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Diversity and composition of freshwater fishes in river systems of Central Western Ghats, India

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Synopsis

The Western Ghats (India) is a region of high biological diversity and endemicity of terrestrial fauna, but very little is known about its freshwater species distributions. Four rivers, Sharavati, Aghanashini, Bedti and Kali, of the central Western Ghats were studied for their fish diversity and composition. A total species richness of 92 species (and an endemicity of 25%) was reported. A comparison of expected species richness (SR) estimates using different statistical estimators was made – these showed the expected SR to be in the range of 92–120 species. Many of the species were found to be shared with those belonging to the southern Western Ghats, but the study also unearthed new findings in terms of description of a new species and extension of the known distribution range of some of the species. The study at varying spatial and temporal scales also showed that while the rivers are very similar to each other in terms of the SR values, they do vary with respect to the species composition. Species compositions across upper (or lower) reaches of these rivers were found to be more similar to one another than the upstream and downstream reaches in the same river. Temporal patterns, with regard to diurnal activity of fishes were studied. These showed that of the 72 species collected at night, 29 were exclusive to night sampling. Though much of the information of the feeding and habitat preferences of the fishes in this region is lacking, it is speculated that the differences in their activity patterns could be related to feeding and predator avoidance.

Introduction

Studies of freshwater fishes in the Indian subcontinent have been limited to scattered works on commercial fisheries and even these have been largely restricted to some of the major river systems like the Ganges and the Yamuna. Out of the 2,500 species of freshwater fishes that have been recognised in the Indian subcontinent, 930 are categorized as freshwater species (Jayaram 1999). Much of the early study on the freshwater systems of the Indian subcontinent started with the works of British officers working for the East India Company, who took great interest in the natural history of the region. Some early contributions were those of Hamilton-Buchanan in 'The Fishes of the Ganges' (1822) and by others like McClelland (1839), Sykes (1839) and Jerdon (1849). Some of the most important contributions to such studies were made by Francis Day in his Fishes of India (1875–1878). Substantial literature is now available on the identification and systematics of freshwater fishes of India, starting with Hora's contributions between the 1920–1950s and the most recent texts by Talwar & Jhingran (1991), and Jayaram (1999).

Though most of these contributions have been taxonomic in nature, there exist some works on the biogeographic distributions of fishes in the region as well (Jayaram 1974). A series of papers published by

Hora in the 1930s to 1950s addressed the problem of the anomalous distribution of hill stream fishes in peninsular India: many species belonging to the peninsular part of India (particularly in the Western Ghats (WG)) were found to be the same, or congeneric to, species found in the North East of India and to some species even in South East Asia.

The levels of endemicity were found to be very high over all the vertebrate taxa in the WG. Fishes in this region are also found to have high endemicity. Of the 218 species recorded, 114 (52%) are endemic to the WG and Sri Lanka (Daniels 2001). Some studies on hill stream fishes have been conducted in the states of Kerala and Tamil Nadu in recent years. Notable earlier works are those of Silas (1951) on the fishes of the Anamalai and the Nelliampathi Hill Ranges of southern WG, and those by Rajan (1963) on the ecology of the fishes of the rivers Moyar and Pykara. Fish diversity and distribution in the Kerala part of the WG has been studied extensively by Shaji & Easa (1995, 1998) and Easa & Shaji (1997). Kerala has about 44 rivers and as many as 200 freshwater fishes, of which 25 have been reported as endemic. In addition to studying the systematics of the fishes of this region, their ranges and status have also been evaluated. But since large parts of the rest of the WG are as yet unexplored, the distribution status of many of these species remains uncertain. Recently, studies have been conducted in some parts of the WG with respect to fish assemblage structure and the association of microhabitat variables to species diversity (Arunachalam 2000); these studies seem to indicate that high habitat diversity is associated with high species diversity and abundance.

Taxonomic collections apart, not much work has been done on the study of freshwater fishes in the central and northern parts of the WG. Given the high levels of faunal diversity and endemicity observed so far, there is an urgent need to understand the fish diversity and distribution of this region. The need is, in fact, made all the more urgent by the recent spurt of human activities in this region in exploiting its water resources for hydroelectric purposes. Not only are the rivers directly affected by the developmental activities, but they are also affected by other threats like introduction of exotic species, over fishing and the disposal of industrial and domestic wastes from new industries and settlements. Before the rich species diversity of this region of the subcontinent is lost forever, the documentation of the species found here as well as their distribution is crucial; this together with the identification of the threats will help in formulating the needed conservation measures. As an initial step in this direction, the main objective of this study was to collect data on species richness and distributions that could serve as baseline information to monitor the potential human impacts. Given that previous studies on fish diversity on the southern WG (Kerala) show that this region is very high in diversity as well as endemicity, one would expect similar trends in the study region as well. The important questions addressed here are as follows. What is the diversity of freshwater fishes in this region and how does it compare to rivers of similar dimensions in other parts of the subcontinent? How does this diversity vary at differing spatial scales like entire river systems, the upper and lower reaches in a river? Finally, we study the species composition and their distributions at these various spatial and temporal (diurnal) scales. Further questions on patterns of species distribution along habitats and environmental parameters have been addressed elsewhere (Bhat 2002).

Materials and methods

Study area

The study was conducted in the central WG, a set of medium to low lying mountain ranges along the western borders of the Indian peninsula. The WG, along with another range of smaller mountains called the Eastern Ghats (EG), form a substantial percentage (approximately 10%) of the forested area of the Indian subcontinent. The study area is located in the Uttara Kannada district of Karnataka state (Figure 1). The region consists of three topographically distinct regions – the higher elevation region (which continues towards the east into the Deccan Plateau), the steep ridge area (where the mountain ranges slopes west wards towards the coastline) and the plainer coastal zone on the west (which touches the Arabian Sea). The climate of the region is mainly tropical with a well defined rainy season between June and October, a very mild winter between December and February and a relatively dry pre-monsoon summer between March and May.

