

INFLUENCE OF ECOLOGICAL FACTORS ON THE PATTERNS OF FISH SPECIES RICHNESS IN TROPICAL INDIAN RIVERS

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Background. Rivers in India harbouring a rich diversity of fish are at present subjected to intense anthropogenic stress leading to degradation of the habitat. An understanding of the complex ecological variables determining species richness in these rivers is lacking. The relation between the ecological parameters (climate, hydrology, and morphometry) and the fish species richness were assessed in fourteen major rivers of India.

Materials and methods. The data of seven ecological variables of fourteen major rivers of India for the years 1994–2009 were quantitatively analysed for determining their influence on fish species richness. Principal factor analysis (PFA) was carried out for dimension reduction and eliminating collinearity. Subsequently, fish richness was regressed on the retained factors under generalised linear model (GLM) for determining contribution of factors towards species richness in rivers.

Results. The most influential determinants of species richness were the factors such as: surface area of the river basin (0.439) followed by fish habitat availability potential (0.326) a synthesis of the variables rainfall, discharge and sediment load. The predicted loss of fish species is evident at a 10% alteration in the ecological variables of the rivers.

Conclusion. The predicted loss of fish species richness is indicated at a 10% alteration of the habitat factors in most of the rivers and can be useful for river planners and conservationists.

Keywords: fish species richness, tropical Indian rivers, ecological factors

INTRODUCTION

India is endowed with a rich and diverse riverine resource of 14 major rivers viz. Ganga, Brahmaputra, Brahmani, Cauvery, Godavari, Indus, Krishna, Mahanadi, Mahi, Narmada, Periyar, Sabarmati, Subarnarekha, and Tapti covering 83% of the drainage basin and accounting for 85% of the surface flow (Anonymous 2004).

The rivers in India harbour one of the richest fish genetic resources in the world (Vass et al. 2009). The present checklist of primary freshwater fishes (Devi and Indra 2012) lists 667 species. The population of the main groups is 62% cyprinoids, 26% siluroids, and 12% of other groups. The species have been assigned to 12 orders, 35 families, and 149 genera. Many of these species are common to the Indian river system. The commercially important fish species groups in the colder stretch of the rivers are the snow trout, rainbow trout, schizothoracids, and a few carp species. In the warm waters the Indian major carps and other cyprinids, catfishes, air-breathing

and feather-back fish species constitute an important fishery.

Unfortunately, over the last few decades the riverine ecosystems have been subjected to intense anthropogenic pressure resulting in its degradation and habitat loss for the fishes. As a consequence, many riverine fish species have become highly endangered (Sarkar et al. 2009). The concern for the habitat degradation in India has at present been compounded by the impact of climate change on these aquatic ecosystems (Vass et al. 2009).

Fish species diversity pattern in rivers is dependent on the complex interaction of the different ecological variables of the river viz., size, surface area of the drainage basin, mean annual river discharge, temperature, depth, flow velocity, channel morphology, substrate, and climate (Welcomme 1985, Huguency 1989, Oberdorff et al. 1995, 1997, Pusey and Kennard 1996, Guégan et al. 1998, Bunn and Arthington 2002, Arrington and Winemiller 2003, Postel and Richter 2003, Poff and Zimmerman 2010). Biological

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factors like food, competition, and predation also have a critical influence in determining the fish diversity pattern in rivers (Moyle and Vondracek 1985). However from the various researches conducted so far the diversity of hydrological pattern appears to be central to the maintenance of habitat heterogeneity and species diversity (Ward et al. 2001, Arrington and Winemiller 2003, Postel and Richter 2003, Welcomme and Halls 2003, Xenopoulos et al. 2005).

It is evident that an understanding of the interaction of the various complex sets of biophysical factors operating in a river over a range of spatial and temporal scale is an urgent necessity for conservationists. A species gets endangered in a given watershed as a result of multiple threats intertwined in a manner difficult to isolate individually (Malmqvist and Rundle 2002). Of importance, in the presently reported study, was the fact that the potential of freshwater fish extinction tends to concentrate in endemic-species-rich tropical and subtropical areas (Oberdorff et al. 1999). Thus, there has been an urgent need to further develop macro-ecological models predicting regional variation in freshwater fish diversity in areas of highest biological importance to draw up conservation plans to protect species from current and impending threats (such as water use and global environmental change) (Oberdorff et al. 1995).

The studies hitherto conducted in India have not given much attention towards assessing the various fish habitat parameters influencing fish species richness in the rivers except the few investigations (Arunachalam 2000, Johal et al. 2002, Bhat 2003, Das 2007, Sarkar and Bain 2007, Sarkar et al. 2009, Vass et al. 2009, Lakra et al. 2010, Singh et al. 2010). We believe that—even though India possesses a diverse tropical riverine resource and a rich diversity of riverine fish species—the knowledge on the influence of the ecological parameters on the fish species richness patterns has been inadequate and it lacks quantification. In the present communication we attempted to explore the relation between species richness and seven macro ecological parameters related to climate, hydrology, and morphometry of 14 major tropical rivers of India.

