Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal

Final Progress Report
(2013-2017)

Submitted by:

Prof. (Dr.) Sumit Homechaudhuri

Principal Investigator

Department of Zoology
University of Calcutta

Annexure - III

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002
STATEMENT OF EXPENDITURE IN RESPECT OF MAJOR RESEARCH PROJECT

1.	Name of Principal Investigator	Prof. Sumit Homechaudhuri
2.	Dept. of Principal Investigator	Zoology Department, University of Calcutta
3.	UGC approval Letter No. and Date	F. No. 42-627/2013 (SR) Dated 20.03.2013
4.	Title of the Research Project	Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal
5.	Effective date of starting the project	01.04.2013
6.	a. Period of Expenditure	From 01.04.2013 to 31.03.2017
	b. Details of Expenditure	

Sl. No.	**Item**	**Amount Approved (Rs.)**	**Expenditure Incurred (Rs.)**
i.	Books & Journals	Nil	Nil
ii.	Equipment	30,000/-	25,912/-
iii.	Contingency	50,000/-	50,000/-
iv.	Field Work/Travel (Give details in the proforma at Annexure-IV).	1,00,000/-	99,999/-
v.	Hiring Services	1,00,000/-	1,00,000/-
vi.	Chemicals & Glassware	50,000/-	50,000/-
vii.	Overhead	72,800/-	72,800/-
viii.	Any other items (Please specify)	Nil	Nil

c. Staff
Date of Appointment: 31.05.2013

Sl. No.	Item	From	To	Amount Approved (Rs.)	Expenditure Incurred (Rs.)
1.	Honorarium to PI (Retired Teachers) @ Rs. 18,000/- p.m.	-	-	Nil	Nil
2.	**Project fellow:** (i) Adwitiya Chaudhuri	31.05.2013 (afternoon)	31.12.2014	2,64,000/-	2,52,000/-
	(ii) Anwesha Roy	22.01.2015 (forenoon)	31.03.2016	1,96,000/-	1,82,000/-

1. It is certified that the appointment(s) have been made in accordance with the terms and conditions laid down by the Commission.
2. If as a result of check or audit objection some irregularly is noticed at later date, action will be taken to refund, adjust or regularize the objected amounts.
3. Payment @ revised rates shall be made with arrears on the availability of additional funds.
4. It is certified that the grant of **Rs. 8,19,200.00** (Rupees Eight Lakh Nineteen Thousand and Two Hundred only) received from the University Grants Commission under the scheme of support for Major Research Project entitled **"Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal"** vide UGC letter No. F. **42-627/2013** dated **20.03.2013** has been fully utilized for the purpose for which it was sanctioned and in accordance with the terms and conditions laid down by the University Grants Commission.

SIGNATURE OF PRINCIPAL INVESTIGATOR

Dr. Sumit Homechaudhuri
PROFESSOR OF ZOOLOGY
UNIVERSITY OF CALCUTTA

REGISTRAR

(Seal)

Registrar
University of Calcutta

Annexure -VIII

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002
Final Report of the work done on the Major Research Project (Report to be submitted within 6 weeks after completion of each year)

1.	**Project report No.**	Final
2.	**UGC Reference No.**	F. 42-627/2013 (SR) and 20.03.2013
3.	**Period of report:**	From 31.05.2013 to 16.02.2017
4.	**Title of research project:**	Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal
5.	**(a) Name of the Principal Investigator**	Prof. Sumit Homechaudhuri
	(b) Department	Department of Zoology
	(c) University/College where work has progressed	University of Calcutta
6.	**Effective date of starting of the project**	01.04.2013
7.	**Grant approved and expenditure incurred during the period of the report:**	
	a. Total amount approved Rs.	8,98,800.00 (Eight lakh ninety eight thousand eight hundred only)
	b. Total expenditure Rs.	10,05,182.00 (Ten lakh five thousand one hundred eighty two only)
	c. Report of the work done: Separate sheet attached with brief objectives of the project and details of the performed work and achieved results	
	i. Brief objective of the project	• Survey of ichthyofaunal and macroinvertebrate (representative indicator groups) diversity of the Teesta river main channel and its tributaries in selected templates (Aquatic Ecological Systems, AES) in Darjeeling and Jalpaiguri districts of West Bengal and selection of representative bio indicator taxa / species. • Study of population dynamics of the prioritized bio indicator taxa based on abundance and functional importance. • Evaluation of faunal assemblage metrics and Index of Biotic

		Integrity (IBI) to represent ecological characteristics including richness, habitat and functional guild. • Integrating faunal assemblage pattern in the river stretch with associated landscape dynamics towards evaluation of riverine health. This is in view to the multimetric assessment approach which considers that freshwater ecosystem is a part of the general landscape (watershed/basin/catchment), and any significant modifications in the natural vegetation of their catchments can have detrimental impacts on the native fauna.
	ii. Publications, if any, resulting from the work : Three	1. Chakrabarty, M and Homechaudhuri, S (2013) Fish guild structure along a longitudinally–determined ecological zonation of Teesta, an eastern Himalayan river in West Bengal, India. *Arxius de Miscel·làniaZoològica*, 11: 196–213. ISSN: 1698- 0476. 2. Chakrabarty, M and Homechaudhuri, S (2014) Analysis of trophic gradient through environ-mental filter influencing fish assemblage structure of the river Teesta in Eastern Himalayas. *Journal of Biodiversity and Environmental Sciences (JBES)*, 4(4) 218-232. ISSN: 2222-3045. 3. Roy, A and Homechaudhuri, S (2017) Comparing diversity of freshwater macroinvertebrate community along habitat gradients within a riverine system in North Bengal, India. *Journal of Entomology and Zoology Studies (JEZS)*, 5(4): 86-93. ISSN: 2320-7078.
	iii. Has the progress been according to original plan of work and towards achieving the objective. if not, state reasons	Yes, the progress has been according to the original plan of work and towards achieving the objectives.
	iv. Please indicate the difficulties, if any, experienced in implementing the project	No difficulties were experienced in implementing the project.
	v. If project has not been completed, please indicate the approximate time by	Not Applicable.

	which it is likely to be completed. A summary of the work done for the period (Annual basis) may please be sent to the Commission on a separate sheet.	
	vi. If the project has been completed, please enclose a summary of the findings of the study.	Separate sheet has been enclosed as the summary of the study. One bound copy of the final report of work done is also attached.
	vii. Any other information which would help in evaluation of work done on the project. At the completion of the project, the first report should indicate the output, such as (a) Manpower trained (b) Ph. D. awarded (c) Publication of results (d) other impact, if any	Not Applicable.

Signature of Principal Investigator

Dr. Sumit Homechaudhuri
PROFESSOR OF ZOOLOGY
UNIVERSITY OF CALCUTTA

Signature of Registrar

Registrar
University of Calcutta

(Seal)

Annexure – IX

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING THEFINAL REPORT OF THE WORK DONE ON THE PROJECT

1.	**Title of the Project**	Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal
2.	**NAME AND ADDRESS OF THE PRINCIPAL INVESTIGATOR**	Prof. Sumit Homechaudhuri Office: 35, Ballygunge Circular Road, Kolkata- 700019 Residential: 1203, Tower I, Rupashree, New Town, Kolkata- 700156
3.	**NAME AND ADDRESS OF THE INSTITUTION**	University of Calcutta, 35, Ballygunge Circular Road, Kolkata- 700019
4.	**UGC APPROVAL LETTER NO. AND DATE**	F. No. 42-627/2013 (SR) and 20.03.2013
5.	**DATE OF IMPLEMENTATION**	01.04.2013
6.	**TENURE OF THE PROJECT**	3 years
7.	**TOTAL GRANT ALLOCATED**	9,30,800/-
8.	**TOTAL GRANT RECEIVED**	8,19,200/-
9.	**FINAL EXPENDITURE**	10,05,182/-
10.	**TITLE OF THE PROJECT**	DIVERSITY AND DYNAMICS OF FISH AND MACROINVERTEBRATES OF TEESTA RIVER AND ITS TRIBUTARIES IN WEST BENGAL
11.	**OBJECTIVES OF THE PROJECT**	Please see Annexure
12.	**WHETHER OBJECTIVES WERE ACHIEVED (GIVE DETAILS)**	Please see Annexure
13.	**ACHIEVEMENTS FROM THE PROJECT**	Please see Annexure
14.	**SUMMARY OF THE FINDINGS (IN 500**	Please see Annexure

	WORDS)	
15.	**CONTRIBUTION TO THE SOCIETY (GIVEDETAILS)**	Please see Annexure
16.	**WHETHER ANY PH.D. ENROLLED/PRODUCED OUT OF THE PROJECT**	Not Applicable
17.	**NO. OF PUBLICATIONS OUT OF THE PROJECT (PLEASE ATTACH):**	3 (Reprints attached). Please see Annexure

11. OBJECTIVES OF THE PROJECT:

- Survey of ichthyofaunal and macroinvertebrate diversity of the Teesta river and its tributaries in selected templates in Darjeeling and Jalpaiguri districts of West Bengal and selection of representative bioindicator taxa/species.
- Study of population dynamics of the prioritized bioindicator taxa based on abundance and functional importance.
- Evaluation of faunal assemblage metrics and Index of Biotic Integrity (IBI) to represent ecological characteristics including richness, habitat and functional guild.
- Integrating faunal assemblage pattern in the river stretch with associated landscape dynamics towards evaluation of riverine health.

12. WHETHER OBJECTIVES WERE ACHIEVED (GIVE DETAILS):

The present study designs to find out diversity and dynamics of ichthyofauna and macroinvertebrates of the Teesta river and its tributaries in selected templates in Darjeeling and Jalpaiguri districts of West Bengal.

Further, we studied to evaluate fish guild structure the faunal assemblage metrics and of Biotic Integrity (IBI) to represent ecological variables and functional guild.

The study has enabled to understand the correlation between faunal assemblage patterns and environmental parameters.

Besides, hydrological parameters, ichthyofaunal and macro invertebrate diversity, estimation of overall riverine health through water quality index, physical habitat index have been also addressed. Hence it can be concluded that objectives of our work have been achieved.

13. ACHIEVEMENTS FROM THE PROJECT:

Species diversity and distributional documentation of ichthyofaunal and macro invertebrates at spatial scale have been studied extensively. According to flow regime ecology & spawning habitat selection an ecological more specifically a spawning preference guild has been constructed for beneficial spawning of respective fishes.

A comprehensive assessment of overall beta diversity of the aquatic habitats with regard to spatial and temporal heterogeneity has been done for proper evaluation of the freshwater riverine ecosystem health. Water quality and physical habitat structure have been assessed by Stream. In addition, Water Index (SWI) and Physical Habitat Index (PHI) have been composed to evaluate aquatic and physical quality of the habitats.

A detailed ecological guild composition has been investigated to construct Index of biotic integrity (IBI). In that aspect, relationship between land use and IBI has given a comprehensive picture where, GIS analyses of satellite-derived land use data in the catchments revealed that, at the whole-catchment scale, land use was largely composed of gradients in primary, secondary and open forests followed by agriculture.

14. SUMMARY OF THE FINDINGS:

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 *Bariliusbendelisis*, *Puntiussophore*, *Schisturacorica*, *Lepidocephalichthys guntea*. Ichthyological biodiversity exhibited maximum value in the middle reaches of the river *viz.*Gojoldoba and Domohonidomimated by Cypriniformes (*Aspidopariamorar*, *Bariliusbendelisis*, *Devariodevario*, *Puntiussophore*, *Esomusdanricus*, *Lepidocephalichthysguntea*) and Siluriformes (*Mystusbleekeri*, *Bagariusyarrelli*, *Glyptothoraxtelchitta*, *Glyptothorax striatus*, *Glyptothoraxindicus*,*Glyptothorax cavia*) fishes.

According to water quality Index, among the seven sampling areas four areas (Rishi Khola, Rungpo, Teesta Bazaar and Gojoldoba) had good SWI (Stream Water Index). Two sites (Sevoke and Domohoni) had fair SWI while one site (Haldibari) had poor water quality index.

As per PHI, Physical habitat assessment suggests not so greater disturbance in the stream stretch. Four sampling areas (Rishi khola, Rungpo, Teesta bazaar and Gojoldoba) were analyzed as good, two areas as fair (Sevoke and Domohoni) and one area (Haldibari) as poor which has also been observed to have high impactful human activities.

From the IBI scoring only Gojoldoba was found to be acceptable site compared to others. Although the overall health of the river Teesta has been found to be acceptable, however, the entire stretch may be considered to be in sensitive state (owing to marginal values between acceptable and impaired conditions) and highly prone to environmental degradation.

A total of 1,500 individuals distributed in nine different taxonomic groups belonging to 39 families were identified in different river tributaries ranges from high altitude mountain sites through the forest regions, where Mayflies (Ephemeroptera) were found to be the most dominant followed by Caddisflies (Trichoptera) and Coleopteran insects in the study. Among them the most ubiquitous insects included family Heptagenidae, Beatidae, Hydropsychidae, Psephenidae. Other commonly occurring insects incorporated family Chironomidae, Gerridae, Leptophlebidae, Lymnidae, Ephemerllidae, Perlidae and Vellidae.

Site Murti Banani was found to the highest in Shannon diversity (2.197), Species density (18) and Species richness (4.135) and Teesta River was found to be lowest (0.7315, 4, 1.443 respectively). But Teesta river represented as the highest (27.5) Whittaker Beta Index value whereas Kalikhola River and Murti Banani were found to be lowest (3.222).A decreasing tendency in total abundance was markedly observed along with increasing altitude. In terms of substrates and temporal factors, higher densities were observed in the cobbles, pebbles, gravels, algal mat cover, woody debris, air temperature and water temperature. Bray Curtis Resemblance Matrices produced groups mostly according to macroinvertebrate sample size of the nine study sites. Two major clusters of sites were formed at the level of 40% similarity where River Teesta formed an isolated cluster and while seven major clusters of sites were observed considering 60% level of similarity. The Principal Component Analysis allowed the nine study sites to be taken into account aiming to envisage the environmental resemblance and dissimilarity within the total studied area.

15. CONTRIBUTION TO THE SOCIETY:

The Eastern Himalayan Biodiversity Hotspot region and its foothills are very rich in both floral and faunal diversity. Especially the region being the home of many large torrential rivers, fish diversity is also very rich. 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. There is a lack of baseline information on freshwater fish species distributions and their ecological requirements throughout the Eastern Himalayas. The aim of the present study is to focus on achieving a desired biotic integrity (IBI) that would represent ecological characteristics including richness, habitat and functional guild. It would give a detailed picture on ichthyofaunal and macroinvertebrate diversity and integrating faunal assemblage pattern in the river stretch with associated landscape dynamics towards evaluation of riverine health.

16. WHETHER ANY PH.D. ENROLLED/PRODUCED OUT OF THE PROJECT:

No

17. NO. OF PUBLICATIONS OUT OF THE PROJECT (PLEASE ATTACH):

Full Paper in Journals

Chakrabarty, M and Homechaudhuri, S (2013) Fish guild structure along a longitudinally–determined ecological zonation of Teesta, an eastern Himalayan river in West Bengal, India. *Arxius de Miscel·làniaZoològica*, 11: 196–213. ISSN: 1698- 0476.

[illegible]. Chakrabarty, M and Homechaudhuri, S (2014) Analysis of trophic gradient through environmental filter influencing fish assemblage structure of the river Teesta in Eastern Himalayas. *Journal of Biodiversity and Environmental Sciences (JBES)*, 4(4) 218-232. ISSN: 2222-3045.

[illegible]. Roy, A and Homechaudhuri, S (2017) Comparing diversity of freshwater macroinvertebrate community along habitat gradients within a riverine system in North Bengal, India. *Journal of Entomology and Zoology Studies (JEZS)*, 5(4): 86-93. ISSN: 2320-7078.

Abstracts published in Conference Proceedings

1. Chaudhuri, A, Chakrabarty, M and Homechaudhuri, S (2014) Components of fish diversity of Murti River in an ecologically sensitive area of North Bengal and Fine Filter Approach for conservation. National Conference on Zoology for Future Education and Research. Department of Zoology, Queens Mary's College, Chennai, Zoological Survey of India.
2. Roy, A, Panja, S and Homechaudhuri, S (2017) Functional Diversity of Macroinvertebrate Correlated with Different Habitat Gradient of Some Ecologically Sensitive Rivers in North Bengal. National Conference on ZooCon 2017: Animal Science in 21st Century. Department of Zoology, University of North Bengal.

Signature of Principal Investigator

Dr. Sumit Homechaudhuri
PROFESSOR OF ZOOLOGY
UNIVERSITY OF CALCUTTA

Signature of Registrar

Registrar
University of Calcutta

(Seal)

Prof. (Dr.) Sumit Homechaudhuri
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To
The Vice Chancellor
University of Calcutta
Senate House
87/1, College Street
Kolkata- 700073,
West Bengal
India

Through: Development & Planning Officer, University of Calcutta

Date: 16.08.2017

Sub: Selection of Subject Experts for evaluation of UGC Major Research Project entitled "Diversity and Dynamics of fish and macroinvertebrates of Teesta River and its tributaries in West Bengal" (Sanction No. F.No.42-627/2013 (SR) dated 20.03.13)

Dear Sir,

This is to inform you that we have completed all the official procedures of auditing and the copy of Audit Statement of Expenditure and Utilization Certificate of the project has been sent to UGC, Delhi.

We have completed the final project report (2013-2017) and as per the regulations I would like to request you to select two subject experts for evaluation.

The list of the following five subject experts is given below:

1. **Prof. Narayan Ghorai** Professor Department of Zoology, West Bengal State University, Berunanpukaria, Malikapur, Barasat, District- 24 Parganas (North) Kolkata-700126, West Bengal. Ph. No. 9830595723 Email: nghorai@gmail.com	2. **Prof. Samiran Chakrabarti,** UGC Emeritus Fellow, (Retd.), Department of Zoology, University of Kalyani. Resi: 32/B, Green Park, Belghoria, Kolkata-700056. Ph. 2553-6636(R)/ 94323 23192 (M) Email: chakrabarti32b@gmail.com/
3. **Prof. Susanta Kumar Chakraborty** Professor Department of Zoology, Vidyasagar University, Mednipur, Pin- 721102 Ph. 9433270591 Email: susantachakraborty@yahoo.com	4. **Dr. Ashok Kumar Das,** Scientist, ZSI, (Retd.) Swaranika Housing, Flat No. B(R)-14/6, Biren Roy Road (West), Kolkata- 700061 Ph. 2498-2383, 9830318412
5. **Prof. Anilava Kaviraj,** Professor, (Retd.) Department of Zoology, University of Kalyani Res. D/2 Basona, 30 Nager Bazar Road, Kolkata- 700074 Ph. 033 2551 0021 Email: akaviraj@gmail.com	

With regards
Yours sincerely

Prof. (Dr.) Sumit Homechaudhuri
Professor & Principal Investigator
Aquatic Bioresource Research Laboratory
Department Of Zoology
University Of Calcutta

Roy 17/08/17

Dr. Kausik Bal
Development and Planning Officer
University of Calcutta

Ref. No. : UGC / 627/MRP/2017
Date : 28/08/ 2017

To
Prof. Sumit Homechaudhuri,
~~Department of Zoology,~~
University of Calcutta.

Dear Sir,

With reference to your letter no. nil dated 16/08/2017 regarding selection of two external experts for evaluation of Final Report of Major Research Project, I am to inform you that the Hon'ble Vice-Chancellor, C.U. has approved the following names for this purpose.

1. Prof. Narayan Ghorai, Deptt. of Zoology, West Bengal State University.

2. Prof. Susanta Kumar Chakraborty, Deptt. of Zoology, Vidyasagar University.

This is for your information & necessary action.

Yours Sincerely,
Kausik Bal 28.08.17
Development & Planning officer,
University of Calcutta.

25.08.17

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Annexure – X

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG
NEW DELHI – 110 002

ASSESSMENT CERTIFICATE

(to be submitted with the proposal)

It is certified that the proposal entitled **"Diversity and Dynamics of Fish and Macroinvertebrates of Teesta River and its tributaries in West Bengal"** by **Prof. Dr. Sumit Homechaudhuri, Department of Zoology, University of Calcutta** has been assessed by the 'Evaluation Committee' consisting the following members for final submission to the University Grants Commission, New Delhi:

Details of Expert Committee:

1. **Prof. Narayan Ghorai, Professor,** Department of Zoology, West Bengal State University
2. **Prof. Susanta Kumar Chakraborty,** Professor, Department of Zoology, Vidyasagar University

The Final Report is found to be satisfactory and as per the guidelines.

Narayan Ghorai 06.09.17

Prof. Narayan Ghorai

Narayan Ghorai, Ph.D.
Professor of Zoology
Department of Zoology
West Bengal State University
Barasat,(N) 24-Pgs. Kol-126
West Bengal, India

Chakraborty 08/09/2017
Susanta Kumar Chakraborty

Prof. Susanta Kumar Chakraborty

Dr. Susanta Kr. Chakraborty
Professor of Zoology
Former, Head of the Dipartment
Former, Dean, Faculty of Science
Vidyasagar University
Midnapore, W.B. India

REGISTRAR

(Seal)

Registrar
University of Calcutta

Appendix 1

Final Report of the Work

Project Title:

DIVERSITY AND DYNAMICS OF FISH AND MACROINVERTEBRATES OF TEESTA RIVER AND ITS TRIBUTARIES IN WEST BENGAL

STUDY I (ICHTHYOFAUNAL DIVERSITY AND DYNAMICS)

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). The Eastern Himalayan Biodiversity Hotspot region and its foothills are very rich in both floral and faunal diversity. Especially the region being the home of many large torrential rivers, fish diversity is also very rich. 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. 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.

Scientific documentation of the Ichthyofaunal diversity of the river Teesta drainage basin is poor and there is scanty documentation on its stretch within West Bengal. However, as a whole there are several studies on the fish diversity of all along North Bengal. 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.

Further, as a step towards evaluation of biological integrity, 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), how the origin and use of food resources varied spatially across the riverine stretch has also been assessed.

Moreover, from the various guilds that have been ascertained to the observed fish fauna of River Teesta, an evaluation of biological metrics combined with the physical habitat (instream and riparian zone that influences the structure and function of the ichthyocenosis) as well as water quality has also been analyzed which is critical to any assessment of ecological integrity. The combination of water quality and physical description can provide insight to the presence ofchemical and non-chemical stressors to the streamecosystem and for this reason we analyzed both components in separate ways, always comparing them to regional reference conditions (Barbour et al., 1999; Casatti et al., 2006).