Sampling

Four of the prominent rivers of the district are the Kalinadi, Bedti, Aghanashini and Sharavati. The present study was conducted on these four river

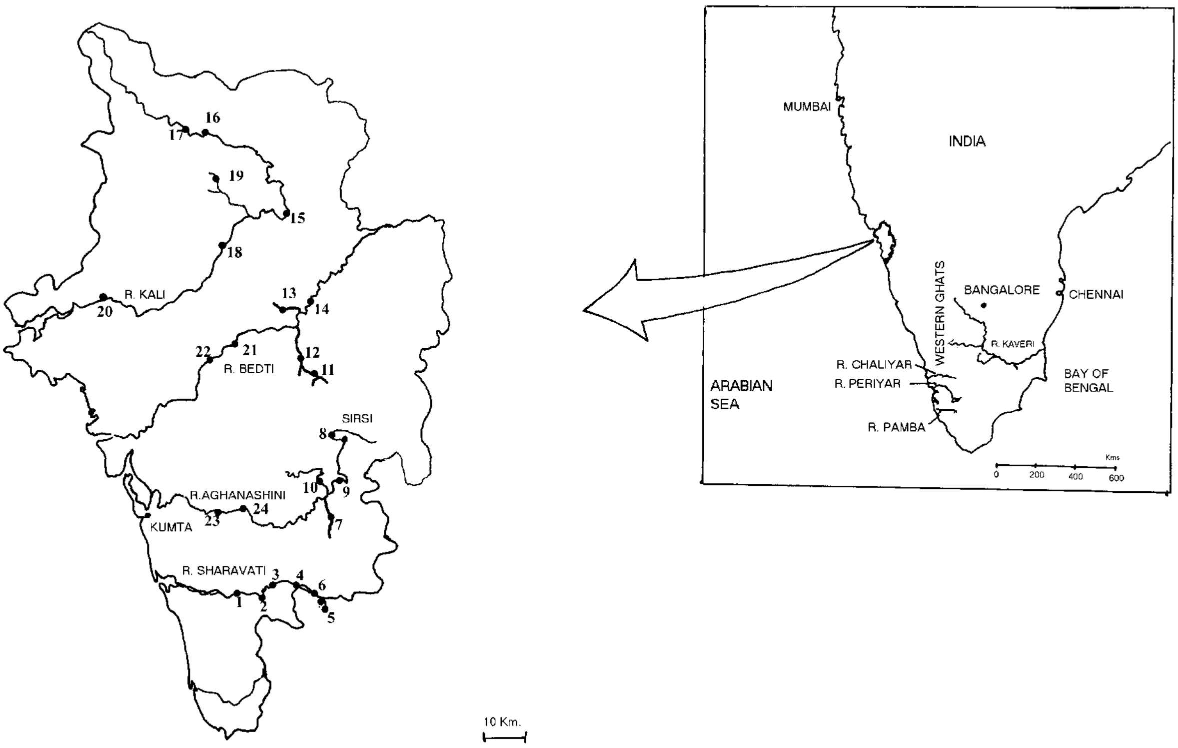

Figure 1. Map showing the location of each of the study sites on the four rivers. Study sites on each river are marked by (•) and their site codes (see Appendix 1 for site names).

Table 1. River lengths, catchment area, annual discharge and other physical attributes.

	Total length (in km)	Catchment area (in sq km)	Annual discharge (in million cu m)	Falls, if any (Height in m)	No. of major dams, if any	Sources of pollution
Sharavati	128	2209	4545	Jog falls(252)	2	Minimal
Aghanashini	75	2146	966	Unchalli falls (116)	None	Minimal
Bedti	152	3902	4925	Magod falls (184)	None	Sewage, pesticides
Kali	184	5179	6537	Lalguli falls	4	Industrial effluents

systems – details of the length, catchment areas and discharge for each river is summarized in Table 1. Fishes on these rivers were sampled regularly over a period of two years (Jan 1997–Apr 1999) (see Table 2 for dates of samplings) on 24 sampling sites (details are tabulated in Appendix 1). The sites were chosen such that each river had 6 sampling sites: three on the higher elevation zone and three on the mid and lower elevation zones. Corresponding to this choice, there was also a difference in altitude along these sites – all the upper region sites were located at an altitude of >250 m above mean sea level (MSL), while all the downstream sites were located at <250 m above MSL. Thus, regional comparisons along a river were made across the upstream and downstream sites.

Sampling was done using a variety of fishing nets of varying mesh sizes – gillnets, cast nets and dragnets (Table 3). The fishes were identified and some representative specimens were collected and preserved in (4% formaldehyde solution) in plastic bottles. Identifications done were based on keys for fishes of the Indian subcontinent (Jayaram 1999, Talwar & Jhingran 1991) and also with the help of taxonomic expertise from the

Table 2. Details of the seasons, dates and times of sampling carried out between February 1997 and April 1999.

Sampling season	Sampling dates	Time of sampling	Duration
Summer	Feb, 1997	Day	8:00–17:00
Premonsoon	Apr, 1997	Day	8:00–17:00
Post monsoon	Oct, 1997	Day	6:00–10:00, 16:00–18:00
Winter	Dec, 1997–Jan, 1998	Day	6:00–10:00, 16:00–18:00
Summer	Mar, 1998–Apr, 1998	Night	17:00–24:00
Winter	Nov, 1998–Jan, 1999	Night	17:00–24:00
Premonsoon	Apr, 1999	Day	8:00–10:00, 16:00–18:00

Table 3. Types of nets used and their mesh sizes.

	Gill net 1	Gill net 2	Gill net 3	Gill net 4	Cast net 2	Cast net 1	Drag net 1	Drag net 2
Length (in m)	17.1	17.1	15.6	26.6			6.0	6.0
Breadth/height (in m)	2.3	2.2	2.4	4.0	2.5	2.4	1.0	1.0
Mesh size (in cm)	1.6	1.7	1.9	4.1	0.9	1.1		
Circumference (in m)					12.0	14.2		

Regional Station of the Zoological Survey of India at Chennai.

Sampling was carried out on 100–150 m of stretches of the river at each site. Collections of fish samples were taken at every habitat type along each stretch, using all the sampling methods, such that as far as possible, the existing species and relative abundance for that site were obtained in the sampling. For the study, a 'sample' is defined as the collection made at a particular habitat using a particular sampling tool (cast nets, gillnets or dragnets). A total of 340 samples were collected from the entire study region (including all the 24 sites on the four rivers).

A pilot survey was carried out prior to the actual sampling wherein the number of species caught with each sampling effort (a single cast net sweep or an hour of gill netting) was counted and a species accumulation curve was obtained thereby. This was used to calculate the minimum sampling effort required to get a plateau in the species vs. sampling effort plot. Based on such pilot surveys carried out at various sites, a sampling effort of 20 cast nets and duration of around 3 h of releasing the gill net was used as a standard for the sampling subsequently carried out at all the sites.

Data analyses

Species richness and distributions

Species richness was used as the index for the estimation of species diversity as well as for comparisons of diversity across rivers and regions, as the relative abundance for the species may not give the true abundance for the communities. Adequacy of sampling was assessed using species accumulation curves. Despite a very rigorous sampling, there is always a possibility of having missed some rare and cryptic species from the sampling effort. Several statistical estimators have been used for calculating and extrapolating species richness; these take into account the possible proportion of rare species and make conservative estimates of the true species richness of an area (Colwell & Coddington 1994). A number of parametric and non-parametric methods have been adopted to make these estimates and which have been reviewed in Bunge & Fitzpatrick (1993) and Colwell & Coddington (1994). Some of the commonly used non-parametric estimates are the Jackknife method described in Heltshe and Forrester (1983), the bootstrap method (derived by Smith & van Belle 1984) and Chao's estimator, Chao 1 (Chao 1984). These three methods of estimation were applied on the data collected from the samplings to check for differences in the estimation of the species richness.