MATERIAL AND METHODS

Fourteen major rivers of India (Brahmaputra, Periyar, Cauvery, Sabarmati, Ganges, Godavari, Tapi, Krishna, Beas, Mahanadi, Sutlej, Mahi, Damodar, Narmada) spanning lat 8°4'N–37°6'N and long 68°7'E–97°25'E were studied in the presently reported investigation. These rivers are distributed (Fig. 1) in four climatic zones based on the amount of rainfall; zone I (above 200 cm rainfall) with more or less moderate temperature, zone II with heavy seasonal rainfall (100–200 cm) with persistent high temperature, zone III with indiscrete rainfall (60–100 cm) and fluctuating high temperature in summer and winter, zone IV with very low rainfall (less than 60 cm) with high temperature fluctuation in summer.

The data on fish species richness, climatic and hydrological parameters from the middle stretch of the rivers for the years (1994–2009) were analysed. These data were articulated from different sources of published literature.

The middle stretch was studied following Oberdorff et al. (1995) who suggested an increase in species diversity with decreasing latitude of the rivers.

Fish data. The values for fish species richness were obtained from published sources: David 1963, Dutta et al. 1973, Jhingran and Sehgal 1978, Ross et al. 1985, Jhingran 1991, Menon and Jacob 1996, Zacharias et al. 1996, Dey and Sinha 1998, Anonymous 1999, Ramakrishniah and Selvaraj 2000, Pathak et al. 2001, 2007, Minimol 2004, Nath et al. 2004, Gupta and Gupta 2006, Sinha 2006, Majumder et al. 2007, Negi 2008, Bagra et al. 2009, Beevi and Ramachandran 2009, Chaudhari et al. 2010, Heda 2009, Shinde et al. 2009, Radhakrishnan and Kurup 2010, Froese and Pauly 2011, Jadhav et al. 2011, Rankhamb 2011. The most recent references of fish species numbers were taken into account and were estimated. For example, the data for 250 fish species from the Brahmaputra River were estimated using the Michaelis–Menten method, based on 13 published papers on the river. The maximum species number, however, recorded in a single paper was 221. We agree with the opinion of Oberdorff et al. (1995), that these values obtained from published literature may be either an underestimate due to inadequate sampling effort or an overestimate due to recent introduction of species in the river, which is not the case for majority of the Indian rivers. Thus, we considered maximum number of species in the river basin during the period of study as fish species richness. It will give a lower bound of the unknown fish species inhabiting the river during the period and thought to be more representative than the estimated species richness for the rivers.

Mean annual water temperature. The mean annual water temperature (°C) for each river was taken as average of available annual temperature in the middle stretch of the river. The sources for the data are Anonymous 1971–2009, 1986–2006.

Mean annual water temperature range. The mean annual water temperature (°C) range data was taken as average of this range available within the period of 1994–2009. As the range is a measure of variability we define this as temperature stability and further analysis and interpretation is based upon this defined variable. The source for the data are Anonymous 1971–2009, 1985–2006, 1986–2006.

Mean annual rainfall in basin area. The annual rainfall (mm) was calculated from the data obtained from Indian Meteorological Department (IMD). We considered the rainfall of the districts/area, through which the middle course of the river passes as rainfall of the middle stretch of the river.

Mean annual discharge. The discharge data ($\text{m}^3 \cdot \text{s}^{-1}$) were acquired from the Central Water Commission. The mean annual discharge values were obtained by taking average of this annual discharge over the period under study (1994–2009) for each river of our interest (Anonymous 1986–2006).

Mean annual sediment load. Data on the annual sediment load ($\text{t} \cdot \text{km}^{-2}$ per year) were obtained from the Central Water Commission (e.g., Integrated hydrological

data book). The mean annual sediment load is the average of the available annual sediment loads in the middle stretch of the rivers (Anonymous 1986–2006).

Total surface area of drainage basin. Total area of drainage basin (km²) was obtained from the Central Water Commission and the Central Pollution Control Board. (Anonymous 1985–2006, 1986–2006).

Mean latitude. Mean latitude of river basin was taken as average of latitude. The values for mean latitude are for

the centre of each river basin (weighted by the length of river reaches at various latitude).

The climatic and hydrological parameters data were obtained from: Anonymous (1958, 1976, 1981, 1986, 1988, 1991, 1993, 1996, 2000, 2006), (1971–2009), (1985–2006), (1986–2006), (1991–2005), (2003), (2004), (2006), Dasgupta (1984), Yadava and Sugunan (1992), Chakrapani and Subramanian (1993), Singh et al. (2003), Moza and Mishra (2004), Vass et al. (2008).

