# MULTIVARIATE ANALYSIS OF FISH ASSEMBLAGE COMPOSITION AND ENVIRONMENTAL CORRELATES IN A HIMALAYAN RIVER - NEPAL'S KALI GANDAKI/NARAYANI

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# DEDICATION

This study is dedicated to the people of Nepal, and to their preservation, conservation, and wise use of the country's natural resources.

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# TABLE OF CONTENTS

Page

# LIST OF TABLES

# LIST OF FIGURES

# INTRODUCTION

A major goal of community ecology is to describe the patterns of nature and to generalize explanations for their causal processes (Wiens 1984). Ecologists have long noted that fish assemblages exhibit patterns of longitudinal zonation in rivers and streams (reviews in Hynes 1970, Hawkes 1975, Fisher 1983). However, investigation of causal mechanisms of zonation continues to be an active area of study (e.g., Matthews 1986, Hughes and Gammon 1987, Schlosser 1987). In this paper, I test for spatial and temporal patterns and environmental correlates of the structure of fish assemblages in the Kali Gandaki/Narayani River of Nepal.

The Kali Gandaki/Narayani River forms the deepest gorge in the world as it flows through the Himalaya Mountains on its way from headwaters on the Tibetan Plateau to a lowland, subtropical confluence with the Ganges River. The Oriental and Palearctic biogeographic realms interdigitate in the Gandaki basin, thus the river lies at the zoogeographic center of Asia. The Kali Gandaki Valley may have the greatest abundance and variety of flora and fauna on the Asian continent. More than 65% of the 182 fish species known to occur in Nepal inhabit the Kali Gandaki/Narayani River (Edds 1986). The diversity of the ichthyofauna, and the tremendous altitudinal and ecological gradients of the drainage make the Kali Gandaki/Narayani system ideal as a case-study in longitudinal zonation of fish assemblage structure. Superimposed on the relatively static physiographic features of the drainage are dramatic changes associated with the monsoon season. Thus, I also test for seasonal changes in assemblage structure. Relatively little is known of the distribution and ecology of fishes in the Himalaya Mountains and lowlands of Nepal. Published records include brief notes by Regan (1907), Hora (1937a) and Menon (1949), and the annotated species lists and accounts of DeWitt (1960), Shrestha (1981), Rajbanshi (1982) and Edds (1985, 1986, 1987).

I also present a comparison of the results obtained from analyses by direct and indirect gradient methods, two commonly used multivariate approaches to community analysis. The indirect approach is a two-step process: first, exploratory multivariate techniques such as principal components analysis (PCA), reciprocal averaging (RA) or detrended correspondence analysis (DCA) are used to ordinate samples of community composition (Gauch 1982). Associations between ordination scores and environmental variables are then examined by correlation and multiple regression analyses (e.g., Chang and Gauch 1986, Matthews and Robison 1988).

Direct gradient analysis relates species occurrence directly to the environment (Gauch 1982, Ter Braak 1986, Ter Braak and Prentice 1988). This technique searches for the patterns of variation in assemblage structure that are most closely associated with variation in measured environmental variables. While the ordination axes obtained by the indirect approach are, by definition, orthogonal, there may be other axes that are better related to the environmental parameters. Direct ordination techniques extract axes of assemblage structure that are both orthogonal and constrained to be maximally associated with linear combinations of environmental variables. For direct gradient analysis, I used canonical correspondence analysis (CCA) and detrended canonical correspondence analysis (DCCA), direct gradient analysis techniques developed by Ter Braak (1986, 1987, 1988a, 1988b) that allow interpretation of the response of individual species as well as species assemblages to environmental gradients.

