Fish diversity in relation to landscape and vegetation in central Western Ghats, India

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The Western Ghats, one of the well-known biodiversity hotspots of the world, harbours 289 species of freshwater fish of which 119 are endemic. The ecosystems in this region have been, over the past 150 years or so, experiencing tumultuous changes due to the ever-increasing human impacts. In this regard, a study was conducted in Sharavathi River, central Western Ghats to understand fish species composition with respect to landscape dynamics. The study, using a combination of remote-sensing data as well as field investigations shows that the streams having their catchments with high levels of evergreenness and endemic tree species of the Western Ghats were also richer in fish diversity and endemism, compared to those catchments with other kinds of vegetation. This illustrates that the composition and distribution of fish species have a strong association with the kind of terrestrial landscape elements and the importance of landscape approach to conservation and management of aquatic ecosystems. Occurrence of endangered, endemic species and the discovery of two new species of genus *Schistura* reaffirm the 'hottest hotspot' status of the Western Ghats, a repository of biological wealth of a rare kind, both in its aquatic and terrestrial ecosystems.

Keywords: Endemism, fish fauna, land-use, landscape elements, Sharavathi River basin, vegetation, Western Ghats.

LANDSCAPE changes such as habitat alterations, fragmentation and loss are causing a decline of many species of flora and fauna at an alarming rate throughout the world[1–3]. Hence, the emergence of a landscape-based approach for biodiversity assessment and management has assumed significance in recent years as it considers a species as part of a landscape consisting of diverse elements. For instance, deer in a pastureland makes use of several elements, such as heterogeneous vegetation patches in search of variation in fodder, temperature regimes (both warm and cold) and a waterbody for drinking[4]. The need for integrated management of various landscape elements constituting an ecosystem to maintain its characteristic biodiversity has also been stressed[5–7]. Various researchers[8–11], highlighted the role of terrestrial ecosystem in the study of freshwater fishes, emphasizing the need to adopt landscape approach, integrating both terrestrial and aquatic ecosystems. Despite the presence of two of the world's biodiversity hotspots in the vast terrain of India, a landscape approach is yet to gain attention in the conservation or management of the rich biodiversity in general and freshwater fishes in particular.

The Western Ghats, one among the 25 biodiversity hotspots of the world[12], is a chain of mountains, stretching north-south along western peninsular India for about 1600 km, harbouring rich flora and fauna. Various forest types such as tropical evergreen, semi-evergreen, moist and dry deciduous and high altitude *sholas* mingle with natural and man-made grasslands, savannas and scrub, in addition to agriculture, plantation crops, tree monocultures, river-valley projects, mining areas and many other land-uses. Over 4000 species of flowering plants (38% endemic), 330 butterflies (11% endemic), 289 fishes (41% endemic), 135 amphibians (75% endemic), 156 reptiles (62% endemic), 508 birds (4% endemic) and 120 mammals (12% endemic)[13–16] are among the known biodiversity wealth of the Western Ghats. This rich biodiversity coupled with higher endemism could be attributed to the humid tropical climate, topographical and geological characteristics, and geographical isolation (Arabian Sea to the west and the semiarid Deccan Plateau to the east).

The Western Ghats forms an important watershed for the entire peninsular India, being the source of 37 west-flowing rivers and three major east-flowing rivers and their numerous tributaries. The 289 freshwater fish species (41% endemic) reported from the Western Ghats belong to 12 orders, 41 families and 109 genera[14,15]. Notable among these are 33 species from Aralam Wildlife Sanctuary[17], 35 from Periyar River[18], 98 from Chalakudy River[19], 33 from the Kalakad–Mundanthurai Tiger Reserve[20], 92 from Nilgiri Biosphere Reserve[21] and 102 from Pune District[22]. Yadav[23] reported 135 species of fish from the part of the Western Ghats covering southern Gujarat, Maharashtra and Karnataka. The four major rivers (Kali, Bedthi, Aghanashini and Sharavathi) in Uttara Kannada District, Karnataka altogether account for 92 fish species[24]. Arunachalam[25] and Bhat[24] showed that fish species diversity and abundance are linked to diversity of aquatic habitats. The studies carried out so far, however, lack landscape ecological approach and have practically little

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information about the nature of terrestrial landscape elements in the watershed.

The present study conducted in the upper catchment area of Sharavathi River in central Western Ghats, India, brings out the diversity of fish species in the selected tributary streams of the river, and their correlation with the predominant vegetation in the catchments of these streams. It also deals with the effects on the fish diversity due to the Linganamakki hydel reservoir. The study indicates that freshwater ecosystems are to be considered as parts of the general landscape (watershed/basin/catchment) and significant modifications in the natural vegetation of their catchments can have detrimental impacts on the native fish fauna.

Materials and methods

Study area

Sharavathi River in central Western Ghats, Karnataka, is a west-flowing river that originates in the hilltops at Ambuthirtha, Thirthahalli taluk, Shimoga District and flows northwest for about 132 km before joining the Arabian Sea near Honnavar town, Uttara Kannada District (Figure 1). The Jog, one of the magnificent waterfalls of India, is situated in the course of this river. We have chosen the upper catchment area (1991.43 sq. km) of Sharavathi River (situated at 74°67′11″–75°30′63″E and 14°7′27″–13°77′08″N, at an average altitude of 512 m) for this study. The water-spread area of Linganamakki reservoir is about 326 sq. km (at full reservoir level), which is sometimes attained during the peak of the rainy season. Several streams (Figure 2) in the western and southern regions of the catchment receiving more rainfall are perennial. Some of the streams drain directly into the reservoir, while others coalesce to form larger streams or tributaries such as Yenneholé, Huruliholé, Nagodiholé, Sharavathi, Hilkunji, Mavinaholé, Haridravathi and Nandiholé. The western and southern streams run through rugged terrain clad in evergreen to semi-evergreen forests, and through narrow valleys lush with areca (betel nut) gardens and paddy fields. The eastern streams flow through gentler topography, presently with moist deciduous forests, agriculture and plantations of forest trees. Rainfall in the east (about 1800 mm), though lesser than the western and southern catchments, nevertheless, is sufficient to support evergreen to semi-evergreen forests, according to the old historical records, and existing patches of relic vegetation. Throughout the catchment, the stream waters are heavily used for cultivation of various crops such as areca nut, spices, paddy, sugarcane, banana and vegetables. This river became a hub of developmental activities ever since the construction of hydroelectric dams. In 1932, a small dam was built at Hirebhaskara (in Sagar taluk). In 1964, a major dam at Linganamakki (74°50′54″E, 14°14′24″N, 512 m asl), having a total water-spread area of 326 sq. km was constructed, which submerged the Hirebhaskara dam and the lands belonging to 32 villages. Later, in the 1990s, another dam was built at Gerusoppa, Uttara Kannada, in the downstream of Sharavathi River, affecting 705 ha of primary forests. Earlier studies assessing cumulative impacts in this region have substantiated the human-induced changes and their implications on regional ecology and biodiversity[26–28].