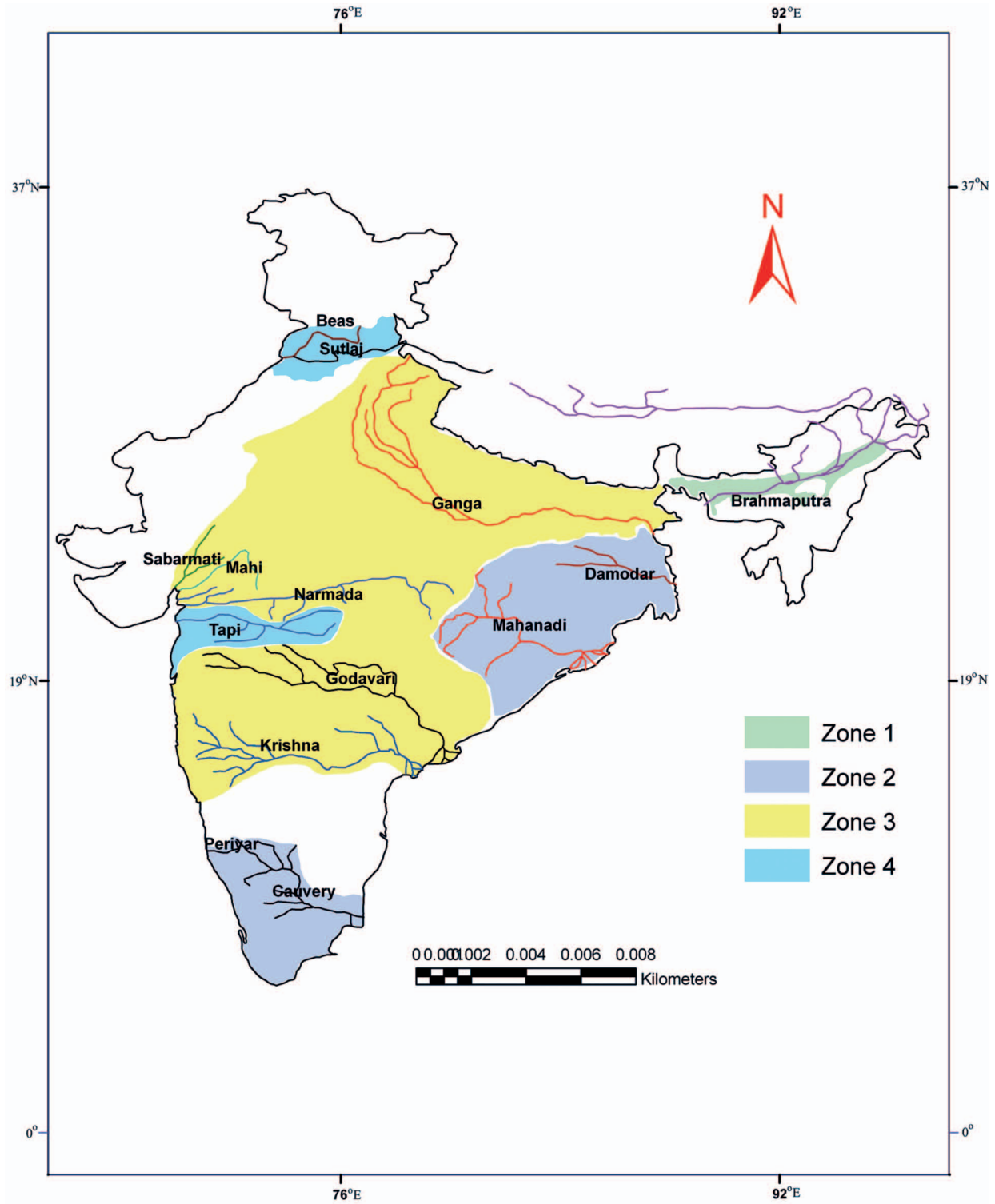


Fig. 1. Map of the study area, depicting rivers and the climatic zones in India

Statistical analysis. Anticipating the compounding effects of climatic, hydrological, and morphometric factors on fish species richness in rivers, it is of substantive importance to extract main factors from the complex system of climatic and hydrological interaction in the river system under study and thereafter quantitatively determine contributing factors and their relative importance to influence river fish species richness. Accordingly, statistical analyses were performed in two steps.

In the first step, we employed principal factor analysis (PFA) (Jolliffe 2002) to identify main factors that explain climato-hydrological variability in the river system considered in the present study. This also eliminates the multicollinearity present among the variables. Statistical test of significance for Pearson's correlation between each pairs of explanatory variable was conducted to detect multicollinearity. The number of factors was selected by the help of scree plot and of the plot of explained cumulative variance. Standard varimax rotation of factors component was performed for realistic interpretation of the extracted factors.

In the second step, contributory ecological factors of fish species richness were determined under generalised linear model (GLM) framework (McCullagh and Nelder 1989). In contrast to classical multivariate regression under normal error, this is more general approach that analyses non-normal data in a better way. Fish species richness being quantified by counted number it is more realistic to model this data under Poisson error term than under normal error term as because normality assumption usually violates for species richness data. Though many workers (Oberdorff et al. 1995) employed classical multivariate regression approach under log transformations, this was an approximate method and might lead to inaccurate results. Recently, GLM is commonly used to model fish species richness (Leprieur et al. 2008). Blanchet et al. (2009) extended this idea and

exploited the approach in a more efficient way to explain context-dependent determinants of non-native fish species richness in global river system. Our approach differs from aforesaid method in terms of tackling collinearity among explanatory variables and extraction of new interpretable factors of fish species richness. Instead of regressing all the perceived influential variables on fish species richness, we incorporated only the extracted factors obtained in the first step under GLM framework with Poisson error.