## STUDY AREA

The Kali Gandaki/Narayani River lies between the latitudes 27° 20' and 29° 30' N and longitudes 83° 20' and

84° 30' E. The river traverses the Himalaya Mountains, with intrusions into the Tibetan Plateau to the north and the Gangetic Plain to the south (Fig. 1). Four major mountain ranges cross the drainage and divide the river basin into at least nine geographic zones (Anonymous 1979). These zones are, from north to south: 1) the Tibetan Plateau, with average altitudes > 5000 m; 2) the Tibetan Marginal Mountains which rise to 7000 m; 3) the Inner Himalaya Zone, consisting of desert-like high mountain valleys, with elevations > 3000 m; 4) the Great Himalaya Range, having snow-covered peaks to 8137 m and deep narrow gorges and glacial valleys; 5) the Midland Zone, or low-lying hills and valleys with relatively smooth topography and altitudes between 600 and 2500 m; 6) the Mahabharat Range, steep and rugged mountains ranging to 2200 m; 7) the Dun valleys, low-gradient wide valleys with steep sides and elevations to 1500 m; 8) the Churia Hills, a low-lying range with altitudes to 1000 m; and 9) the Tarai, the Nepalese section of the Great Gangetic Plain, with elevations as low as 50 m above sea level. Herein, I group these zones into five regions: trans-Himalaya (zones 1-3), mountain (zone 4), high hills (zones 5-6), low hills (zones 7-8), and lowlands (zone 9) (Fig 1).

The ecology of all zones south of the Great Himalaya Range is greatly influenced by the summer monsoon from the Bay of Bengal. Much of the Gandaki basin receives more than 250 cm of rain during the June - September rainy season. Two other distinct seasons occur in this area: a cool and dry season from October - January, and a hot and dry season from February - May.

The headwaters of the Kali Gandaki River flow approximately 60 km southward before collecting the Chalunga River to become a fourth-order stream north of the Great Himalaya Range. The Kali Gandaki then traverses this mountain range at a riverbed elevation of about 2500 m near Kalapani and flows 80 km before joining the Myagdi at Beni to become a fifth-order stream. Near Ridi Bazar, the Kali Gandaki meets the Badigarh River and is a sixth-order stream that flows nearly 200 km to the east before joining the Trisuli. At the confluence with the Trisuli, the river becomes a seventh-order stream and is known as the Sapta (seven) Gandaki, or Narayani River. The Narayani flows south and then west with a low gradient before breaking through the Churia Hills to spill south onto the Gangetic Plain (Fig. 1).

River gradients vary between 0.1% and 0.5% for the Narayani. The slope of the Kali Gandaki in its middle zones ranges between 0.5% and 5%, with the highest gradients occurring near the Great Himalaya Range. Gradients may exceed 10% where the river cuts through the Himalayas. Stream gradients are only about 1% in the trans-Himalayan region (Fig. 2).

## SAMPLING METHODS

I made 172 samples at 85 sites along the Kali Gandaki/Narayani River from March 1984 to May 1986. Fourteen sites were sampled in each of the three seasons (Fig. 1). Sample sites were chosen so as to adequately sample all geographic zones. However, sampling was limited in some areas due to difficulties of access. Fishes were collected by a variety of methods, including seine, cast net, gill net, and backpack electrofisher. Choice of method at individual sites was based on the need to sample all distinct microhabitats (riffle, pool, raceway, backwaters, etc.). Collections from each type of microhabitat were maintained separately.

Specimens were preserved in 10% formalin. Identification of species followed Hamilton (1822), M'Clelland (1839), Day (1878), Hora (1921a, 1937b, 1935), Shaw and Shebbeare (1937), Roberts (1980, 1983), Shrivastava (1980), Jayaram (1981), Shrestha (1981) and Rainboth (1983). Problematical specimens were identified by comparison with collections housed at the Nepal Natural History Museum, California Academy of Sciences, Chicago Field Museum of Natural History, National Museum of Natural History, American Museum of Natural History, and Philadelphia Academy of Natural Sciences. Higher taxonomy herein follows Nelson (1984) except for the

Cobitoidea, which is after Sawada (1982). Voucher specimens were deposited in the Nepal Natural History Museum, Kathmandu and the Oklahoma State University Department of Zoology Collection of Vertebrates, Stillwater.

