in rocks or gravels	Changes to flow regimes may result in eggs and larvae in the rivers being delayed in impoundments or carried past desirable nursery areas, resulting in mortality
Speleophils	Eggs deposited in interstitial spaces or crevices	Generally resistant
Polyphils	Non–specialised spawners / no preferred habitats	
Flow preference guilds		
Rheophilic	All freshwater life stages confined to lotic waters	Disturbed by changes to the flow regime that desiccate the pools or leave them for long periods without flow
Eurytopic	All life stages can occur in both lentic and lotic water	Sensitive to the drawdown phase of the hydrological cycle. Usually non–migratory
Limnophilic	All life stages confined to lentic waters	Tolerant of low dissolved oxygen tensions

Biodiversity in the upper regions *viz.* Teesta bazaar and Sevoke was limited and specialized (fish groups of mainly *Barilius* spp., *Schistura* spp. and *Garra* spp. dominate in this stretch) and lowest in further upper stretches *viz.* Rishi Khola and Rungpo. These groups of fishes were highly habitat specific and survived only in clear stream waters with adequate water current, low temperature and with rocky substrate. Species abundance and richness again decrease in lower reach *viz.* Haldibari (table 3). This is attributed to limitations induced by shifting and homogenous substratum and high turbidity as after this point River Teesta enters the Bramhaputra River drainage. The species richness per zone increases downstream (Gojoldoba and Domohoni) but decreases further downstream (Haldibari). Five freshwater fish orders have been deduced with Cypriniformes being the most dominant, followed by Siluriformes and Perciformes (fig. 2).

Widely used in zoology, fish can be grouped into guilds according to their flow regime ecology and spawning habitat selection. The ecological classification applied in this study is the one based on the flow preference of adult fishes. It considers rheophilic (all stages of life confined to lotic waters); eurytopic (all stages can occur both in lotic or lentic waters) and limnophilic (all life stages confined to lentic waters) groups. In the present study, after detailed observation and analysis of the habitat requirements, we classified fish in the River Teesta as rheophilic, limnophilic or eurytopic (fig. 3). Rheophilic fish species formed the dominant group in the upper reaches of the river where altitude was significantly higher. The proportion of rheophilic fish community more or less decreased sharply downstream and the proportions of limnophilic and eurytopic species increased. The stretches of the river falling in plains *viz.* Gojoldoba, Domohoni and Haldibari was characterized by stagnant zones, higher temperatures and less water current, as reflected in the increase in limnophilic and eurytopic species in these zones. The fish species were found to use seven spawning habitat types within each site (1 km^2 quadrate area considerations at respective sites) and were accordingly classified into seven spawning preference guilds (fig. 4). Changes in flow preference and reproductive guilds were closely linked: in the rheophilic zone, lithophilic (50.0–58.0%) and psammophilic spawners (15%) were dominant in upper reaches, whereas limnophilic, phytophilic spawners and eurytopic phytolithophilic or polyphilic spawners predominated in lowland reaches. The regions preferred for spawning for respective fish species are illustrated in table 4.

Table 3. Diversity indices of the fish community of the River Teesta, West Bengal.
Tabla 3. Índices de diversidad de la comunidad de peces del río Teesta, Bengala Occidental.

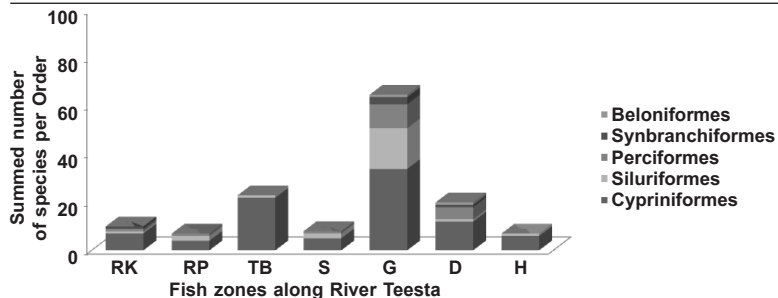| Sites	Total species (S)	Species richness (d)	Pielou's evenness (J')
Rishi Khola	9	3.154	0.9307
Rungpo	7	1.78	0.9662
Teesta Bazzar	22	4.543	0.9802
Sevoke	8	1.98	0.9819
Gojoldoba	65	11.56	0.966
Domohoni	20	4.556	0.9641
Haldibari	7	1.675	0.9677