Implementation of river-valley projects and the consequent immigration of people into the region and resettlement of the dam evacuees (from 32 villages) elsewhere, mainly in the catchment itself, impacted the natural ecosystems[26]. In addition, this region witnessed intensified selection felling of industrial timbers in the catchment-area forests, during the 1950s. Conversions of several patches, totalling 188.7 sq. km of natural forests into monocultures of teak (*Tectona grandis*) and various exotic tree species like *Casuarina*, *Eucalyptus* spp., *Acacia auriculiformis* and *Pinus* spp. (particularly during the post-independence era), were major ecological changes in the region. Opening up of more areas of forests due to creation of roads and power lines, expansion of agriculture, mining and quarrying would also have had an impact on the waterbodies[26,28]. Introduction of exotic fishes into the reservoir to boost commercial fish production is also expected to impact the local fish fauna. Apart from these, in the Linganamakki reservoir, several fish species were introduced to boost commercial fish production[29].

Land-use analysis of the catchment area

Land-use dynamics was analysed for the catchments of the streams studied for fish using temporal remote sensing data along with collateral data. Integration of remote-sensing data with collateral data has been done using Geographic Information System (GIS). Survey of India toposheet of scale 1 : 50,000 (48 J, K, N and O), which covers the Sharavathi River basin were used for digitization of base layers such as region's boundary, vegetation types, forest types and drainage networks. Multispectral data of IRS 1C (Indian Remote Sensing Satellite 1C) with spatial resolution of 23.5 m corresponding to green, red and NIR bands in 0.5–0.6, 0.6–0.7, 0.7–0.9 μm were used for land-use analyses. Satellite imageries of Path 97–Row 63, provide the entire image of the Sharavathi catchment region. The temporal data (of two seasons corresponding to the study period) 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). Supervised classification technique based on Gaussian maximum likelihood algorithm was used for land-use analysis. The land-use categories considered were ever-

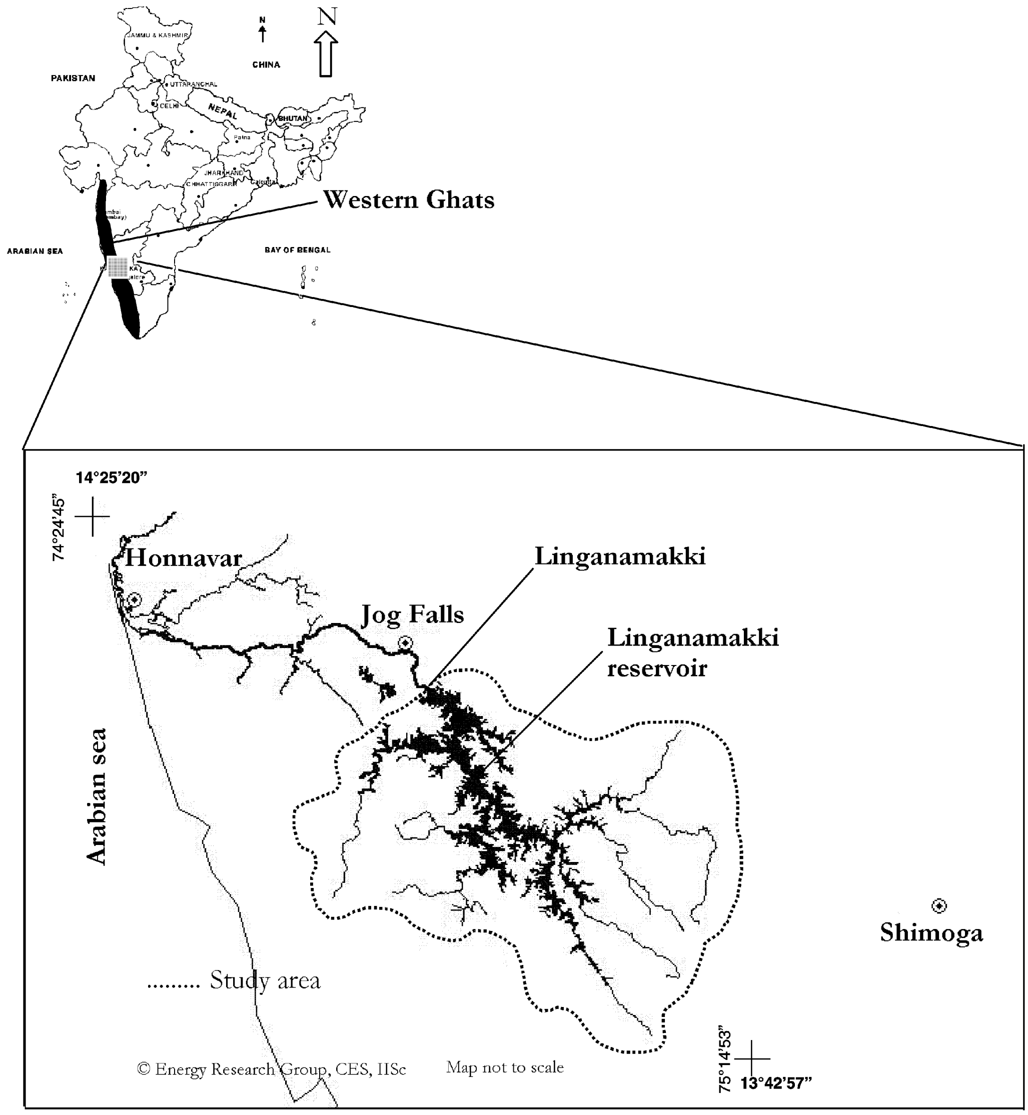

Figure 1. Map showing location of Sharavathi River basin and study area in the Western Ghats of India.