At each site I measured 37 environmental variables which I have grouped into five categories: geography, water quality, season, substrate, and vegetation (see Appendix A for values of variables at each site). Geographic factors included: altitude, measured from 1:250,000 U.S. Army Corps of Engineers maps and a Thommen 2000 altimeter; percent gradient of the riverbed, calculated from map and altimeter readings; river kilometer, or distance from the source of the Kali Gandaki, also measured from these maps; stream order, determined from these 1:250,000 maps and concomitant ground-truth studies which verified the smallest tributaries as first-order streams, streams formed by the joining of two first-order streams as second-order, streams formed by the joining of two second-order streams as third-order, etc.; predominantly exposed geological strata at the site, from Sharma (1977a), coded from 1 to 5 in order of geologic age, from Pleistocene to Precambrian (Appendix A); estimated maximum width of stream; and natural region, including trans-Himalaya, mountain, hill, lowland valley, and lowland plain, coded sequentially from 1 to 5.

Water quality factors included current speed (measured with a Teledyne Gurley pygmy current meter no. 625 at 60% depth) and stream depth. I measured both depth and current at 10 locations spaced at 1 m intervals in 3 to 5 transects across each microhabitat and calculated means of these measurements to arrive at an estimate of average depth and current speed for each site. Other water quality factors were: surface temperature, water clarity, and the following parameters measured with a Hach kit (model AL-36B): dissolved oxygen (mg/L), dissolved carbon dioxide (mg/L), pH, free acidity and total acidity (grains/gallon calcium carbonate -- gpg $CaCO_3$), free alkalinity and total alkalinity (gpg $CaCO_3$), and total hardness (gpg $CaCO_3$).

Substrate parameters were quantified with a modification of the Wentworth scale (Cummins 1962, Hynes 1970) by estimating the percent comprised of mud ( < ca. 0.0625 mm), sand (ca. 0.0625-1 mm), gravel (ca. 2-16 mm), stone (ca. 16-64 mm), rubble (ca. 64-256 mm), and boulder ( > ca. 256 mm), and by noting the dominant substrate and total number of substrate types at each site.

Vegetation was measured as percent of the site covered by filamentous algae, submerged vegetation, emergent vegetation, floating vegetation, debris, and detritus, and by noting the dominant vegetation, number of vegetation types, and percent of each site covered by vegetation.

## ANALYTICAL METHODS

Twenty-two collections were not considered in the analysis. These included sixteen collections that were qualitative only and/or had no environmental parameters measured and six collection efforts that produced no fish. Two collections having only two and four specimens eventually were excluded because they were outliers in the ordination analysis. Three environmental variables, free acidity, free alkalinity, and percent floating vegetation, were effectively invariant and were also excluded. Thus my results are based on 34 environmental variables measured for each of 148 collections at 73 sites (Fig. 1, Appendix B).

Fifty-two of the 120 fish species I collected are included in the analysis. The remaining 68 species occurred in less than 5% of the samples and were eliminated following Gauch (1982). Species abundances were coded for each collection on a scale of 0-4, with 0 = absent, 1 = 1-5 individuals, 2 = 6-10, 3 = 11-20, and 4 = > 20. Only adult fishes were included. Coded abundances improved normality of fish species distributions, but further transformation to log of coded abundance resulted in no improvement (Kolomogorov D-test, PROC UNIVARIATE, SAS Institute 1985a). Therefore, coded abundances were used as the raw data for final analysis.

Transformation of environmental variables to $\log_{10}(x + 1)$, or to $\arcsin\sqrt{x}$ for percentage data, markedly improved normality (reduced skewness and kurtosis) for 21 variables, including: altitude, percent stream gradient, stream width, dissolved $CO_2$, total alkalinity, total hardness, percent substrate comprised of mud, percent sand, percent gravel, percent stone, percent rubble, percent boulder, dominant substrate type, percent of cover by filamentous algae, percent submerged vegetation, percent emergent vegetation, percent detritus, percent debris, percent total cover by vegetation, number of vegetation types, and stream depth. These transformed variables were used in all subsequent analyses, while the remaining 13 variables were input as untransformed values. Transformation of non-normal data allows a closer approximation to the normality assumption on which correlation and regression analyses are based, and also decreases the chance that analyses will be unduly affected by extreme but infrequent values (Sokal and Rohlf 1981).