Fig. 2. Taxonomic composition of fish zones of River Teesta in West Bengal. (For abbreviations of fish zones see table 4.)
Fig. 2. Composición taxonómica de las zonas piscícolas del río Teesta en Bengala Occidental. (Para las abreviaturas de las zonas piscícolas ver tabla 4.)

Fig. 3. Composition of flow preference guilds of the ecological fish zones of River Teesta. (For abbreviations of fish zones and flow preference guilds see table 4.)
Fig. 3. Composición de los gremios según su preferencia por curso fluvial en las zonas piscícolas ecológicas del río Teesta. (Para las abreviaturas de las zonas piscícolas y de los gremios segun preferencias del curso fluvial, ver tabla 4.)
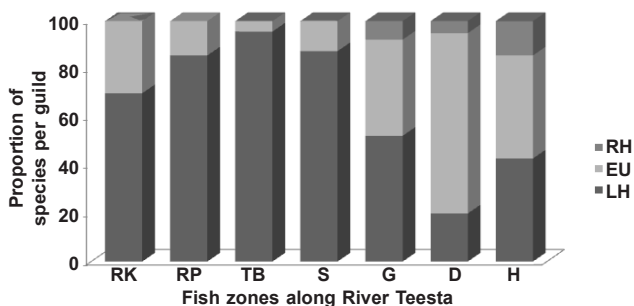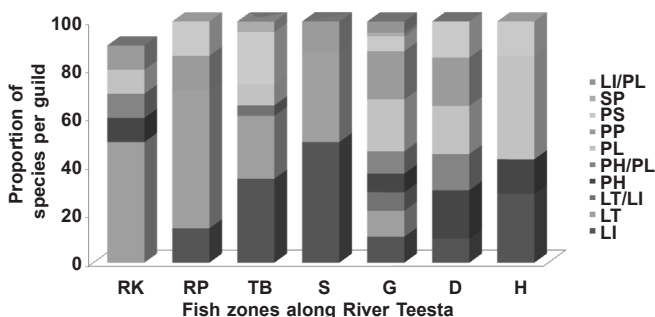

Fig. 4. Composition of spawning preference guilds of the ecological fish zones of River Teesta. (For abbreviations of fish zones and reproductive guild see table 4.)
Fig. 4. Composición de los gremios según su preferencia de desove en las zonas piscícolas ecológicas del río Teesta. (Para las abreviaturas de las zonas piscícolas y de los gremios reproductivos, ver tabla 4.)

Table 4. Ichthyofaunal diversity of the River Teesta in West Bengal, India: RK. Rishi Khola; RP. Rungpo; TB. Teesta Bazaar; S. Sevoke; G. Gojoldoba; D. Domohoni; H. Haldibari; RG. Reproductive guild (LT. Lithophils; PH. Phytophils; PL. Phytolithiphils; PS. Psammophils; LI. Lithopelagophils; SP. Speleophils; PP. Polyphils); FPG. Flow preference guild (RH. Rheophilic; EU. Eurytopic; LH. Limnophilic); IUCN. IUCN status (LC. Least concern; VU. Vulnerable; NT. Near threatened; DD. Data deficient); + Present; – Absent.

Tabla 4. Diversidad de la ictiofauna del río Teesta en Bengala Occidental, India: RK. Rishi Khola; RP. Rungpo; TB. Teesta Bazaar; S. Sevoke; G. Gojoldoba; D. Domohoni; H. Haldibari; RG. Gremio reproductivo (LT. Litófilos; PH. Fitófilos; PL. Fitolitófilos; PS. Psamófilos; LI. Litopelagófilos; SP. Espeleófilos; PP. Polífilos); FPG. Gremio según preferencia del curso fluvial (RH. Reofílico; EU. Eurítópico; LH. Limnofílico); IUCN. Estado en la lista del IUCN (LC. Preocupación menor; VU. Vulnerable; NT. Casi amenazada; DD. Datos insuficientes); + Presente; – Ausente.