Materials and methods

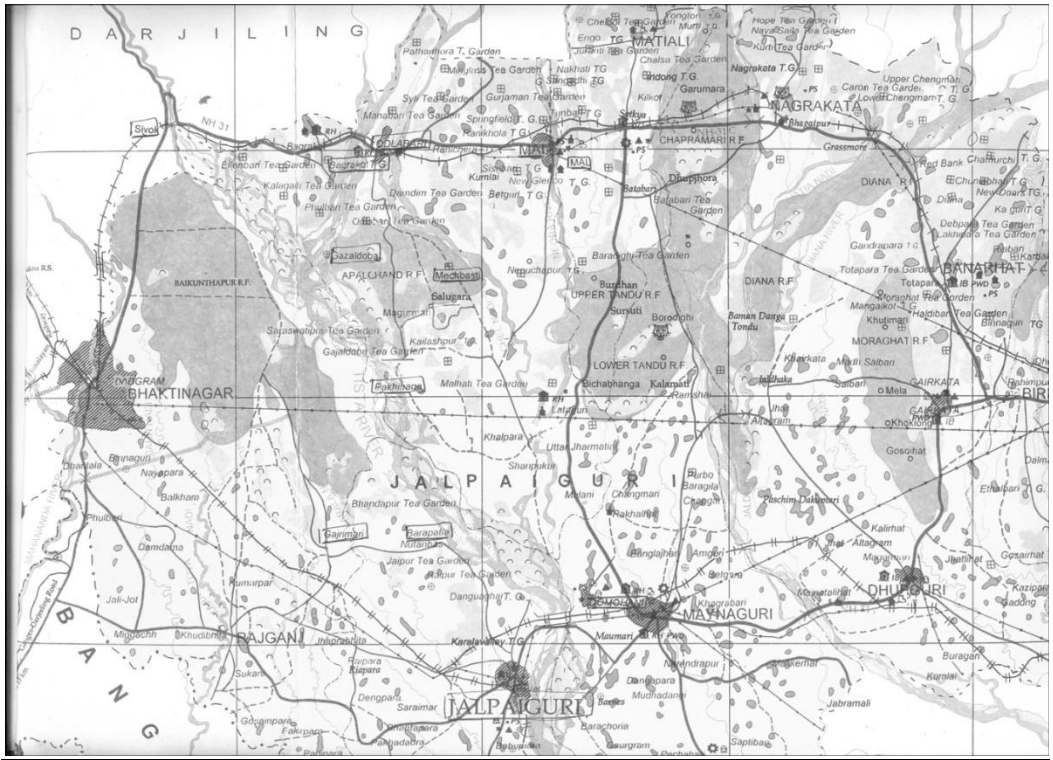


Fig 1: Teesta River drainage in West Bengal, India

Ichthyologic biodiversity in perspective of longitudinal zonation concepts of River Teesta

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.

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 4 sampling sites (approx. 1-2 km apart) totalling 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.

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, 2001). Diversity indices included species richness (d), Pielou's evenness (J') (Pielou, 1969), and Shannon-Wiener (1949) index and Simpson's index of dominance (1-λ).

Fish diversity and indices

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 *Bariliusbendelisis, Puntiussophore, Schisturacorica, Lepidocephalichthys guntea*. Ichthyological biodiversity exhibited maximum value in the middle reaches of the river *viz.* Gojoldoba and Domohoni domimated by Cypriniformes (*Aspidopariamorar*, *Bariliusbendelisis*, *Devariodevario*, *Puntiussophore*, *Esomusdanricus*, *Lepidocephalichthysguntea*) and Siluriformes (*Mystusbleekeri*, *Bagariusyarrelli*, *Glyptothorax telchitta*, *Glyptothorax striatus*, *Glyptothoraxindicus,Glyptothorax cavia*) fishes. 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 reaches *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).

Ecological guilds of the fish fauna

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 ($1km^2$ quadrate area considerations at respective sites) and were accordingly classified into seven spawning preference guilds. 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.

Fish populations 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, the fish in the River Teesta were classified as rheophilic, limnophilic or eurytopic (Fig.10). 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 ($1km^2$ quadrate area considerations at respective sites) and were accordingly classified into seven spawning preference guilds (Fig. 11). Changes in flow preference and reproductive guilds were closely linked: in the rheophilic zone, lithophilic (50.0 – 58.0 %) and psammophilicspawners (15%) were dominant in upper reaches, whereas limnophilic, phytophilicspawners and eurytopic phytolithophilic or polyphilicspawners predominated in lowland reaches. The regions preferred for spawning for respective fish species are illustrated in Table 8.

Sample	S	d	J'	H'(loge)	1-Lambda'
Rishi Khola	9	3.154	0.9307	2.045	0.9273
Rungpo	7	1.78	0.9662	1.88	0.8675
Teesta Bazzar	22	4.543	0.9802	3.03	0.9585
Sevoke	8	1.98	0.9819	2.042	0.8921
Gojoldoba	65	11.56	0.966	4.032	0.9843
Domohoni	20	4.556	0.9641	2.888	0.9559
Haldibari	7	1.675	0.9677	1.883	0.8631

Table 7.Species Diversity indices of the fish community of the River Teesta, West Bengal.

S: Species Richness; d: Species Dominance; J': Species Evenness; H': Shannon diversity index; 1-lambda': Simpson's index.

Table 8. Ichthyofaunal diversity of the River Teesta in West Bengal, India.

Order	Family	Species	RK	RP	TB	S	G	D	H	RG	FPG	IUCN status
Cypriniformes	Cyprinidae	*Amblypharyngodonmola*(Hamilton, 1822)	-	-	-	-	+	+	-	PL	EU	LC
		Aspidopariamorar (Hamilton, 1822)	-	-	-	-	+	-	+	PL	EU	LC
		Aspidoparia jaya (Hamilton, 1822)	-	-	-	-	-	-	+	PL	EU	LC
		Banganadero (Hamilton, 1822)	-	-	-	-	+	-	-	PP	LH	LC
		Bariliusbarna (Hamilton 1822)	-	-	+	-	+	-	-	LI	RH	LC
		Bariliusbarila (Hamilton, 1822)	-	+	+	+	+	-	+	LI	RH	LC
		Bariliusbendelisis (Hamilton, 1807)	-	-	+	+	+	-	-	LI	RH	LC
		Bariliusshacra(Hamilton 1822)	-	-	+	-	-	-	-	LI	RH	LC
		Bariliustileo(Hamilton, 1822)	-	-	-	-	-	+	-	LI	RH	LC
		Bariliusvagra (Hamilton, 1822)	-	-	+	-	+	+	+	LI	RH	LC
		Crossocheiluslatiuslatius (Hamilton, 1822)	-	-	+	-	+	-	-	PL	RH	LC
		Daniodangila (Hamilton, 1822)	-	-	+	-	-	-	-	PL	RH	LC
		Daniorerio (Hamilton, 1822)	+	-	+	-	-	-	-	SP	RH	LC
		Devarioaequipinnatus(McClelland, 1839)	+	-	-	-	-	-	-	PL	RH	LC
		Devariodevario (Hamilton 1822)	-	-	-	-	+	+	-	PL	RH	VU
		Devario acuticephala (Hora, 1921)	-	-	-	-	+	-	-	PL	EU	LC
		Esomusdanricus (Hamilton 1822)	-	-	-	-	+	+	-	PL	EU	LC
		Garraannandalei (Hora, 1921)	-	-	+	-	+	-	-	LI	RH	LC

		Garragotylagotyla (Gray, 1830)	-	-	+	+	-	-	-	LI	RH	LC
		Garralamta (Hamilton, 1822)	-	-	+	+	+	-	-	LI	RH	LC
		Labeopangusia (Hamilton 1822)	-	-	-	-	+	-	-	PH	LH	NT
		Labeo angra (Hamilton, 1822)	-	-	-	-	-	+	+	PH	LH	LC
		Neolissochilushexagonolepis (McClelland, 1839)	-	+	+	-	+	-	+	PS	RH	NT
		Neolissochilushexastichus(McClelland 1839)	-	-	+	-	-	-	-	PS	RH	NT
		Osteobrama cotiocotio (Hamilton, 1822)	-	-	-	-	-	-	+	PL	LH	LC
		Psilorhynchusbalitora(Hamilton, 1822)	+	-	-	-	-	-	-	LT	RH	LC
		Psilorhynchussucatio (Hamilton 1822)	+	-	-	-	+	-	-	LT	RH	LC
		Puntiusconchonius (Hamilton, 1822)	-	-	-	-	+	-	-	PH/PL	EU	LC
		Pethiaphutunio (Hamilton, 1822)	-	-	-	-	+	-	-	PH/PL	EU	LC
		Puntiussarana (Hamilton, 1822)	-	-	-	-	+	-	-	PH/PL	LH	LC
		Puntiussophore (Hamilton 1822)	-	-	-	-	+	+	-	PH/PL	EU	LC
		Puntiusterio(Hamilton, 1822)	+	-	-	-	+	+	-	PH/PL	EU	LC
		Pethiaticto(Hamilton, 1822)	-	-	-	-	+	+	-	PH/PL	EU	LC
		Raiamas bola (Hamilton, 1822)	-	-	-	-	-	+	-	PP	EU	LC
		Rasborarasbora (Hamilton 1822)	-	-	-	-	+	-	-	PP	EU	LC
		Salmophasiabacaila (Hamilton, 1822)	-	-	-	-	+	-	-	PP	LH	LC
		Salmophasiaphulo (Hamilton 1822)	-	-	-	-	+	-	-	PP	LH	LC
		Schizothoraxrichardsonii (Gray 1832)	-	+	+	-	-	-	-	LT	RH	VU
		Tor tor (Hamilton 1822)	-	+	-	-	-	-	-	LT	RH	NT
	Nemacheilidae	*Acanthocobitisbotia* (Hamilton, 1822)	-	-	+	-	+	-	-	LT	RH	LC
		Aborichthys elongatus Hora, 1921	-	-	-	+	-	-	-	LT/LI	RH	LC
		Schisturacorica (Hamilton, 1822)	-	-	+	+	+	-	-	LT	RH	NT
		Schisturadevdevi Hora, 1935	-	-	+	-	-	-	-	LT	RH	LC
		Schistura multifasciata(Day, 1878)	-	-	+	-	-	-	-	LT	RH	LC
		Physoschistura elongata Sen & Nalbant, 1982	-	-	-	+	-	-	-	LT	RH	LC
		Schisturasavona (Hamilton, 1822)	+	-	+	-	+	-	-	LT	RH	LC
		Schisturascaturigina McClelland, 1839	-	-	+	-	+	-	-	LT	RH	LC
		Schistura beavani (Günther, 1868)	-	-	+	-	-	-	-	LT	RH	VU
		Schistura sikmaiensis (Hora, 1921)	-	-	+	-	-	-	-	LT	RH	LC

	Cobitidae	*Botialohachata*Chaudhuri, 1912	-	-	+	-	+	-	-	PS	RH	LC
		*Botiarostrata*Günther, 1868	-	-	-	-	+	-	-	PS	RH	VU
		Canthophrysgongota (Hamilton, 1822)	-	-	-	-	+	-	-	PL	RH	LC
		Lepidocephalichthysannandalei (Chaudhuri, 1912)	-	-	-	-	-	+	-	PS	RH	LC
		Lepidocephalichthysberdmorei(Blyth, 1860)	-	-	-	-	+	-	-	PS	RH	LC
		Lepidocephalichthysguntea (Hamilton, 1822)	-	-	+	-	+	+	-	PS	EU	LC
Siluriformes	Amblycipitidae	*Amblycepsmangois* (Hamilton, 1822)	+	+	-	+	+	-	-	PL	EU	LC
	Bagridae	*Batasiotengana* (Hamilton, 1822)	-	-	-	-	+	-	-	PL	EU	LC
		Mystusbleekeri (Day 1877)	-	-	-	-	+	+	+	PL	EU	LC
		Mystustengara (Hamilton, 1822)	-	-	-	-	+	-	-	PL	EU	LC
		Mystus vittatus (Bloch, 1794)	-	-	-	-	+	+	-	LT	RH	LC
	Chacidae	*Chacachaca* (Hamilton 1822)	-	-	-	-	+	-	-	PP	EU	LC
	Eresthistidae	*Hara horai* Misra 1976	-	-	-	-	+	-	-	LI	RH	LC
		Pseudolaguviaribeiroi (Hora 1921)	-	-	-	-	+	-	-	LI/PL	RH	LC
		Pseudolaguvia foveolata Ng, 2005	-	-	-	-	+	-	-	LI/PL	RH	DD
	Heterpneustidae	*Heteropneustes fossilis* (Bloch, 1794)	-	-	-	-	-	-	+	PP	EU	LC
	Olyridae	*Olyra kempi* Chaudhuri, 1912	-	+	-	+	+	-	-	LT	RH	LC
		Olyra longicaudata McClelland,1842	-	-	-	-	+	-	-	LT	RH	LC
	Siluridae	*Ompok pabda* (Hamilton, 1822)	-	-	-	-	+	-	-	PP	RH	NT
	Sisoridae	*Bagariusyarrelli* (Sykes 1839)	-	-	-	-	+	-	-	PL	RH	LC
		*Glyptothoraxindicus*Talwar, 1991	-	-	-	-	+	-	-	LT/LI	RH	LC
		Glyptothoraxtelchitta (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
		Pseudecheneissulcata (McClelland, 1842)	-	-	+	-	-	-	-	LT	RH	LC
Perciformes	Badidae	*Badisbadis* (Hamilton, 1822)	-	+	-	+	+	-	-	PP	EU	LC
	Channidae	*Channagachua* (Hamilton, 1822)	-	-	-	-	+	-	-	PP	EU	LC
		Channamarulius (Hamilton, 1822)	+	-	-	-	+	-	-	PP	EU	LC

		Channapunctata (Bloch, 1793)	-	-	-	-	+	+	-	PP	EU	LC
		Channastewartii (Playfair, 1867)	-	-	-	-	+	-	-	PS	RH	LC
	Gobidae	*Glossogobiusgiuris*(Hamilton 1822)	-	-	-	-	+	-	-	PP	EU	LC
	Osphronemidae	*Trichogasterfasciata* Bloch & Schneider, 1801	-	-	-	-	+	+	-	PH	EU	LC
		Trichogasterlalius (Hamilton, 1822)	-	-	-	-	+	+	-	PH	EU	LC
	Ambassidae	*Chandanama* Hamilton, 1822	-	-	-	-	+	-	-	PP	EU	NT
		Parambassislala (Hamilton, 1822)	-	-	-	-	+	+	-	PP	EU	LC
		Parambassisranga(Hamilton, 1822)	-	-	-	-	-	+	-	PP	EU	NT
Synbranchiformes	Mastacembelidae	*Macrognathusaral* (Bloch & Schneider, 1801)	-	-	-	-	-	+	-	PS	RH	LC
		Macrognathuspancalus Hamilton 1822.	+	-	-	-	+	-	-	PH	EU	LC
		Mastacembelusarmatus (Lacepède, 1800)	-	-	-	-	+	-	-	PL	RH	LC
	Synbranchidae	*Monopterus hodgarti* (Chaudhuri, 1913)	-	-	-	-	+	-	-	PL	RH	LC
Beloniformes	Belonidae	*Xenentodoncancila* (Hamilton, 1822)	-	-	-	-	+	+	-	PH	EU	LC

RK: Rishi Khola; RP: Rungpo; TB: Teesta Bazaar; S: Sevoke; G: Gojoldoba; D: Domohoni; H: Haldibari; RG: Reproductive guild; + present; - absent

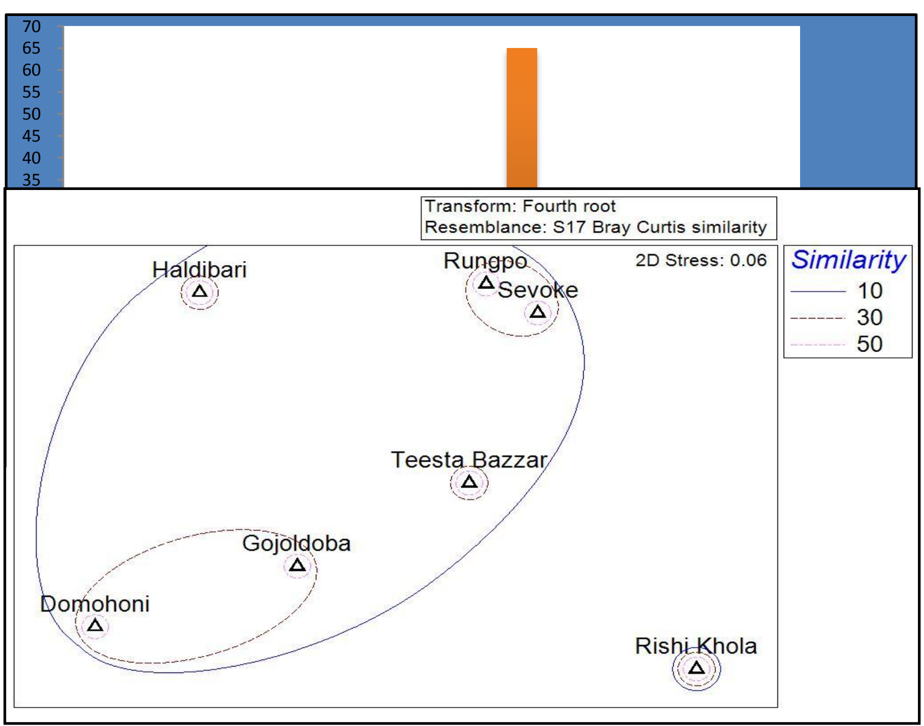


Fig. 8 (a & b).

a) Species richness (S) and Shannon-Wiener diversity index (H') along respective sites of stretch of River Teesta at West Bengal.

b) Two-dimensional MDS ordination plot of the sites based on species abundance.

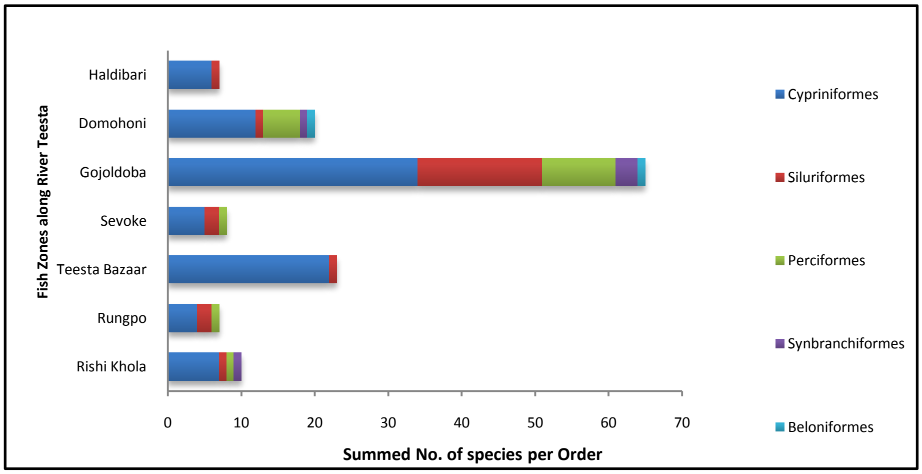


Fig 9. Taxonomic composition of fish zones of River Teesta in West Bengal.

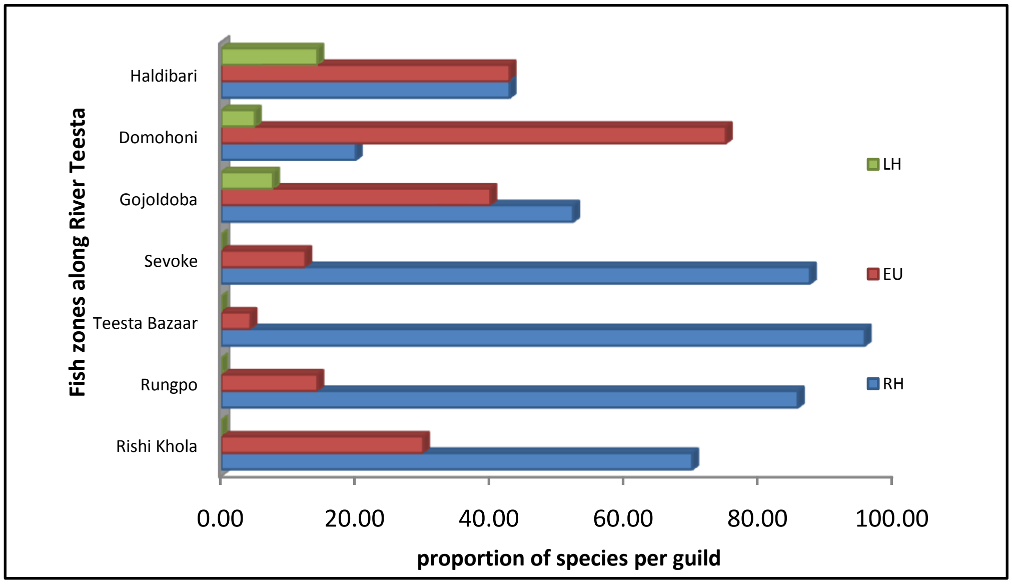


Fig 10. Composition of flow preference guilds of the ecological fish zones of River Teesta. RH.Rheophilic; EU.Eurytopic; LH.Limnophilic.

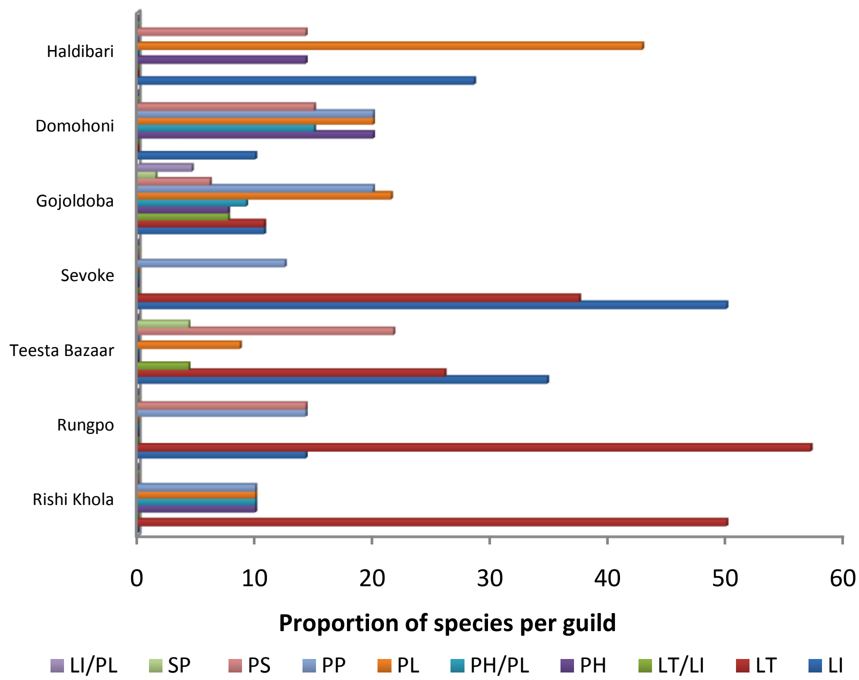


Fig 11. Composition of spawning preference guilds of the ecological fish zones of River Teesta. LT. Lithophils; PH. Phytophils; PL. Phytolithiphils; PS. Psammophils; LI. Lithopelagophils; SP. Speleophils; PP. Polyphils.

Environmental stimulants in functional group structure

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 (TerBraak&Verdonschot, 1995).

Environmental characteristics (Table 10) were measured for pH, Dissolved Oxygen (DO), Temperature (WT & AT), pH, Conductivity (CON), Turbidity (TUR),Water current (WC) and Salinity (SAL). Draftsmann's plot (Fig.13) shows the retained chemical parameters retained for the analysis of the fish assemblage relation with the abiotic environment. PCA analysis shows the positions of the environmental vectors indicate their correlation to the axes as well as to each other (Table 11 & Fig. 14). Moreover, it was observed that water temperature and water velocity show marked changes in respect to altitudinal variation (Fig. 15).