Indirect gradient analysis included initial DCA ordination of the fish collections on the basis of species abundances. Two different algorithms were used to obtain DCA ordinations: the DECORANA program of Hill (1979a) and the CANOCO procedures of Ter Braak (1988a).

DCA ordination axes were subsequently compared with environmental parameters by correlation analysis (PROC CORR, SAS Institute 1985a) and stepwise multiple regression (PROC STEPWISE, SAS Institute 1985b). Mallows' $C_p$ statistic (Mallows 1964) was used as the criterion for selecting a regression model.

Two other indirect multivariate ordination techniques, PCA and RA, were also performed but DCA provided more interpretable results. Linear ordination methods, such as PCA and redundancy analysis are appropriate if the range of sample scores along the length of the first axis, ordinated by reciprocal averaging (RA), is less than about 1.5 SD (Gauch et al. 1977; Ter Braak and Prentice 1988). However, where gradients are longer and where species have unimodal (Gaussian) responses along the gradient, nonlinear methods like RA, DCA, CCA, and DCCA more consistently and accurately recover the structure of data (Gauch et al. 1977; Peet 1980; Pielou 1984; Ter Braak and Prentice 1988).

DCA is a variance maximization method of ordination based on RA, which is itself similar to PCA (Hill 1973). PCA is based on a Euclidean distance matrix, and the correlation matrix between all variables is decomposed using eigenvector analysis; standardized data are then projected onto the first few resulting axes. These linear, orthogonal axes typically account for a large portion of the residual variance. RA is algebraically similar, except that it decomposes an association matrix based on the chi-square distance metric.

DCA corrects for the two major faults of RA, which can cause difficulties in attempts to interpret the axes: the arch effect, caused by a quadratic relationship of axis 2 on axis 1 (Hill and Gauch 1980); and distortion of ecological distances along the axes (Hill 1979a). DCA also aids interpretation by scaling the axes (gradient length) to average standard deviation units (SD) of species turnover, where 1 SD = half change and 4 SD = total change in species composition. DCA also calculates separate sample scores and species scores that can be superimposed on the same figure, providing an approximation of species' optima along the axes.

In DECORANA, the arch effect of RA is removed by an ad-hoc DCA algorithm known as detrending by segments. DCA has been criticized by Pielou (1984) as "overzealous" and by Wartenberg et al. (1987) as "without theoretical justification". However, others, using real and simulated data, have found it to give useful and ecologically correct interpretations (Gauch 1982; Peet et al. 1988). DCA is the ordination method presently favored by the majority of ecologists for nonlinear data from a variety of organisms (e.g., Chang and Gauch 1986; Leland et al. 1986; Ben-Shahar and Skinner 1988), including fishes (e.g., Rahel 1984; Larsen et al. 1986; Hughes and Gammon 1987; Hughes et al. 1987; Matthews and Robison 1988; Meffe and Sheldon 1988; Townsend and Peirson 1988; Ibarra and Stewart 1989). Ter Braak and Prentice (1988) developed a less "brute-force" algorithm for DCA, available in CANOCO, known as detrending by polynomials, which eliminates systematic relations between axes by making subsequent axes orthogonal not only to axes already extracted, but also to quadratic, cubic, and quartic functions of those axes.

RA and DCA axes are obtained by a converging sequence of weighted averaging regressions and calibrations such that sample axes are linear combinations of weighted mean species scores with the constraint that successive axes are uncorrelated with previous ones. Direct ordination methods of CCA and DCCA impose the additional constraint that ordination axes based on species abundances be linear combinations of supplied environmental variables (Ter Braak 1986; Ter Braak and Prentice 1988). Thus, these methods produce community ordinations with an environmental basis (Ter Braak 1986; 1987). In resulting ordination diagrams, sites and species are represented by points, and environmental variables are represented by arrows. Thus, the axes can be interpreted directly from the pattern of community variation along environmental gradients. Also visible in these biplots are the approximate distributions of species with respect to plotted variables. Eigenvalues measure the separation of species distributions along these environmental axes.