Order, Family

Species	RK	RP	TB	S	G	D	H	RG	FPG	IUCN
Cypriniformes, Cyprinidae										
Amblypharyngodon mola (Hamilton, 1822)	–	–	–	–	+	+	–	PL	EU	LC
Aspidoparia morar (Hamilton, 1822)	–	–	–	–	+	–	+	PL	EU	LC
Aspidoparia jaya (Hamilton, 1822)	–	–	–	–	–	–	+	PL	EU	LC
Bangana dero (Hamilton, 1822)	–	–	–	–	+	–	–	PP	LH	LC
Barilius barna (Hamilton 1822)	–	–	+	–	+	–	–	LI	RH	LC
Barilius barila (Hamilton, 1822)	–	+	+	+	+	–	+	LI	RH	LC
Barilius bendelisis (Hamilton, 1807)	–	–	+	+	+	–	–	LI	RH	LC
Barilius shacra (Hamilton 1822)	–	–	+	–	–	–	–	LI	RH	LC
Barilius tileo (Hamilton, 1822)	–	–	–	–	–	+	–	LI	RH	LC
Barilius vagra (Hamilton, 1822)	–	–	+	–	+	+	+	LI	RH	LC
Crossocheilus latius latius (Hamilton, 1822)	–	–	+	–	+	–	–	PL	RH	LC
Danio dangila (Hamilton, 1822)	–	–	+	–	–	–	–	PL	RH	LC
Danio rerio (Hamilton, 1822)	+	–	+	–	–	–	–	SP	RH	LC
Devario aequipinnatus (McClelland, 1839)	+	–	–	–	–	–	–	PL	RH	LC
Devario devario (Hamilton 1822)	–	–	–	–	+	+	–	PL	RH	VU
Devario acuticephala (Hora, 1921)	–	–	–	–	+	–	–	PL	EU	LC
Esomus danricus (Hamilton 1822)	–	–	–	–	+	+	–	PL	EU	LC

Table 4. (Cont.)

Order, Family										
Species	**RK**	**RP**	**TB**	**S**	**G**	**D**	**H**	**RG**	**FPG**	**IUCN**
Garra annandalei (Hora, 1921)	–	–	+	–	+	–	–	LI	RH	LC
Garra gotyl agotyla (Gray, 1830)	–	–	+	+	–	–	–	LI	RH	LC
Garra lamta (Hamilton, 1822)	–	–	+	+	+	–	–	LI	RH	LC
Labeo pangusia (Hamilton 1822)	–	–	–	–	+	–	–	PH	LH	NT
Labeo angra (Hamilton, 1822)	–	–	–	–	–	+	+	PH	LH	LC
Neolissochilus hexagonolepis (McClelland, 1839)	–	+	+	–	+	–	+	PS	RH	NT
Neolissochilus hexastichus (McClelland 1839)	–	–	+	–	–	–	–	PS	RH	NT
Osteobrama cotio cotio (Hamilton, 1822)	–	–	–	–	–	–	+	PL	LH	LC
Psilorhynchus balitora (Hamilton, 1822)	+	–	–	–	–	–	–	LT	RH	LC
Psilorhynchus sucatio (Hamilton 1822)	+	–	–	–	+	–	–	LT	RH	LC
Puntius conchonius (Hamilton, 1822)	–	–	–	–	+	–	–	PH/PL	EU	LC
Pethia phutunio (Hamilton, 1822)	–	–	–	–	+	–	–	PH/PL	EU	LC
Puntius sarana (Hamilton, 1822)	–	–	–	–	+	–	–	PH/PL	LH	LC
Puntius sophore (Hamilton 1822)	–	–	–	–	+	+	–	PH/PL	EU	LC
Puntius terio (Hamilton, 1822)	+	–	–	–	+	+	–	PH/PL	EU	LC
Pethia ticto (Hamilton, 1822)	–	–	–	–	+	+	–	PH/PL	EU	LC
Raiamas bola (Hamilton, 1822)	–	–	–	–	–	+	–	PP	EU	LC
Rasbora rasbora (Hamilton 1822)	–	–	–	–	+	–	–	PP	EU	LC
Salmophasia bacaila (Hamilton, 1822)	–	–	–	–	+	–	–	PP	LH	LC
Salmophasia phulo (Hamilton 1822)	–	–	–	–	+	–	–	PP	LH	LC
Schizothorax richardsonii (Gray 1832)	–	+	+	–	–	–	–	LT	RH	VU
Tor tor (Hamilton 1822)	–	+	–	–	–	–	–	LT	RH	NT
Cypriniformes, Nemacheilidae										
Acanthocobitis botia (Hamilton, 1822)	–	–	+	–	+	–	–	LT	RH	LC
Aborichthys elongatus Hora, 1921	–	–	–	+	–	–	–	LT/LI	RH	LC