Frequency distributions of the species across the rivers and sites were plotted for studying the extent of skewness of the data sets. Species richness, as well as compositions, was compared (across rivers) to study the extent of species shared between them and in identifying those found exclusively in particular regions in a river.

Due to the differences in numbers and kinds of habitats at each site, there were differences in the total sampling effort applied at each site. Comparisons of species richness across various spatial scales (rivers, regions) and diurnal scale (i.e. day and night variations) were carried out using the method of rarefaction – a statistical technique of estimating the expected number of species for a given random sample of size n; species richness is then estimated as the sum of the probabilities that each species will be included in the sample (Sander 1968, Hurlbert 1971). This method thus allows for comparisons to be made when sample sizes across two datasets are unequal (due to differences in sampling efforts). The number of species that can be expected in a sample of n individuals (denoted by $E(S_n)$) drawn from a population of N total individuals distributed among the various species is

$$E(S_n) = \sum_{1}^{n} \left\{ 1 - \left[\binom{N - n_i}{n} \Big/ \binom{N}{n} \right] \right\}.$$

where $n_i =$ number of individuals of the ith species, and $N =$ total number of individuals in a sample

Species accumulation curves, including the various estimators, were plotted for making these comparisons; these curves were generated using the EstimateS (version 5) software, which uses Monte Carlo simulations of random samples drawn from the total set of samples for estimating the average species richness.[1] Here, 200 randomisations were run for a given number of samples for the estimation of species richness values and their means were used in plotting the species accumulation curves. The difference in species richness across rivers tested with the Mann–Whitney U-test. To reduce the chances of type I errors from multiple pairwise comparisons, the Bonferroni method has been applied (Harris 1975). By this method, if the p (probability of error) value for overall comparisons is taken as 0.05, the adjusted 'alpha' (error) value for each pairwise test is estimated as 0.05/(the number of pairwise tests). Thus, for the comparisons of species richness across the four rivers, 6 pairwise tests were involved and the alpha value for each pairwise test was fixed at 0.008.

[1]Colwell, 1996. User's Guide to EstimateS – Statistical estimation of Species richness and shared species from samples. Version 5. User's Guide and application published at: http://viceroy.eeb.uconn.edu/estimates.

Faunal similarities at different spatial and temporal scales

Matrices of presence–absence data were used to analyse the differences in species composition at various spatial scales – river wise differences as well as differences between upstream and downstream regions. These were measured using the Jaccard index of species dissimilarity, which is based on the proportion of species not shared between two datasets/samples as well as using the Chord distance, which uses the relative proportion of species in the samples, in addition to the number of species. This is done by projecting the samples in a circle of unit radius using direction cosines (Ludwig and Reynolds 1988).
Chord index is measured as

$$CRD_{jk} = \sqrt{2(1 - ccos_{jk})}$$

where, the chord cosine (ccos) is

$$ccos_{jk} = \sum_{i=1}^{S}(X_{ij}X_{ik}) \Big/ \sqrt{\sum_{i}^{2} X_{ij}^2 \sum_{i}^{S} X_{ik}^2}$$

and where, j and k refer to the samples being compared, X_i stands for the abundance of the species i, and S refers to the total species in the two samples. Dendrograms using the average linkage clustering were prepared to study the relationships based on the similarity in species composition between various datasets – rivers, regions as well as study sites. Regional differences in species diversity and composition were measured and tested for significance across upstream and downstream regions.

There are species which are active at certain times of the diurnal cycle and which might hide in crevices and unreachable sections of a stream during inactive periods. To check if the time of sampling had any effect on the kind of catch, the data was divided into that collected in the daytime (between 6:00 and 18:00 hours) and that collected in the night (between 18:00 and 1:00 hours). Samples collected during the daytime and at night were then compared for differences in species richness as well as composition. All the accumulation curves from randomisation were generated using the EstimateS software developed by Colwell (1996). The other analyses were carried out using the Statistica package.[2]

[2]StatSoft, Inc. 1999. Electronic Statistics Textbook. Tulsa, OK: StatSoft. WEB: http://www.statsoft.com/textbook/stathome.html.

Results

Diversity studies

A total of 92 species were identified from the 10 771 individuals collected, representing 25 families and 48 genera. Figure 2(a,b) shows the species accumulation curves plotted against the number of samples (a) and number of individuals (b). The curves were found to best fit (r = 0.99) the generalized Michelis–Menton family model given by the equation

$$Y = (ab + cx^d)/(b + x^d).$$

Based on the three non parametric methods of species richness estimations, the expected species richness for the region were calculated (Figure 3). The simplest estimation of species richness by rarefaction of the observed species is usually an underestimate of the true richness, since it does not take into account the rare unrepresented species in the sample. The results of