I performed direct gradient analysis with the CCA and DCCA algorithms provided by the CANOCO package. The downweighting option, which supplies lesser weights to rare species, was employed in all direct and indirect ordinations. The species-environment correlation (Ter Braak 1986, 1988a) is equal to the correlation between site scores that are weighted mean species scores and site scores that are linear combinations of the environmental variables. CANOCO provides a facility for testing statistical significance of the canonical axes with a Monte Carlo permutation test (Ter Braak 1988a). It allows an overall test of the effect of the environmental variables on the species, as well as significance tests on individual axes. The fraction of variance accounted for by an axis, i.e., variance in the weighted averages of fish species with respect to environmental variables, can be expressed as a percentage, and is calculated by dividing the eigenvalue of the axis by the sum of all canonical eigenvalues (the trace). It is important to remember that 100% is not expected, since part of the total variance is due to noise. Also, the percent accounted for depends on the number of variables ( = the number of canonical axes extracted) in the analysis. Thus, for example, with only three environmental variables in an analysis, three canonical axes explain 100% of the variance, whether or not the result is ecologically meaningful. The importance of an axis is better judged by its eigenvalue and a Monte Carlo significance test (Ter Braak 1988a).

## RESULTS

Appendix C shows, for each collection, coded abundance of the 52 species included in my analysis. Seventy-one percent (37) are cypriniforms (Cyprinidae, Cobitidae, Homalopteridae) and 15% (8) are siluriforms (Schilbeidae, Amblycipitidae, Sisoridae). Other orders represented are Cyprinodontiformes (Belonidae) 2% (1) and Perciformes (Centropomidae, Gobiidae, Channidae, Mastacembelidae) 12% (6).

Longitudinal succession of species is evident in the Kali Gandaki/Narayani, with the number of species increasing steadily from upper reaches of the river to the downstream areas ($r = 0.69$, $P < .0001$; Fig. 3). No fish were captured in first or second order streams, and only one species, Schizothorax richardsoni, was present in the trans-Himalayan portion of the Kali Gandaki. Proceeding downstream, numbers of species ranged from one to four per site in the mountain region ($\bar{x} = 1.9$; SD = 0.9), 3 to 18 ($\bar{x} = 7.8$; SD = 4.1) in the high hills, 4 to 18 ($\bar{x}$ = 10.7; SD = 4.4) in the low hills, and 6 to 33 ($\bar{x}$ = 15.6; SD = 6.1) in the lowlands.

## Indirect Gradient Analysis

Plots of the first two axes from both the PCA and the RA computations showed an uninterpretable horseshoe or arch effect. DCA from DECORANA provided better results; however, its detrending by segments algorithm produced a systematic relation between axes. Scores on axes 1 and 3 ($r = 0.206$, $P = 0.0116$), axes 1 and 4 ($r = -0.257$, $P = 0.0015$), and axes 3 and 4 ($r = -0.273$, $P = 0.0007$) were significantly correlated. CANOCO's DCA with detrending by fourth-order polynomials produced more desirable uncorrelated axes and the most interpretable ordination; consequently, this technique was used in all subsequent indirect gradient analyses.

### Axis 1

DCA axis 1 (DCA 1) displays an extremely long gradient, more than 10 SD, from the mountains to the lowlands. Samples from the high hills showed the greatest variability in DCA 1 scores (Fig. 4). Mountain samples formed a discrete cluster widely separated from the remaining samples. Samples from the high hills and low hills were completely separated in the biplot of DCA 1 versus DCA 2. Samples from the low hills and the lowlands overlapped broadly on both DCA 1 and DCA 2. DCA 1 scores for samples from the low hills were shifted somewhat toward those for the high hills.

DCA 1 represents the tremendous altitudinal gradient of the Kali Gandaki/Narayani, with scores most highly and significantly correlated with major geographic factors (Table 1). Pearson product-moment correlations with DCA 1 scores are highest for stream gradient, stream order, altitude and natural region. Highly significant correlations also occur between DCA 1 scores and some water quality, substrate, and vegetation factors, such as stream depth, total hardness, percent substrate comprised of boulders, and percent cover by debris (Table 1).