Table 4. (Cont.)

Order, Family										
Species	**RK**	**RP**	**TB**	**S**	**G**	**D**	**H**	**RG**	**FPG**	**IUCN**
Schistura corica (Hamilton, 1822)	–	–	+	+	+	–	–	LT	RH	NT
Schistura devdevi Hora, 1935	–	–	+	–	–	–	–	LT	RH	LC
Schistura multifasciata (Day, 1878)	–	–	+	–	–	–	–	LT	RH	LC
Physoschistura elongata Sen & Nalbant, 1982	–	–	–	+	–	–	–	LT	RH	LC
Schistura savona (Hamilton, 1822)	+	–	+	–	+	–	–	LT	RH	LC
Schistura scaturigina McClelland, 1839	–	–	+	–	+	–	–	LT	RH	LC
Schistura beavani (Günther, 1868)	–	–	+	–	–	–	–	LT	RH	VU
Schistura sikmaiensis (Hora, 1921)	–	–	+	–	–	–	–	LT	RH	LC
Cypriniformes, Cobitidae										
Botia lohachata Chaudhuri, 1912	–	–	+	–	+	–	–	PS	RH	LC
Botia rostrata Günther, 1868	–	–	–	–	+	–	–	PS	RH	VU
Canthophrys gongota (Hamilton, 1822)	–	–	–	–	+	–	–	PL	RH	LC
Lepidocephalichthys annandalei (Chaudhuri, 1912)	–	–	–	–	–	+	–	PS	RH	LC
Lepidocephalichthys berdmorei (Blyth, 1860)	–	–	–	–	+	–	–	PS	RH	LC
Lepidocephalichthys guntea (Hamilton, 1822)	–	–	+	–	+	+	–	PS	EU	LC
Siluriformes, Amblycipitidae										
Amblyceps mangois (Hamilton, 1822)	+	+	–	+	+	–	–	PL	EU	LC
Siluriformes, Bagridae										
Batasio tengana (Hamilton, 1822)	–	–	–	–	+	–	–	PL	EU	LC
Mystus bleekeri (Day 1877)	–	–	–	–	+	+	+	PL	EU	LC
Mystus tengara (Hamilton, 1822)	–	–	–	–	+	–	–	PL	EU	LC
Mystus vittatus (Bloch, 1794)	–	–	–	–	+	+	–	LT	RH	LC
Siluriformes, Chacidae										
Chaca chaca (Hamilton 1822)	–	–	–	–	+	–	–	PP	EU	LC

Table 4. (Cont.)