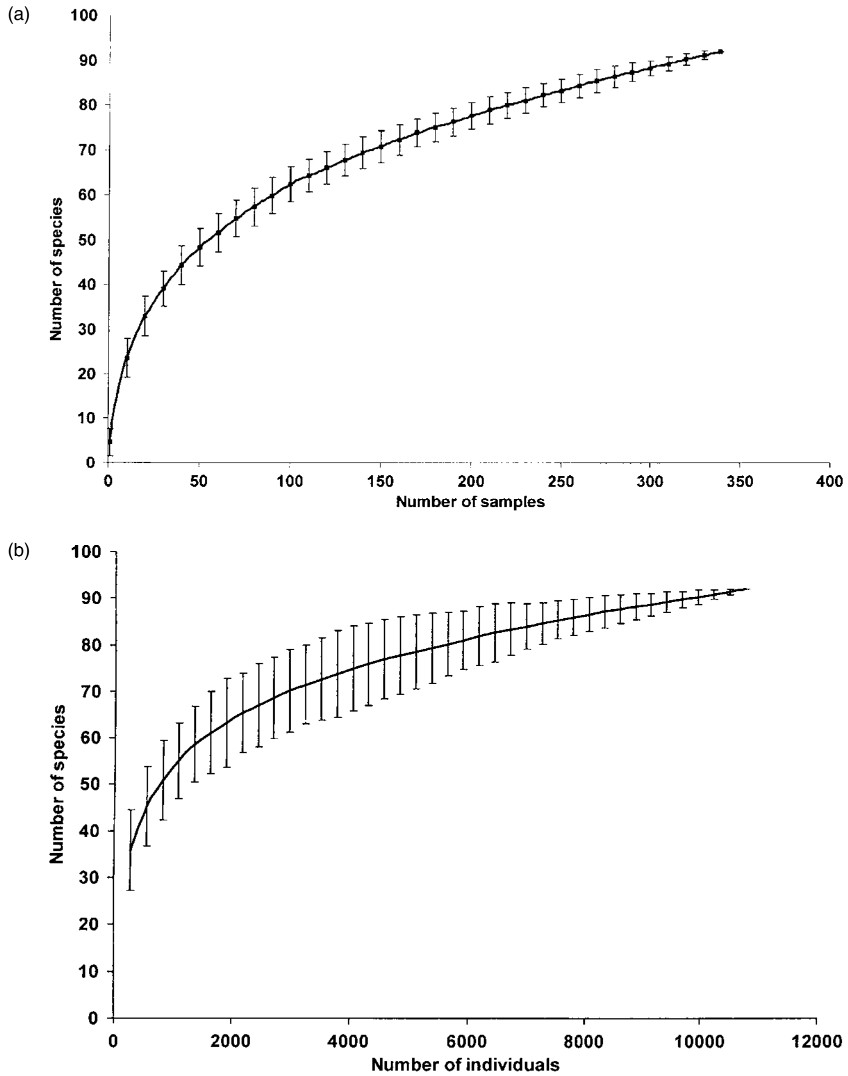

Figure 2. (a) Species accumulation curve – samples vs. species richness (vertical bars indicate the standard deviation). (b) Species accumulation curve – individuals vs. species richness (vertical bars indicate the standard deviation).

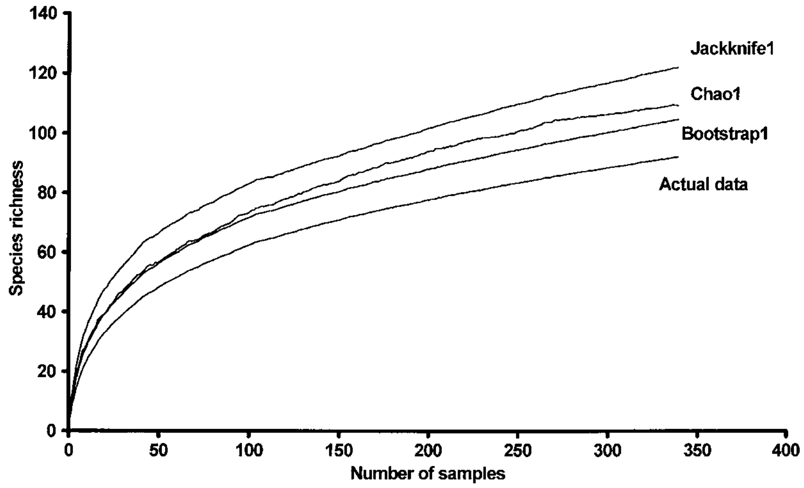

Figure 3. Comparison of species accumulation curves generated by various species richness estimators as against the actual data (without any estimator).

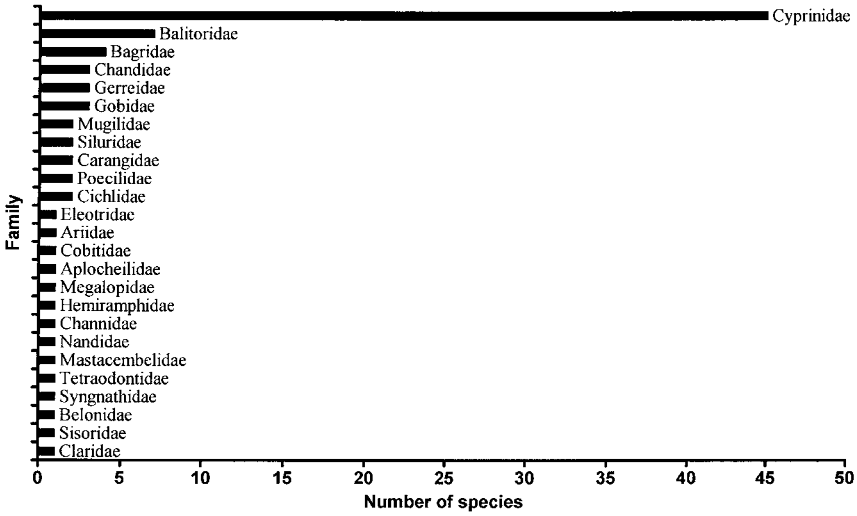

Figure 4. Diagrammatic representation of the number of species occurring in each family.

this study show that a total of 92 species were enumerated from this region, while the Jackknife 1 estimator gives an estimate of 120, Chao1 109 species and the Bootstrap method 104 species.

Faunal compositions

The family Cyprinidae of whom 45 species were identified, dominated the samples collected. Other abundant groups were the loaches Balitoridae and the catfish family Bagridae (Figure 4). Almost 30% of the total species identified (N = 25) are endemic to the WG. A similar study conducted in the southern WG (in Kerala state) showed that out of the 200 species enumerated from the rivers of that region, 25 were endemic to Kerala (Shaji & Easa 1998). While the distribution ranges of most of the species are not fully demarcated, some species have not yet even been described (Bhat & Jayaram, in press). The bagrid catfish *Horabagrus brachysoma* recorded so far only in the southern

WG rivers, was found to be also present in these rivers (Bhat 2001). Another interesting discovery was made, of a new species of catfish, *Batasio sharavatiensis*, which was found to be restricted to the upstream of Sharavati (Bhat & Jayaram, in press).

The abundance distribution (Figure 5) of the species across sites sampled shows a typical left skew; this is also observed in studies of birds, butterflies and other communities. This means that most of the fish species are relatively rare, while a few species dominate an area in terms of their abundances. We found that as many as 67 species had an abundance of only around 50 individuals out of the total of 10,771. Only one species, *Garra gotyla stenorhynchus* had an abundance of about 2,200 individuals. Species like *Puntius jerdoni*, *P. filamentosus*, *P. amphibius*, *Danio aequipinnatus*, and *Rasbora daniconius* (all belonging to the family Cyprinidae) were the other abundant species. Species like *Bhavania australis* and *Silurus wynaadensis,* which constitute some of the rare and endemic species of the WG, were also found during the sampling. Though most of the study sites were located in undisturbed areas, some of the introduced exotic species were found here as well (e.g. *Oreochromis mossambica*, *Lebestis reticulates*, *Cyprinus carpio*, etc.). These species were collected in sites located around the townships of Dandeli (on Kali) and Gersoppa (on Sharavati). Some of the rare species like the *Tor* spp., which have been subjected to a rapid decline in their population because of their popularity as game fish and have been