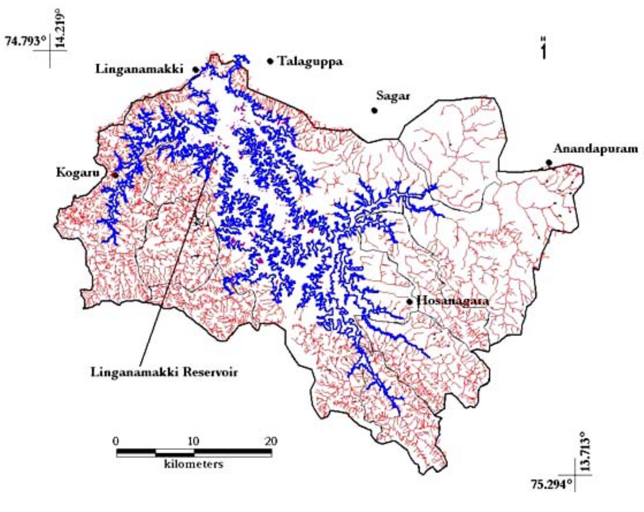

Figure 2. Drainage map of upper catchment of Sharavathi River basin.

green to semi-evergreen forests, moist deciduous forests, plantations, agricultural land and open land.

Fish sampling

Fish sampling was carried out from January 2002 to August 2004 in 41 localities (Figure 3) representing the eastern and western streams and the Linganamakki reservoir. Stratified random sampling method was adopted to locate the sampling sites considering the stream densities. Overall, 261 samplings were made with approximately 40 samplings per season (summer, winter and monsoon) in all the important aquatic microhabitats (riffles, pools, cascade, falls, embayment, run, backwater, etc.) using gill nets, cast nets, dragnets, and hooks and lines of varying dimensions. Standard keys[30–33] were followed for species identification.

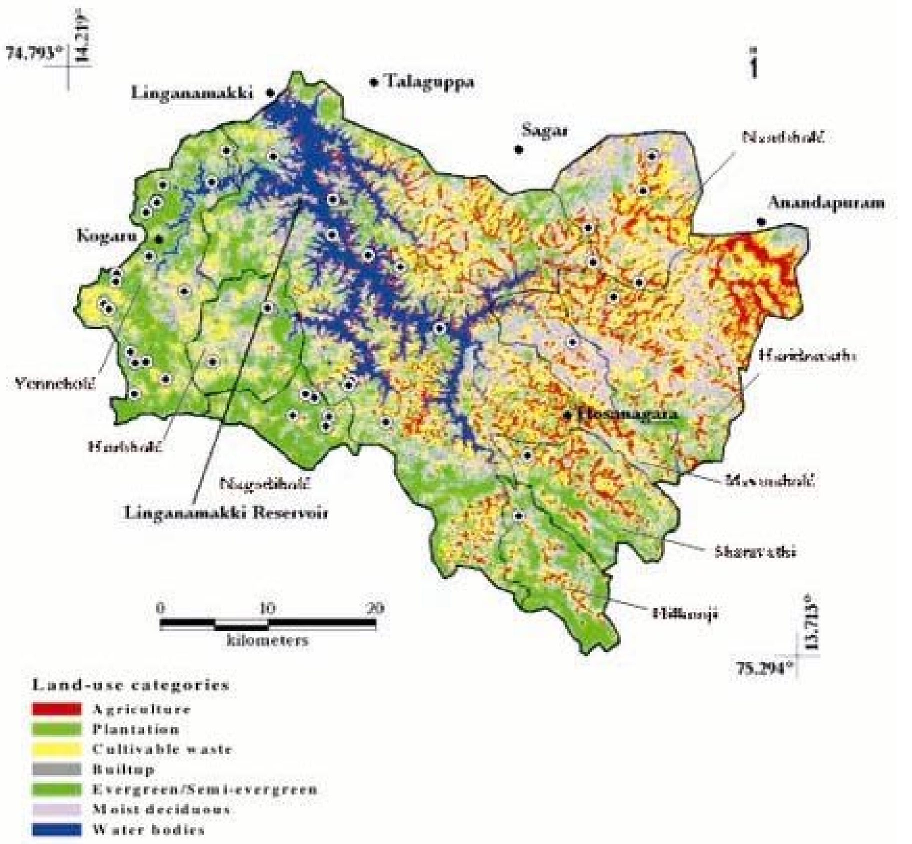

Figure 3. Classified image of the study area with major sub-basins and sampling points.

Unidentified fish specimens were preserved and subsequently identified at the Zoological Survey of India, Southern Regional Station, Chennai.

Fish species and terrestrial habitats

In order to understand the linkages between terrestrial vegetation and stream-fish distribution, eight stream localities were selected among the 41 sampling localities in which sampling was carried out using cast net, drag net and gill net to maximize fish diversity. Vegetation sampling was carried out in the catchment of these streams.

A combination of transects and quadrat method was used for tree sampling within the stream catchments. Five quadrats, each of 400 sq. m, were laid alternatively along the sides of the transect, keeping an inter-quadrat distance of 20 m. In each quadrat, trees (≥30 cm girth at 130 cm above ground) were recorded species-wise. Thereby we could gather data on the actual number of trees in each quadrat, the species to which they belong, and their girth. The transect data were used to estimate the number of trees per ha in a given patch of vegetation. Trees were categorized as 'evergreen' and 'deciduous' (palms excluded). The percentage of evergreen trees in the sample has been expressed as 'evergreenness'. The total endemic tree population in each sample was estimated and the same has been expressed as the 'percentage of endemism'.

Analysis of variance (ANOVA) was carried out to test the significance of variance among rainfall zones. As data pertaining to fish species richness and ecological status measures (i.e. endemic, endangered, vulnerable, lower risk and data deficient status)[15] and landscape variables were not normally distributed, they were transformed into $\log_e$ and those values with 'zero' into $\log_e + 1$. These data were first analysed for Pearson's correlation coefficient (*r*) to find the linear relationship between them. In order to reduce the number of landscape variables, Principal Component Analysis (PCA) of the transformed data was performed. Partial correlation coefficients were calculated between principal components with fish species richness and ecological status, to understand the influence of landscape variables on them.