Order, Family										
Species	**RK**	**RP**	**TB**	**S**	**G**	**D**	**H**	**RG**	**FPG**	**IUCN**
Siluriformes, Eresthistidae										
Hara horai Misra 1976	–	–	–	–	+	–	–	LI	RH	LC
Pseudolaguvia ribeiroi (Hora 1921)	–	–	–	–	+	–	–	LI/PL	RH	LC
Pseudolaguvia foveolata Ng, 2005	–	–	–	–	+	–	–	LI/PL	RH	DD
Siluriformes, Heterpneustidae										
Heteropneustes fossilis (Bloch, 1794)	–	–	–	–	–	–	+	PP	EU	LC
Siluriformes, Olyridae										
Olyra kempi Chaudhuri, 1912	–	+	–	+	+	–	–	LT	RH	LC
Olyra longicaudata McClelland,1842	–	–	–	–	+	–	–	LT	RH	LC
Siluriformes, Siluridae										
Ompok pabda (Hamilton, 1822)	–	–	–	–	+	–	–	PP	RH	NT
Siluriformes, Sisoridae										
Bagarius yarrelli (Sykes 1839)	–	–	–	–	+	–	–	PL	RH	LC
Glyptothorax indicus Talwar, 1991	–	–	–	–	+	–	–	LT/LI	RH	LC
Glyptothorax telchitta (Hamilton 1822)	–	–	–	–	+	–	–	LT/LI	RH	LC
Glyptothorax cavia (Hamilton, 1822)	–	–	–	–	+	–	–	LT/LI	RH	DD
Glyptothorax conirostris (Steindachner, 1867)	–	–	–	–	+	–	–	LT/LI	RH	NT
Glyptothorax striatus (McClelland, 1842)	–	–	–	–	+	–	–	LT/LI	RH	LC
Gogangra viridescens (Hamilton, 1822)	–	–	–	–	+	–	–	PL	RH	LC
Pseudecheneis sulcata (McClelland, 1842)	–	–	+	–	–	–	–	LT	RH	LC
Perciformes, Badidae										
Badis badis (Hamilton, 1822)	–	+	–	+	+	–	–	PP	EU	LC

Table 4. (Cont.)

| Order, Family | | | | | | | | | | |
Species	RK	RP	TB	S	G	D	H	RG	FPG	IUCN
Perciformes, Channidae										
Channa gachua (Hamilton, 1822)	–	–	–	–	+	–	–	PP	EU	LC
Channa marulius (Hamilton, 1822)	+	–	–	–	+	–	–	PP	EU	LC
Channa punctata (Bloch, 1793)	–	–	–	–	+	+	–	PP	EU	LC
Channa stewartii (Playfair, 1867)	–	–	–	–	+	–	–	PS	RH	LC
Perciformes, Gobidae										
Glossogobius giuris (Hamilton 1822)	–	–	–	–	+	–	–	PP	EU	LC
Perciformes, Osphronemidae										
Trichogaster fasciata Bloch & Schneider, 1801	–	–	–	–	+	+	–	PH	EU	LC
Trichogaster lalius (Hamilton, 1822)	–	–	–	–	+	+	–	PH	EU	LC
Perciformes, Ambassidae										
Chanda nama Hamilton, 1822	–	–	–	–	+	–	–	PP	EU	NT
Parambassis lala (Hamilton, 1822)	–	–	–	–	+	+	–	PP	EU	LC
Parambassis ranga (Hamilton, 1822)	–	–	–	–	–	+	–	PP	EU	NT
Synbranchiformes, Mastacembelidae										
Macrognathus aral (Bloch & Schneider, 1801)	–	–	–	–	–	+	–	PS	RH	LC
Macrognathus pancalus Hamilton 1822.	+	–	–	–	+	–	–	PH	EU	LC
Mastacembelus armatus (Lacepède, 1800)	–	–	–	–	+	–	–	PL	RH	LC
Synbranchiformes, Synbranchidae										
Monopterus hodgarti (Chaudhuri, 1913)	–	–	–	–	+	–	–	PL	RH	LC
Beloniformes, Belonidae										
Xenentodon cancila (Hamilton, 1822)	–	–	–	–	+	+	–	PH	EU	LC