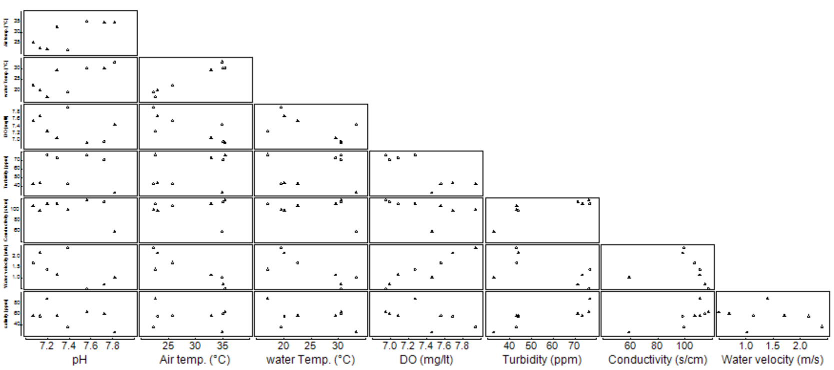


Fig 13. Draftsman plot (all possible pair wise scatter plots) for the seven abiotic variables recorded at seven sampling zones along the river Teesta.

Table 10. Environmental Parameters of River Teesta.

		pH	**AT (°C)**	**WT (°C)**	**DO (mg/lt)**	**TUR (ppm)**	**CON (s/cm)**	**WC (m/s)**	**SAL (ppm)**
	stndev	0.16	1.14	0.92	0.10	1.78	0.34	0.36	2.55
Rungpo	avg	7.13	22.98	20.10	7.69	43.93	98.23	2.16	56.00
	stndev	0.09	1.06	0.51	0.07	1.24	1.12	0.21	0.99
Teesta Bazar	avg	7.07	25.72	22.53	7.56	43.14	107.10	1.71	56.95
	stndev	0.07	1.13	1.92	0.10	1.52	3.21	0.10	1.31
Sevoke	avg	7.19	22.57	17.03	7.28	76.78	110.93	1.40	88.10
	stndev	0.09	2.60	0.99	0.11	1.24	0.78	0.11	0.85
Gojoldoba	avg	7.28	32.82	29.52	7.09	73.28	110.85	1.14	56.47
	stndev	0.17	2.04	1.01	0.07	1.68	0.81	0.15	1.94

Domohoni	avg	7.72	35.02	30.47	6.99	71.18	114.73	0.70	60.60
	stndev	0.43	0.57	0.31	0.12	0.90	1.20	0.18	0.92
Haldibari	avg	7.56	35.38	30.53	6.95	76.32	117.20	0.50	63.42
	stndev	0.11	1.32	0.53	0.11	1.34	2.21	0.04	0.97

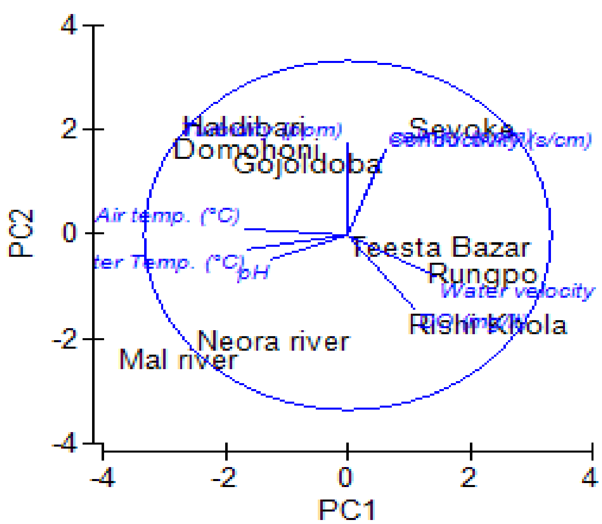


Table 11. Principal Component axis values

Fig 14. Principle component analysis of the environmental correlates

Canonical component analysis (CCA) ordination graph (Fig. 16) showed that the major fish assemblage groups based on their feeding habits along longitudinal gradient of River Teesta in West Bengal are positively correlated with 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 ($p < 0.05$).

PC	Eigenvalues	%Variation	Cum.%Variation
1	3.88	48.6	48.6
2	3.26	40.8	89.3
3	0.494	6.2	95.5
4	0.242	3	98.5
5	9.02E-02	1.1	99.7

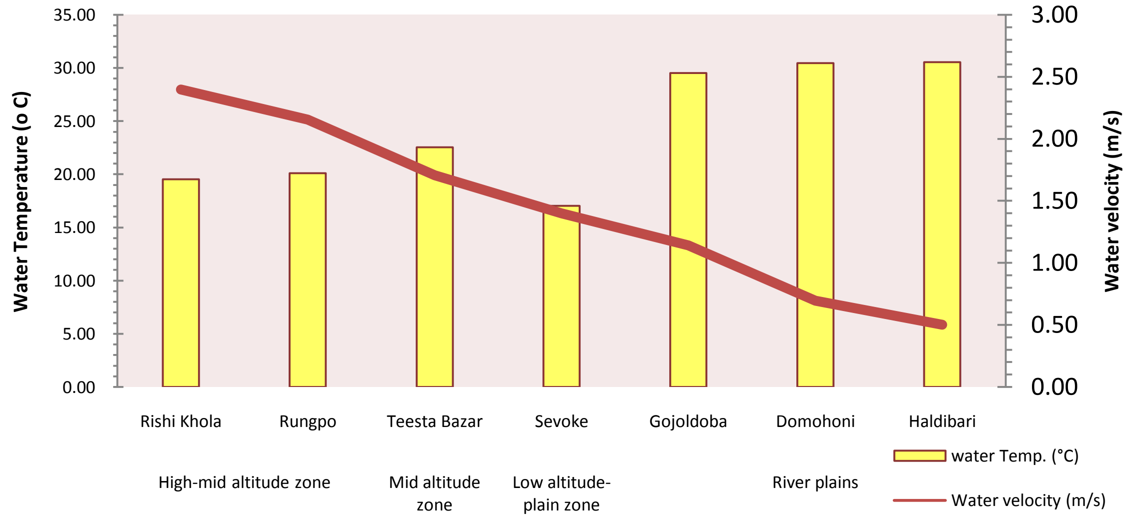


Fig 15.Variations of key water chemical components within sites.

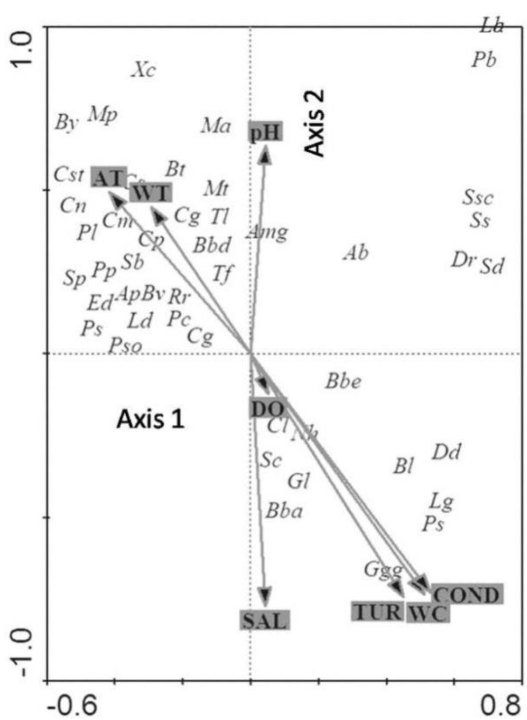


Fig 16. CCA plot showing species scores along environmental vectors.

Shepard diagram (Fig.17) shows a scatter plot that is drawn of distance against dissimilarity for pairs of values. The plot is used to determine stress level among the zones. The figure represents a non-parametric regression line. This is a best fitting line which modules itself to the shape of scatter plot. Large scatter clearly indicate large stress and vice-versa. This diagram based on chemical components of water shows that the zones are in less stressed condition as seen by small scatter of values. However, stress factor will be further evaluated based on index scoring method in the following sections.

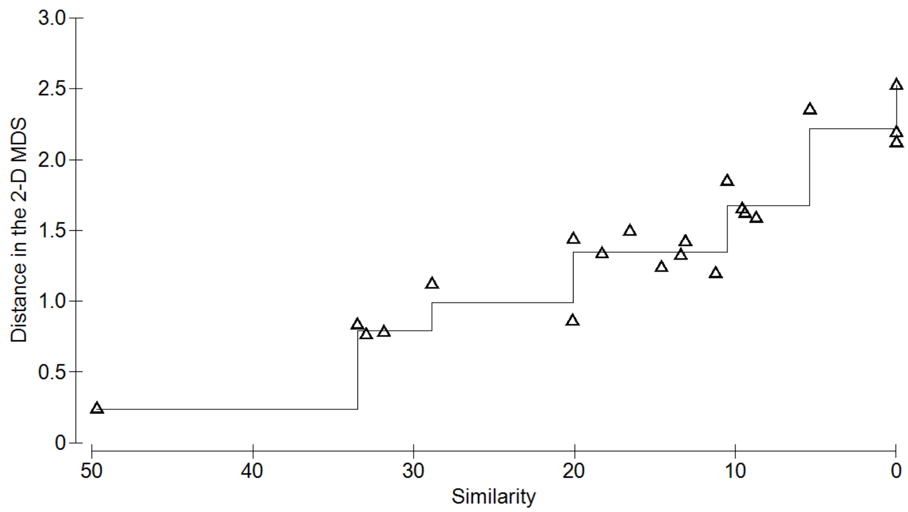


Fig17. Shepard diagram of the distances in MDS plot against the dissimilarities in the Bray-Curtis matrix.

Analysis and development of abiotic component (habitat quality) and biotic traits (Index of biotic integrity) for River Teesta in West Bengal.

Developing water quality Index for River Teesta

A water quality index for small streams (Stream Water Index, SWI) of the upper Rio Paraná basin was proposed by Casatti et al. 2006. It includes physicochemical descriptors usually linked to fish health, specifically dissolved oxygen, conductivity, pH, turbidity (all measured through digital meter). Based on the above study and continuous scoring method by Ganasan and Hughes, 1998, the present scoring criteria has been modified. Scores 4 to 1 were determined based on their deviation from the reference conditions and the final score for each site was derived by multiplying the summed score for individual metrics at each site and divided by the number of metrics scored (four in this case) to avoid percentage anomalies. The final scores were classified in four categories *viz.* good, fair, poor, very poor.

Developing of Physical habitat Index for River Teesta

For the physical assessment of the habitat, a visual-based habitat approach was conducted. Many protocols are applied around the world, all of them including descriptors which describe the stream micro/macro features, riparian condition, and bank structure (Barbour et al., 1999).

Scores were established a priori according to reference conditions, usually separating sites into high-gradient and low-gradient reaches. To minimize subjectivity, the same person evaluated all sites. All descriptors were evaluated and rated on a numerical scale of 0 to 20 for each sampling reach. The sum of all scores represented three habitat integrity categories (Pool substrate, Velocity/ Depth combination and Riparian vegetation zone width) of the Physical Habitat Index (PHI).

Developing the Fish-IBI for the Teesta river

A careful selection of the metrics was made aiming to assure that various aspects of the fish communities were assessed (measures of richness, composition, habitat use and trophic status), in order to represent different responses, thus increasing the ecological information included in the index (Barbour et al., 1999). The species richness and abundance were obtained and these were later used for calculation of biological metrics. Dominance was calculated using Simpson index with the computational software PRIMER V6 and values close to zero indicate low dominance. Based on literature data and present study, fish assemblage in River Teesta was classified according to its richness (native species), composition and dominance (Karr, 1981; Ferreira & Casatti, 2006; Snyder et al., 2004). Further each species was assigned a guild according to its habitat use (Karr, 1981; Snyder et al., 2003; Lyons, et al. 1995; Harris, 1995; Ferreira & Casatti, 2006), trophic structure (Snyder et al., 2004; Harris et al., 1999; Harris et al., 2000; Snyder et al., 2005) and reproductive habitat preference (Snyder et al., 2007). The IBI as proposed by Karr (1981) includes 12 metrics that were adjusted worldwide depending on habitat features, bio-geographical regions, and several environmental factors (Karr & Chu, 1999). A) qualitative analysis of attributes listed in the literature was conducted (Hughes & Oberdorff 1998, Casatti et al., 2009; Karr, 1981;Casatti & Teresa, 2012; Ganasan & Hughes, 1998; Baptista et al., 2007) and metrics were selected following metrics sensitivity test (Box-and-whiskers plot) and metrics redundancy analysis (Spearman correlation test) for the present local fish fauna of Teesta river. The IBI was calculated for each site according to the methods of Ganasan and Hughes, 1998; Fauschet al. (1984), Hughes & Gammon (1987) and Hughes et al. (1993). After the set of metrics was identified, the individual metrics to be used in the IBI were scored as 1, 3, or 5 on the basis of comparisons with the distributions of the metric values at the reference site. A score of 5 indicates that a sample can be considered equivalent to the reference condition, a score of 3 indicates an intermediate condition, and a score of 1 indicates the greatest deviation from the expected reference condition (Baptista et al., 2007). Trisections of maximum obtained values when those were considered indicative of least disturbed conditions (number of native species, number of siluriformes, percentage of siluriformes richness, number of cyprnid species, number of species of suckers, number of benthic species, percentage abundance of benthic species, number of rheophilic species, percentage abundance of rheophilic species, percentage of fish as maco-carnivores, percentage of fish as macro-carnivores, percentage of fish as insectivores and percentage of fish as lithophilic spawners). When minimum values were considered indicative of least disturbed conditions (% omnivores, Dominance and % of micro-carnivores), the minimum metric values were doubled to determine the range receiving a 5. The values were doubled this again to set scoring criteria for a score of 3.

A continuous score of the metrics from 0 to 10 and the IBI from 0 to 100 was also calculated as proposed by Minns et al. (1994) and following Ganasan and Hughes, 1998. Upper thresholds were based on the highest value obtained for most metrics in this study (scored as 10) and lower thresholds were zero (scored as 0) for most metrics. For the omnivore and tolerant metrics (where high scores are considered undesirable), the upper thresholds were the lowest scores for each metric and the lower thresholds were 50%. We set the upper and lower thresholds at 0% and 50%, respectively, for non natives because they would have been absent from natural rivers.

Qualitative evaluations (acceptable, marginally impaired/ fair, impaired) were given to the total IBI scores in a manner similar to that of Hughes et al. (1998) and Karr et al. (1986). An impaired IBI score was one that was less than 60% of the maximum (Karr et al., 1986 called these poor or very poor). A marginally impaired score was one ranging between 60% and 80% of the highest score; Karr et al. (1986) considered these fair. Since most of the scores fall into this range and it is difficult to state whether they represent an acceptable or impaired condition, hence the term marginally impaired was proposed by Ganasan& Hughes, 1998.

Water quality Index for River Teesta

Among the seven sampling areas four areas (Rishi Khola, Rungpo, Teesta Bazaar and Gojoldoba) had good SWI (Stream Water Index). Two sites (Sevoke and Domohoni) had fair SWI while one site (Haldibari) had poor water quality index (Table 6).

Physical Habitat Index (PHI) for River Teesta

Physical habitat assessment suggests not so greater disturbance in the stream stretch. Four sampling areas (Rishikhola, Rungpo, Teesta bazaar and Gojoldoba)were analyzed as good, two areas as fair (Sevoke and Domohoni) and one area (Haldibari) as poor which has also been observed to have high impactful human activities (Table 7).

IBI scoring for River Teesta

Box-and-Whisker plots were used to determine if a metric was sensitive, i.e. if it could be used to discriminate between reference and impaired sites. From the candidate metrics evaluated in this study, 15 were considered sensitive according to this test, with a sensitivity score 3 between reference and impaired sites, and statistically different according to the Mann–Whitney U-test ($p < 0.05$). further following spearman correlation test, the final metrics used were: total number of fish species, Dominance (Simpson index), number of siluriformes, percentage of siluriformes richness, number of cyprnid species, number of species of suckers, number of benthic species, percentage abundance of benthic species, number of rheophilic species, percentage abundance of rheophilic species, percentage of fish as generalist (omnivores) feeders, percentage of fish as maco-carnivores, percentage of fish as micro-carnivores, percentage of fish as insectivores and percentage of fish as lithophilic spawners. The metric score was found to be highest at Gojoldoba based from both traditional as well as continuous scoring method. Overall the differing scoring methods made little difference in IBI metric scores or assessments of integrity (Table 8). The omnivore metric appeared to perform differently when scored continuously (0±10) than when scored traditionally (1, 3 or 5), receiving relatively high scores at many sites compared to scores resulting from continuous scoring. Two sites (Teesta bazaar and Haldibari) fell into different integrity classes as a result of the scoring methods. These distinctions may have resulted from the scoring criteria used or the tendency for small differences in metric values to occasionally produce relatively large differences when scored as 1, 3or 5. From the IBI scoring only Gojoldoba was found to be acceptable site compared to others. Although the overall health of the river Teesta has been found to be acceptable, however, the entire stretch may be considered to be in sensitive state (owing to marginal values between acceptable and impaired conditions) and highly prone to environmental degradation.

Relationship between landuse and IBI

Landuse analysis of the catchment area of River Teesta

Land-use dynamics was analysed for the catchments of the streams studied for fish using spatial remote sensing data (Pinto et al., 2006; Snyder et al., 2003; Sreekantha et al., 2007). Survey of India toposheet of scale 1: 50,000 which cover the Teesta River basin were used for digitization of base layers such as region's boundary, vegetation types, forest types and drainage networks. Satellite imageries of ISRO (NRSC), provide the entire image of the Teesta catchment region. The spatial data were geometrically corrected taking the location (latitude and longitude) values of known points from the image as well as their corresponding ground values with the help of Survey of India toposheet and ground control points (GCPs) using Global Positioning Systems GPS (E-Trex Vista). Supervised classification technique based on Gaussian maximum likelihood algorithm was used for land-use analysis. The land-use categories of the entire study stretch of River Teesta has been equally divided into eight zones and percentage vegetation cover of the catchment area have been delineated respectively for each zone. A local buffer area of $8km^2$ was assessed (2 km upriver and 2 km down river of the sampling site, and 1 km land ward from each river margin).

Land-use patterns of the catchment area of River Teesta

GIS analyses of satellite-derived land use data in the catchments revealed that, at the whole-catchment scale, land use was largely composed of gradients in primary, secondary and open forests followed by agriculture (Table 9). Other land uses including scrub land, water mud, secondary water mud and settlement categories represented relatively minor components of the watershed (< 5% combined). Agriculture although was not associated with the upper stretch (high altitude-mid altitude zone: Rishi khola, Rungpo, Teesta bazaar and Sevoke) of the river, it significantly contributed in the lower stretches (river plains: Domohoni and Haldibari).

Relationships between IBI, landuse and fish assemblage

Correlation strengths between IBI, land use attributes, riparian zone width and species richness varied with sites. (Table 10). Species richness is negatively correlated to settlement, agriculture and water mud while positively with primary and secondary forest and riparian width. This linkage is highly depictive of strong association of species diversity with that of habitat quality and land-use forms. Water mud seems to significantly influence (p-values <0.05) species richness across the riverine stretch. IBI seem to be significantly affected by agricultural land form.

Development of Fish-IBI (Index of Biotic Integrity) for River Teesta in West Bengal

In general, little difference in IBI metric scores was observed due to the differing scoring methods made on assessments of integrity (Table 14). Three (Rishi khola, Rungpo and Sevoke) out of seven sites were considered moderately impaired, only one site (Gojoldoba) was considered as acceptable and one site (Domohoni) as impaired based on both traditional as well as continuous scoring methods (Fig. 24). The macro-carnivore metric appeared to perform differently when scored continuously (0–10) than traditionally (1, 3, 5) having relatively high scores at many sites in continuous scoring than its traditional score. Two sites (Teesta bazaar and Haldibari) fell into different integrity classes as a result of the scoring methods. These distinctions may have resulted from the scoring criteria used or the tendency for small differences in metric values to occasionally produce relatively large differences when scored as 1, 3or 5. From the IBI scoring only Gojoldoba was found to be acceptable site compared to others. Although the overall health of the river Teesta has been found to be moderately acceptable, however, the entire stretch may be considered to be in sensitive state (owing to marginal values between acceptable and impaired conditions) and highly prone to environmental degradation. Detailed descriptions of the river Teesta biological integrity associated with each of the IBI categories has been given in Table 15.

Table 14. IBI metric values (Traditional and Continuous scores) of the seven sites along longitudinal stretch of River Teesta in West Bengal.