All the statistical analyses were performed in SAS version 9.2 and R version 2.12.1 (Anonymous 2006–2008, 2001). Principal Factor analysis was performed in SAS and output from SAS was further analysed in R 2.12.1 under GLM framework.

In case of multiple model comparisons we chose the Akaike information criterion (AIC) (Akaike 1974) which is available in the software. Though statistical significance of GLM model was available in the software, model accuracy in terms of co-efficient of determination (R^2) is not available in any of the above-mentioned software. We computed it by using the basic formula:

$$R^2 = 1 - \frac{\text{Residual Deviance}}{\text{Null Deviance}}$$

where null and residual deviance are obtained from analysis of deviance module available in R for GLM fitting.

RESULTS AND DISCUSSION

The pair-wise Pearson's correlation coefficients of explanatory variables under study and the corresponding statistical test of significance are shown in Table 1. There is a clear indication of multicollinearity among the explanatory variables. For example, correlation between surface area of drainage basin and weighted latitude was highly significant ($r = 0.96$, $P < 0.001$). This multicollinearity would produce spurious coefficient of deter-

Table 1

Pearson Correlation coefficients among explanatory variables

Explanatory Variables	1	2	3	4	5	6	7
1	1.000						
2	0.209 (0.474)	1.000					
3	0.572 ^s (0.033) ^s	0.596 ^s (0.025) ^s	1.000				
4	0.180 (0.539)	0.784 ^s (<0.001) ^s	0.678 ^s (0.008) ^s	1.000			
5	0.549 ^s (0.041) ^s	0.033 (0.910)	0.689 ^s (0.006) ^s	0.052 (0.859)	1.000		
6	0.596 ^s (0.024) ^s	-0.022 (0.941)	0.649 ^s (0.012) ^s	-0.020 (0.946)	0.960 ^s (<0.0001) ^s	1.000	
7	0.113 (0.700)	-0.049 (0.868)	-0.152 (0.603)	-0.190 (0.516)	0.145 (0.620)	0.091 (0.757)	1.000

Explanatory variables: 1 = temperature stability, 2 = rainfall, 3 = discharge, 4 = sediment load, 5 = surface area of drainage basin, 6 = weighted latitude, 7 = water temperature; Values within parenthesis indicate P -values ($\text{Prob} > |r|$ under $H_0: \rho = 0$); Statistical significance level of below 0.05 was marked with a superscript letter (^s).

mination in the GLM and thus might mislead the results.

We eliminate this source of error due to multicollinearity by using principal factor analysis (PFA). The analysis showed that three factors (eigenvalue ≥ 1 , a thumb rule for number of factors selection) could be selected to explain reasonable amount of variability (88.7 %) for further analysis (Fig. 2). However, the variables were not well segregated in defining the extracted factor in a meaningful way. Though 4th factor (eigenvalue = 0.51) explain very little amount of variation (7.3%), factors interpretation became meaningful with the inclusion of this factor. In addition such inclusion ascertained 96% of total variability present in the included climate-hydro and morphometric variables in the study, which restricts us to retain only 4 factors.

Factor interpretation. A river is a fluvial hydrosystem comprising the river channel, riparian zone, floodplain, and alluvial aquifer and the system is influenced not only by hydrological and geomorphological changes longitudinally but also laterally and vertically and by temporal changes (Ward 1989, Arthington and Welcomme 1995). These processes consequently determine the habitat heterogeneity for fish. The ecological response expressing ecological integrity in terms of species richness in the river will be in relation to the above multiple drivers and not a single one. As

observed by (Kennard et al. 2007, Stewart-Koster et al. 2007, Kennen et al. 2008, Konrad et al. 2008) the ecological integrity in rivers is reflected not only by the river flow but also by the water quality and habitat structure. Therefore to extract determinant factors of fish species richness from the complex climate-hydro and morphometric variables interaction operating in the river systems of India, we took the help of factor loading patterns of each variable under study.

The loading patterns of each variable for varimax rotated state are depicted in Table 2. We determined that factor 4 is dominated by the influence of temperature stability (loading = 0.906) where as factor 3 is explaining the variability of the water temperature (loading = 0.992). This is clearly depicted in Fig. 3 in which the gradients of temperature stability towards factor 4 and of water temperature towards factor 3 are almost zero. Moreover, extent of contribution (length of the line in Fig. 3) is very near to unit circle. This leads us to define factor 4 as temperature stability and factor 3 as water temperature. Changes in water temperature occur less abruptly, allowing fish (as opposed to terrestrial organisms) to move into more favourable conditions, thus avoiding the potentially lethal effects of temperature variation.