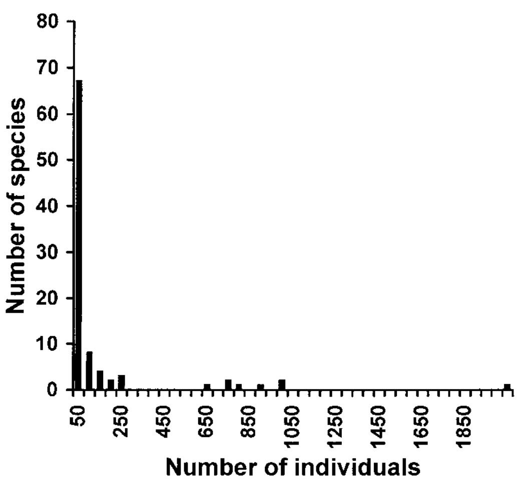

Figure 5. Distribution of individuals collected per species sampled from the entire region.

listed as endangered, were collected on all the four rivers.

Table 4 shows the number of species, total number of individuals and the total sampling effort in each river. Sharavati has the least number of individuals (1429) collected compared to the other rivers and this lowest number is used for comparison across all the rivers. Using 1000 as a cut-off number of individuals for the comparison, the table shows the highest species richness for Sharavati (mean = 44.0) and the least for Aghanashini (mean = 36.4). However, in terms of fish density and abundance per sampling effort, Sharavati is the least, while Bedti shows a higher abundance per sample. The results of the species richness values from rarefaction were compared using the non-parametric Mann–Whitney U-test (multiple pair wise comparisons after the Bonferroni adjustments, for $p \leq 0.05$). The test showed that Bedti is significantly different from the three rivers while the other paired comparisons among the remaining three rivers showed no significant differences.

The differences in species composition among the rivers were analysed using the Jaccard index for calculating the extent of dissimilarity between pairs of data sets. Pairwise comparisons of Jaccard Index values are shown in the Table 5. The JI value between Sharavati and Kali was the highest while it was the lowest for the comparison between Aghanashini and Bedti. The similarity in species composition across rivers is shown as a dendrogram in Figure 6, obtained from the JI coefficients of similarity using the average linkage method. Kali and Sharavati were found to be the least similar while Bedti and Aghanashini show the greatest similarity in species composition. The differences observed between sites belonging to different rivers when compared to the differences within the sites in any river were found to be significant (Mann–Whitney U-test, $p \leq 0.05$) for all rivers with the dissimilarity between rivers generally being greater than within rivers (Table 4).

Table 4. Number of species and individuals sampled in each river and average species richness (SR).

River	Number of samples	Number of individuals sampled	Number of species	SR per 1000 individuals
Sharavati	71	1429	51	44
Aghanashini	99	2964	52	36.4
Bedti	107	4429	63	37.6
Kali	63	1949	53	39.7

Table 5. Within and between river comparisons of Jaccard index values calculated by comparison of differences in species composition between sites within a river and sites across rivers (all values are means of the comparisons made between sites within a river and across rivers). p values are based on the Mann–Whitney tests conducted on the means of Jaccard index values generated using random simulations.

	Sharavati	Aghanashini	Bedti	Kali
Sharavati	0.70 ± 0.11	0.67 ± 0.07 p = 0.00	0.71 ± 0.07 p = 0.03	0.73 ± 0.09 p = 0.0000
Aghanashini	p = 0.00	0.57 ± 0.12	0.62 ± 0.09 p = 0.00	0.68 ± 0.13 p = 0.00
Bedti	p = 0.00	p = 0.0000	0.65 ± 0.11	0.72 ± 0.1 p = 0.00
Kali	p = 0.003	p = 0.00	p = 0.0000	0.74 ± 0.11

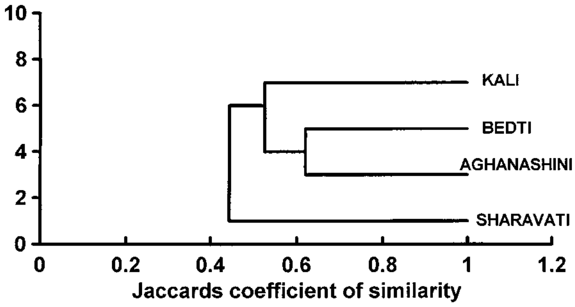

Figure 6. Dendrogram showing similarity in species composition across rivers based on Jaccard index of similarity.

Differences at the regional scale

Regional differentiation in species composition is shown in Table 6. Difference between Sharavati upstream and downstream was found to be the largest amongst the pair wise comparisons (JI = 0.81). Upstream and downstream reaches on Aghanashini and Bedti were the most similar, with the JI value between Aghanashini and Bedti downstream reaches being the least (JI = 0.40). On the other hand, the chord distance results between Aghanashini upstream and Kali downstream reaches showed the highest distance value (1.16), though the least distance was still between Aghanashini upstream and Bedti upstream (0.33) and Aghanashini downstream and Bedti downstream (0.44). In general, it was found that upper reaches were more similar to each other than lower reaches, even when comparing upper and lower reaches on the same river. The dendrogram in Figure 7 shows the clusters (using the average linkage method) based on the Jaccard index of similarity. Interestingly, two main clusters were found, one with all the upper reaches grouped together and the other with all the lower reaches grouped together, with geographically closer regions showing the greatest similarities. Regions in Aghanashini and Bedti downstream were closest while those in Kali and Sharavati were found to be farthest.

Temporal studies

A total of 200 samples were collected during the day and 139 samples were collected at night. These yielded a total of 64 species in the day and 72 at night. The species accumulation curves of the two kinds of samples are shown in Figure 8. Though the abundances or density of individuals caught during the night was higher than that during the daytime, differences in species richness across the two temporal states were not found to be significant. Moreover, as the two curves indicate, the asymptote for the day and the night samplings differ, with a value approaching 60 species for daytime sampling and a value of around 70 species for nighttime samplings.

29 out of the 72 species collected during night sampling were found exclusively at night, while 20 species out of the total of 63 collected during day sampling were found exclusively in the day. Species which were collected during the night were those like *Clarias batrachus, Caranx* spp., *Arius*, *Horabagrus*, *Batasio sharavatiensis*, *Mugil cephalus*, *Hyporhampus limbatus*, *Gerres* spp., *Ompok bimaculatus* and *Silurus wynaadansis*. Of these, *Clarias batrachus,*

Table 6. Differences in species composition across region. Upper part of the diagonal shows the chord distance values of comparisons across regions (averages of comparisons across sites). Lower part of the diagonal shows the Jaccard index values of dissimilarity across regions (averages of comparisons across sites).