Candidate Metrics	RK		R		TB		S		G		D		H	
	TS	**CS**	TS	**CS**	TS	**CS**	TS	**CS**	TS	**CS**	TS	**CS**	TS	**CS**
Total no. of native fish species	3	**1.5**	1	**1.0**	5	**3.5**	3	**1.2**	5	**10.0**	3	**3.0**	1	**1.0**
Dominance (Simpson index)	3	**0.5**	5	**0.0**	1	**2.5**	5	**0.2**	1	**9.0**	1	**2.0**	5	**0.0**
No. of siluriformes	1	**0.5**	1	**1.1**	1	**0.5**	1	**1.1**	5	**10.0**	1	**0.5**	1	**0.5**
percentage of siluriformes richness	3	**3.5**	5	**10.0**	1	**1.5**	3	**8.7**	5	**9.1**	1	**1.7**	3	**5.0**
No. of cyprnid species	3	**2.1**	1	**1.2**	5	**6.5**	1	**1.5**	5	**10.0**	3	**3.5**	3	**1.8**
No. of species of suckers	1	**0.0**	1	**0.0**	5	**6.7**	3	**3.3**	5	**10.0**	1	**0.0**	1	**0.0**
Number of benthic species	3	**1.5**	1	**1.1**	3	**3.6**	3	**1.5**	5	**10.0**	3	**3.6**	1	**1.3**
Percentage abundance of benthic species	1	**8.0**	3	**8.2**	3	**8.4**	5	**10.0**	3	**8.3**	3	**9.7**	5	**9.8**
Number of rheophilic species	3	**2.1**	3	**1.8**	5	**6.5**	3	**2.1**	5	**10.0**	1	**1.2**	1	**0.9**
Percentage abundance of rheophilic species	3	**7.3**	3	**9.0**	5	**10.0**	5	**9.1**	3	**5.5**	1	**2.1**	1	**4.5**
% of fish as generalist (omnivores) feeeders	5	**8.9**	3	**6.8**	3	**7.6**	3	**5.8**	3	**6.8**	1	**5.0**	3	**6.8**
% of fish as maco-carnivores	3	**4.1**	1	**0.0**	1	**0.0**	1	**0.0**	5	**10.0**	3	**6.1**	3	**5.8**
% of fish as micro-carnivores	1	**9.0**	5	**10.0**	1	**9.1**	5	**10.0**	1	**9.2**	3	**9.5**	5	**10.0**
% of fish as insectivores	5	**10.0**	3	**2.9**	5	**7.8**	3	**5.0**	3	**2.5**	1	**2.0**	1	**0.0**
% of fish as lithophilicspawners	5	**8.8**	5	**10.0**	3	**4.6**	3	**6.6**	3	**1.9**	1	**0.0**	1	**0.0**
IBI score	43	**44.0**	41	**42.0**	47	**49.0**	47	**44.0**	57	**69.0**	27	**31.0**	35	**32.0**
Evaluation	MI	**MI**	MI	**MI**	A	**MI**	MI	**MI**	A	**A**	I	**I**	MI	**I**

*RK: Rishi Khola; R: Rungpo; TB: Teesta Bazaar; S: Sevoke; G: Gojoldoba; D: Domohoni; H: Haldibari; TS: Traditional Scoring; CS: Continuous Scoring; A: Acceptable, MI: Moderately Acceptable; I: Impaired

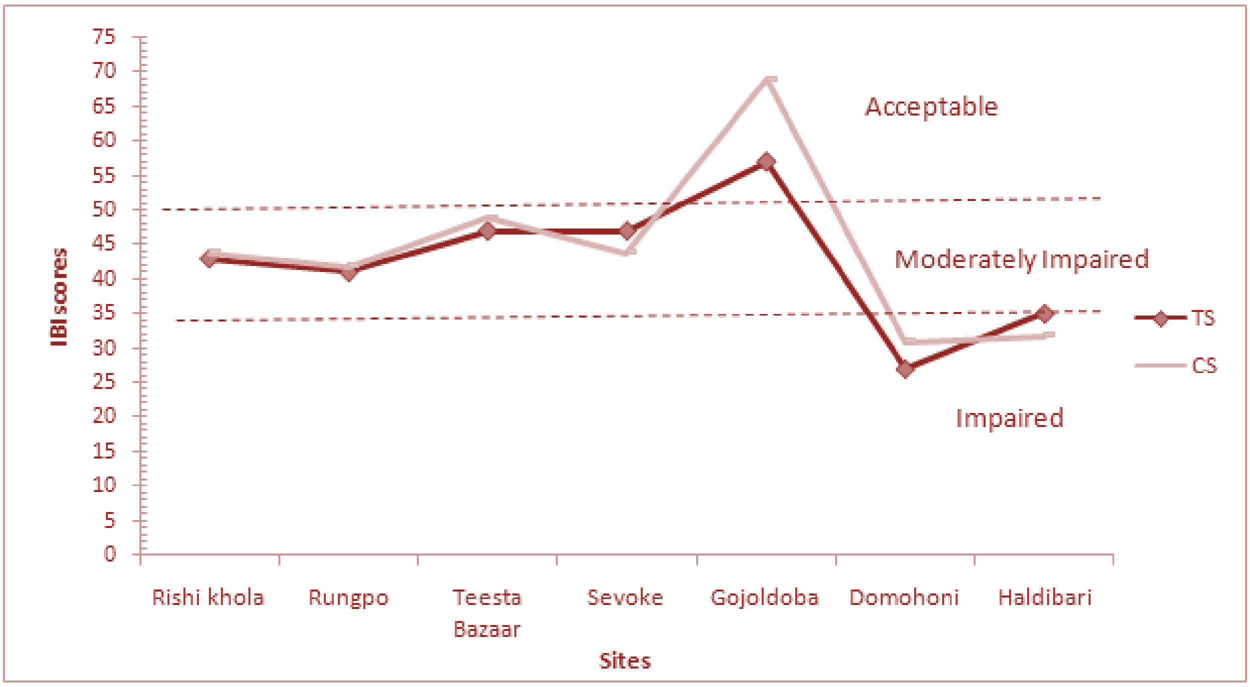


Fig 24. Index of biological integrity scores for each site in the River Teesta using traditional stepwise (1, 3, 5) and continuous (0–10) metric scoring. Maximum score for traditional is 57.

Table 15. Detailed descriptions of riverine biological integrity associated with each of the IBI categories (adapted from Casatti and Ferreira, 2009)

Categories	Values		Description
	TS	CS	
Acceptable	>46	>49	Comparable with reference values (highest metric value among all sites) and regarded as minimally affected. Includes biological metrics fall within the upper 80 % of the reference value.
Moderately Impaired	34-46	41-49	Comparable with reference values (highest metric value among all sites) but some aspects of biological metrics compromised. Includes biological metrics fall within 80% and 60 % of the reference value.
Impaired	<34	<41	Strong deviation from reference condition indicating severe

		degradation. Includes biological metrics fall below 60% of the reference value.

*TS: Traditional Scoring; CS: Continuous Scoring

Development of Stream Water Index (SWI) and its comparison with IBI for River Teesta in West Bengal

Among the seven sampling areas four areas (Rishi Khola, Rungpo, Teesta Bazaar and Gojoldoba) had good SWI (Stream Water Index). Two sites (Sevoke and Domohoni) had fair SWI while one site (Haldibari) had poor water quality index (Table 16). Comparing the analysis of Fish-IBI and SWI, sites Domohoni and Haldibari is seen to have poor environmental conditions, whereas Gojoldoba sustains good aquatic health as depicted from both the indices. However, Rishi Khola and Rungpo seem to behave differently under the two different metrics evaluation.

Table 16. Water quality Index scoring of River Teesta in West Bengal

	Rishi Khola	Rungpo	Teesta Bazar	Sevoke	Gojoldoba	Domohoni	Haldibari
pH	4	4	4	4	4	4	4
DO (mg/lt)	4	4	3	3	3	2	2
Turbidity (ppm)	3	3	3	1	2	3	1
Conductivity (µS/cm)	3	3	2	2	3	1	1
IBI score	14	14	12	10	12	10	8
Evaluation	good	good	good	fair	good	fair	poor

*DO: Dissolved Oxygen; IBI: Index of Biotic Integrity

Landuse dynamics of the Riparian cover of River Teesta and its relationship with Index of Biotic Intergrity.

Land-use patterns of the catchment area of River Teesta

GIS analyses of satellite-derived land use data in the catchments revealed that along the whole-longitudinal stretch of River Teesta in West Bengal (divided into eight equal zones), land use was largely composed of gradients in primary, secondary and open forests followed by agriculture (Table 17 & Fig. 25). Other land uses including scrub land, water mud, secondary water mud and settlement categories represented relatively minor components of the watershed (< 5% combined). Agriculture although was not associated with the upper stretch (high altitude-mid altitude zone: Rishi khola, Rungpo, Teesta bazaar and Sevoke) of the river, it significantly contributed in the lower stretches (river plains: Domohoni and Haldibari).

land use categories	1	2	3	4	5	6	7	8	overall
Unclassified	0.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1
Shadow	7.38	5.17	8.75	14.13	2.44	6.67	0.00	0.00	5.3
Scrub land	0.02	0.47	7.93	1.34	0.33	0.38	4.23	0.00	2.0
Open Forest	17.28	39.63	11.28	13.68	9.58	0.46	2.13	38.71	15.8
river water	3.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.4
water mud	1.49	1.46	0.60	5.09	11.56	3.00	2.79	6.73	4.0
Settlement	0.85	0.07	8.51	2.24	0.66	0.22	0.02	0.12	1.5
Secondary Forest	5.30	13.27	9.03	10.48	26.75	38.71	13.69	5.37	15.2
Primary Forest	63.37	37.57	51.49	51.89	44.30	18.15	50.24	27.22	43.4
water	0.00	2.35	2.41	1.15	1.21	3.32	4.37	3.79	2.4
Agriculture	0.00	0.00	0.00	0.00	0.00	24.44	12.76	7.78	6.0
Secondary Water	0.00	0.00	0.00	0.00	0.00	4.64	6.42	2.71	2.0
Secondary Watermud	0.00	0.00	0.00	0.00	0.00	0.00	3.36	7.57	1.5

Table 17. Zone-wise landuse cover (%) of River Teesta in West Bengal.

Physical Habitat Index (PHI) for River Teesta

Physical habitat assessment suggests not so greater disturbance in the stream stretch. Four sampling areas (Rishikhola, Rungpo, Teesta bazaar and Gojoldoba)were analyzed as good, two areas as fair (Sevoke and Domohoni) and one area (Haldibari) as poor which has also been observed to have high impactful human activities (**Table 18**).

Table 18. Physical Habitat Index scoring of River Teesta in West Bengal

	Rishi Khola	Rungpo	Teesta Bazar	Sevoke	Gojoldoba	Domohoni	Haldibari
Pool substrate	10	11	16	7	18	10	9

Velocity/ Depth combination	16	15	18	9	7	6	5
Riparian vegetation zone width	18	13	11	7	10	11	6
IBI score	**44**	**39**	**45**	**23**	**35**	**27**	**20**
Evaluation	good	good	good	fair	good	fair	poor

Relationship of IBI with landscape variable and fish diversityEstimators

Correlation strengths between IBI, land use attributes, riparian zone width and species richness varied with sites (Table 19). Species richness is negatively correlated to settlement, agriculture and watermud while positively with primary and secondary forest and riparian width. This linkage is highly depictive of strong association of species diversity with that of habitat quality and land-use forms. Water mud seems to significantly influence (p-values <0.05) species richness across the riverine stretch. IBI seem to be significantly affected by agricultural land form.

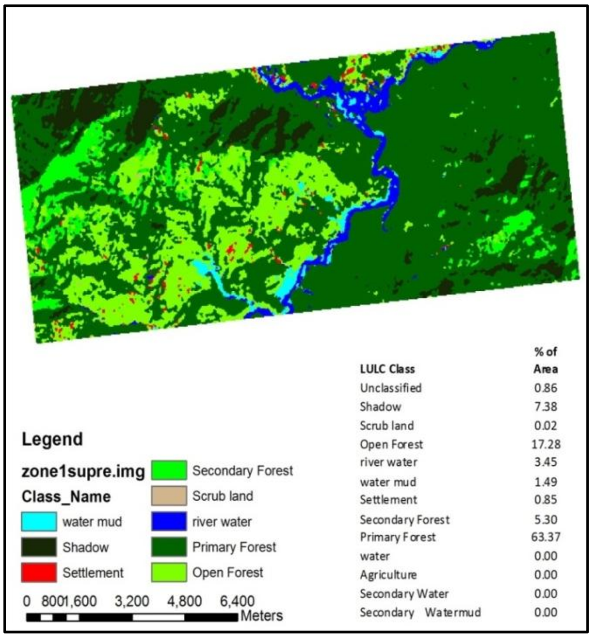
Table 19.Spearman correlation between IBI, land use attributes riparian zone width and fish species richness.

	Species richness	Scrub land	Open Forest	water mud	Settlement	Secondary Forest	Primary Forest	Agriculture	Secondary Water	Secondary Watermud	IBI
Scrub land	-.115(.807)										
Open Forest	-.255(.582)	-.254(.582)									
water mud	**.840*(.018)**	-.385(.394)	.243(.600)								
Settlement	-.033(.943)	**.823*(.023)**	.076(.871)	.297(.517)							
Secondary Forest	.487(.268)	-.348(.444)	.444(.318)	.431(.334)	.362(.425)						
Primary Forest	.152(.744)	.257(.578)	.139(.766)	.081(.862)	.289(.530)	**-.879**(.009)**					
Agriculture	-.128(.785)	-.086(.854)	.610(.146)	.133(.776)	.344(.449)	.727(.064)	.721(.067)				

Secondary Water	-.233(.616)	.118(.802)	.619(.138)	.149(.750)	.371(.412)	.423(.344)	.399(.376)	**.856*(.014)**			
Secondary Watermud	-.268(.562)	.319(.486)	.383(.396)	.109(.817)	.256(.579)	-.114(.807)	.152(.744)	.339(.457)	**.777*(.040)**		
IBI	.626(.133)	.064(.891)	.249(.590)	.580(.172)	.316(.490)	-.334(.463)	.535(.216)	**-.841*(.018)**	-.746(.054)	.334(.465)	
Riparian zone width	.071(.880)	-.336(.461)	.447(.315)	.322(.482)	.025(.957)	-.202(.664)	.178(.702)	-.253(.584)	-.466(.292)	.539(.212)	.058(.901)

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed).

Zone 1



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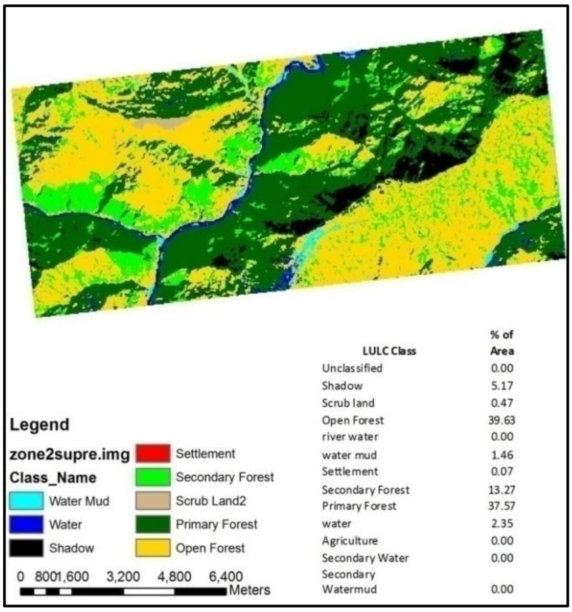
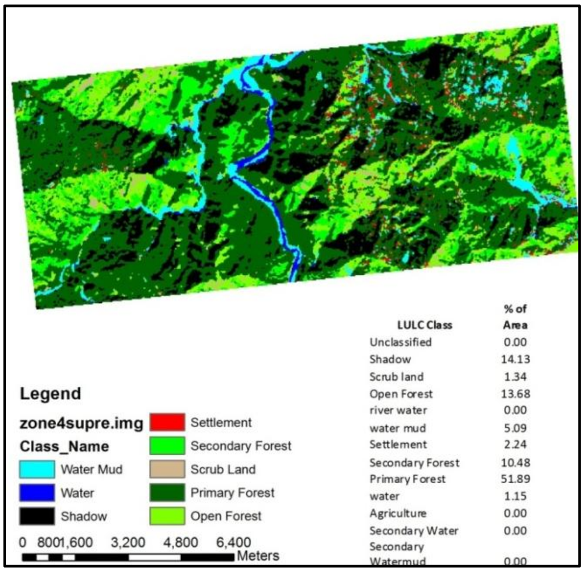
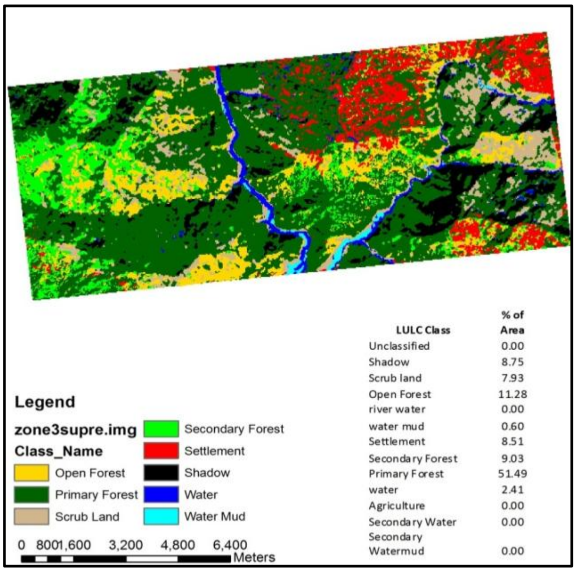


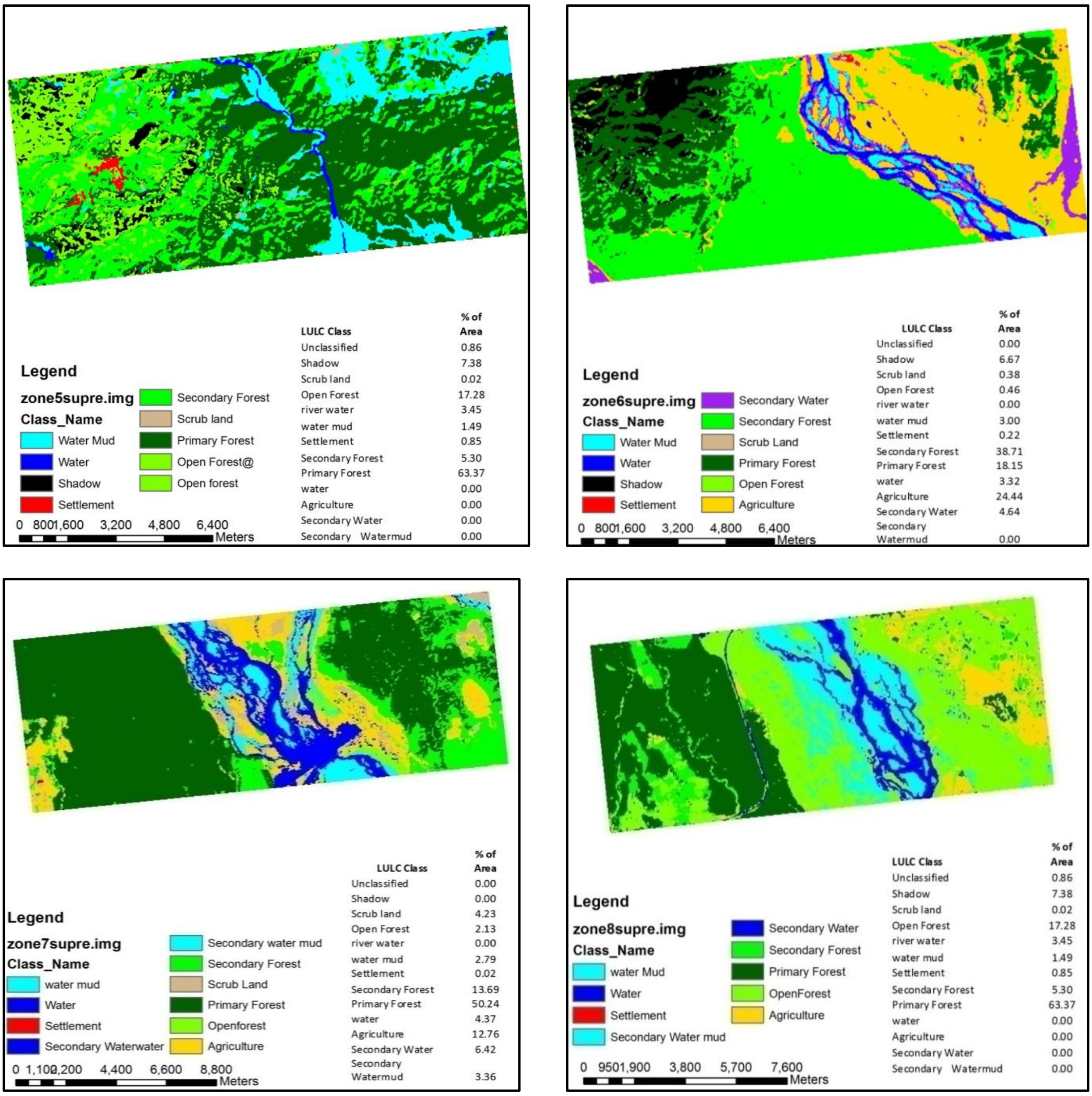




Zone 3

Zone 4

Zone 5 Zone 6



Zone 7 Zone 8

Fig 25. Classified image of the study area (divided into 8 equal zones) with major sub-basins and sampling points.

STUDY II (MACROINVERTEBRATE DIVERSITY AND DYNAMICS)

1. Introduction:

The benthic macroinvertebrate association is an important component of stream diversity, because its members are integral link between the different habitat types of streams. As such, study on one of the major components of aquatic trophic structure *viz*. aquatic macro-invertebrate can provide a useful tool for measuring habitat quality.

Any environmental alteration is considered as one of most important factors of aquatic ecosystem in determination of aquatic biodiversity (Vinson and Hawkins 1998; Sharma et al. 2004).Various studies have extensively described the significance of substratum type for the construction of stream macroinvertebrate communities (Pardo and Armitage, 1997; Robson and Chester, 1999; Buss et al., 2004; Costa and Melo, 2008) and distinctive connection of trophic resources and sheltering against predation or flow disturbance (Buss et al., 2004).The usual geographical scale of stream habitats, microhabitats, watercourses and its tributary stretches incorporate their divergence at level of biotic and abiotic conditions (Li et al., 2001; Louhi and Muotka, 2004; Allan and Castillo, 2007).

Biological diversity in a particular belt is divisible into two segments. The first segment is alpha diversity which constitutes the diversity of species within sites. The second segment, beta diversity, reveals the contrast of communities along gradients or the scale of species change among sites. Beta diversity is a measure of biological dissimilarities among environments. From their previous studies, the two main causes i.e. difference in environmental conditions and geographical distance, are considered as important factors in stream macroinvertebrate assemblages affecting beta diversity (Costa and Melo, 2008).

Another well studied effect and its importance for macroinvertebrate community is the modification of the natural flow regime. Constructions of physical barriers interrupting the riverine flow are expected to decrease macroinvertebrate diversity because they deeply vary downstream environment, especially in altitudinal Rivers. However, development planning process is not always compatible with the conservation of this diversity. No such clear evidence relating the effects of geographical distance of North Bengal to variation of stream macroinvertebrate assemblages have been done yet. Thus proper restoration of bio resource and bio indicator of ecosystem has become challenge to the ecologists.

Biological diversity is mainly important as the river systems in North Bengal have potential hotspots of important biological resources. Any habitat alteration would have potential to destabilize the bio resource relationship as happened in the case with many important ecosystems. The main aim of this study:

1. Determination of taxonomic and species diversity of macro-invertebrates in some river streams in Jalpaiguri and Darjeeling district, West Bengal.

2. Analysis of the interrelationship of macro-invertebrate (aquatic insects) diversity and physico-chemical parameters.

3. Evaluation of spatial dynamics of macro-invertebrate (aquatic insects) population to understand their response to various environmental variables and types of substrata on stream bed.

4. Assessment of overall beta diversity of the aquatic habitats with regard to spatial and temporal heterogeneity for proper evaluation of the freshwater riverine ecosystem health.

The role of various environmental gradients on shaping macroinvertebrate community structure was also investigated. We also figured to find differences in habitat disparity and overall beta-diversity among sites and its relationship with habitat differentiation.