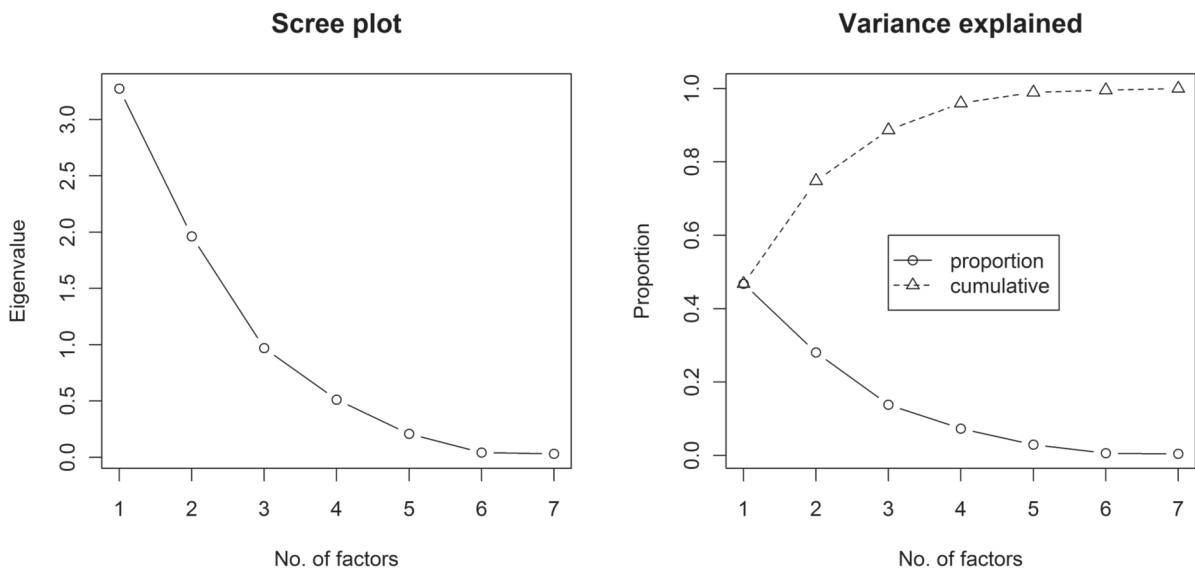


Fig. 2. Scree plot and variance explained for factor selection under PFA

Table 2

Varimax rotated factor loading of each variable

Variable	Varimax rotated factor patterns			
	Factor 1	Factor 2	Factor 3	Factor 4
Temperature stability	0.391	0.149	0.062	0.906
Rainfall	-0.029	0.936	0.047	0.094
Discharge	0.370	0.864	-0.155	0.247
Sediment load	0.028	0.943	-0.135	0.032
Surface area of drainage basin	0.971	0.036	0.092	0.173
Weighted latitude	0.954	-0.043	0.0287	0.254
Water temperature	0.054	-0.080	0.992	0.047

In the similar way we identify (Fig. 3) that surface area of drainage basin and weighted latitude are main contributory variables for factor 1. The surface area of the river basin has a dominating effect on the species richness, where bigger the surface area of the river basin the greater would be the diversity of the fish habitats and greater the number of fish species that would be available (Oberdorff et al. 1995, Guégan et al. 1998). The other variable, latitude has also an established influence on species richness. Fish assemblages in the down stream regions of the river exhibit complex fish assemblage as a function of increased complexity and extent of environment (Welcomme 2002) and in general the species diversity increases with decreasing latitude (Guégan et al. 1998). This factor 1 can be termed ‘surface area of the river basin’. The factor 2 based on the gradient (Fig. 3) and loading (Table 2) is observed to be the integrated effect of rainfall, discharge and sediment load.

Rainfall is one of the renewal sources of water and greatly influence the water retentiveness of the river. The intra- and inter-annual flood level in the river during the monsoon season have a significant effect on the geomorphological and sedimentary process and greatly amplify the hydrological connectivity in the river (Arthington et al. 2003). Where as a sequential decline in rainfall disrupt the connectivity (Lake 2003). Changes in sedimentary processes can affect not only the quantity of fish habitat available but also its quality, especially the type of substrate available (Arthington et al. 2003).

Discharge in the river channel is an index of ecological space and habitat heterogeneity for fish survival, growth and reproduction. Discharge and sediment load also plays important role in determining the water depth and habitat space available for riverine fish, though there are other parameters e.g., water extraction to influence water depth.

Therefore the discharge or flow regime determine the ecological consequence in a river resulting in the sustenance or loss of fish species (Arthington et al. 2003), these three variables related to river hydrology and morphology thus significantly influence the riverine habitat structure for fish and their alteration may lead to changes in fish species richness in the river. We call this compounded effect of the three variables representing factor 2 as ‘Fish habitat availability potential of river’.

After redefining the variables in terms of four factors as ‘regional surface area of river basin’, ‘fish habitat availability potential of the river’, water temperature and temperature stability, we computed the factors’ standardized scores for each river for utilisation in GLM framework. This transformation helped us to determine quantitatively the relative contribution of these factors on the fish species richness in the river. In our GLM framework, we consider these four factors as independent variables and fish species richness as dependent variables and fitted the model assuming Poisson error term with log-linear link function.