Discussion

Already in the 19th century, Eastern European ichthyologists had drawn up a rough clas-sification system for the longitudinal succession of characteristic or dominant fish species that occur in rivers (Holcík, 1989). Huet (1949, 1959, 1962) improved this classic scheme by determining the characteristic physical and chemical parameters of each zone: the slope, the width, the depth, the current velocity and the water temperature. Downstream changes in fish assemblage structure along river courses have been a dominant theme in running water ecology (Hawkes, 1975). Aarts & Nienhuis (2003) divided the entire course of a river, from the spring to the sea, into five basic zones: trout (*Salmo trutta*), grayling (*Thymallu thymallus*), barbel (*Barbus barbus*), bream (*Abramis brama*) and smelt (*Osmeruse perlanus*) zone in near–natural and in regulated large rivers in Europe (the River Doubs in France and the Rivers Rhine and Meuse in the Netherlands). However, no such zonation concept has been applied to Indian rivers as such. In the present study, the stretch of River Teesta in the state of West Bengal, India was classified into four zones based on the physiological attributes of the riverine habitat and accordingly fish assemblage patterns were analyzed. The biodiversity pattern was delineated according to the river continuum model. What sets this model apart from others is the importance of the spatial arrangement of habitats for spawning and regugia (Schlosser, 1991).

Incorporation of the River Continuum Concept in view of multimetric approach considers a river system as a longitudinal gradient of environmental and ecological conditions. This gradient ranges from a heterotrophic headwater regime (allochthonous nutrient sources) to a regime of autotrophy in midreaches (autochthonous production), followed by a gradual return to heterotrophic processes in the semi–lentic downstream waters. In view to the River Continuum Concept, fish diversity and composition of ecological guilds (functional groups) change longitudinally along this river continuum (Van der Velde & Van den Brink, 1994), and the highest biodiversity normally occurs in the midreaches, which are more productive due to warmer temperatures and high nutrient load creating maximum habitat diversity and environmental variations. Fish populations show a shift from cool water species low in diversity to more diverse warm water communities (Huet, 1949; Vannote et al., 1980). In the present study, highest species diversity was recorded at the midreaches (Gojoldoba) and the fish assemblage shifts from tolerant groups to thermally inclined specific groups both upstream and further downstream reaches. The study therefore elaborates the patterns in ecological guild structure that can be inferred from the predictions of the river continuum concept (Ward, 1998; Bhat et al., 2012). Besides, the elevation gradient (driven by water temperature and river substratum variations) seems to act as the main influencing factor for the observed fish assemblage patterns.

Moreover, in our study, the highest species evenness at Gojoldoba and Domohoni stret-ches was attributed to optimal habitat and environment conditions as seen by high water clarity and substratum with mosaic habitat patches. The Teesta River bed can be seen as a mosaic of different substratum patches, *viz*. mainly stones, gravels, sand and silt,that may affect differential nutrient uptake. The size, distribution and density of the patches enable the catchments as a whole to retain nutrients. Variations in patch characteristics that occur over extremes in spatial scales can influence stream structure and function (Angermeier & Karr, 1984; Hunt, 1971; Sheldon, 1968). The dynamics of fish populations are influenced by spatial variations in habitat patch mosaics, ranging in size from localized substratum patches to entire catchments. In stream segments, the presence of instream cover or habitat patches such as undercut banks, logs, etc., are important determinants of fish biomass, species diversity, and community composition. High water clarity ensures an increase in primary production of the aquatic body causing uniform nutrient cycling in the water column. This enables availability of a wide variety of food resources for fishes, so that all feeding groups can be sustained.

Acknowledgements

References

Aarts, B. G. W. & Nienhuis, P. H., 2003. Fish zonations and guilds as the basis for assessment of ecological integrity of large rivers. *Hydrobiologia*, 500: 157–178.

Abell, R., Thieme, M. L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S. C., Bussing, W., Stiassny, M. L. J., Skelton, P., Allen, G. R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J.,. Armijo, E., Higgins, J. V., Heibel, T. J., Wikramanayake, E., Olson, D., López, H. L., Reis, R. E., Lundberg, J. G., Sabaj Pérez, M. H. & Petry, P., 2008. Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *Bioscience,* 58(5): 403–414.

Allen, D. J., Molur, S. & Daniel, B. A., 2010. *The Status and Distribution of Freshwater Biodiversity in the eastern Himalaya. IUCN (International Union for Conservation of Nature).* Publications Services, 28 Rue Mauverney, 1196 Gland, Switzerland.