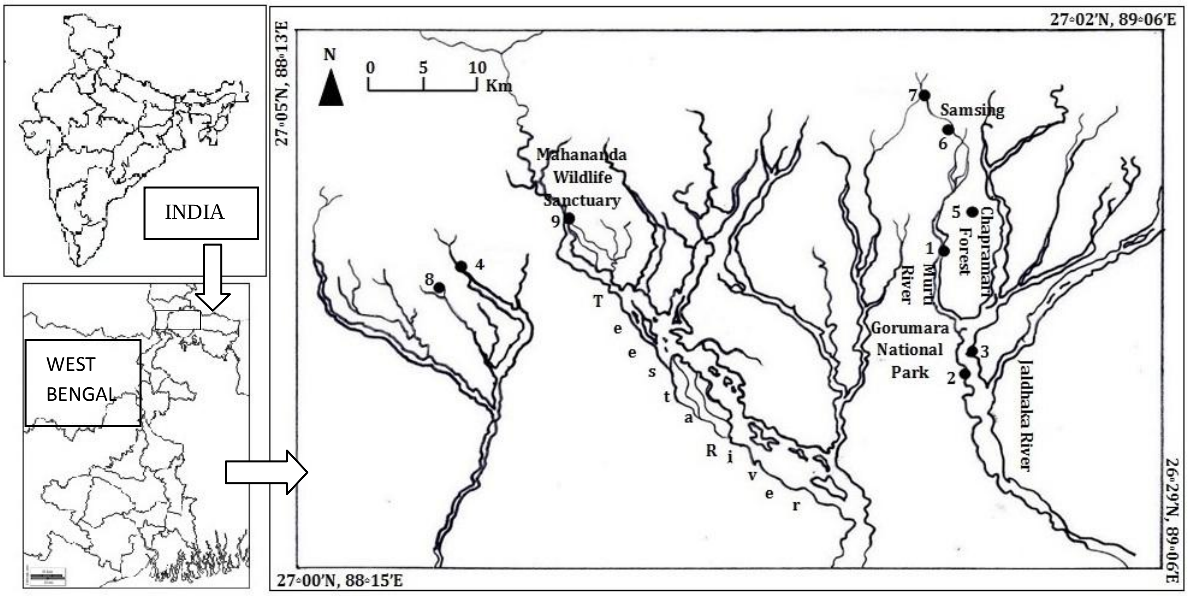


Figure 1: Map of the Darjeeling and Jalpaiguri district showing the locations of study sites and sampling stations marked as numbered black dots.

Note: 1=Murti Banani, 2=Murti GNP, 3=Jaldhaka GNP, 4=Mahananda River, 5=Kalikhola River, 6=Murti Samsing, 7=Murti Rocky Island, 8=Panchnoi River, 9=Teesta River.

2.Materials and methods:

2. 1. Study area and sampling design:

Nine study sites(Figure 2 to 10), with different physical features (tributaries ranges from high altitude mountain sites through the forest regions) were selected randomly covering about

5200 km^{2}keeping in mind the presence of diversity according to different influencing environmental parameters. The study was conducted from November 2013 to October 2014 in Jalpaiguri (26° 32' N, 88° 46' E) and Darjeeling (27° 03' N, 88° 18' E) districtin West Bengal (Figure1). Sampling was carried out from November 2013 to October 2014. At each replicative sampling site fifteen to twenty 4x4 m^2 quadrats were established randomly.

Field measurements (Table 1) were recorded for variables, viz. air temperature, water temperature and total dissolved solids (Multiparameter, HDS1014), pH (Control Dynamics pH meter, pHep HI 98107), dissolved oxygen (Dissolved Oxygen Meter, Lutton, DO-5509). Water velocity was measured at each site using locally built the floatation method at run of at least five meters along the transect. Habitat composition, which included woody debris parts and algal mat cover on the riverbed, were visually estimated by indigenous method (Cordova et.al. 2006, Woodall et. a. 2008, Dethier, et. al.1993), while percentage of bank vegetation cover was determined using a locally built densiometer. The percentage cover of different-sized substrata withineach site was estimated by visual inspection using the substrate size classes (Bovee and Milhous 1978) of sand (0.06–2 mm), fine gravel (2–32 mm), coarse gravel (32–64 mm), cobbles (64–256 mm) and boulders (256 mm).

Figure 2: Murti river (Banani)

Figure 3: Murti river (Gorumara National Park)

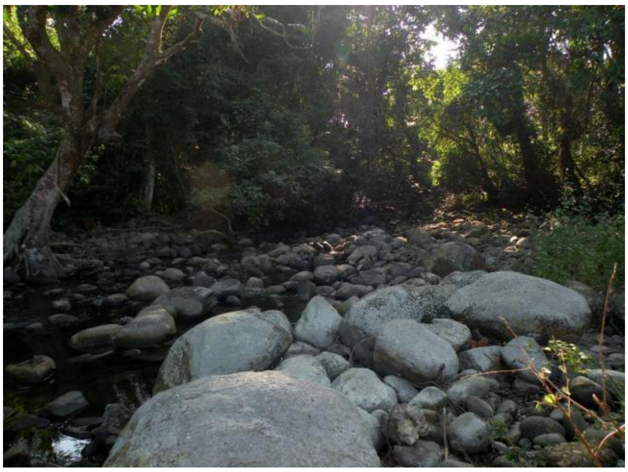


Figure 4: Jaldhaka river (Gorumara National Park)

Figure 5: Kalikhola river (ChapramariWildlife Sanctuary)

Figure 6: Murti river (Samsing)

Figure 7: Murti river (Rocky Island)

2.2. Habitat morphology and physico-chemical parameters:

Geographical information on latitude, longitude and altitude were recorded by GPS digital meter (Garmin, eTrex HC series).Substrate composition (boulders, cobbles, pebbles, gravel and sand) and width of rivers were estimated by visual inspection. The measurements of water velocity were taken at each site using indigenous method. Riparian vegetation was characterized with a visual estimate of shading and canopy cover. Other characteristics of habitat composition estimated visually included the amount of woody debris parts, and algal mat cover on the riverbed. Water temperature (by HDS1014), TDS (total dissolved solids) (by HDS1014), pH (by pHep HI 98107), D.O (dissolved oxygen) (by Lutron DO-5509) were recorded.

Figure 8: Panchonoiriver (Mahananda Wildlife Sanctuary)

Figure 9: Mahanandariver (Mahananda Wildlife Sanctuary)

Figure 10: Teesta river (Sevok)

2.3. Macro-invertebrate specimen sampling:

Macro-invertebrates were collected by sweeping 500-µm mesh D-shaped net and attached macroinvertebrates were removed from rocks and other substrates by brushing and hand picking method (Brown and May 2004). All macro-invertebrates were preserved in the field in 70% ethyl alcohol. Identification of macro-invertebrate specimens in the laboratory up to family level was performed with the help of identification keys (Clifford, 1991; Morse et al., 1994; Bouchard, 2004).

3. Data Analysis:

Macro-invertebrates were compared with different influencing environmental parameters at different sites. Diversity indices were used to obtain species diversity, dominance and evenness of macro-invertebrates between nine different sites (Primer version 6). In order to assess the interaction between different hydrological and physical parameters and assemblage of Macro-invertebrates, unimodal distribution of samples was used to explain the abundance of species with environmental variables (altitude, air temperature, water temperature, water current, dissolved oxygen, pH, total dissolved solids, boulders%, cobbles%, pebbles%, gravels%, sand%, woody debris%, algal mat cover%, bank vegetation cover%).

Dissimilarity metrics was constructed to find the beta-diversity value between sampling sites (Van Dyke 2008). The similarity in species composition at each site was studied by calculating the Bray-Curtis coefficient based on the fourth-root-transformed species abundance data. The result was displayed by non-metric multidimensional scaling (nMDS) plot (Clarke 1993). Bray-Curtis similarity and Principal Component Analysis, a multivariate technique was used to describe the environmental dissimilarity between the sites (PRIMER-E Software (v. 6). Pearson correlation was plotted to get comparative results between macro-invertebrate abundances and environmental parameters and one way ANOVA represented significant differences between study sites according to ambient disparity between sites (SPSS version 17).

3. Results:

A total of 1,500 individualsdistributed in nine different taxonomic groups belonging to 39 families were identified in different river tributaries ranges from high altitude mountain sites through the forest regions, where Mayflies (Ephemeroptera) were found to be the most dominant followed by Caddisflies (Trichoptera) and Coleopteran insects in the study. Among them the most ubiquitous insects included family Heptagenidae, Beatidae, Hydropsychidae, Psephenidae. Other commonly occurring insects incorporated family Chironomidae, Gerridae, Leptophlebidae, Lymnidae, Ephemerllidae, Perlidae and Vellidae. Macro-invertebrate abundance varied considerably among sites. The variability of density of macro-invertebrates is markedly observed along with increasing altitude. The highest number of individuals (119) was obtained at Murti GNP, followed by Kalikhola (80), Jaldhaka GNP (79) Mahananda River (62) and Murti Banani (61). Environmental characteristics were recorded in Table 1. Subjected to spatial comparison Shannon diversity (2.197), Species density (18) and Species richness (4.135) were found to be highest in the site Murti Banani and lowest in Teesta River (0.7315, 4, 1.443 respectively). Teesta river represented as the highest (27.5) Whittaker Beta Index value whereas Kalikhola River and Murti Banani were found to be lowest (3.222) (Table 2).

A decreasing tendency in total abundance was markedly observed along with increasing altitude (Figure 11). Water temperature showed a positive correlation with the total abundance of macroinvertebrates (Figure 12), however cumulative abundance of Ephemeropteran, Trichopteran, Coleopteran insects showed more dependence on water temperature (Figure 13). An inversely proportional relationship between total abundance and water current was observed in Figure 14. Among the macro-invertebrates, particularly the groups Ephemeroptera, Trichoptera, Coleoptera, Lepidoptera, Mollusca were closely associated with algal mat cover (Figure 15). A positive relationship was observed between percentage of cobbles and macro-invertebrates density in Figure 17. Total abundance of macro-invertebrates was found to be posivity correlated with percentage of woody debris (figure 16). Figure 18, showed a positive correlation between water and surrounding vegetation cover (% SVC), and both of which were observed to correlate positively with total abundance of macro-invertebrates.

In terms of substrates and temporal factors, higher densities were observed in the cobbles, pebbles, gravels, algal mat cover, woody debris, air temperature and water temperature. Most of the environmental parameters were correlated with each other according to Pearson correlation coefficient (Table 3). Total abundance showed significant positive correlation with cobbles (r=0.829), woody debris (r=0.871), and algal mat cover (r=0.865, p<0.01) whereas species richness (d) showed positive correlation with pebbles (r=0.709, p<0.05). Water temperature and air temperature were positively correlated with Species densities(S) (r=0.845, p<0.01), (r=0.805, p<0.01); Pielou's evenness (J') (r=0.967, p<0.01), (r=0.849, p<0.01); Shannon index (H') (r=0.947, p<0.01), (r=0.745, p<0.05); Simpson index (1-Lamda') (r=0.958, p<0.01), (r=0.680, p<0.05); and total abundance (r=0.806, p<0.01), (r=0.789, p<0.05) respectively but negatively correlated with Whittaker beta index (r=-0.878, p<0.01), (r=-0.773, p<0.05). Species richness (d) showed positive correlation with velocity (r=0.846, p<0.01). With more emphasis, percentage of cobbles showed positive correlation with Ephemeropterans (r=680, p<0.05), Plecopterans (r=675, p<0.05) and Trichopterans (r=708, p<0.05). Similarly Ephemeropterans (r=737, p<0.05) and Plecopterans(r=674, p<0.05) along with Pulmonates (r=738, p<0.05) showed positive correlation with algal mat cover. Coleopterans was positively correlated with pH (r=0.712, p<0.05) but negatively correlated with gravels (r=0.727, p<0.05).

Three major clusters of sites were observed considering 80% level of Bray Curtis similarity based on environmental variables (figure 19). River Murti (Samsing) and Murti (Rocky Island) clustered (second) at 80% level of similarity. River Teesta formed an isolated (third) cluster at 80% level. Even at 60% level of similarity all the sites appeared to be similar except for the site Teesta. All the nine different sites formed a single common cluster at 40% level of similarity. The rivers Panchonoi, Murti (Gorumara National Park), Jaldhaka (Gorumara National Park) and Kalikhola were overlapped above 80% level of similarity where the river Mahananda and Murti (Banani) were placed in the same manner.

For differences between the study sites, formal significance tests for dissimilarity were performed using a dissimilarity matrix among sites obtained by computing the sample size value for all pairwise combinations of reaches (*Looy et. al.* 2005). The dissimilarity matrix of the nine different sites (Table 4), illustrated the highest beta-diversity value (0.89) between river Teesta and Kalikhola followed by Murti (Banani)-Teesta, Murti (Gorumara National Park)-Teesta and Mahananda-Teesta (0.84, 0.83, 0.8 respectively). The significant dissimilarity value was 0.8-1. The lowest dissimilarity value was found between Mahananda and Kalikhola (0.428). S17 Bray Curtis Resemblance Matrices produced groups mostly according to macroinvertebrate sample size of the nine study sites. Two major clusters of sites were formed at the level of 40% similarity where River Teesta formed an isolated cluster and while seven major cluster of sites were observed considering 60% level of similarity (Figure 20).

The Principal Component Analysis (Figure 21) allowed the nine study sites to be taken into account simultaneously aiming to visualise the environmental resemblance and dissimilarity within the total studied area. The plots of all the nine sites showed five principal components (PC1-PC5), with the first four components (factors) explaining 84.8% of total variation. The percentage of variation explain by each factor is presented in table 5.Considering this PC1 axis showed an opposition between three sites (Murti Samsing, Murti Rocky and Teesta) from six other sites (Murti Banani, Murti GNP, Jaldhaka GNP, Kalikhola River, Mahananda River and Panchonoi River). Axis PC1 clearly separated these sites on the basis of variables i.e. cobbles (-0.375), pebbles (-0.257), TDS (-0.119), BVC (-0.164), AMC (-0.329), woody debris (-0.365), air temperature (-0.364) and water temperature (-0.288). The second axis PC2 showed an opposition between two study sites (Panchonoi River and Teesta River) and seven sites (Murti Samsing, Murti Rocky, Murti Banani, Kalikhola River, Murti GNP, Jaldhaka GNP and Mahananda River) according to gravels (0.519) and sand (0.446).

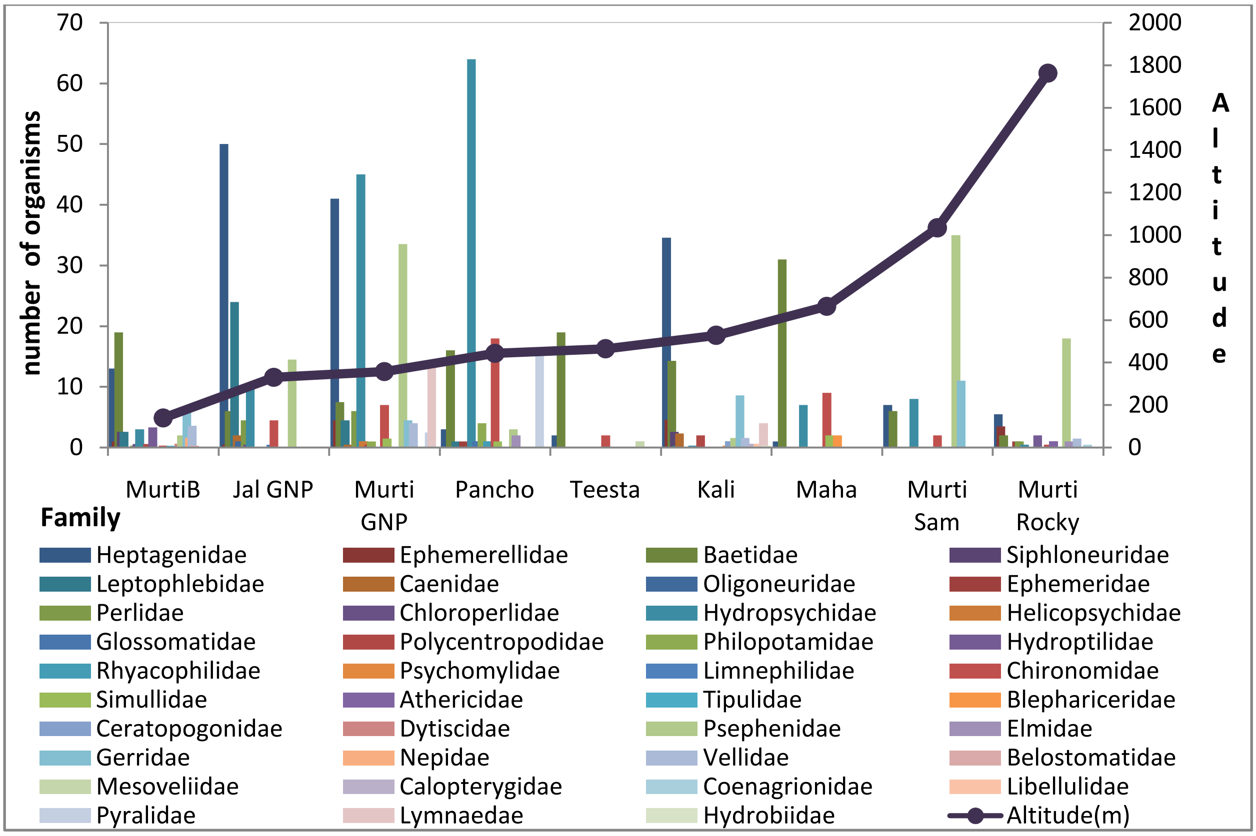


Figure 11: Comparison of distribution of 39 different taxonomic groups collected at different altitude

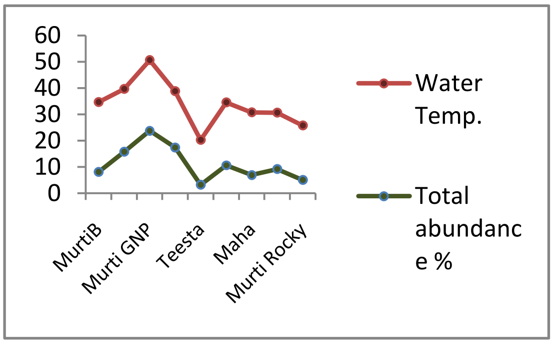


Figure 12: Relationship between WT and %TA

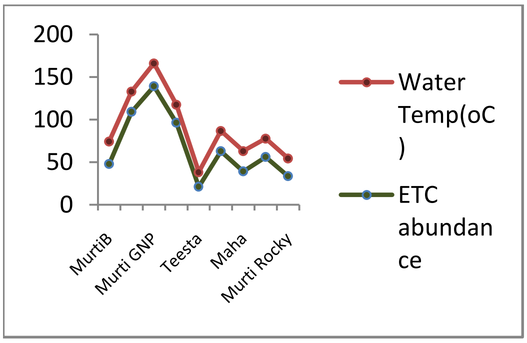
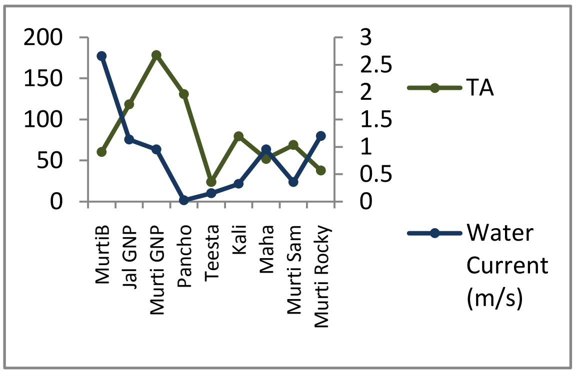


Figure 13: Relationship between WT and ETC (Ephemeroptera,Trichoptera,Chironomidae) Abundance



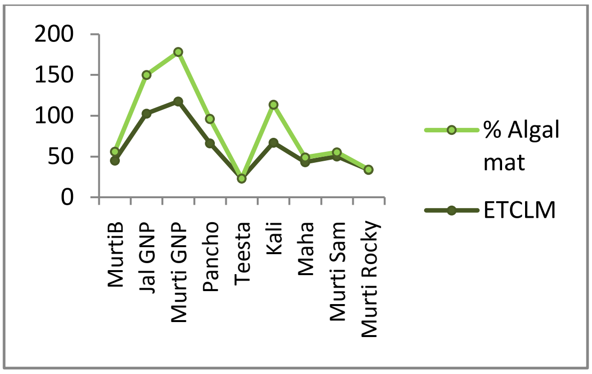
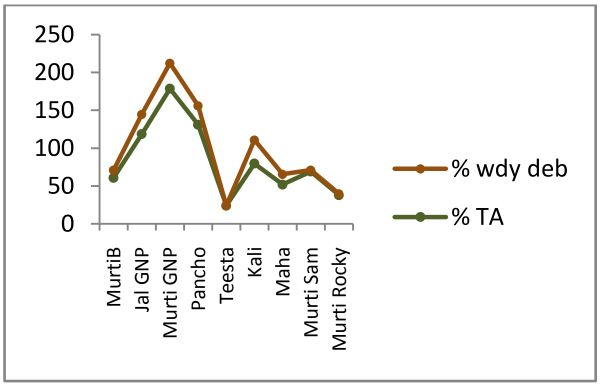


Figure 14: Relationship between %TA and WC

Figure 15: Relationship between % AMC and ETCLM



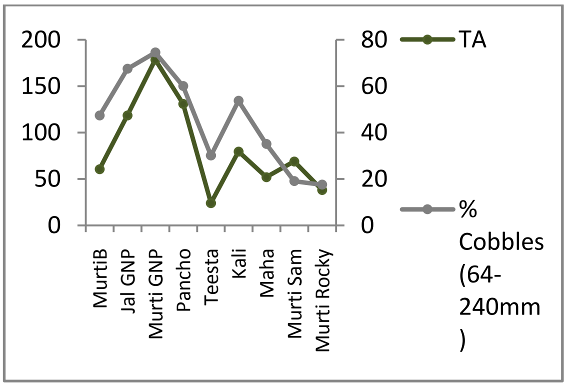


Figure 16: Relationship between %TA and % Woody Debris

Figure 17: Relationship between TA and % Cobbles

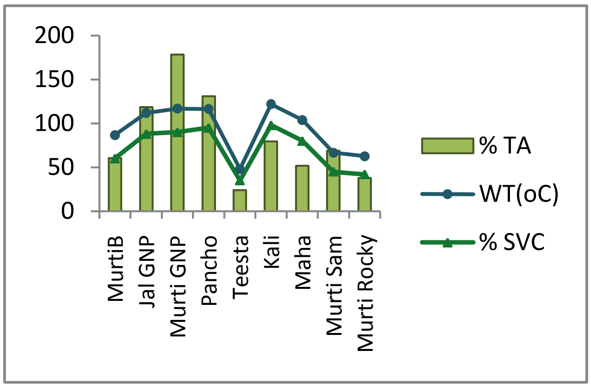


Figure 18: Relationship of %TA with WT and % SVC

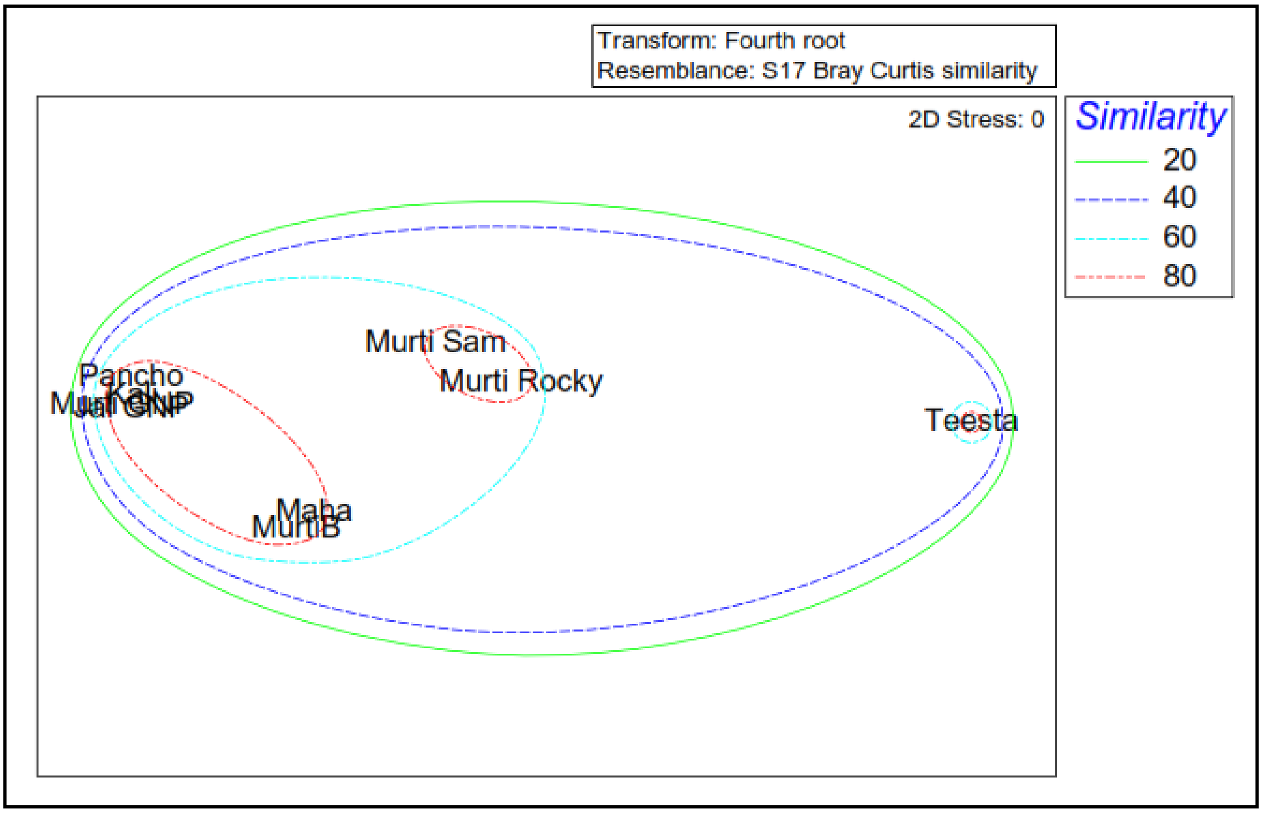


Figure 19: Multi Dimentional Scaling plot

One way ANOVA represented significant differences in macroinvertebrate assemblage structure and environmental condition between nine sites ($p<0.001$). Post hoc Duncan analysis revealed that altitude and species evenness were significantly different in each study sites ($p<0.05$) whereas high variability in environmental conditions across rivers also was evidenced by significant differences in habitat heterogeneity among the sites. In terms of resemblance, site 2 (Murti, GNP), site 3 (Jaldhaka, GNP) and site 4 (Mahananda River) were not found to be significantly different according to air temperature, water velocity, dissolved oxygen, boulders percentage, species density, Whittaker beta diversity ($p>0.05$). With regard to beta diversity, site 9(Teesta River) showed highly significant difference in Whittaker beta diversity index, species density, water temperature, gravels, cobbles, boulders ($p<0.05$).