Model diagnostics and refinement. Goodness of fit for model was tested based on the Pearson’s Chi-square (χ^2) statistic obtained from maximum likelihood fitting of the model. It turns out to be statistically significant ($\chi^2 = 37.36$, $df = 9$, $P < 0.001$) for the model. Model accuracy for prediction was evaluated on the basis of the co-efficient of determination $R^2 (=0.60)$. Though the model was statistically significant, it could explain only 60% of variation in fish species richness that reflects a bit poor predictive power of the model. It motivates us for further model diagnostics based on graphical method. We plotted the predicted values obtained from the model against observed values of fish species richness and depicted in Fig. 4 to identify outlier or influential data points. It is

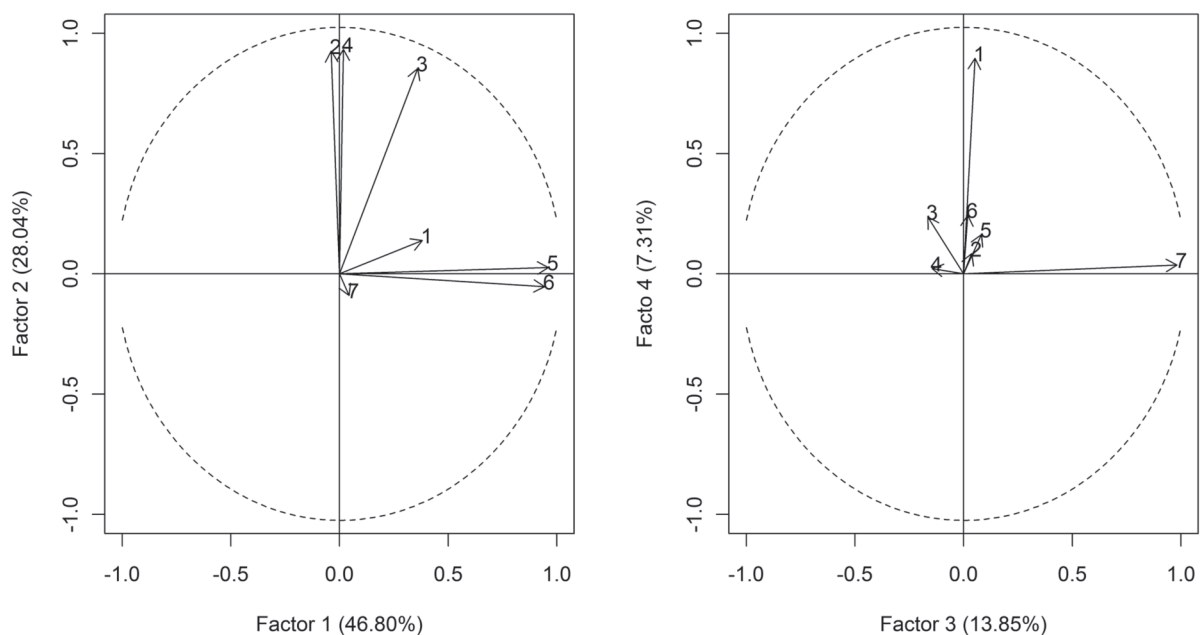


Fig. 3. Factors pattern after varimax rotation. Following are the symbol descriptions: 1: temperature stability, 2: rainfall, 3: discharge, 4: sediment load, 5: surface area of drainage basin, 6: weighted latitude, 7: water temperature

observed that (Fig. 4 a) one point corresponding to the Mahanadi River lies far below from ideal predictive line. The other points are reasonably closer to the same. So, the Mahanadi was detected as outlier and become nuisance for prediction overall species richness by the model for Indian river system.

To enhance the model’s predictive power we deleted the nuisance observation corresponding to the Mahanadi River from the model and re-fitted the model for the remaining 13 rivers. For clear distinction, the former model was named as Model 1 that includes data for all the rivers and the later one was named as Model 2 that excluded the influential data corresponding to the Mahanadi. The results obtained from Model 1 and Model 2 were shown in (Table 2) for a comparative study and the diagnostic plot was shown in (Fig. 4b). The diagnostic plot for Model 2 (Fig. 4b) now ensured good agreement between observed and predicted fish species richness. The R^2 value (=0.91) significantly improved (Table 3) after deleting the abnormal data corresponding to the Mahanadi River.

Between the two models considered, Model 2 produced higher R^2 value and lower AIC value as compared to that of Model 1. This indicates that performance of Model 2 is better than that of Model 1. So we selected Model 2 for further interpretation of the results. It was

observed (Table 3) that all the four extracted factors were statistically significant at least 5% level of significance ($P < 0.05$). However, relative contribution of the hydro and morphometric factors (e.g., regional surface area of river basin and Fish habitat availability potential of river) is greater on fish species richness as compared to that of water temperature and temperature stability. It is evident from the result (Table 3) that the factor regional surface area of river basin is most influential determinants (0.439) of river fish species richness followed by fish habitat availability potential of river (0.326). Both of them have a positive impact on the fish species richness and alteration in those two factors would significantly change species richness in the rivers under study.

Water temperature and temperature stability have very little effect on the fish species richness, though they are statistically significant. Water temperature has positive effect on fish species richness, whereas temperature stability has the negative effect on fish species richness in Indian river system.