Results and discussion

Rainfall and stream hydrology

The drainage pattern of the study area (Figure 2) indicates higher drainage density (3.82 km of stream per sq. km) towards the western and southern catchments with rugged hills and deep valleys, while the eastern flatter terrain has lower drainage density (1.54 km/sq. km). Analysis of rainfall data for 20 years (1981–2001) indicates that it varies from 4980 ± 1104 mm (west); 4092 ± 1167 mm (south) to 1883 ± 452 mm (east), and the variation is significant (ANOVA, $F = 94.24$, $P = 0.0001$). Streams range from perennial (on the western side), to intermittent (south and parts of west) to ephemeral (east).

Land-use analysis

Land-use analysis of the study area using remote-sensing data (Figure 3), supported by ground studies reveals that about 25% of the area is under moist deciduous forest and 16% under evergreen to semi-evergreen forest. Plantations (*Acacia auriculiformis*, *Casuarina equisetifolia*, *Pinus* spp., *Eucalyptus* spp. and areca nut orchards) cover 9.7% of the total landscape. About 21% of the land comes under the combination of grassland, scrub and cultivable waste. Agriculture (excluding areca nut orchards) covers 8.5%. The total water-spread area was 7.1% and the dry reservoir bed was 5.4% (both subject to seasonal changes). Barren lands, which include built-up area, roads and rocky areas, constitute 7.14% of the landscape. Vegetation analysis shows that natural vegetation is poor towards the eastern side, due to intense anthropogenic activities. This region has more of agriculture, monoculture plantations of exotic tree species, scrub and savanna, and built-up area. The forest is predominantly of moist deciduous type, with small isolated bits of semi-evergreen vegetation. In contrast, the western region with rugged hilly terrain and heavier rainfall (~5000 mm) has characteristic evergreen to semi-evergreen forests as the natural cover. These are interspersed with grassy blanks, scrub and savanna, areca nut gardens and paddy fields.

Ichthyodiversity: richness, endemism, threat status and distribution

We have recorded 64 species of fishes belonging to 38 genera and 17 families from the upper catchment of Sharavathi River. The maximum number of species that is likely to occur in the upper catchment of Sharavathi River is 67 according to Michaelis–Menten equation[15], requiring a sampling effort of 334 (Table 1). Similarly, maximum number of species in the reservoir is 41, requiring sampling effort of 98 and in the streams it is 37, requiring a sampling effort of 236. Cyprinidae with 31 species was the dominant family, followed by Balitoridae and Bagridae with 8 and 6 species respectively. Among the genera, *Puntius* was more diverse with seven species, followed by *Schistura* with six species. Annexure I details the species recorded from the region with their ecological status. Of the 64 species, 18 are endemic to the Western Ghats and 28 are confined to peninsular India. Varied ecological status of the twenty-two species indicates the uniqueness of the region and the need for its urgent conservation. The study area accounts for 6.88% of Indian freshwater fish (930 species) and 22.2% of the Western Ghats species (289), while constituting only 0.006% of the geographical area of the latter. Figure 4 depicts the percentage of endemism, threatened and data-deficient fish species in India, the Western Ghats and upper catchment of the Sharavathi River.

The discovery of two new species of genus, *Schistura* namely *S. nagodiensis* and *S. sharavathiensis*, in the perennial streams of the western side with evergreen to semi-evergreen clad landscape[34] highlights the ecological significance of the region. A critically endangered species, *Tor mussullah*, and the recently described *Batasio sharavathiensis*[35], a rare species restricted only to the Sharavathi River basin, are also candidates for the 'Critically endangered' status, and were recorded in the western part of the reservoir. *S. nilgiriensis* has been reported for the first time in Karnataka from this river basin[36].

Table 1. Probable relationship between cumulative species richness and number of samplings

Samplings	Collected species	$Y = a + b \ln(X)$: *a*	*b*	*r*	*P*	Estimated species
Total	64	–9.044	12.544	0.971	<0.001	67
Reservoir	39	10.011	6.765	0.938	<0.001	41
Stream	33	–7.036	8.127	0.953	<0.001	37

Y, Cumulative species richness, *X*, Number of samplings.

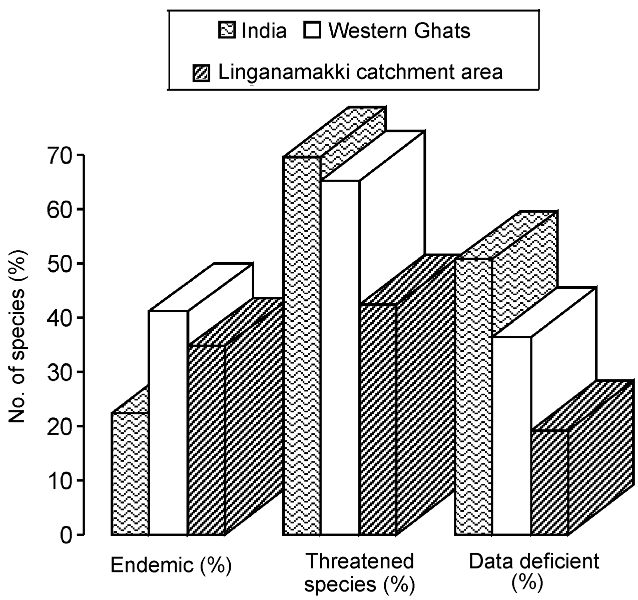

Figure 4. Percentage endemism, threatened and data-deficient freshwater fish species of India, the Western Ghats and the Linganamakki catchment area.

The reservoir had 39 species (Annexure I) of fish (ten endemic to the Western Ghats, three restricted to peninsular India, seven introduced and 18 non-endemics having distribution all over India). The streams studied had 33 species of which 12 were endemic to the Western Ghats, seven to peninsular India and 11 had all-India distribution (three with unknown status). Ecological status of reservoir and stream fish species is given in Table 2, indicating species richness is more in reservoir compared to stream habitats, due to generalist species (having wider distribution) and species introduced since 1969 for commercial production. On the contrary, endemics having narrow range of distribution were more associated with the western streams. This emphasizes the importance and high conservation values of stream habitats of the Western Ghats.