	Sharavati upper	Sharavati lower	Aghanashini upper	Aghanashini lower	Bedti upper	Bedti lower	Kali upper	Kali lower
Sharavati upper		0.99	0.65	0.73	0.77	0.67	0.93	0.85
Sharavati lower	0.81		1.07	0.8	1.18	0.99	1.04	0.79
Aghanashini upper	0.5	0.74		0.61	0.33	0.56	1.1	1.16
Aghanashini lower	0.6	0.66	0.52		0.76	0.44	1.06	1
Bedti upper	0.48	0.79	0.43	0.56		0.62	1.08	1.25
Bedti lower	0.56	0.7	0.61	0.4	0.59		1.1	1.06
Kali upper	0.63	0.73	0.57	0.64	0.55	0.64		0.93
Kali lower	0.63	0.67	0.55	0.42	0.66	0.53	0.62	

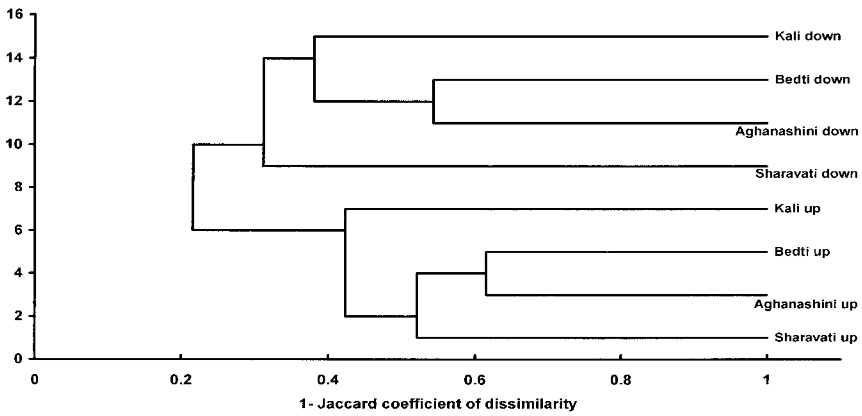

Figure 7. Dendrogram showing similarity in species composition across regions based on Jaccard index of similarity.

Caranx, *Arius, Hyporhampus* and *Ompok* are omnivores and carnivores – their activity could depend on the vertical migratory behaviour of their prey. In general, it was found that collections of species made exclusively at night had a higher abundance of carnivorous and piscivorous species (44%) than those made during the day (23%). Amongst species that are shared in both the day and night sampling, most belong to the family Cyprinidiae like the *Puntius* spp., *Danio aequipinnatus*, *Gonoproktopterus* spp. etc. Their food consists mainly of algae, but some are also known to be omnivorous or carnivorous. Some of the cyprinids were collected in the day samplings – e.g. *Puntius chola*, *P. dorsalis*, *P. coorgensis*. These species are insectivores and herbivores. More, however, needs to be found about the exact feeding habits of these species in order to get a better understanding of this temporal separation in activity patterns of these species.

Discussion

Efforts have been made recently in bringing together the studies of fish diversity in various parts of the WG. Kerala has been studied quite extensively with regards to its freshwater fish diversity and is known to have one of the highest levels of diversity as well as endemism within the WG (Ponniah & Gopalakrishnan 2001). However, as large parts of northern WG are as yet unexplored, we do not have an idea of the extent of diversity and distribution of many of the species. Similar efforts are needed in the other parts of the WG so as to obtain a better understanding of the extent of distribution and status of these species.

This study largely focuses on fish species richness and its estimation for the rivers of the Uttara Kannada district of the WG. Caution must be taken while using any one method as an estimator of species richness in any study, since different methods may

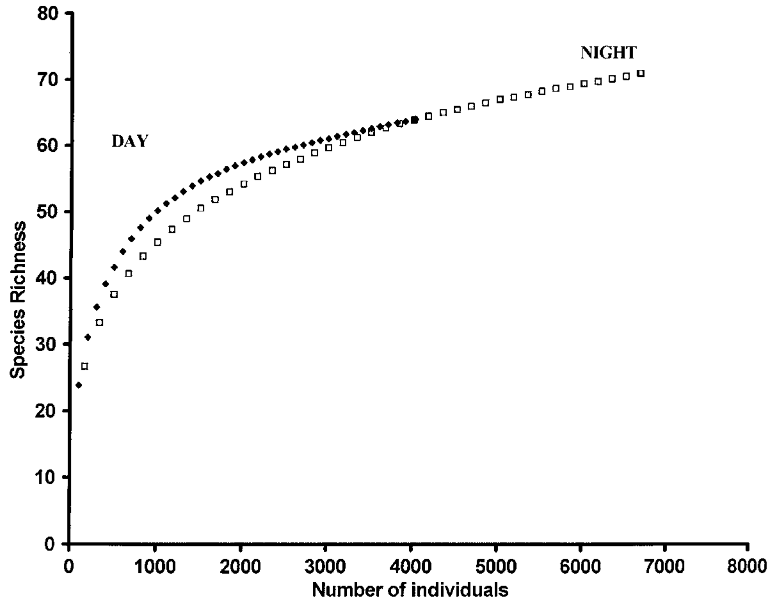

Figure 8. Species individual curves for day and night samplings.

yield varying results for different kinds of data sets. A comparative study was conducted by Palmer (1990), of some methods of species richness estimation by extrapolation, integration of log-normal distributions and non-parametric estimates (Bootstrap and Jackknife method) on plant species data for a given area. He found that the non-parametric estimators (and especially the Jackknife method) gave the most precise estimate, though it was an underestimate of the true species richness. Our study shows that out of the three estimators, the Jackknife method shows the highest estimate of 120 species. Hence, based on the findings of the study by Palmer, the estimate from the Jackknife method would seem to be a 'safe' upper limit for the actual species richness of the fishes of the region.

Thus, we find that fish diversity in this region is high and is comparable to that in other parts of the WG studied earlier (Shaji & Easa 1998). Many of the species earlier considered to be restricted geographically to only the southern WG (e.g. the bagrid catfish *Horabagrus brachysoma*) were found to occur in this region as well, thereby extending the geographical distribution of these species further north (Bhat 2001). Further, our study indicates that the fish fauna of the Uttara Kannada region is composed of taxa that are common to those in many Southeast Asian riverine ecosystems as well as those in Africa. Studies in other river systems in Southeast Asia have also found the Cyprinids to dominate over other groups. For instance, many of the species found in this region including the Cyprinids (e.g. *Barilius*, *Garra*, *Labeo*), Siluriform catfishes (e.g. *Clarias*), Channids (*Channa*), Mastacembelids (*Mastacembelus*) as well as Notopterids are common to Africa as well. It is well known that most Southeast Asian rivers, as well as those in the Indian subcontinent, are dominated by Cyprinids and Balitorids, whereas African rivers as well as lakes abound with an astounding number of Cichlids and Characids. Amongst the Cichlids, only the genus *Etroplus* is found in the Indian subcontinent.