	MurtiBanani	Murti GNP	Jaldhaka GNP	Mahananda River	Kalikhola River	MurtiSamsing	Murti Rocky Island	Panchonoi River	Teesta River
Alt(m)	139±0.57	357±1.73	330±5.77	664.5±0.89	528.3±0.17	1034±1.78	1762±1.15	443±0.76	465±0.57
AT(°C)	32.03±1.15	32.4±0.03	30.6±0.05	31±1.15	28.16±0.56	22.5±0.24	24.5±0.17	31.1±0.03	22.7±0.14
WT(°C)	26.6±0.05	26.85±0.58	23.9±0.54	23.8±0.57	23.89±0.003	21.5±0.26	20.7±0.11	21.5±0.02	12.9±0.03
WC(m/s)	2.66±0.005	0.95±0.01	1.13±0.07	0.95±0.06	0.324±0.01	0.36±0.009	1.2±0.14	0.024±0.0002	0.14±0.01
D.O	8.73±0.67	8.95±0.49	8.5±0.21	8.55±0.65	7.28±0.16	9.6±0.04	13±1.15	9.1±0.03	11.1±0.44
pH	8.16±0.15	8.33±0.51	7.7±0.43	9±1.15	7.8±0.11	7.6±0.17	8.8±0.51	7.2±0.05	7.4±0.03
TDS	28.16±0.57	2±0.57	2±0.05	47.5±1.12	10.4±0.26	0.004±0.001	12.25±0.14	90.3±0.54	0.002±0.001
Boulders (%)	2.66±0.09	4±1.15	4.5±0.86	5.6±0.05	57±0.57	74±0.89	72.6±0.72	3±0.03	9.9±0.26
Cobbles (%)	47.3±0.69	74.5±2.54	67.5±0.37	35±2.3	53.6±0.23	19.1±0.56	17.5±0.11	60.1±0.38	29.9±1.15
Pebbles (%)	32.64±1.23	10.06±1.09	17.5±0.86	5±1.15	26.3±0.02	4±0.13	4.5±0.2	14±0.24	10.2±0.95
Gravels (%)	10.06±1.67	7±1.15	6.5±0.49	1.5±0.2	10.4±0.05	2±0.44	3.5±0.09	19.8±0.16	25±0.57
Sand (%)	7.33±0.54	4.5±0.57	3±0.57	1±0.05	4±0.17	1±0.08	2±0.13	3±0.13	25.3±1.1
Wdy Deb (%)	10.6±0.73	33.5±1.7	26±1.15	13.5±0.86	31±0.57	1.9±0.46	1.5±0.12	25.3±0.55	0.003±0.002
AMC(%)	11±0.57	60.5±0.57	47.5±1.12	6±0.28	46.6±0.37	5±0.44	0.5±0.02	29.7±0.21	0.001±0.001
BVC(%)	15±1.15	3.5±0.77	2.5±0.11	30±1.73	94.3±0.17	5±1.34	9.5±0.28	47.1±0.38	0.002±0.001

Table 1: Environmental characteristics between nine different study sites (Mean SE±)

Note: The highest value of each parameter has been presented in bold

Table 2: Diversity indices in different study sites

Diversity Indices	Murti Banani	Murti GNP	Jaldhaka GNP	Mahananda River	Kalikhola River	Murti Samsing	Murti Rocky Island	Panchonoi River	Teesta River
Species density (S)	**18**	17	12	14	17	6	13	13	4
Total individual (N)	61	**119**	79	62	80	23	25	44	8
Margalef's Index(d)	**4.135**	3.348	2.517	3.146	3.648	1.595	3.713	3.177	1.443
Shannon index (H')	**2.197**	2.128	1.737	1.963	1.919	1.434	1.845	1.666	0.7315
Brillouin	1.844	**1.948**	1.559	1.684	1.637	1.098	1.365	1.449	0.503
Whittaker's Beta Index	3.222	4.184	5.333	5.333	3.222	18	6.125	7.7692	**27.5**
1 Lamda	**0.846**	0.842	0.761	0.811	0.770	0.716	0.766	0.726	0.408

	N	d	J'	Brillouin	Fisher	H'	1 Lamda	W Beta	Alt(m)	AT(°C)	WT(°C)	Velocity(m/s)	D.O	pH	TDS	% Bould	% Cobbles	% Pebbles	% Gravels	% Sand	Wdy Deb (%)	AMC(%)	BVC(%)
S	.549	.448	.424	**.933****	.633	**.931****	**.831****	**-.936****	-.260	**.805****	**.845****	.543	-.455	.455	.256	-.220	.558	.561	-.307	-.502	.641	.523	.441
N		-.322	.242	.653	-.106	.523	.512	-.576	-.309	.606	.607	-.083	-.545	.188	-.097	-.245	**.762***	.049	-.301	-.405	**.882****	**.889****	.242
d			.277	.365	.428	.423	.335	-.296	-.372	.366	.404	**.846****	-.159	.106	.099	-.271	.057	**.709***	.009	.060	-.134	-.175	-.074
J'				.646	.198	**.712***	**.827****	-.545	.194	.273	**.775***	.485	-.208	.480	-.066	.271	-.024	-.039	**-.876****	**-.802****	.084	.084	-.106
Brillouin					.442	**.976****	**.946****	**-.946****	-.265	**.849****	**.967****	.542	-.525	.475	.222	-.243	.592	.398	-.517	**-.683***	**.668***	.573	.270
Fisher						.584	.475	-.602	.377	.238	.315	.529	.320	.580	.255	.181	-.104	.261	-.189	-.293	-.036	-.128	.220
H'							**.972****	**-.953****	-.095	**.745***	**.947****	.614	-.393	.577	.201	-.090	.420	.371	-.598	**-.724***	.521	.424	.262
1 Lamda								-.917**	-.020	**.680***	**.958****	.547	-.396	.537	.197	-.002	.364	.253	-.711*	**-.849****	.485	.401	.207
W Beta									.101	**-.773***	**-.878****	-.500	.416	-.496	-.276	.116	-.511	-.413	.501	**.726***	-.632	-.518	-.391
Alt(m)										-.617	-.270	-.151	.739*	.433	-.156	**.792***	-.727*	-.626	-.421	-.285	-.531	-.488	-.123
AT(°C)											**.763***	.434	-.608	.218	.455	-.697*	**.798****	.466	-.104	-.374	**.735***	.599	.205
WT(°C)												.567	-.570	.391	.100	-.151	.539	.402	-.608	**-.723***	.606	.552	.193
WC (m/s)													-.017	.489	-.109	-.225	.069	.482	-.373	-.161	-.096	-.091	-.295
D.O														.238	-.173	.360	-.638	-.556	.065	.267	**-.708***	-.604	-.542
pH															-.043	.106	-.229	-.260	**-.674***	-.397	-.112	-.189	-.112
TDS																-.373	.161	.062	.254	-.265	.184	-.075	.371
% Bould																	-.633	-.278	-.404	-.290	-.369	-.283	.184
% Cobbles																		.467	.173	-.133	**.917****	**.910****	.203
% Pebbles																			.246	.086	.380	.339	.431
% Gravels																				**.774***	-.007	-.021	.110
% Sand																					-.356	-.273	-.249

Wdy Deb (%)																						**.952****	.483
AMC(%)																							.303
BVC(%)																							

Table 3: Pearson Correlation matrix among Macroinverterate diversity and environmental parameters of study sites.

Note: ***** Correlation is significant at the 0.01 level.* Correlation is significant at the 0.05 level.***

Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, WC= Water Current, DO= Dissolved Oxygen, TDS= Total Dissolved Solute, WL= Water Length, % Bld= Percentage of boulders, % Peb= Percentage of pebbles, % Grav= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

Table 4: Beta Dissimilarity Matrix of Different Study Sites

	MurtiBanani	**Murti GNP**	**Jaldhaka GNP**	**Mahananda River**	**Kalikhola River**	**MurtiSamsing**	**Murti Rocky Island**	**Panchonoi River**	**Teesta River**
MurtiBanani									
Murti GNP	0.5								
Jaldhaka GNP	0.57	0.55							
Mahananda River	0.47	0.45	0.47						
Kalikhola River	0.58	0.52	0.68	0.428					
MurtiSamsing	0.66	0.64	0.61	0.57	0.72				
Murti Rocky Island	0.59	0.63	0.61	0.65	0.75	0.64			
Panchonoi River	0.76	0.57	0.68	0.65	**0.8**	0.64	0.63		
Teesta River	**0.84**	**0.83**	0.76	**0.8**	**0.89**	0.57	0.78	0.78	

Note: The value 0.8-1 shows high beta dissimilarity tendency

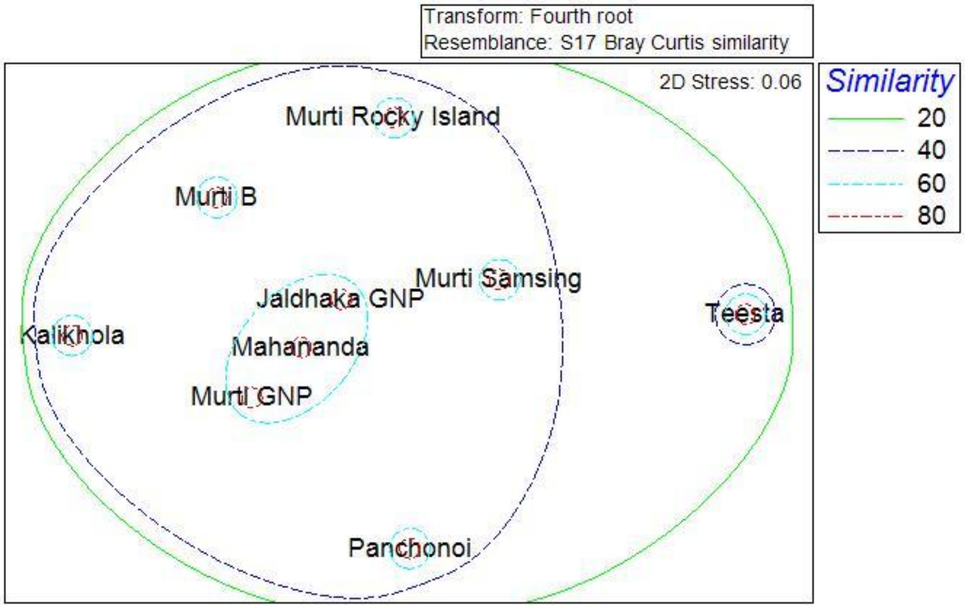


Figure 20: Two-dimensional nMDS plot of the macroinvertebrate assemblages (based on macroinvertebrate abundances) according to Bray-Curtis similarity. Stress value (2D): 0.06.

Table 5: Results of principal components analyses (PCA) based on environmental condition of the nine study sites

PC axis	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.02	3.34	1.98	1.37	1.23
Proportion of variation	40.1	22.2	13.2	9.1	8.2
Cumulative variation	40.1	62.4	75.6	84.8	92.9
Eigenvectors					
Altitude (m)	0.314	-0.263	-0.208	-0.059	-0.064
Air Temp. (°C)	-0.364	-0.117	0.182	-0.217	-0.129
Water Temp. (°C)	-0.288	-0.366	0.059	0.048	0.073
Velocity (m/s)	-0.088	-0.258	0.542	0.032	0.314
D. O	0.338	-0.017	0.150	-0.046	-0.204
pH	0.050	-0.430	0.199	-0.151	-0.095
TDS	-0.119	0.049	-0.080	-0.790	-0.072
Boulders %	0.242	-0.209	-0.393	0.207	0.297
Cobbles %	-0.375	0.080	0.002	0.143	-0.246

Pebbles %	-0.257	0.095	0.140	0.071	0.627
Gravels %	-0.015	0.519	0.029	-0.146	0.029
Sand %	0.115	0.446	0.252	0.151	0.065
Wdy Deb %	-0.365	-0.020	-0.232	-.109	-0.190
AMC %	-0.329	-0.006	-0.205	0.340	-0.235
BVC %	-0.164	0.018	-0.473	-0.239	0.426

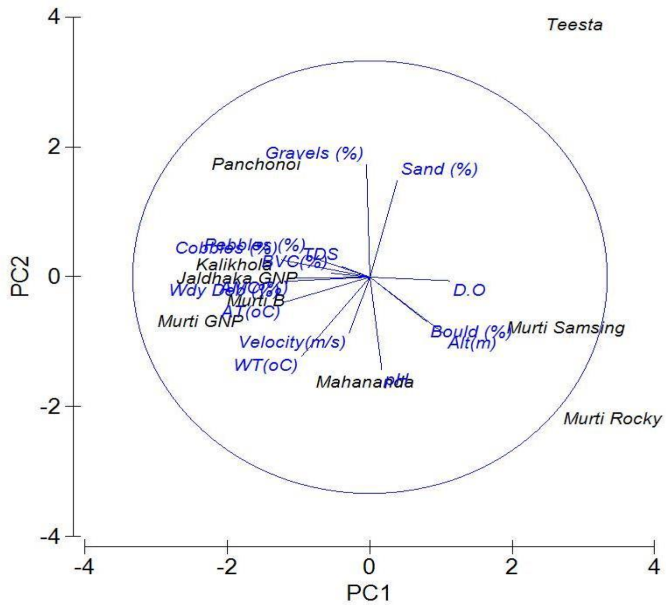


Figure 21: The PCA Graph showing environmental condition at nine study sites. Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, D.O= Dissolved Oxygen, TDS= Total Dissolved Solid, Bould (%)= Percentage of boulders, Pebbles (%)= Percentage of pebbles, Gravels (%)= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

3. Conclusion: The determinant role of the habitat characteristics in controlling macroinvertebrate species abundance and diversity has been postulated. Our study supports the statement that beta diversity within a stream should bear a close relationship with habitat heterogeneity at the same scale (Heino et al. 2013).Thus, functional diversity of macroinvertebrates would be explored further to ascertain the ecosystem services they provide.

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(Seal)

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Appendix 2

Photoplates of Fish species collected from River Teesta and its tributaries, West Bengal

Amblyceps mangois

Acanthocobitis botia

Barilius bendelisis

Danio dangila

Danio rerio

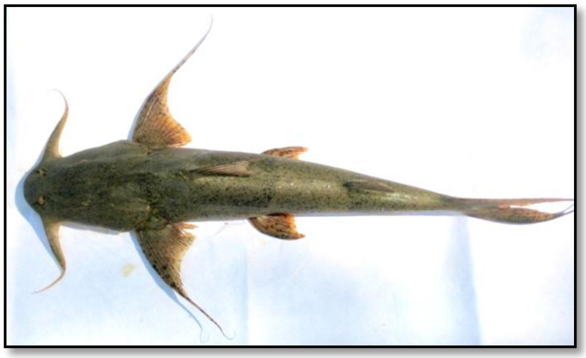
Schistura savona

Batasio tengana

Garra lamta

Badis badis

Macrognathus pancalas



Bagarius bagarius

Monopterus hodgarti

Xenontodon cancilla

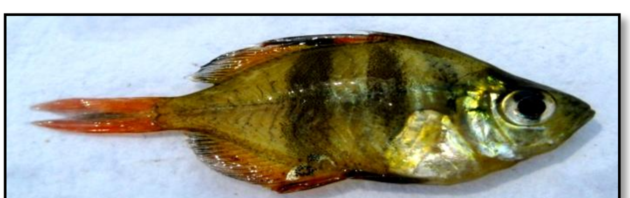
Puntius phutunio

Salmostoma bacaila

Puntius terio

Rasbora rasbora

Samostoma phulo



Parambassis lala

Chaca chaca

Barilius vagra ***Schistura corica***

Botia lohachata ***Trichogaster lalius***

Macrognathus aral ***Schizothorax sp.***

Schistura beavani ***Scistura scaturigina***

Channa gachua ***Channa punctatus***

Mystus vittatus

Puntius sophore

Canthophrys gongota

Glossogobius giuris

Barilius sp.

Davario devario

Hara horai

Glyptothorax telcitta

Olyra kempi

Schistura sp.

Schistura sp.

Lepidocephalichtys guntea

Garra gotyla gotyla

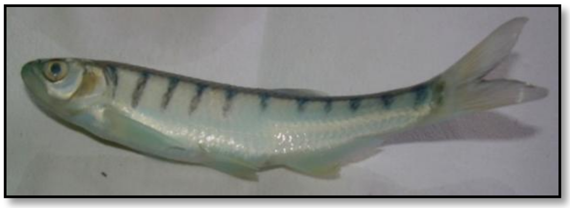
Botia derio

Mastacembelus armatus

Schistura devdevi

Schistura multifasciata

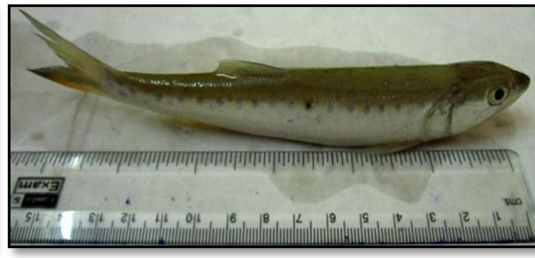
Aborichthys elongatus



Barilius barila

Barilius barna

Neolissocheilus hexagonolepis



Barilius tileo

Esomus danricus

Labeo pangusia

Danio aequipinnatus

Amblypharyngodon mola

Mystus bleekeri

Ompok pabda

Trichogaster fasciatus

Puntius sarana

Glyptothorax cavia

Botia rostrata

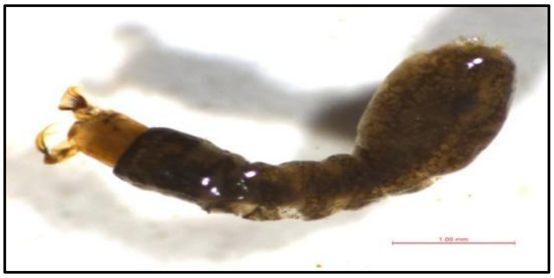
Psilorhynchus balitora

Lepidocephalus berdmorei

<u>Photoplates of Macroinvertebrate sample collected from River Teesta and its tributaries, West Bengal</u>

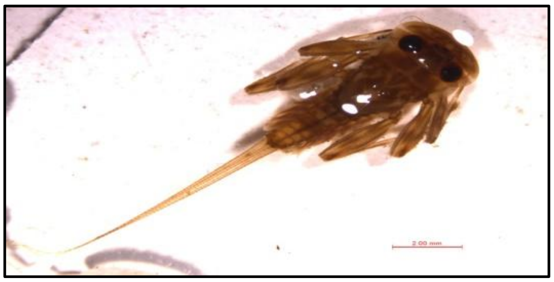
Chironomidae

Athericidae



Simuliidae

Tipulidae



Heptagenidae

Ephimerillidae

Siphloneuridae

Baetidae

Caenidae

Leptophlebidae

Chloroperlidae

Hydropsychidae

Limnephillidae

Philopotamidae

Polycentropotidae

Psychomyiidae

Rhyacophilidae

Glossosomatidae

Blephariceridae

Psephenidae

Dytiscidae

Elmidae

Libellulidae

Ceratopogonidae

Arxius de Miscel·lània Zoològica, 11(2013): 196–213 ISSN: 1698–0476

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

M. Chakrabarty & S. Homechaudhuri

Chakrabarty, M. & Homechaudhuri, S., 2013. Fish guild structure along a longitudinally–determined ecological zonation of Teesta, an eastern Himalayan river in West Bengal, India. *Arxius de Miscel·lània Zoològica*, 11: 196–213.

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 C*ontinuum 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.

Palabras clave: Himalaya Oriental, Teesta, Agua lótica, Biodiversidad, Gremios según preferencia del curso fluvial, Gradiente altitudinal.

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 C*ontínuum 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.

Paraules clau: Himàlaia Oriental, Teesta, Aigua lòtica, Biodiversitat, Gremis segons preferència del curs fluvial, Gradient altitudinal.