Fish richness, ecological status and vegetation variables: Table 3 details parameters such as fish species richness, endemism, ecological status, forest types and quality in the catchment areas as well as rainfall. There is significant positive correlation between tree evergreenness and tree endemism ($r = 0.859$, $P = 0.003$). Evergreen to semi-evergreen forests have more endemic tree species than deciduous forests. In fact, such forests should have been the natural climax vegetation all over the upper catchment of the Sharavathi River, because of the higher rainfall. A forest-working plan by Rao[37] for the Belandur State Forest of Anandapuram (Ananthapur) Range, Shimoga District (in the eastern catchment of Sharavathi River) stated that this region, receiving rainfall of 1130–1700 mm, had 15% of the forest area under evergreen *kans*. Nevertheless, during the 19th century and even during the early 20th century, there were substantial patches of evergreen to semi-evergreen *kan* forests in the central Western Ghats. Investigations by Chandran and Gadgil[38], indicate that the *kans* were sacred forests during the pre-colonial period, when the forest management was decentralized and was under the local community control. Agriculture, fuel-wood collection and cattle grazing through the last many centuries have altered the forests of the eastern catchment[26].

Stream fishes and catchment vegetation

Western streams: The western streams, running through rugged terrain, have more of their catchment area under evergreen to semi-evergreen forests. Notable among the evergreen trees (many of them endemics) were *Actinodaphne hookeri*, *Aglaia* spp., *Beilschmedia fagifolia*, *Cinnamomum* spp., *Diospyros* spp., *Dipterocarpus indicus*, *Euonymus indicus*, *Garcinia* spp., *Holigarna* spp., *Hopea ponga*, *Knema attenuata*, *Litsea* spp., *Myristica malabarica*, *Nothopegia colebrookeana*, *Olea dioica*, *Palaquium ellipticum*, *Persea macrantha*, *Poeciloneuron indicum*, *Symplocos beddomei* and *Syzygium* spp. These stream catchments have higher evergreenness and higher endemism among the trees.

The catchments of western streams in Yennehole and Nagodi sub-basins with patches of evergreen forests are rich in endemic tree population (Table 3). Fish diversity and endemism are also highest in these streams. In addition to the evergreens, both these sub-basins have some relic patches of primaeval forests with characteristic endemic trees *P. indicum*, *P. ellipticum* and *D. indicus*. Though the catchment area of the Algod stream is covered more with secondary evergreen to semi-evergreen forests, it has 16 fish species of which six are endemic. Similarly, Huruli stream has 12 fish species of which five are endemic. Endemic fishes like *Barilius bakeri*, *B. canarensis* and *Schistura* spp. are exclusive to the western parts.

The commonly occurring deciduous tree species amidst the evergreen vegetation are *Terminalia paniculata*, *Lagerstroemia microcarpa*, *Careya arborea*, *Dillenia pentagyna*, *Vitex altissima* and *Ervatamia heyneana*. Older individuals represent most of these trees. Except the latter two, which are usually gap-finders, other deciduous species probably appeared in this high-rainfall zone because these forests have had a history of slash-and-burn cultivation until the late 19th century[39]. Banning of shifting cultivation led to the return of the evergreen species. These evergreen species with closed canopy prevented the regeneration of the more light-loving (heliophilous) deciduous trees.

Eastern streams: Catchments of the eastern streams were dominated by deciduous forests. The eastern landscape is much more fragmented with several tree monoculture industrial plantations. Annual rainfall of 1500–2000 mm here is sufficient to support evergreen to semi-evergreen forests, as described in the historical documents of the Forest Department, dating back to late 19th century and early 20th century. Brandis and Grant[40] reported the presence of 171 evergreen to semi-evergreen *kan* forests covering a total area of over 130 sq. km in the Sorab taluk, Shimoga District, immediate north of our study area, where the annual rainfall is around 1500 mm only. A forest-working plan of 1919 reported the presence of 11.6 sq. km of evergreen *kans* amidst the otherwise drier forests of the eastern catchment. These *kans* were reported to be the source of several perennial streams. The *kan* forests had several en-

Table 2. Ecological status of fish species in two major habitats of the catchment

Ecological status	Reservoir	Stream
Species richness	39	33
Endemic species (%)	25.0	42.4
Restricted to peninsular India (%)	7.5	21.2
Distributed throughout India (%)	47.5	36.3
Introduced species (%)	17.5	3.0

Table 3. Fish species richness, ecological status, rainfall and vegetation in streams and reservoir of the study area

Zone	Stream	Fish species richness	Total species richness	Endemic	Total endemic	Endangered	Vulnerable	Rainfall (mm)	Evergreenness (%) (trees)	Endemism (%) (trees)
Western	Yenneholé	18	22	8	10	3	6	4410.1–5597.5	86–100	46–58
	Huruli	12		5					88–94	52–57
	Algod	16		6					60–88	25–58
	Nagodi	19		8					68–99	36–71
Eastern	Nandiholé	14	14	2	2	0	2	1715.2–1156.7	0–16	0–11
	Hunsavalli	6		1					2–31	8–14
	Hosur	3		1					0–15	0–6
	Hebbailu	3		0					0–15	0–4
Reservoir		39	39	8	8	4	1	3423.2		

Table 4. Principal components derived from PCA of fish species richness and their ecological status in eight streams of Sharavathi River basin

Principal component analysis	PC1	PC2
Eigenvalues	4.484	0.31
Proportion of variance (%)	89.68	6.20
Loading score		
Species richness	0.443	–0.204
Endemism	0.421	0.792
Endangered	0.469	0.017
Lower risk	–0.432	0.575
Data-deficient	0.47	–0.005

demic and evergreen tree species such as *Vateria indica*, *Artocarpus hirsuta*, *Cinnamomum* spp. and *Litsea* spp.[37]. Even today, enmeshed in the landscape of deciduous forests, agriculture and scrub, occasional small, relic semi-evergreen forest patches are observable.

Hunsavalli stream catchment in the east is dominated by deciduous forests, with low percentage of endemism (8–14). However, one of the patches sampled in this catchment, perhaps the remains of an ancient *kan*, at Gentinakoppa village had 84% evergreenness and 50% tree endemism. The stream had six fish species, of which one was endemic. In Hosur stream catchment, also dominated by deciduous forests, tree endemism varies from 0 to 6%. However, a semi-evergreen forest patch at Aduru had 79% evergreenness and 58% tree endemism. Hosur stream had only three fish species, out of which one was endemic to the Western Ghats. Hebbailu stream catchment had moist deciduous forests, which do not exceed 15% in evergreenness. However, a forest sample at Kallukoppa village had 70% evergreenness with 30% tree endemism, while Hebbailu had only three fish species and no endemic species. We presume from these facts that the eastern streams also could have had more number of endemic fish species in the olden days than the present (only two species). Due to the spread of agriculture and intensified forest removal in their catchments, the forests became drier and the streams turned seasonal[26,28], with understandable adverse consequences on fish diversity and endemism.