Angermeer, P. L. & Karr, J. R., 1984. Relationships between eroding debris and fish habitat in a small stream. *Transactions of the American Fisheries Society,* 113: 716–726.

Bain, M. B., Finn, J. T. & Booke, H. E., 1988. Streamflow regulation and fish community structure. *Ecology*, 69: 382–392.

Balon, E. K., 1975a. Reproductive guilds of fishes: a proposal and definition. *J. Fish. Res. Board Can.*, 32: 821–864.

Balon, E. K., 1975b. Ecological guilds of fishes: a short summary of the concept and its application. Verh. Int. Ver. *Theor. Angew. Limnol.*, 19: 2430–2439.

Balon, E. K., 1981. Additions and amendments to the classification of reproductive styles in fishes. *Environ. Biol. Fish.,* 6: 377–389.

Bergers, P. J. M., 1991. Voedselecologie van vissen in de Nederlandse Rijntakken. *Publications and Reports of the Project Ecological Rehabilitation of the River Rhine*, 28: 1–119 (in Dutch, Summary in English). Toernooiveld, 6525 ED Nijmegen.

Bhatt, J. P., Manish, K. & Pandit, M. K., 2012. Elevational Gradients in Fish Diversity in the Himalaya: Water Discharge Is the Key Driver of Distribution Patterns. *Plos one*, 7(9): e46237.

Casatti, L., Ferreira, C. P. & Langeani, F., 2009. A fish–based biotic integrity index for assessment of lowland streams in southeastern Brazil. *Hydrobiologia,* 623: 173–189.

Clarke, K. R. & Gorley, R. N., 2006. PRIMER v6: User Manual/Tutorial. PRIMER–E, Plymouth.

Day, F., 1889. *The fauna of British India: Fishes.* Taylor and Francis, London.

Donaldson, E. M., 1990. Reproductive indices as measures of the effects of environmental stressors in fish. In: *Biological indicators of Stress in Fish*: 109–122 (S. M. Adams, Ed.). American Fisheries Symposium 8, Bethesda, MD.

Fausch, K. D., Christian, E. T., Colden,V. B. & Hiram, W. L., 2002. Landscapes to Riverscapes: Bridging the Gap between Research and Conservation of Stream Fishes. *BioScience,* 52(6): 1–16.

Hawkes, H. A., 1975. River zonation and classification. In: *River Ecology*: 312–374 (B. A. Whitton, Ed.). Oxford, Blackwell.

Holcík, J. (Ed.), 1989. *The Freshwater Fishes of Europe.* Vol. 1, Part II. AULA–Verlag, Wiesbaden.

Hora, S. L. & Gupta, J. C., 1941. On a collection of fish from Kalimpong, Duars and Siliguri Terai, North Bengal. *Journal of Asiatic Society of Bengal*, 47: 183–202.

Horwitz, R. J., 1978. Temporal variability patterns and the distributional patterns of stream fishes. *Ecol. Monogr.*, 48: 307–321.

Huet, M., 1949. Aperçu des relations entre la pente et les populations piscicoles des eaux courantes. Schweiz. Z. Hydrol., 11: 333–351.

Huet, M., 1959. Profiles and biology of Western European streams as related to fish management. *Trans. Am. Fish. Soc.*, 88: 155–163.

Huet, M., 1962. Influence du courant sur la distribution des poisons dans les eaux courantes. *Schweiz. Z. Hydrol.*, 24: 413–432.

Hunt, R. L., 1971. Responses of a brook trout population to habitat development in Lawrence Creek. Wisconsin Department of Natural Resources, Madison, Technical Bulletin No. 48.

IUCN (International Union for Conservation of Nature) http://www.iucnredlist.org.

Jayaram, K. C. & Singh, K. P., 1977. On a collection of fish from North Bengal. *Rec. Zoo. Surv. India,* 72: 243–275.

Jayaram, K. C., 2006. *Catfishes of India.* Delhi, Narendra Publishing House.

Jayaram, K. C., 2010. *The Freshwater Fishes of the Indian Region*, Narendra Publishing House, Revised Second Edition.