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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

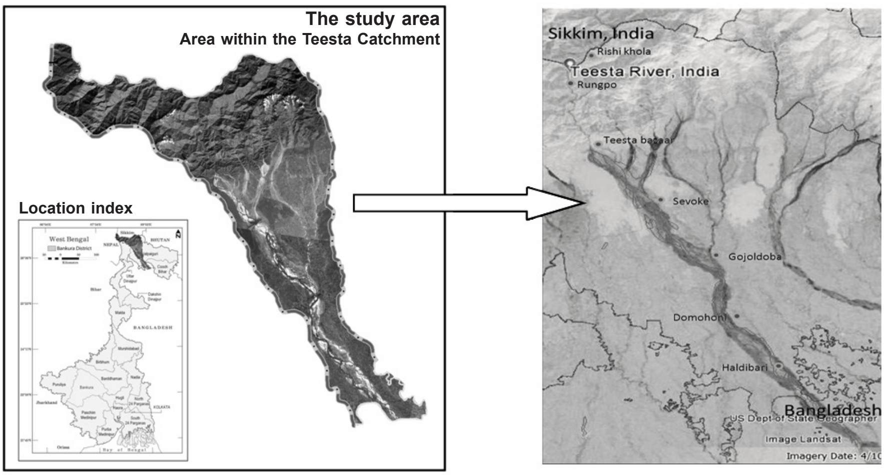

Fig. 1. Teesta River in West Bengal.
Fig. 1. Río Teesta en Bengala Occidental.

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) AT	WT	Water velocity (m/sec)	Stream (ft) with	depth	Habitat guilds	Preferred spawning habitat
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

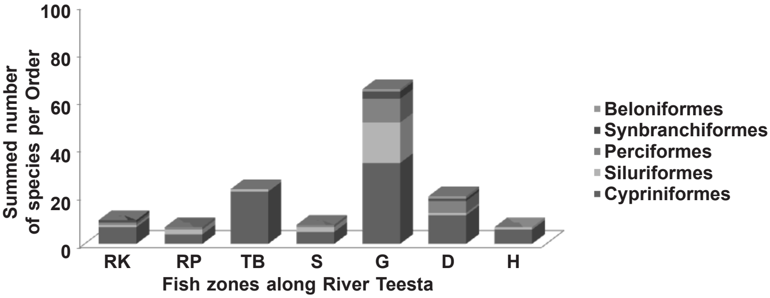

Fig. 2. Taxonomic composition of fish zones of River Teesta in West Bengal. (For abbreviations of fish zones see table 4.)

Fig. 2. Composición taxonómica de las zonas piscícolas del río Teesta en Bengala Occidental. (Para las abreviaturas de las zonas piscícolas ver tabla 4.)

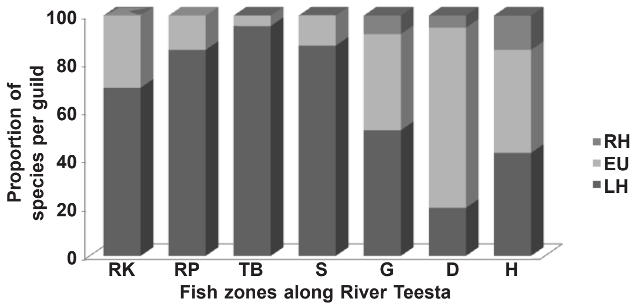

Fig. 3. Composition of flow preference guilds of the ecological fish zones of River Teesta. (For abbreviations of fish zones and flow preference guilds see table 4.)

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.)

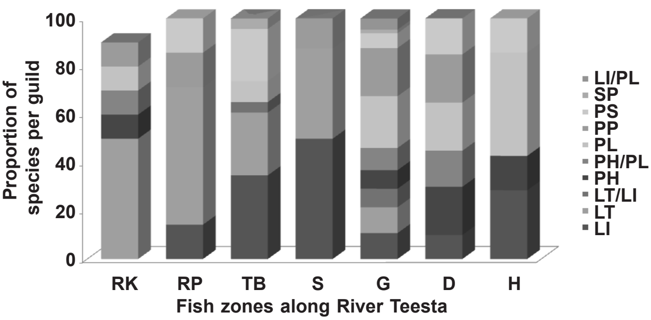

Fig. 4. Composition of spawning preference guilds of the ecological fish zones of River Teesta. (For abbreviations of fish zones and reproductive guild see table 4.)

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. Euritópico; 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 classification 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 stretches 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.

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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

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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.

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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 Km². 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

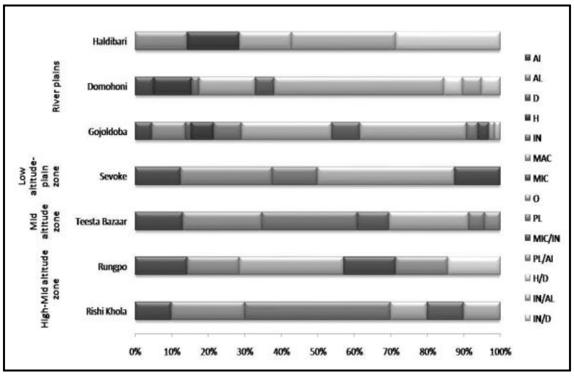
Altitudinal zones	Species	LV	FR	HR	AL	TI	PL	CR	AI	FI	DU
Mid altitude zone	*Barilius barila (Bba)* (Hamilton, 1822)	17.2	0	19.5	0	0	13.9	0	29.1	0	20.3
	Barilius barna (Bbr) (Hamilton 1822)	0	0	0	0	0	0	0	79.2	0	20.8
	Barilius bendelisis (Bbe) (Hamilton, 1807)	19.2	0	17.5	0	0	15.6	0	24.5	0	23.2
	Barilius 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

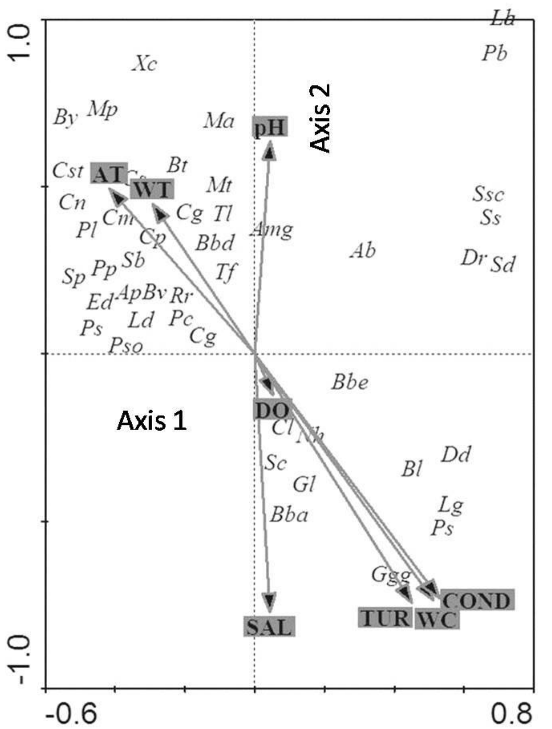


Fig. 3 CCA plot showing species scores along environmental vectors.

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.

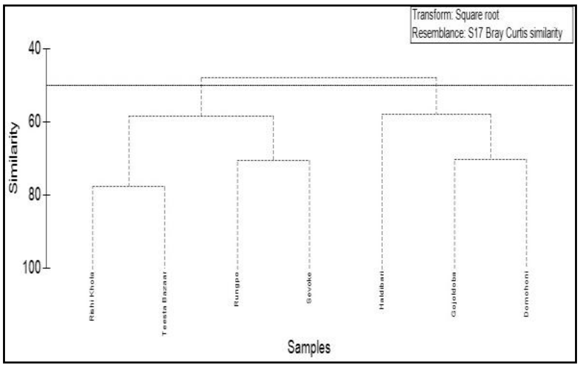


Fig. 4 Similarity dendogram for hierarchial clustering of sites constitutive of respective altitudinal zones showing linking of Bray-Curtis similarities calculated on obtained feeding groups at each site.

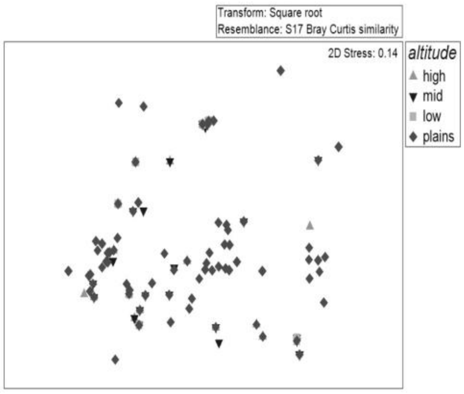


Fig. 5 Two-dimensional MDS ordination plot of the volumetric dietary data for respective fish species coded for habitat/altitudinal gradient.

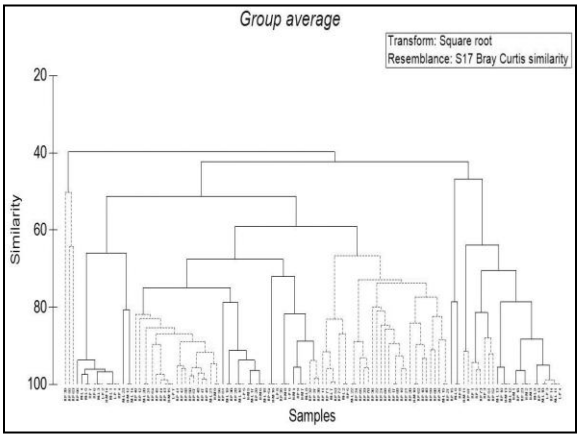


Fig. 6 Sequence of SIMPROF tests on dendrogram from standard hierarchical clustering based on the diet composition fish species.

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.

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Comparing diversity of freshwater macroinvertebrate community along habitat gradients within a riverine system in North Bengal, India

Anwesha Roy and Sumit Homechaudhuri

Abstract
The main aim of the study was to estimate macroinvertebrate species diversity and overall beta-diversity with respect to interrelationship of environmental gradients-substrate types in some river streams of Jalpaiguri and Darjeeling district, West Bengal. Macroinvertebrates were collected by D-shaped net sampling-hand picking method and field measurements were recorded for one year from November 2013 to October 2014. A total of 1,500 individuals belonging to 39 families distributed in nine different study sites. The results indicated the tendency of species densities towards higher habitat substrates, air temperature and water temperature. Site Teesta, which was found to have highest beta diversity at the level of beta-dissimilarity matrix (0.8-0.89) and Whittaker beta-diversity (27.5), which was significantly negatively correlated with species density (r=-0.936), air temperature (r=-0.773) and water temperature (r=-0.878) and significantly positively correlated with sand (r=0.726) from rest of study sites. Thus habitat characteristics control macroinvertebrate species abundance and diversity.

Keywords: Macro invertebrate association, species diversity, habitat substrata, environmental variables, beta diversity, diversity-habitat interrelationship

1. Introduction
The benthic macroinvertebrate association is an important component of stream diversity, because its members are integral link between the different habitat types of streams [4]. As such, study on one of the major components of aquatic trophic structure *viz*. aquatic macro-invertebrate can provide a useful tool for measuring habitat quality.
Any environmental alteration is considered as one of most important factors of aquatic ecosystem in determination of aquatic biodiversity [35, 30]. Various studies have extensively described the significance of substratum type for the construction of stream macroinvertebrate communities [26, 27, 8, 12] and distinctive connection of trophic resources and sheltering against predation or flow disturbance [8].The usual geographical scale of stream habitats, microhabitats, watercourses and its tributary stretches incorporate their divergence at level of biotic and abiotic conditions [19, 17, 1].
Biological diversity in a particular belt is divisible into two segments. The first segment is alpha diversity which constitutes the diversity of species within sites. The second segment, beta diversity, reveals the contrast of communities along gradients or the scale of species change among sites[12]. Beta diversity is a measure of biological dissimilarities among environments. From their previous studies, the two main causes i.e. difference in environmental conditions and geographical distance, are considered as important factors in stream macroinvertebrate assemblages affecting beta diversity [12].
Another well studied effect and its importance for macroinvertebrate community is the modification of the natural flow regime. Constructions of physical barriers interrupting the riverine flow are expected to decrease macroinvertebrate diversity because they deeply vary downstream environment, especially in altitudinal rivers [32, 24]. However, development planning process is not always compatible with the conservation of this diversity. No such clear evidence relating the effects of geographical distance of North Bengal to variation of stream macroinvertebrate assemblages have been done yet. Thus proper restoration of bio resource and bio indicator of ecosystem has become challenge to the ecologists.
Biological diversity is mainly important as the river systems in North Bengal have potential hotspots of important biological resources.

Any habitat alteration would have potential to destabilize the bio resource relationship as happened in the case with many important ecosystems. The main aim of this study was:

1. Determination of taxonomic and species diversity of macro-invertebrates in some river streams in Jalpaiguri and Darjeeling district, West Bengal.
2. Analysis of the interrelationship of macro-invertebrate (aquatic insects) diversity and physico-chemical parameters.
3. Evaluation of spatial dynamics of macro-invertebrate (aquatic insects) population to understand their response to various environmental variables and types of substrata on stream bed.
4. Assessment of overall beta diversity of the aquatic habitats with regard to spatial and temporal heterogeneity for proper evaluation of the freshwater riverine ecosystem health.

The role of various environmental gradients on shaping macroinvertebrate community structure was also investigated. We also figured to find differences in habitat disparity and overall beta-diversity among sites and its relationship with habitat differentiation.

2. Materials and Methods

2.1 Study area and sampling design

Nine study sites, with different physical features (tributaries ranges from high altitude mountain sites through the forest regions) were selected randomly covering about 5200 km^2 keeping in mind the presence of diversity according to different influencing environmental parameters. The study was conducted from November 2013 to October 2014 in Jalpaiguri (26° 32' N, 88° 46' E) and Darjeeling (27° 03' N, 88° 18' E) districtin West Bengal (Figure1). Sampling was carried out from November 2013 to October 2014. At each replicative sampling site fifteen to twenty 4x4 m^2 quadrats were established randomly.

Field measurements (Table 1) were recorded for variables, viz. air temperature, water temperature and total dissolved solids (Multiparameter, HDS1014), pH (Control Dynamics pH meter, pHep HI 98107), dissolved oxygen (Dissolved Oxygen Meter, Lutton, DO-5509). Water velocity was measured at each site using locally built the floatation method at run of at least five meters along the transect. Habitat composition, which included woody debris parts and algal mat cover on the riverbed, were visually estimated by indigenous method [11, 37, 13], while percentage of bank vegetation cover was determined using a locally built densitometer. The percentage cover of different-sized substrata within each site was estimated by visual inspection using the substrate size classes [6] of sand (0.06–2 mm), fine gravel (2–32 mm), coarse gravel (32–64 mm), cobbles (64–256 mm) and boulders (256 mm).

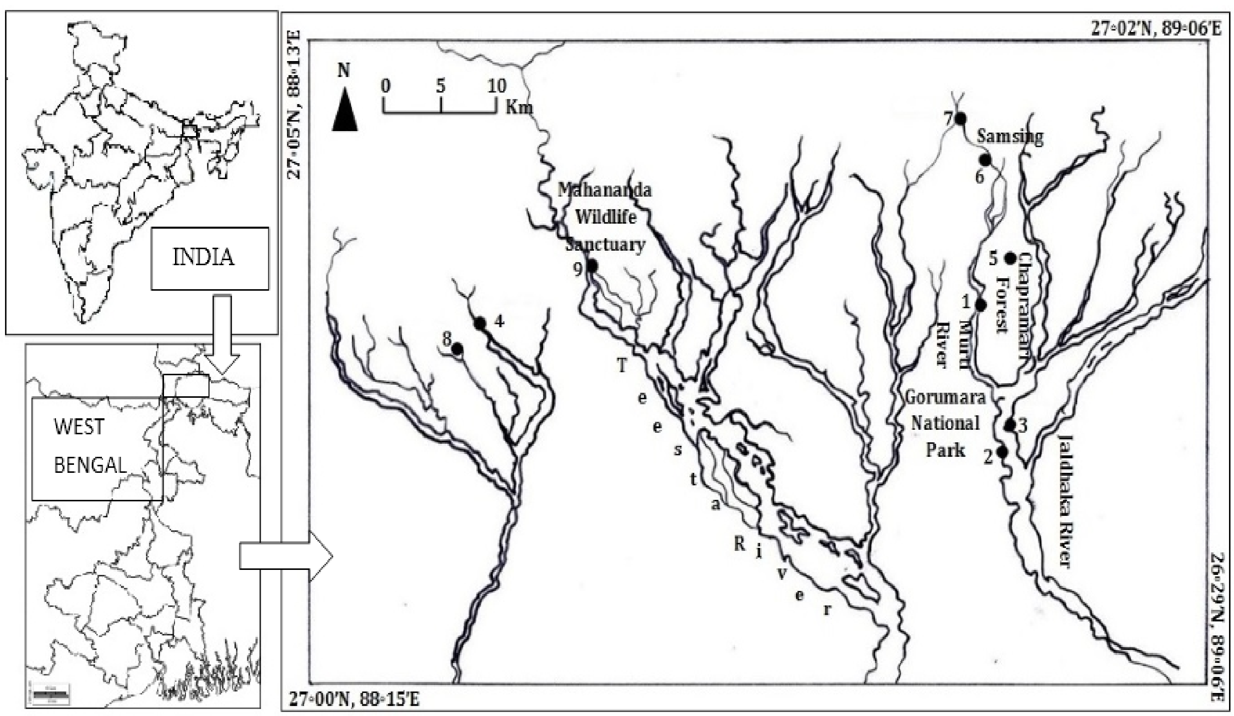

Fig 1: Map of the Darjeeling and Jalpaiguri districtshowing the locations of study sites and sampling stations marked as numbered black dots.
Note: 1=Murti Banani, 2=Murti GNP, 3=Jaldhaka GNP, 4=Mahananda River, 5=Kalikhola River, 6=Murti Samsing, 7=Murti Rocky Island, 8=Panchnoi River, 9=Teesta River

2.2. Macro-invertebrate sampling and identification

Macro-invertebrates were collected by sweeping 500-µm mesh D-shaped net and attached macro invertebrates were removed from rocks and other substrates by brushing and hand picking method[7]. All macro-invertebrates were preserved in the field in 70% ethyl alcohol. Identification of macro-invertebrate specimens in the laboratory up to family level was performed with the help of identification keys [10, 25, 5].

2.3. Data analysis

Macro-invertebrates were compared with different influencing environmental parameters at different sites. Diversity indices were used to obtain species diversity, dominance and evenness of macro-invertebrates between nine different sites (Primer version 6). In order to assess the interaction between different hydrological and physical parameters and assemblage of Macro-invertebrates, unimodal distribution of samples was used to explain the abundance of species with environmental variables (altitude, air temperature, water temperature, water current, dissolved oxygen, pH, total dissolved solids, boulders%, cobbles%, pebbles%, gravels%, sand%, woody debris%, algal mat cover%, bank vegetation cover%). Dissimilarity metrics was constructed to find the beta-diversity value between sampling sites[33]. The similarity in species composition at each site was studied by calculating the Bray-Curtis coefficient based on the fourth-root-transformed species abundance data. The result was displayed by non-metric multidimensional scaling (nMDS) plot [9]. Bray-Curtis similarity and Principal Component Analysis, a multivariate technique was used to describe the environmental dissimilarity between the sites (PRIMER-E Software (v. 6). Pearson correlation was plotted to get comparative results between macro-invertebrate abundances and environmental parameters and one way ANOVA represented significant differences between study sites according to ambient disparity between sites (SPSS version 17).

3. Results

A total of 1,500 individualsdistributed in nine different taxonomic groups belonging to 39 families were identified in different river tributaries ranges from high altitude mountain sites through the forest regions. The highest number of individuals (119) was obtained at Murti GNP, followed by Kalikhola (80), Jaldhaka GNP (79) Mahananda River (62) and Murti Banani (61). Subjected to spatial comparison Shannon diversity (2.197), Species density (18) and Species richness (4.135) were found to be highest in the site Murti Banani and lowest in Teesta River (0.7315, 4, 1.443 respectively). Teesta river represented as the highest (27.5) Whittaker Beta Index value whereas Kalikhola River and Murti Banani were found to be lowest (3.222) (Table 2). In terms of substrates and temporal factors, higher densities were observed in the cobbles, pebbles, gravels, algal mat cover, woody debris, air temperature and water temperature. Most of the environmental parameters were correlated with each other according to Pearson correlation coefficient (Table 3). Species richness (d) showed positive correlation with pebbles ($r=0.709$, $p<0.05$). Water temperature and air temperature were positively correlated with Species densities(S) ($r=0.845$, $p<0.01$), ($r=0.805$, $p<0.01$); Brilloiun index ($r=0.967$, $p<0.01$), ($r=0.849$, $p<0.01$); Shannon index (H') ($r=0.947$, $p<0.01$), ($r=0.745$, $p<0.05$)and Simpson index (1-Lamda') ($r=0.958$, $p<0.01$), ($r=0.680$, $p<0.05$) respectively but negatively correlated with Whittaker beta index ($r=-0.878$, $p<0.01$), ($r=-0.773$, $p<0.05$). Species richness (d) showed positive correlation with velocity ($r=0.846$, $p<0.01$)

Table 1: Environmental characteristics between nine different study sites (Mean SE±)

	Murti Banani	Murti GNP	Jaldhaka GNP	Mahananda River	Kalikhola River	MurtiSamsing	Murti Rocky Island	Panchonoi River	Teesta River
Alt(m)	139±0.57	357±1.73	330±5.77	664.5±0.89	528.3±0.17	1034±1.78	1762±1.15	443±0.76	465±0.57
AT(ºC)	32.03±1.15	32.4±0.03	30.6±0.05	31±1.15	28.16±0.56	22.5±0.24	24.5±0.17	31.1±0.03	22.7±0.14
WT(ºC)	26.6±0.05	26.85±0.58	23.9±0.54	23.8±0.57	23.89±0.003	21.5±0.26	20.7±0.11	21.5±0.02	12.9±0.03
WC(m/s)	2.66±0.005	0.95±0.01	1.13±0.07	0.95±0.06	0.324±0.01	0.36±0.009	1.2±0.14	0.024±0.0002	0.14±0.01
D.O	8.73±0.67	8.95±0.49	8.5±0.21	8.55±0.65	7.28±0.16	9.6±0.04	13±1.15	9.1±0.03	11.1±0.44
pH	8.16±0.15	8.33±0.51	7.7±0.43	9±1.15	7.8±0.11	7.6±0.17	8.8±0.51	7.2±0.05	7.4±0.03
TDS	28.16±0.57	2±0.57	2±0.05	47.5±1.12	10.4±0.26	0.004±0.001	12.25±0.14	90.3±0.54	0.002±0.001
Boulders (%)	2.66±0.09	4±1.15	4.5±0.86	5.6±0.05	57±0.57	74±0.89	72.6±0.72	3±0.03	9.9±0.26
Cobbles (%)	47.3±0.69	74.5±2.54	67.5±0.37	35±2.3	53.6±0.23	19.1±0.56	17.5±0.11	60.1±0.38	29.9±1.15
Pebbles (%)	32.64±1.23	10.06±1.09	17.5±0.86	5±1.15	26.3±0.02	4±0.13	4.5±0.2	14±0.24	10.2±0.95
Gravels (%)	10.06±1.67	7±1.15	6.5±0.49	1.5±0.2	10.4±0.05	2±0.44	3.5±0.09	19.8±0.16	25±0.57
Sand (%)	7.33±0.54	4.5±0.57	3±0.57	1±0.05	4±0.17	1±0.08	2±0.13	3±0.13	25.3±1.1
Wdy Deb (%)	10.6±0.73	33.5±1.7	26±1.15	13.5±0.86	31±0.57	1.9±0.46	1.5±0.12	25.3±0.55	0.003±0.002
AMC(%)	11±0.57	60.5±0.57	47.5±1.12	6±0.28	46.6±0.37	5±0.44	0.5±0.02	29.7±0.21	0.001±0.001
BVC(%)	15±1.15	3.5±0.77	2.5±0.11	30±1.73	94.3±0.17	5±1.34	9.5±0.28	47.1±0.38	0.002±0.001