Relationship between fish species richness and their ecological status

Pearson's correlation coefficient shows that fish species richness was positively related to the number of endemic (r = 0.752, P = 0.016), endangered (r = 0.935, P = 0.001) and data-deficient (r = 0.924, P = 0.001) species. Similarly, endangered fish species increased with an increase in endemic (r = 0.873, P = 0.002) and data-deficient (r = 0.984, P = 0.001) species. Lower risk category had negative influence on richness, endemism, endangered, vulnerable and data-deficient species (r = –0.802, P = 0.008; r = –0.732, P = 0.02; r = –0.889, P = 0.002; r = –0.657, P = 0.039 and r = –0.915, P = 0.001 respectively). Considering ecological status, vulnerability did not show significant relationship, except for lower risk category. Hence, it was removed from further analysis. Since fish parameters were correlated with each other, PCA provided reduced components out of them (Table 4). Principal component 1 (PC1) explained for 89.68% variance comprising species richness, endemism and ecological status, and PC2 for 6.2% contributed by endemism and lower risk category. Biplot of this analysis given in Figure 5, shows distinct clusters of streams from the eastern side versus western side, which conform the results indicating that the streams on the western side have higher species richness, dominated by endemic and endangered species[41].

Influence of landscape variables on fish species richness and their ecological status

Table 5 lists correlation coefficients highlighting the influence of land-use and vegetation in eight selected stream catchments. Results of PCA are detailed in Table 6, wherein PC1 explains for 77.27% variance from all land-

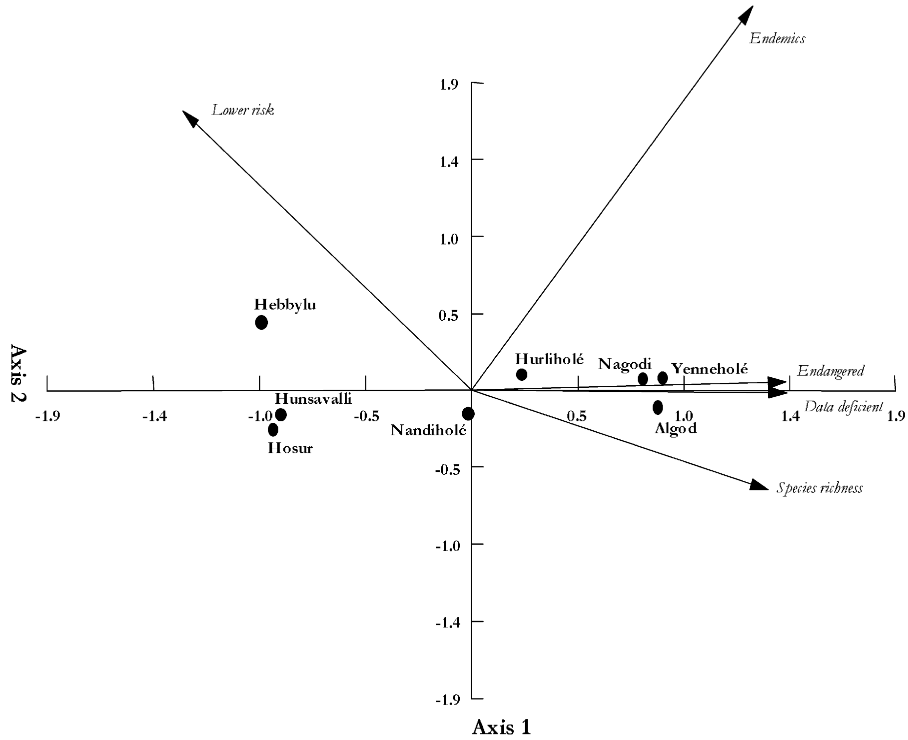

Figure 5. Biplot of principal components derived from eight studied streams of Sharavathi River basin on fish species richness, endemism and their ecological status. Vector scaled at 3.

Table 5. Correlation coefficient (r) for rainfall, land-use and vegetation variables among the eight stream localities in Sharavathi River basin (N = 8). Values in parenthesis denote level of significance (P)

Parameter	Rainfall	Evergreen–semi-evergreen	Moist deciduous	Agriculture	Open land	Tree endemics
Evergreen–semi-evergreen	0.977 (0.001)					
Moist deciduous	–0.701 (0.026)	–0.670 (0.035)				
Agriculture	–0.846 (0.004)	–0.775 (0.012)	0.355 (0.194)			
Open land	–0.875 (0.002)	–0.887 (0.002)	0.497 (0.105)	0.805 (0.008)		
Tree endemics	0.799 (0.009)	0.681 (0.031)	–0.756 (0.015)	–0.617 (0.050)	–0.558 (0.075)	
Tree evergreenness	0.854 (0.003)	0.766 (0.013)	–0.503 (0.102)	–0.774 (0.012)	–0.731 (0.020)	0.859 (0.003)

Table 6. Eigenvalues and loading scores of rainfall, land-use and vegetation variables derived from PCA of eight streams from Sharavathi River

Principal component analysis	PC1	PC2
Eigenvalues	5.409	0.813
Proportion of variance (%)	77.27	11.61
Loading score		
Rainfall	0.425	0.039
Evergreen–semi-evergreen	0.405	0.083
Moist deciduous	–0.308	0.705
Agriculture	–0.366	–0.454
Open land	–0.378	–0.34
Tree endemics	0.367	–0.412
Tree evergreenness	0.386	0.06

scape variables, while PC2 accounts for 11.61% variance, mainly by moist deciduous forest, agriculture and tree endemism. Figure 6 depicts the biplot generated in PCA with score-loading and vectors, and highlights the influence of evergreen to semi-evergreen-type forests, rainfall, tree endemics, and evergreenness on streams on the western side compared to the influence of human-induced land-uses (agriculture and open land) and remnants of moist deciduous-type forests on streams located on the eastern side. Partial correlation coefficient (r_{xyz}) was calculated between PC1 and PC2 with fish species richness and their ecological status. Table 7 details the partial correlation coefficient values. It is evident that PC1 (derived from