The predicted species richness for each river is depicted in Fig. 5. The 95% confidence interval along with observed values was also plotted for comparison. It was observed that the values of Mahi, Narmada, Periyar, and Sabarmati were not inside the 95% confidence interval

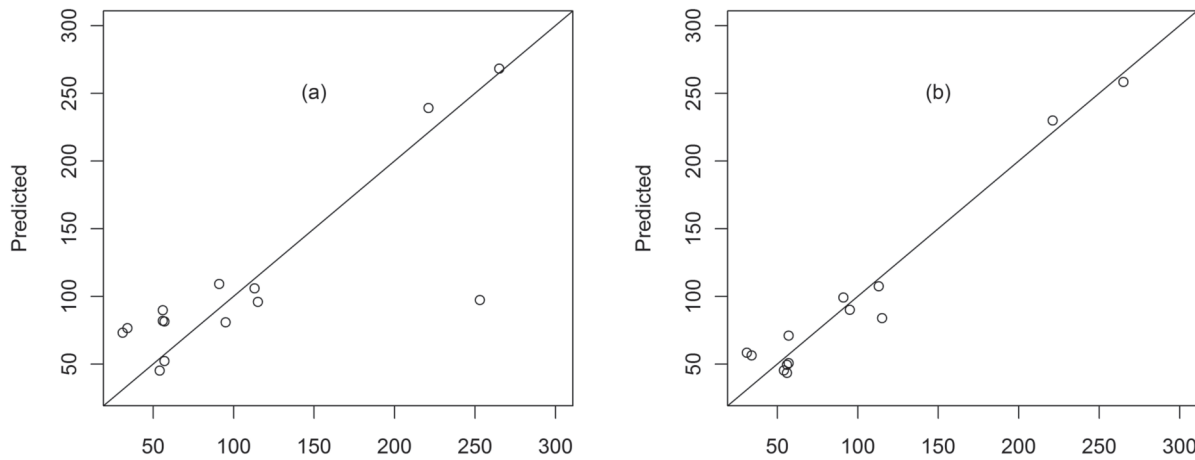


Fig. 3. Factors pattern after varimax rotation. Following are the symbol descriptions: 1: temperature stability, 2: rain-fall, 3: discharge, 4: sediment load, 5: surface area of drainage basin, 6: weighted latitude, 7: water temperature

Table 3

Model fitting under GLM framework; Model 1 is based on all the 14 rivers; Model 2 is based on data with exclusion of influential/outlier river (Mahanadi) identified by model diagnostics

Factor	Model 1			Model 2		
	Estimate	SE	P	Estimate	SE	P
Intercept	4.548	0.029	< 0.001	4.368	0.034	< 0.001
Regional surface area	0.331	0.021	< 0.001	0.439	0.024	< 0.001
Fish habitat availability potential	0.296	0.021	< 0.001	0.326	0.021	< 0.001
Water temperature	0.165	0.037	< 0.001	0.078	0.038	0.042
Temperature stability	0.104	0.028	0.0003	-0.081	0.035	0.021
Model accuracy	$R^2 = 0.60, AIC = 376.5, df = 9$			$R^2 = 0.910, AIC = 137.9, df = 8$		

SE = standard error, R^2 = coefficient of determination, AIC = Akaike information criterion (Akaike 1974), df = degrees of freedom of residual deviance.

indicating a somewhat low performance in predicting. However, they are not too far from the predictive values. For all other rivers predictions were quite strong.

The river Mahanadi remained an outlier in spite of being rich in fish species. It can possibly be explained by the fact that prior to the coming up of the large number of hydraulic structures the overall physical and biological structure and function of the Mahanadi River system, was conducive to the maintaining of the ecological integrity of the river. The transport of water sediment and nutrients downstream was adequate. The floodplains were connect-

breeding and recruitment. This provided great variety of ecological habitats, for harbouring rich ichthyofaunal diversity. However, in recent years the fragmentation of the river basin by series of dams (15 in numbers) have converted river sections from lotic to lentic systems and disconnected the main channel from their flood plain wetlands. Thus, the fish habitat availability potential has been reduced. This type of fragmentation of the continuity of the river remains unaccounted in the model. As a result the model reflects the predicted species richness to be much below the observed number. The percentage change in fish species richness recorded with respect to percent-

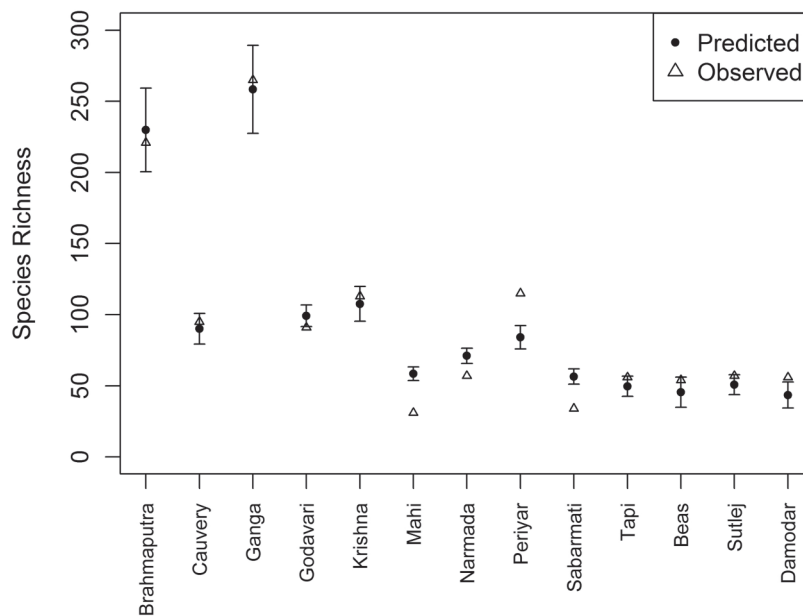


Fig. 5. The 95% confidence interval with predicted and observed values of fish species richness of each of the studied Indian rivers