A very interesting observation was with regards to species composition patterns at the regional scale. As has been explained earlier, these regions are demarcated by altitudinal differences, such that all sites >250 m are considered as upstream and those below it as downstream regions. We find that regions that are in the same altitudinal regime (and river gradient) are more similar to each other than regions in different altitudinal regimes. Thus, we find that Sharavati downstream is more similar in species composition to Aghanashini downstream than the upstream region on Sharavati itself. This supports the importance of habitat structure in shaping fish community structure. It was also found that even within the regional subdivisions, the similarity in species composition followed a geographical distance pattern where all reaches closer to each other geographically were also closer with respect to their species compositions (Figure 7).

Though extensive literature exists on the freshwater fishes of Asia, most of them focus on taxonomy or are directed towards capture fisheries and aquaculture. Resource assessments are mostly lacking in much of Southeast Asia (Welcomme 1987), and data on the ecology of many species of Southeast Asian fishes are very limited (Kottelat 1984). However, studies by Wikramanayake & Moyle (1989) and others have shown that resource partitioning is an important feature in tropical Asian streams and indicating that niche segregation can occur on the basis of seasonality, diet or habitat use (de Silva and Kortmulder 1977, Moyle & Senanayake 1984). Increases in species richness and niche packing were associated with a reduction in body size and length of life and an increase in complexity of life history and reproductive styles. From the present study on the Uttara Kannada rivers, we found that there was a definite temporal partitioning of niche with some species found to be active at night (e.g. *Clarias batrachus*, *Horabagrus brachysoma*, *Ompok bimaculatus*), and some more active during the day (e.g. *Puntius vittatus*, *P. chola*, *P. coorgensis*). Vertical movements in fishes could be the result of their avoidance of high water temperatures during the day. River fishes in tropical Asia exploit a wide range of foods, both from allochthonous sources (such as terrestrial insects and fruits) as well as endogenous benthos. Literature reviews (Welcomme 1979) on the dietary studies of Asian fishes suggest that allochthonous food is a major resource used by fishes inhabiting forest streams and floodplains unlike in temperate latitudinal stream fishes. Migratory movements could also be dictated by avoidance of predation by larger piscivores and large carnivorous vertebrates in these waters. More piscivorous and carnivorous fishes may venture out for feeding during the night, when low visibilities are favourable for predation. In accordance with this idea, we find an increased abundance of piscivores and carnivores in our night samples. It is already known that phytoplankton and zooplankton show a regular diel vertical migration along the water column; it is likely that fish which feed on these might also develop their feeding habits according to the time when they can catch maximum prey with the least effort. Very little is so far known about the feeding habits and vertical movement behaviour of these species, and this lacuna definitely needed to be filled before we can better understand the habitat and ecological preferences of these fishes.

The geographical distribution of many of the species collected is restricted to the WG region and such findings as well as description of an entirely new species reinforces our belief that much needs to be studied before a loss of these communities due to habitat alterations (Bhat & Jayaram, in press). This study is the first of its kind for the Uttara Kannada district and tries to quantify the species and their abundances in the four rivers. Until recently, this region was largely undisturbed by human development and hence most of the streams constituting these rivers were pristine. However, over the last few decades, this district has suddenly seen a spurt of major development projects, particularly in the direction of tapping hydroelectric power to meet the demands of the growing populations around as well in far away cities. A number of hydroelectric dams are being constructed in this region – at least four projects on Kali are already underway while two are on the river Sharavati. As a result of this, Sharavati and Kali have been subjected to huge habitat destruction and alteration. This is reflected in our study by the fact that some of the species which are commonly distributed in Aghanashini and Bedti are not found in Sharavati and Kali. Associated with these projects, a number of small industries are also springing up along the rivers, especially on Kali. All of these are causing severe damage to the natural habitat and water quality of the aquatic fauna. A study of the effect of habitat loss and pollution due to developmental activities can be made by comparing the faunal structure and composition between the affected and unaffected sites (Bhat, 2002).

In this light, the importance and need for such studies is clear – with hardly anything known about the aquatic fauna of the region (some of the species are yet to be described), much of the fauna in these rivers could be lost forever even before they are known to us.

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References

Arunachalam, M. 2000. Assemblage structure of stream fishes in the Western Ghats (India). Hydrobiologia 430: 1–31.

Bhat, A. 2001. New report of the species, *Horabagrus brachysoma* in the Uttara Kannada District of Karnataka. J. Bombay Nat. Hist. Soc. 98: 294–296.

Bhat, A. 2002. A study of the diversity and ecology of freshwater fishes of four river systems of the Uttara Kannada District, Karnataka, India. PhD Dissertation, Indian Institute of Science, Bangalore, India, 178 pp.

Bhat, A. & K.C. Jayaram. On a new species of a Bagrid catfish from Uttara Kannada Distt., Karnataka, *Batasio sharavatiensis* Anuradha Bhat and Jayaram K.C. (Siluriformes, Bagridae). J. Bombay Nat. Hist. 00: 000–000.

Bunge, J. & M. Fitzpatrick 1993. Estimating the number of species: A review. J. Am. Stat. Assoc. 88: 364–373.

Chao, A. 1984. Non-parametric estimation of the number of classes in a population. Scand. J. Stat. 11: 265–270.

Colwell, R.K. & J.A. Coddington 1994. Estimating terrestrial biodiversity through extrapolation. Phil. Trans. R. Soc. Lond. B 345: 101–118.

Daniels, R.J.R. 2001. Endemic fishes of the Western Ghats and the Satpura Hypothesis. Curr. Sci. 81(3): 240–244.

Day, F. (1875–78). Fishes of India; being a natural history of the fishes known to inhabit the seas and freshwaters of India, Burma, and Ceylon. Text and atlas in 4 parts. London: xx + 778, 195 pls.

De Silva, S.S. & K. Kortmulder. 1977. Some aspects of the biology of three species of *Puntius* (=*Barbus*) (Pisces, Cyprinidae), endemic to Sri Lanka. Neth. J. Zool. 22: 182–194.

Easa, P.S. & C.P. Shaji. 1997. Freshwater fish diversity in Kerala part of the Nilgiri Biosphere reserve. Curr. Sci. 73: 180–182.

Hamilton-Buchanan, F. 1822. An account of the fishes of river Ganges and its branches. Edinburgh and London, vii + 405 pp.

Harris, R.J. 1985. A Primer of Multivariate Statistics, 2nd edition, Academic Publications International, Orlando, 576 pp.