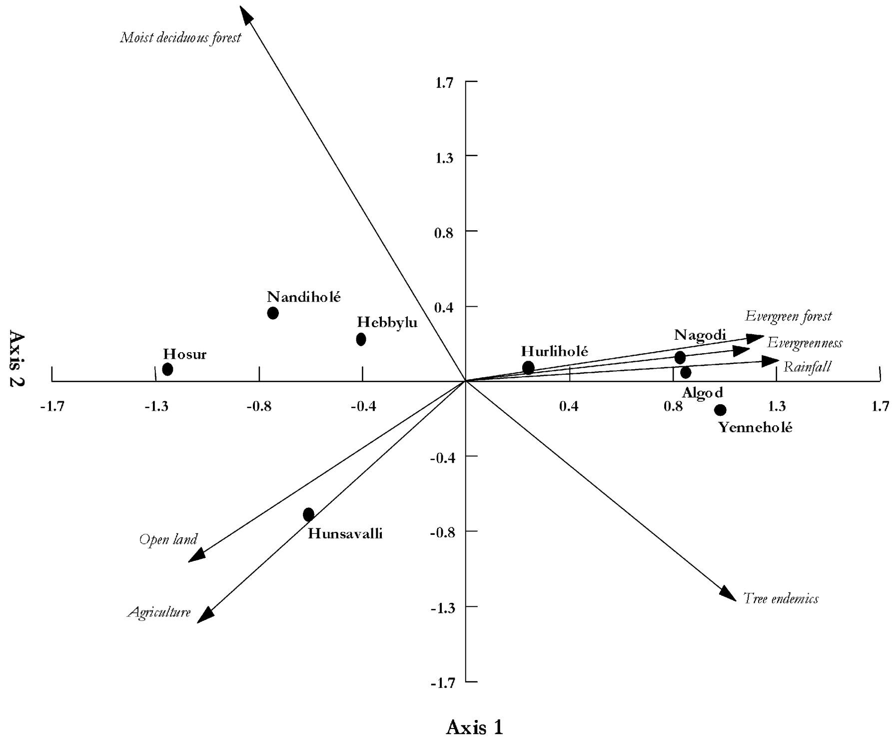

Figure 6. Biplot of principal components derived from eight studied streams of Sharavathi River basin based on landscape variables. Vector scaled at 3.

Table 7. Partial correlation coefficients between fish species richness, and their ecological status and principal components of landscape variables of the eight streams of Sharavathi River. Values in parenthesis denote level of significance (*P*)

Species variable	PC1*	PC2*
Species richness	0.764	–0.193
	(0.014)	(0.323)
Endemic species	0.971	–0.734
	(0.001)	(0.019)
Endangered	0.914	–0.504
	(0.001)	(0.101)
Vulnerability	0.222	0.202
	(0.299)	(0.316)
Lower risk	–0.852	0.095
	(0.004)	(0.412)
Data-deficient	0.931	–0.496
	(0.001)	(0.106)

*PC2 and PC1 were kept as control variables in the respective analysis.

rainfall and landscape variables from dominant land-use with vegetation of evergreen to semi-evergreen-type forests, tree endemics, and evergreenness) has positive influence on fish species richness, endemism, endangered and data-deficient species and has negative influence on the lower risk category. In contrast, PC2 (derived by moist deciduous-type forests) has negative influence on endemic fish species. These analyses substantiate that the perennial streams with their catchments clad in evergreen to semi-evergreen forests and higher levels of plant endemism are the habitats for rich and endemic fish fauna. Linkages of perennial streams, higher rainfall and vegetation type with the regional biodiversity highlight the need for decision makers to adopt landscape approach in the management of natural resources to conserve the hotspots of biodiversity.

Conclusion

Analysis of fish species composition, distribution and ecological status with reference to the terrestrial ecosystem in the catchment, revealed preference of the endemic fish fauna to perennial streams with their catchments having evergreen to semi-evergreen forests, which also have higher levels of plant endemism. On the contrary, streams whose catchments have moist deciduous forest or its degraded stages with low degree of endemism, have fishes with wider distribution ranges and few endemic species. PCA and partial correlation coefficient have revealed the influence of landscape variables on fish species richness, endemism and their ecological status. The fact that the eastern catchment, having relatively lesser rainfall and deciduous forest as the dominant type, had evergreen forests once, indicates that the stream of the eastern catchment also would have had high species richness and higher endemism among the fishes. Due to the spread of agriculture, large areas under forest monoculture and deciduous forests – resultant of fire, there is a decline in

Annexure I. Freshwater fishes in the upper catchment area of Sharavathi River with their distribution and ecological status