Table 2: Diversity indices in different study sites

Diversity Indices	Murti Banani	Murti GNP	Jaldhaka GNP	Mahananda River	Kalikhola River	Murti Samsing	Murti Rocky Island	Panchonoi River	Teesta River
Species density (S)	18	17	12	14	17	6	13	13	4
Total individual (N)	61	119	79	62	80	23	25	44	8
Margalef's Index(d)	4.135	3.348	2.517	3.146	3.648	1.595	3.713	3.177	1.443
Shannon index (H')	2.197	2.128	1.737	1.963	1.919	1.434	1.845	1.666	0.7315
Brillouin	1.844	1.948	1.559	1.684	1.637	1.098	1.365	1.449	0.503
Whittaker's Beta Index	3.222	4.184	5.333	5.333	3.222	18	6.125	7.7692	27.5
1 Lamda	0.846	0.842	0.761	0.811	0.770	0.716	0.766	0.726	0.408

Note: The highest value of each parameter has been presented in bold

Table 3: Pearson Correlation matrix among Total abundance and physical parameters of study sites

	N	d	J'	Brillouin	Fisher	H'	1 Lamda	W Beta	Alt(m)	AT (°C)	WT (°C)	Velocity (m/s)	D.O	pH	TDS	% Bould	% Cobbles	% Pebbles	% Gravels	% Sand	Wdy Deb (%)	AMC (%)	BVC (%)
S	.549	.448	.424	.933**	.633	.931**	.831**	-.936**	-.260	.805**	.845**	.543	-.455	.455	.256	-.220	.558	.561	-.307	-.502	.641	.523	.441
N		-.322	.242	.653	-.106	.523	.512	-.576	-.309	.606	.607	-.083	-.545	.188	-.097	-.245	.762*	.049	-.301	-.405	.882**	.889**	.242
d			.277	.365	.428	.423	.335	-.296	-.372	.366	.404	.846**	-.159	.106	.099	-.271	.057	.709*	.009	.060	-.134	-.175	-.074
J'				.646	.198	.712*	.827**	-.545	.194	.273	.775*	.485	-.208	.480	-.066	.271	-.024	-.039	-.876**	-.802**	.084	.084	-.106
Brillouin					.442	.976**	.946**	-.946**	-.265	.849**	.967**	.542	-.525	.475	.222	-.243	.592	.398	-.517	-.683*	.668*	.573	.270
Fisher						.584	.475	-.602	.377	.238	.315	.529	.320	.580	.255	.181	-.104	.261	-.189	-.293	-.036	-.128	.220
H'							.972**	-.953**	-.095	.745*	.947**	.614	-.393	.577	.201	-.090	.420	.371	-.598	-.724*	.521	.424	.262
1 Lamda								-.917**	-.020	.680*	.958**	.547	-.396	.537	.197	-.002	.364	.253	-.711*	-.849**	.485	.401	.207
W Beta									.101	-.773*	-.878**	-.500	.416	-.496	-.276	.116	-.511	-.413	.501	.726*	-.632	-.518	-.391
Alt(m)										-.617	-.270	-.151	.739*	.433	-.156	.792*	-.727*	-.626	-.421	-.285	-.531	-.488	-.123
AT(°C)											.763*	.434	-.608	.218	.455	-.697*	.798**	.466	-.104	-.374	.735*	.599	.205
WT(°C)												.567	-.570	.391	.100	-.151	.539	.402	-.608	-.723*	.606	.552	.193
WC (m/s)													-.017	.489	-.109	-.225	.069	.482	-.373	-.161	-.096	-.091	-.295
D.O														.238	-.173	.360	-.638	-.556	.065	.267	-.708*	-.604	-.542
pH															-.043	.106	-.229	-.260	-.674*	-.397	-.112	-.189	-.112
TDS																-.373	.161	.062	.254	-.265	.184	-.075	.371
% Bould																	-.633	-.278	-.404	-.290	-.369	-.283	.184
% Cobbles																		.467	.173	-.133	.917**	.910**	.203
% Pebbles																			.246	.086	.380	.339	.431
% Gravels																				.774*	-.007	-.021	.110
% Sand																					-.356	-.273	-.249
Wdy Deb (%)																						.952**	.483
AMC(%)																							.303
BVC(%)																							

Note: *** Correlation is significant at the 0.01 level.* Correlation is significant at the 0.05 level.*

Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, WC= Water Current, DO= Dissolved Oxygen, TDS= Total Dissolved Solute, WL= Water Length, % Bld= Percentage of boulders, % Peb= Percentage of pebbles, % Grav= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

Table 4: Beta Dissimilarity Matrix of different study sites

	Murti Banani	Murti GNP	Jaldhaka GNP	MahanandaRiver	Kalikhola River	Murti Samsing	Murti Rocky Island	Panchonoi River	Teesta River
Murti Banani									
Murti GNP	0.5								
Jaldhaka GNP	0.57	0.55							
Mahananda River	0.47	0.45	0.47						
Kalikhola River	0.58	0.52	0.68	0.428					
Murti Samsing	0.66	0.64	0.61	0.57	0.72				
Murti Rocky Island	0.59	0.63	0.61	0.65	0.75	0.64			
Panchonoi River	0.76	0.57	0.68	0.65	0.8	0.64	0.63		
Teesta River	0.84	0.83	0.76	0.8	0.89	0.57	0.78	0.78	

Note: The value 0.8-1 shows high beta dissimilarity tendency

For differences between the study sites, formal significance tests for dissimilarity were performed using a dissimilarity matrix among sites obtained by computing the sample size value for all pairwise combinations of reaches [34]. The dissimilarity matrix of the nine different sites (Table4), illustrated the highest beta-diversity value (0.89) between river Teesta and Kalikhola followed by Murti (Banani)-Teesta, Murti (Gorumara National Park)-Teesta and Mahananda-Teesta(0.84, 0.83, 0.8 respectively). The significant dissimilarity value was 0.8-1. The lowest dissimilarity value was found between Mahananda and Kalikhola (0.428). S17 Bray Curtis Resemblance Matrices produced groups mostly according to macroinvertebrate sample size of the nine study sites. Two major clusters of sites were formed at the level of 40% similarity where River Teesta formed an isolated cluster andwhile seven major clusters of sites were observed considering 60% level of similarity (Fig. 2).

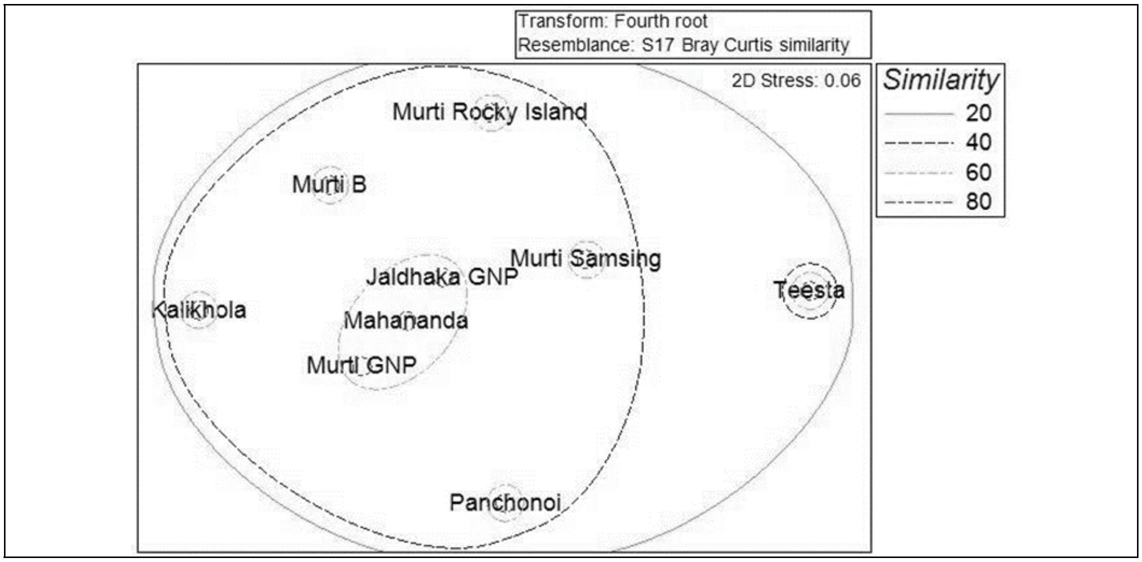

Fig 2: Two-dimensional nMDS plot of the macroinvertebrate assemblages (based on macroinvertebrate abundances) according to Bray-Curtis similarity. Stress value (2D): 0.06

The Principal Component Analysis (Fig. 3) allowed the nine study sites to be taken into account simultaneously aiming to visualise the environmental resemblance and dissimilarity within the total studied area. The plots of all the nine sites showed five principal components (PC1-PC5), with the first four components (factors) explaining 84.8% of total variation. The percentage of variation explain by each factor is presented in table 5.

Table 5: Results of principal components analyses (PCA) based on environmental condition of the nine study sites

PC axis	PC1	PC2	PC3	PC4	PC5
Eigenvalue	6.02	3.34	1.98	1.37	1.23
Proportion of variation	40.1	22.2	13.2	9.1	8.2
Cumulative variation	40.1	62.4	75.6	84.8	92.9
Eigenvectors					
Altitude (m)	0.314	-0.263	-0.208	-0.059	-0.064
Air Temp. (°C)	-0.364	-0.117	0.182	-0.217	-0.129
Water Temp. (°C)	-0.288	-0.366	0.059	0.048	0.073
Velocity (m/s)	-0.088	-0.258	0.542	0.032	0.314
D. O	0.338	-0.017	0.150	-0.046	-0.204
pH	0.050	-0.430	0.199	-0.151	-0.095
TDS	-0.119	0.049	-0.080	-0.790	-0.072
Boulders %	0.242	-0.209	-0.393	0.207	0.297
Cobbles %	-0.375	0.080	0.002	0.143	-0.246
Pebbles %	-0.257	0.095	0.140	0.071	0.627
Gravels %	-0.015	0.519	0.029	-0.146	0.029
Sand %	0.115	0.446	0.252	0.151	0.065
Wdy Deb %	-0.365	-0.020	-0.232	-.109	-0.190
AMC %	-0.329	-0.006	-0.205	0.340	-0.235
BVC %	-0.164	0.018	-0.473	-0.239	0.426

Considering this PC1 axis showed an opposition between three sites (Murti Samsing, Murti Rocky and Teesta) from six other sites (Murti Banani, Murti GNP, Jaldhaka GNP, Kalikhola River, Mahananda River and Panchonoi River). Axis PC1 clearly separated these sites on the basis of variables i.e. cobbles (-0.375), pebbles (-0.257), TDS (-0.119), BVC (-0.164), AMC (-0.329), woody debris (-0.365), air temperature (-0.364) and water temperature (-0.288). The second axis PC2 showed an opposition between two study sites (Panchonoi River and Teesta River) and seven sites (Murti Samsing, Murti Rocky, Murti Banani, Kalikhola River, Murti GNP, Jaldhaka GNP and Mahananda River) according to gravels (0.519) and sand (0.446).

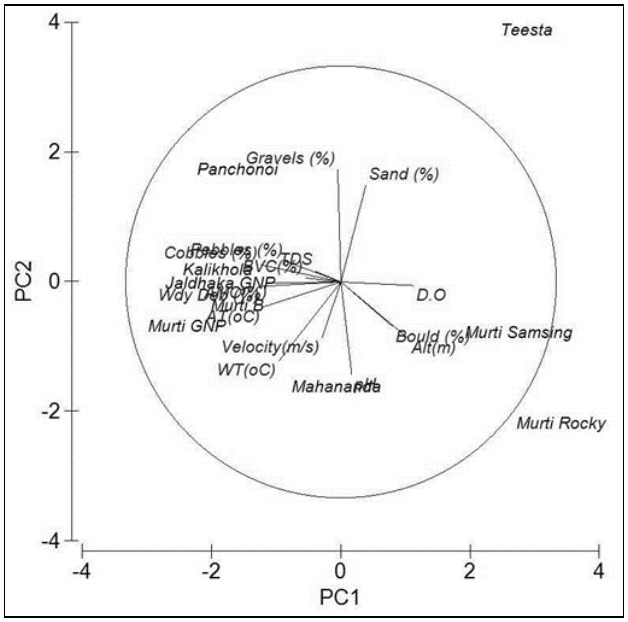

Fig 3: The PCA Graph showing environmental condition at nine study sites

Abbreviations: Alt= Altitude, AT= Air Temperature, WT= Water Temperature, D.O= Dissolved Oxygen, TDS= Total Dissolved Solid, Bould (%)= Percentage of boulders, Pebbles (%)= Percentage of pebbles, Gravels (%)= Percentage of gravels, Wdy Deb (%)= Percentage of woody debris, AMC (%)= Percentage of algal mat cover, BVC (%)= Percentage of bank vegetation cover.

One way ANOVA represented significant differences in macroinvertebrate assemblage structure and environmental condition between nine sites (p<0.001). Post hoc Duncan analysis revealed that altitude and species evenness were significantly different in each study sites (p<0.05) whereas high variability in environmental conditions across rivers also was evidenced by significant differences in habitat heterogeneity among the sites. In terms of resemblance, site 2(Murti, GNP), site 3(Jaldhaka, GNP) and site 4(Mahananda River) were not found to be significantly different according to air temperature, water velocity, dissolved oxygen, boulders percentage, species density, Whittaker beta diversity (p>0.05). With regard to beta diversity, site 9(Teesta River) showed highly significant difference in Whittaker beta diversity index, species density, water temperature, gravels, cobbles, boulders (p<0.05).

4. Discussion

A number of environmental factors such as water temperature, water velocity, substrate composition, hydro median depth and turbidity are likely to influence the diversity, abundance and larger differences in faunal composition of aquatic benthic invertebrates [36, 20]. Environmentally composite substrata such as leaves, gravel, wood and macrophytes generally support more richness than structurally simple substrates such as sand and bedrock [3]. Alteration of habitat quality leads to change of their assemblage structure [30]. Some specific types of rocky substrata such as gravel, stones provide different food resources to aquatic faunal species and support them to construct their population structure [20]. In some cases canopy type was found to be more important than substrate quality to have effect on total abundance and guild structure. It was reported that streams without shading had higher abundances of invertebrates than did shaded streams [15]. Based on these other previous studies, some contrasting results had come out and some studies also supported the present investigations.

Townsend*et al*. [31] suggested that elevated stream water currents homogenise organismal distribution on river bed, whereas [22, 23] investigated that outpouring of stream flow may drive aquatic species to disarrange insect association and some substrates (e.g. loose or fixed stones) on the stream bed. These findings supported the present investigation. Species richness (d) showed significant positive correlation with water velocity (0.846, p<0.01) which might help macro invertebrates to shift and concentrate in number on some particular substrata (cobbles, pebbles, woody debris).

Species growth and life history are restrained with the influence of water temperature variationin a specific temperature range[36]. Sharma *et al*. [29] represented an inverse relationship between aquatic insects and water temperature. However, these facts did not corroborate with the present study, while water temperature showed a remarkable positive correlation with species density, Brilloiun index, Shannon index, Simpson index and total abundance (0.845, p<0.01; 0.967, p<0.01; 0.958, p<0.01; 0.806, p<0.01).The high abundance of aquatic insects in higher water temperature might be due to higher growth of algae on substrates and greater number of litter patch, woody debris due to higher growth of canopy on river bed.

Dependence of spatial level of beta diversity component on substratum type appeared to be significant in most cases.In present context of the study, the beta dissimilarity value of site 9 appeared to be highest with site 5 and followed by the site 1, 2 and 4 (Table 3). One way ANOVA and Post Hoc Duncan analysis of nine study sites indicated that site 9 varied significantly (p<0.05) in terms of water temperature, boulders, cobbles, gravels and also species density. These faunal dissimilarities were observed to be lower among litter patches, intermediate among stonesand higher among gravel patches in the same riffle [28]. Whittaker beta diversity index value (27.5, p<0.05) also supported the fact of dissimilarity. In contrast, beta diversity was observed to be higher at the level of stream segments for all microhabitat types [20].

Hydrological parameters played a pivotal role to influence richness of benthic invertebrates which was supported by observations from different substrata of river bed [18]. Accordingly, Yazdian *et al*. [38] stated that different environmental variables such as DO and temperature appeared to be more important component to control macroinvertebrate diversity structure. Similarly, in the present study, air temperature, water temperature, velocity, cobbles, pebbles, woody debris, algal mat cover, bank vegetation cover were presented as PC1 which was found to deviate at site 6, 7 and 9 from the rest of study sites while sand and gravels appeared as PC2 to isolate site 8 and 9 from other seven study sites (Figure 3). ANOVA result of variety of substrata such as sand (0.202, p>0.05), cobbles (0.379, p>0.05), gravels (0.095, p>0.05), pebbles (0.432, p>0.05), boulders (0.172, p>0.05) led to the fact that the site 6 and 7 were to be placed together. In addition, the other substratum i.e. woody debris (0.191, p>0.05) also pointed to the aggregation of three sites(site 6, 7, 9). Although PC2 separated site 8 and 9 from other sites, the two sites varied significantly (p<0.05) in terms of gravel percentage. pH of site 8 (p<0.05) and sand percentage of site 9 (p<0.05) varied significantly from the rest of study sites.

The extent of stream macroinvertebrate community was

constructed by Bray-Curtis similarity analysis. Marchant *et al.* [21] showed that out of 10 ecoregions, 3 individual zones were deviated from other 7 zones according to macroinvertebrate composition.Similarly, in the current study of macroinvertebrate assemblage, site 2, 3 and 4 formed a separate cluster at 60% similarity (Figure 3). Site 9 showed an isolated single cluster at the level of 40% similarity which supports the Whittaker beta dissimilarity index, Beta dissimilarity matrix as well as Post Hoc Result of ANOVA.
Macroinvertebrate assemblage structure, within stream habitat discrepancy and beta diversity were significantly variable among streams. Different spatial and environmental gradients among riffles in some streams were shown to be quite divergent and also homogenous in some other streams [14, 2]. The streams of nine study sites in the rocky, forested and plain region of district Jalpaiguri and Darjeeling areimportant habitats for macro invertebrates. Benthic macro invertebrates contribute a favourable indigenous diet for most of insectivorous fishes [29].
The total riverine ecosystem is under several natural (landslides,Flash floods and sedimentation) and anthropogenic pressures (deforestation, intensification of agriculture, speeding of human settlement, soil erosion, extraction of sand, pebbles and stones in the catchment area) and these gradients have some influences on diversity and abundance of aquatic macroinvertebrate [29].
Eastern Himalayan regions perform pivotal ecological roles in maintaining the integrity of the ecosystems. Anthropogenic disturbances; habitat fragmentation and loss are causing a decline of many species at an alarming rate emphasizing the need to use macroinvertebrate as bioindicatiors. Constructions of physical barriers interrupting the riverine flow are expected to decrease macroinvertebrate diversity because they deeply vary downstream environment, especially in altitudinal rivers. However, the ecosystem requirements of biodiversity are frequently not considered in the development planning process.

5. Conclusion
Habitat heterogeneity along with different hydrological parameters influences a wide range of macroinvertebrate diversity. Correlation and ANOVA analysis between diversity indices and environmental variables viz. water and air temperature, water current, dissolved oxygen and percentage availability of algal mat cover, woody debris and bank vegetation cover revealed that the data was significant. The determinant role of the habitat characteristics in controlling macroinvertebrate species abundance and diversity has been postulated. Thus, functional diversity of macroinvertebrate would be explored further to ascertain the ecosystem services they provide.

6. Acknowledgements
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SUMMARY OF THE PROJECT

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 *Bariliusbendelisis, Puntiussophore, Schisturacorica, Lepidocephalichthys guntea*. Ichthyological biodiversity exhibited maximum value in the middle reaches of the river *viz.*Gojoldoba and Domohonidomimated by Cypriniformes (*Aspidopariamorar*, *Bariliusbendelisis*, *Devariodevario*, *Puntiussophore*, *Esomusdanricus*, *Lepidocephalichthysguntea*) and Siluriformes (*Mystusbleekeri*, *Bagariusyarrelli*, *Glyptothoraxtelchitta*, *Glyptothorax striatus*, *Glyptothoraxindicus*,*Glyptothorax cavia*) fishes.

According to water quality Index, among the seven sampling areas four areas (Rishi Khola, Rungpo, Teesta Bazaar and Gojoldoba) had good SWI (Stream Water Index). Two sites (Sevoke and Domohoni) had fair SWI while one site (Haldibari) had poor water quality index.

As per PHI, Physical habitat assessment suggests not so greater disturbance in the stream stretch. Four sampling areas (Rishi khola, Rungpo, Teesta bazaar and Gojoldoba) were analyzed as good, two areas as fair (Sevoke and Domohoni) and one area (Haldibari) as poor which has also been observed to have high impactful human activities.

From the IBI scoring only Gojoldoba was found to be acceptable site compared to others. Although the overall health of the river Teesta has been found to be acceptable, however, the entire stretch may be considered to be in sensitive state (owing to marginal values between acceptable and impaired conditions) and highly prone to environmental degradation.

A total of 1,500 individuals distributed in nine different taxonomic groups belonging to 39 families were identified in different river tributaries ranges from high altitude mountain sites through the forest regions, where Mayflies (Ephemeroptera) were found to be the most dominant followed by Caddisflies (Trichoptera) and Coleopteran insects in the study. Among them the most ubiquitous insects included family Heptagenidae, Beatidae, Hydropsychidae, Psephenidae. Other commonly occurring insects incorporated family Chironomidae, Gerridae, Leptophlebidae, Lymnidae, Ephemerllidae, Perlidae and Vellidae.

Site Murti Banani was found to the highest in Shannon diversity (2.197), Species density (18) and Species richness (4.135) and Teesta River was found to be lowest (0.7315, 4, 1.443 respectively). But Teesta river represented as the highest (27.5) Whittaker Beta Index value whereas Kalikhola River and Murti Banani were found to be lowest (3.222).A decreasing tendency in total abundance was markedly observed along with increasing altitude. In terms of substrates and temporal factors, higher densities were observed in the cobbles, pebbles, gravels, algal mat cover, woody debris, air temperature and water temperature. Bray Curtis Resemblance Matrices produced groups mostly according to macroinvertebrate sample size of the nine study sites. Two major clusters of sites were formed at the level of 40% similarity where River Teesta formed an isolated cluster and while seven major clusters of sites were observed considering 60% level of similarity. The Principal Component Analysis allowed the nine study sites to be taken into account aiming to envisage the environmental resemblance and dissimilarity within the total studied area.