Heltshe, J.F. & Forrester, N.E. 1983. Estimating species richness using the jacknife procedure. Biometrics 39: 1–11.

Hora, S.L. 1949. Satpura Hypothesis of the Distribution of the Malayan Fauna and Flora to Peninsular India. Proc. Nat. Inst. Sci. India 15: 309–314.

Hurlbert, S. H. 1971. The non-concept of species diversity: A critique and alternative parameters. Ecology 52: 577–586.

Jayaram, K.C. 1974. Ecology and distribution of fresh-water fishes, amphibia and reptiles. pp. 517–584. *In*: M.S. Mani (ed.) Ecology and Biogeography in India, Dr W. Junk, B.V. Publ., The Hague.

Jayaram, K.C. 1999. The freshwater fishes of the Indian Region. Narendra Publishing House, Delhi-6, 551 pp.

Jerdon, T.C. 1849. On the freshwater fishes of Southern India. Madras. J. Lit. Sci. 15: 302–346.

Kottelat, M. 1984. Zoogeography of fishes from Indochinese inland waters with an annoted checklist. Bull. Zool. Mus. Univ. Amsterdam 12: 1–56.

Ludwig, J.A. & J.F. Reynolds. 1988. Statistical Ecology: A primer on methods and computing. John Wiley and Sons, USA, 336 pp.

McClelland, J. 1839. Indian Cyprinidae. 19, Asiatic Researches, Bishop College Press, Calcutta, 217–468.

Moyle, P.B. & F.R. Senanayake. 1984. Resource partitioning among the fishes of rainforest in Sri Lankan. Journal of Zoology (London) 202: 195–223.

Palmer, M.W. 1990. The estimation of species richness by extrapolation. Ecology 71: 1195–1198.

Ponnaiah, A.G. & A. Gopalakrishnan 2001. (ed.). Endemic Fish diversity of Western Ghats. NBFGR-NATP Publication – 1. National Bureau of Fish Genetic Resources, Lucknow, UP, India, 347 pp.

Rajan, S. 1963. Ecology of the fishes of the rivers Pykara and Moyar (Nilgiris), South India. Proc. Ind. Acad. Sci. 58(B): 291–323.

Sanders, H.L. 1968. Marine benthos diversity: A comparative study. Am. Nat. 102: 243–282.

Shaji, C.P. & P.S. Easa. 1995. Freshwater fish diversity in Wayanad, Kerala, South India. J. Zool. Soc. Kerala 5: 30–36. (Also refer to Easa and Shaji, 1997).

Shaji, C.P. & P.S. Easa. 1998. Status and Distribution of endemic freshwater fishes in Kerala, Western Ghats, India. Tigerpaper 25: 21–24.

Silas, E.G. 1951. On a collection of fishes from Anamalai and Nelliampathi hill ranges (Western Ghats) with notes on its zoogeographical significances. J. Bombay Nat. Hist. Soc. 49: 670–681.

Smith, E.P. & G. van Belle. 1984. Non-parametric estimation of species richness. Biometrics 40: 119–129.

Sykes, W.H. 1839. An account of the fishes of the Dukhen. In Proceedings of learned societies. Zoological Society. Ann. Mag. Nat. Hist. (n.s.) 4: 54–62.

Talwar, P.K., & A. Jhingran. 1991. Inland fishes of India and adjacent countries. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, 2 volumes: xix + 1158 pp.

Welcomme, R.L. 1979. Fisheries ecology of floodplain rivers. Longman, London, 317 pp.

Welcomme, R.L. 1987. Riverine and swamp fisheries. Arch. Hydrobiol. Beih. Ergebn. Limnol. 28: 237–238.

Wikramanayake, E.D. & P.B. Moyle. 1989. Ecological structure of tropical fish assemblages in wet-zone streams of Sri Lanka. Journal of Zoology (London) 218: 503–526.

Appendix 1. Study locations with latitude, longitude, altitude and habitats types (Runs = R; Riffles = Ri; Pools = P; Cascades = C).

Sampling site	Site code	Region	River	Altitude (in m.)	Latitude	Longitude	Types of habitats
Allanki	1	Lower	Sharavati	30	14° 14′ 584	74° 34′ 177	R
Gersoppa bate	2	Lower	Sharavati	40	14° 14′ 272	74° 38′ 986	R
Gersoppa nursery	3	Lower	Sharavati	40	14° 14′ 571	74° 40′ 121	R
Jog falls	4	Upper	Sharavati	496	14° 13′ 882	74° 49′ 112	P, Ri
Joginmatha	6	Upper	Sharavati	476	14° 13′ 882	74° 49′ 394	P
Chaina Gate	5	Upper	Sharavati	374	14° 11′ 578	74° 49′ 660	P, Ri
Kirtigadde	23	Lower	Aghanashini	28	14° 25′ 778	74° 36′ 109	R, P and Ri
Hulidevarakodlu	24	Lower	Aghanashini	38	14° 26′ 540	74° 38′ 489	R, P and Ri
Bilgi Bridge	7	Mid elevation	Aghanashini	630	14° 21′ 542	74° 47′ 432	R, P and Ri
Tattikai	8	Up ghat	Aghanashini	500	14° 30′ 417	74° 45′ 465	P, Ri
Manihole	9	Upper	Aghanashini	603	14° 26′ 083	74° 47′ 341	R, P
Balur	10	Upper	Aghanashini	633	14° 28′ 861	74° 48′ 584	R, P and Ri
Hoskambi	22	Lower	Bedti	20	14° 40′ 798	74° 29′ 380	R, P and Ri
Ramanguli	21	Down ghat	Bedti	60	14° 47′ 798	74° 36′ 504	R
Pattnahole	11	Mid elevation	Bedti	472	14° 42′ 959	74° 42′ 275	R, Ri
Bedti Bridge	13	Upper	Bedti	422	14° 53′ 467	74° 47′ 178	R, P and Ri
Kumbri	14	Upper	Bedti	428	14° 54′ 751	74° 48′ 228	P, R
Ganeshpal	12	Upper	Bedti	395	14° 46′ 993	74° 45′ 551	R, P, Ri and C
Kadra	20	Lower	Kali	20	14° 54′ 404	74° 19′ 353	R
Nujji	19	Lower	Kali	560	15° 06′ 107	74° 22′ 886	P, Ri and C
Ganeshgudi	18	Lower	Kali	80	15° 16′ 627	74° 32′ 157	R
Maulangi	17	Upper	Kali	460	15° 15′ 371	74° 35′ 536	R
Dandeli	16	Upper	Kali	440	15° 14′ 725	74° 38′ 204	R
B.P. Damsite	15	Upper	Kali	427	15° 09′ 991	74° 42′ 611	P