Table 4

Predictive changes (percentage point) of fish species richness in different rivers due to change (percentage point) in individual factor scores

River	Regional surface Area		Fish habitat availability potential		Water Temperature		Temperature Stability	
	-5%	-10%	-5%	-10%	5%	10%	5%	10%
Brahmaputra	-0.2	-0.4	-5.5	-11.4	0.2	0.4	0	-0.1
Cauvery	-0.3	-0.5	-0.4	-0.8	0.1	0.2	-0.7	-1.3
Ganga	-7.0	-14.5	-0.4	-0.7	0	0.1	-0.4	-0.8
Godavari	-1.2	-2.5	-0.5	-1.0	0.2	0.5	-0.2	-0.4
Krishna	-1.1	-2.3	-0.5	-1.0	0.4	0.8	-0.5	-1
Mahi	-1.0	-1.9	-0.6	-1.3	0	0.1	0	-0.1
Narmada	-0.3	-0.6	-0.8	-1.6	0.1	0.2	0	-0.1
Periyar	-1.4	-2.9	-1.1	-2.1	0.3	0.6	-0.4	-0.7
Sabarmati	-1.4	-2.8	-0.5	-0.9	0.2	0.4	0	0
Tapi	-1.3	-2.5	-0.8	-1.6	0.2	0.4	-0.4	-0.9
Beas	-0.8	-1.7	-0.8	-1.7	1.1	2.2	0	0
Sutlej	-1.0	-2.0	-1.0	-2.0	0.5	1	-0.2	-0.5
Damodar	-2.3	-4.6	-0.2	-0.4	0.3	0.5	-0.8	-1.6

% = percentage point change; (-) indicate loss in fish species.

age change in each identified factor score is depicted in (Table 4). Applying the results obtained we tried to develop scenarios of losses of riverine fish species richness with respect to 5- and 10 percentage-point reduction in the scores of the identified influential factors viz., Surface area of drainage basin and fish habitat availability potential for each river (Table 4). The score values of each factor were used for comparison in the same scale. The other remaining factors were assumed to be constant while assessing such changes. For example, there will be 14.5 percentage-point loss of species richness in the Ganga River due to 10 percentage-point loss in regional surface area of river basin provided there is no change in the fish habitat availability potential of river, water temperature and water temperature stability. In general, visible changes in fish species richness were found only after 10 percentage-point change of factor score. Relative comparison among rivers shows that the Brahmaputra River is more sensitive to loss of fish species richness (11.4 percentage points) due to loss of fish habitat availability potential of river (10 percentage points) compared to other rivers (Table 3). Similarly the Ganges River will have highest loss of fish species richness due to loss of regional surface area of river basin in comparison to other rivers. While the Beas River may observe increase in species richness (2.2 percentage points) due to 10 percentage-point increase in the temperature score and fish species richness of the Damodar River may decrease by 1.6 percentage points due to 10 percentage-point increase in score of water temperature stability. Though the model produces reasonably good estimates for species loss, increase in species richness is not well explainable from the model prediction. For example, model predicts an increase of 7 percentage points in species richness with an increase of temperature by 1°C provided other factors remain unchanged. In natural system hydrological parameters are more prone to change than to change of temperature. As the relative contribution of temperature to change in species richness is very low with respect to hydrological factors (Table 3), change due to temperature will be nullified by the change due to those factors. Other possibility is that hydrological parameters remain unchanged while temperature increases. In this situation, the possibility to increase species richness may occur due to invasion of exotic species and possible shift of warm water species towards colder stretch. This possibility is recently emerging in the Ganges River (Vass et al. 2009, Singh et al. 2010). These factors of invasive species and spatial variability have remained unaccounted in the model and are the limitations of model applicability. This will be of interest for further investigation.

However, the loss in fish species as predicted in the model could be more if the other anthropogenic factors viz., rapid urbanization, industrialization, and intensification of agriculture which are at present affecting the rivers in India is taken into account. These anthropogenic activities have placed a greater demand on water availability in

the rivers thereby modifying quantitatively and qualitatively the hydrological cycle in most agro-climatic regions and river basins in India (Mall et al. 2006, Das et al. 2007). At the same time the water quality of the rivers have degraded impacting fish. These affects are likely to be compounded by the impact of climate change in India. Globally the effect of climate change assessed in 273 river basins by Xenopoulos et al. (2005), within which greater than 10 percentage-point reduction in discharge has been predicted by the Anonymous (2001) climate scenario A1 and A2 indicate that the combination of increased evapotranspiration and reduced precipitation as the most important driver of freshwater fish losses. The projection obtained for the Indian rivers also indicated a similar trend (Vass et al. 2009). Future work should consider studying along with hydrological factors, parameters of water quality and exotic species invasion influencing species diversity in the rivers systems of India.

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