Karr, J. R., 1995. Using biological criteria to protect ecological health. In: *Evaluating and Monitoring the Health of Large–Scale Ecosystems*, *NATO ASI Series*, 1(28): 137–152 (D. J. Rapport, C. L. Gaudet & P. Calow, Eds.). Springer–Verlag, Berlin.

Maxwell, J. R., Edwards, C. J., Jensen, M. E., Paustian, S. J., Parrott, H. & Hill, D. M., 1995. *A Hierarchical Framework of Aquatic Ecological Units in North America (Neararctic Zone).* General Technical Report NC–176, St. Paul, MN, U.S. Department of Agriculture, Forest Service.

Meffe, G. K., & Sheldon, A. L., 1988. The influence of habitat structure on–fish assemblage composition in southeastern black water streams. *American Midland Naturalist*, 120: 225–240.

Menon, A. G. K., 1962. A distributional list of fishes of the Himalayas. *J. Zool. Soc. India,* 14 (1 and 2): 23–32.

Menon, A. G. K., 1987. *Fauna of India and the Adjacent Countries: Pisces, Vol. IV; Teleostei – Cobitoidae, Part I, Homalopteridae*, Zoological Survey of India.

Morin, R. & Naiman, R. J., 1990. The relation of stream order to fish community dynamics in boreal forest watersheds. *Pol. Arch. Hydrobiol.,* 37: 135–150.

Noble, R. A. A. & Cowx, I. G., 2007. Assessing the health of European rivers using functional ecological guilds of fish communities: standardising species classification and approaches to metric selection. *Fisheries Management and Ecology*, 14: 381–392.

Pielou, E. C., 1969. *An Introduction to Mathematical Ecology*. Wiley, New York.

Redeke, H. C., 1941. *Fauna van Nederland X (Pisces)*. Sijthoff's, Leiden (in Dutch).

Roberts, T. H. & O'Neil, L. J., 1985. *Species selection for habitat assessments*. Miscellaneous Paper EL–85–8. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

Root, R. B., 1967. The niche exploitation pattern of the blue–gray gnatcatcher. *Ecology,* 37: 317–350.

Schlosser, I. J., 1991. Stream fish ecology:A landscape perspective. *BioScience*, 41: 704–712.

Shannon, C. E. & Weaver, W., 1949. *A Mathematical Model of Communication*. University of Illinois Press, Urbana.

Shaw, G. E. & Shebbeare, E. O., 1937. The Fishes of North Bengal. *Journal of Royal Asiatic Society of Bengal Science,* 3(1): 1–137.

Sheldon, A. L. 1968. Species diversity and longitudinal succession in stream fishes. *Ecology,* 49: 193–198.

Talwar, P. K. & Jhingran, A. G., 1991. *Inland fishes of India and adjacent countries, Volume 1&2.* Oxford and IBH Publishing Company, New Delhi.

Vandewalle, M., De Bello, F., Berg, M. P., Bolger, T., Dole´dec, S., Dubs, F., Feld, C. K., Harrington, R., Harrison, P. A., Lavorel, S., da Silva, P. M., Moretti, M., Niemelä, J., Santos, P., Sattler, T., Sousa, J. P., Sykes, M. T., Vanbergen, A. J. & Woodcock, B. A., 2010. Functional traits as indicators of biodiversity response to land use changes across ecosystems and organisms. *Biodivers. Conserv.*, 19: 2921–2947.

Vannote, R. L., Minshall, G. W. K., Cummins, W., Sedell, J. R. & Cushing, C. E., 1980. The river continuum concept. *Can. J. Fish. Aquat. Sci.,* 37: 130–137.

Van der Velde, G. & Van den Brink, F. W. B., 1994. Does the Rhine still have characteristics of a river ecosystem? The longitudinal distribution of macroinvertebrates. *Water Sci. Technol*., 29: 1–8.

Ward, J. V., 1998. Riverine landscapes: Biodiversity patterns, disturbance regimes, and aquatic conservation. *Biological Conservation*, 83: 269–278.