				Eastern sub-basins				Western sub-basins			
Species name	Global distribution	Ecological status*	Reservoir	1	2	3	4	5	6	7	8
Family: Cyprinidae											
Amblypharyngodon mellettinus	India	LR	–	–	–	–	–	+	–	–	+
Barilius bakeri	The Western Ghats	VU	–	–	–	–	–	–	+	–	+
Barilius bendelisis	India	LR	+	–	–	–	–	–	–	–	–
Barilius canarensis	The Western Ghats	DD	–	–	–	–	–	–	–	–	+
Barilius gatensis	The Western Ghats	DD	–	–	–	–	–	–	–	–	+
Brachydanio rerio	India	LR		+	+	+	+	+	+	+	+
Catla catla	Translocated		+	–	–	–	–	–	–	–	–
Cirrhinus mrigala	Translocated		+	–	–	–	–	–	–	–	–
Cirrhinus fulungee	India	LR	+	–	–	–	–	–	–	–	–
Cyprinus carpio communis	Translocated		+	–	–	–	–	–	–	–	–
Cyprinus carpio sp.	Translocated		+	–	–	–	–	–	–	–	–
Cyprinus carpio specularis	Translocated		+	–	–	–	–	–	–	–	–
Danio aequipinnatus	India	LR	–	+	+	+	+	+	+	+	+
Garra gotyla stenorhynchus	The Western Ghats	EN	+	–	+	+	+	+	+	+	+
Gonoproktopterus dubius?	The Western Ghats	EN	–	–	–	–	–	–	+	–	–
Gonoproktopterus kolus	The Western Ghats	EN	+	–	–	–	–	–	–	–	–
Labeo kontius	The Western Ghats	LR	+	–	–	–	–	–	–	–	–
Labeo rohita	Translocated		+	–	–	–	–	–	–	–	–
Oreichthys cosuatis	India	DD	–	+	–	–	–	–	–	–	+
Osteocheilichthys nashii	The Western Ghats	VU	+	–	–	–	–	–	+	–	+
Puntius arulius	The Western Ghats	EN	+	–	–	–	–	–	–	–	+
Puntius chola	India	VU	+	–	–	–	–	–	+	+	+
Puntius fasciatus	India	EN	–	–	–	–	–	–	+	+	+
Puntius filamentosus	India	DD	+	–	+	+	+	+	+	+	+
Puntius sahyadriensis	The Western Ghats	DD	–	–	–	–	–	–	+	+	+
Puntius sophore	India	LR	–	+	+	+	+	+	+	+	+
Puntius ticto	India	LR	–	–	+	+	+	+	+	+	+
Rasbora daniconius	India	LR	–	+	+	+	+	+	+	+	+
Salmostoma boopis	The Western Ghats	LR	+	+	–	–	+	+	+	+	+
Tor khudree	India	VU	+	–	–	–	–	–	–	–	–
Tor mussullah	The Western Ghats	CR	+	–	–	–	–	–	–	–	–
Family: Balitoridae			–								
Acanthocobitis botia	India	LR	–	–	+	–	+	–	+	+	+
Nemacheilus anguilla	The Western Ghats	LR	–	–	–	–	+	–	+	+	+
Schistura denisonii denisonii	India	VU	–	+	+	–	+	–	+	+	+
Schistura nilgiriensis	The Western Ghats	EN	–	–	–	–	–	+	–	–	–
Schistura semiarmatus	The Western Ghats	VU	–	–	+	–	+	–	+	–	+
Schistura nagodiensis	Unknown	DD	–	–	–	–	–	–	+	–	+
Schistura sharavathiensis	Unknown	DD	–	–	–	–	–	–	+	–	–
Schistura sp.?	Unknown	DD		–	–	–	–	–	–	–	+
Family: Cobitidae											
Lepidocephalus thermalis	India	LR	–	+	+	+	+	+	+	–	+
Family: Aplocheilidae											
Aplocheilus lineatus	India	LR	–	+	+	+	+	+	+	+	+
Family: Belonidae											
Xenentodon cancilla	India	LR	+	–	–	–	–	–	–	–	–
Family: Belontidae											
Pseudophromenus cupanus	India	DD	–	–	–	–	–	–	–	–	+
Family: Chandidae											
Chanda nama	India	VU	+	+	+	+	+	+	+	+	+
Parambassis ranga	India	DD	+	+	+	+	+	+	+	+	+
Family: Channidae											
Channa marulius	India	LR	+	–	–	–	–	–	–	–	–
Channa orientalis	India	VU	–	–	–	–	–	–	–	–	+
Family: Cichlidae											
Oreochromis mossambica	Translocated		+	+	–	–	+	–	–	–	–
Family: Gobiidae											
Glossogobius giuris	India	LR	+	–	–	–	+	+	+	–	+

(*Contd…*)

Annexure I. (*Contd.*.)

Species name	Global distribution	Ecological status*	Reservoir	Eastern sub-basins 1	2	3	4	Western sub-basins 5	6	7	8
Family: Mastacembelidae											
Mastacembelus armatus	India	LR	+	–	–	–	–	–	–	–	–
Family: Bagridae											
Aorichthys sp.	Unknown		+	–	–	–	–	–	–	–	–
Batasio sharavatiensis	The Western Ghats	DD	+	–	–	–	–	–	–	–	–
Mystus bleekeri	India	VU	+	–	–	–	–	–	–	–	–
Mystus cavesius	India	LR	+	–	–	–	–	–	–	–	–
Mystus keletius	India	DD	+	–	–	–	–	–	–	–	–
Mystus malabaricus	The Western Ghats	EN	+	–	–	–	–	–	–	–	–
Family: Claridae											
Clarias batrachus	India	VU	+	–	–	–	–	–	–	–	–
Clarias dussumieri dussumieri	India	VU	+	–	–	–	–	–	–	–	–
Family: Heteropneustidae											
Heteropneustis fossilis	India	VU	+	–	–	–	–	–	–	–	–
Family: Schilbeidae											
Pseudeutropius atherinoides	India	EN	+	–	–	–	–	–	–	–	–
Family: Siluridae											
Ompok bimaculatus	India	EN	+	–	–	–	–	–	–	–	–
Ompok pabo	India	DD	+	–	–	–	–	–	–	–	–
Wallago attu	India	LR	+	–	–	–	–	–	–	–	–
Family: Sisoridae											
Glyptothorax lonah	The Western Ghats	LR	+	–	–	–	–	–	–	–	–

*Dahanukar *et al.*[15]; CR, Critically endangered; EN, Endangered; VU, Vulnerable; LR, Lower risk; DD, Data-deficient; ?, Identification incomplete due to lack of multiple specimens; +, Present; –, Absent.
1, Nandiholé; 2, Haridravathi; 3, Mavinaholé; 4, Sharavathi; 5, Hilkunji; 6, Nagodi; 7, Huruli; 8, Yenneholé.

fish species richness, particularly pushing the endemic fish fauna of the streams to the verge of extinction.

While conceding the need for adopting more sophisticated experimental designs in future, this study indicates the need for adoption of a holistic ecosystem management for conservation of particularly the rare and endemic fish fauna of the Western Ghats. The premium should be on conservation of the remaining evergreen and semi-evergreen forests, which are vital for the perenniality of streams. Through appropriate management there still exists a chance to restore the lost natural evergreen to semi-evergreen forests in those catchments where the annual rainfall is down to 1800 mm. Historical records and relic patches provide ample evidence that such vegetation existed in the past. Natural forests in the lower rainfall areas of the Western Ghats are more fragile and are therefore prone to lose their evergreenness faster than those in high-rainfall areas.

This study highlights that endangered and endemic fish species are precariously clinging onto the stream habitats where patches of primaeval forests, though degraded substantially, still persist.

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