Results of stepwise multiple regression analysis also suggest a geographic interpretation for DCA 1. The following multiple regression equation provided the best predictive model for DCA 1 scores:

$$\begin{aligned} \mathrm{DCA}\ 1 = {} & -3110.18 + 1402.11\mathrm{SG} - 75.61\mathrm{G} + 16.62\mathrm{RK} \\ & + 108.68\mathrm{SW} + 216.05\mathrm{TH} + 972.93\mathrm{A} + 176.96\mathrm{D} \\ & (R^2 = 0.93;\ df = 140) \end{aligned}$$

where SG = stream gradient, G = geology, RK = river kilometer, SW = stream width, TH = total hardness, A = altitude, and D = debris (Table 2).

Fishes having the highest scores on DCA 1 ( and thus = "mountain" fishes) were *Schizothorax richardsoni*, *Euchiloglanis hodgarti*, and *Noemacheilus rupecula*. Highest negative loadings were for *Rasbora daniconius*, *Channa punctatus*, *Mastacembelus pancalus*, *Puntius guganio*, and *Chela cachius*, species which occurred only in the lowlands (Fig. 4).

### Axis 2

Patterns of sample scores along DCA 2 are less conspicuous by inspection (Fig. 4). Gradient length is 3 SD, with greatest variability in the lowlands. DCA 2 scores are most highly correlated with season, water clarity, water temperature, and dissolved oxygen (Table 1), suggesting an association with the seasons. Stepwise regression results (Table 2) also point to a seasonal effect. The model best predicting DCA 2 scores is:

$$\begin{aligned} \mathrm{DCA\ 2} = {} & 268.90 - 27.26\mathrm{S} + 91.76\mathrm{SV} + 82.70\mathrm{SW} \\ & + 55.47\mathrm{B} - 70.73\mathrm{NV} + 122.69\mathrm{D} + 1.05\mathrm{WC} \\ & - 134.71\mathrm{TH} - 30.85\mathrm{SO} + 55.12\mathrm{FA} + 18.63\mathrm{M} \\ & (R^2 = 0.46;\ df = 136) \end{aligned}$$

where S = season, SV = submerged vegetation, B = boulders, NV = number of vegetation types, WC = water clarity, SO = stream order, FA = filamentous algae, M = mud, and other terms are as above. Several variables retained in the regression model for DCA 2 scores are expected to change seasonally: e.g., percent of habitat covered by submerged vegetation, stream width, number of vegetation types, percent cover by debris, water clarity, total hardness, percent cover by filamentous algae, and percent of substrate comprised of mud.

Fishes loading high on axis 2 are Rasbora daniconius, Puntius guganio, Danio devario, Esomus danricus, Barilius tileo, and Puntius ticto. Species with the largest negative scores include Glyptothorax telchitta, Barilius barila, Clupisoma garua, Crossocheilus latius, Tor tor, Garra gotyla, and Tor putitora (Fig. 4).

## Axis 3

DCA 3 spans 3 SD, with greatest variability in the lowlands. Plots of DCA 3 versus DCA 1 and DCA 2 showed no obvious patterns in samples or species. Pearson product-moment correlations between DCA 3 and environmental variables are significant for current speed, three substrate factors, and three vegetation factors (Table 1), suggesting a possible current and related substrate/

vegetation component. This interpretation is supported by stepwise multiple regression analysis (Table 2), which provides the model:

$$\begin{aligned} DCA\ 3 = {} & 568.21 - 91.75SW + 0.48C - 143.96A - 22.31G \\ & + 71.34D + 94.63Z - 127.41SA - 86.44ST \\ & - 76.21M - 58.67B \\ & (R^2 = 0.45;\ df = 137) \end{aligned}$$

where C = current speed, Z = stream depth, SA = sand, ST = stone, and other terms are as above.

Fishes with highest scores on DCA 3 include Labeo dero, Botia lohachata, Chela cachius, Pseudecheneis sulcatus, Glyptothorax kashmirensis, Chanda baculis, Mastacembelus armatus, and Garra gotyla. Species with lowest scores are Noemacheilus scaturigina, Semiplotus semiplotus, Chagunius chagunio, Barilius bola, and Aspidoparia jaya.

## Ordination without mountain samples

To better differentiate high hills, low hills and lowland samples, I removed the distinctive mountain collections and reordinated the remaining samples, leaving 120 collections at 59 sites. Separation of disjunct sample sets allows a more critical analysis of the relationship between environmental parameters and fish assemblage structure outside the extreme mountain zone (e.g., Peet 1980, Green 1980, Gauch 1982).

### Axis 1

Without the mountain samples, the axis 1 eigenvalue, a measure of separation of species' distributions along the axis, is considerably smaller than when mountain samples are included in the ordination (0.76 vs. 0.43). However, even without these collections, DCA axis 1 displays a dominant geographic component, spanning nearly 5.5 SD from high hills to lowlands (Fig. 5). Correlation coefficients remain most significantly correlated with geographic factors such as river kilometer, stream order, altitude, geology, stream gradient and natural region (Table 3). Highly significant correlations with DCA 1 scores also occur for some water quality, substrate and vegetation factors (e.g., water temperature, dominant substrate type, percent cover by submerged vegetation, and current speed) (Table 3).

The results of stepwise multiple regression analysis also demonstrate the geographic component of DCA 1 (Table 4). The model best predicting axis 1 scores without mountain samples is:

$$\text{DCA } 1 = 518.70 - 4.62RK - 64.78SO + 62.60NR - 60.39SV - 34.55FA - 3.42WT - 75.73D - 73.98B$$

$$(R^2 = 0.88;\ df = 111)$$

where NR = natural region, WT = water temperature, and other terms are as above.

Species loading highest on the DCA 1 obtained without mountain samples are *Euchiloglanis hodgarti*, *Schizothorax richardsoni*, *S. progastus*, *Acrossocheilus hexagonolepis*, and *Noemacheilus shebbearei*. Fishes with highest negative loadings on DCA 1 include *Rasbora daniconius*, *Puntius guganio*, *Mastacembelus pancalus*, *Channa punctatus*, *Puntius ticto*, *Barilius tileo*, *Danio devario*, *Chela cachius*, and *Lepidocephalus guntea* (Fig. 5).

### Axis 2

Environmental interpretation of DCA 2 without mountain samples is not obvious from Fig. 5. Scores span 3 SD, with lowland samples most variable. Scores are most highly correlated with current speed, season, and water temperature (Table 3), suggesting a seasonal effect. Stepwise regression results also support a seasonal interpretation (Table 4). The model best predicting axis 2 scores without mountain samples is:

$$\begin{aligned} DCA\ 2 = {} & 670.12 + 21.99S + 0.51C - 199.61A - 151.55SW \\ & - 100.75M - 93.46ST + 138.88Z - 144.49SA \\ & - 78.59B - 18.91G \\ & (R^2 = 0.62;\ df = 109) \end{aligned}$$

where terms are as above.

Fish species with highest scores on DCA 2 without mountain samples are Labeo dero, Botia lohachata, Glyptothorax telchitta, Pseudecheneis sulcatus, and Glyptothorax trilineatus, followed by Chanda baculis, Glyptothorax kashmirensis, Clupisoma garua, Barilius barila, Crossocheilus latius, and Garra gotyla. Highest negative loadings on DCA 2 are for Semiplotus semiplotus, Rasbora daniconius, Esomus danricus, Puntius sophore, Barilius bola, Chagunius chagunio, and Barilius tileo (Fig. 5).

### Axis 3

Plots of the DCA 3 obtained without mountain samples showed no readily discernable patterns. However, Pearson product-moment correlations between DCA 3 scores and environmental variables are highly significant for percent cover by detritus and number of vegetation types (Table 3). Correlations were also significant for current speed, percent substrate composed of gravel, and percent cover by vegetation, suggesting a current-related substrate/vegetation component to DCA 3. Multiple regression results are similar (Table 4). DCA 3 scores are best predicted by the equation:

$$\begin{aligned} \text{DCA } 3 = &- 106.77 + 276.70\text{DET} + 0.95\text{C} + 50.83\text{NV} \\ &+ 49.18\text{GR} - 14.26\text{S} + 3.41\text{WT} \\ &(R^2 = 0.39;\ df = 113) \end{aligned}$$

where DET = detritus, GR = gravel, and other terms are as above.

Species loading high on DCA 3 without mountain samples are _Noemacheilus shebbearei_, _Tor putitora_, _T. tor_, _Semiplotus semiplotus_, and _Acrossocheilus hexagonolepis_. Highest negative loadings on DCA 3 are for _Glyptothorax telchitta_, _Osteobrama cotio_, _Clupisoma garua_ and _Chanda ranga_.

## Direct Gradient Analysis

### Axis 1

A plot of canonical correspondence analysis axis 1 versus axis 2 showed an uninterpretable arch effect, thus I used detrended canonical correspondence analysis for all direct gradient analyses, with detrending by fourth-order polynomials.

The overall ordination and the first DCCA axis (DCCA 1) are both highly significant ($P < 0.001$), with DCCA 1 explaining 34% of the variability in species scores. DCCA 1 spans 8.7 SD and displays a gradient from mountains to lowlands (Fig. 6), with mountain samples quite distinctive, as in the DCA ordination. Correlations between environmental variables and DCCA 1 (= "intra-set correlations"; Ter Braak 1986, 1988a) again suggest a geographic component. DCCA 1 scores are most highly and significantly correlated with stream gradient, stream order, altitude, geology, natural region, and river kilometer (Table 5). DCCA 1 is also highly correlated with certain water quality and substrate factors, including stream depth, current speed, total hardness, water temperature, total alkalinity, percent substrate comprised of boulders, dominant substrate type, percent gravel, and percent mud.

The species-environment correlation for DCCA 1 of 0.951 shows the extracted variation in assemblage composition is well explained by the measured environmental variables. Multiple regression of site scores for DCCA 1 on the environmental variables demonstrates the geographic basis of DCCA 1 (Table 6). Variables making significant contributions to the model explaining DCCA 1 scores include stream gradient, river kilometer, altitude, and geology.

Environmental variables are represented by arrows on the species-environment biplot of DCCA scores (Fig. 6). Trajectory and length of arrows represent the direction and magnitude of correlations between environmental variables and assemblage composition along the gradient (Ter Braak 1988a, Ter Braak and Prentice 1988). Thus, the arrows in Fig. 6 demonstrate the importance of stream gradient, altitude, stream order, and river kilometer on DCCA 1. The approximate distribution of fish species with respect to these environmental gradients can be inferred from their position along these arrows.

Fishes loading highest on DCCA axis 1 are *Euchiloglanis hodgarti*, *Schizothorax richardsoni*, and *Noemacheilus rupecula*. Fishes with highest negative loadings on DCCA 1 include *Mastecembelus pancalus*, *Chela cachius*, *Puntius ticto*, *P. guganio*, *Channa punctatus*, *Chanda baculis*, *Danio devario*, and *Esomus danricus* (Fig. 6).

### Axis 2

DCCA 2 (Fig. 6) is highly significant ($P < 0.01$) and explains 7.6% of the variability in the species scores. DCCA 2 scores are most variable in the lowlands and are most highly correlated with season, water temperature, dissolved oxygen, water clarity, and current speed (Table 5), again supporting a seasonal interpretation. The species-environment correlation is 0.874. A multiple regression model incorporates stream width, percent cover by submerged vegetation, water temperature, geology, river kilometer, percent filamentous algae, season, and stream order to predict DCCA 2 scores (Table 6). The arrows for environmental variables on Fig. 6 indicate the effect of seasonal factors on fish assemblage composition.

Fishes with highest scores on DCCA axis 2 are *Glyptothorax telchitta*, *Labeo dero*, *Clupisoma garua*, and *Barilius barila*. Species with highest negative loadings on DCCA 2 include *Rasbora daniconius*, *Esomus danricus*, *Danio devario*, *Puntius guganio*, and *Barilius tileo* (Fig. 6).

### Axis 3

DCCA 3 is statistically significant ($P < 0.05$) and is also most variable in the lowlands. It explains 4.2% of the variance in the species data; however, plots of DCCA 3 showed no obvious pattern in samples or species. DCCA 3 scores are most highly correlated with vegetation factors, including number of vegetation types, percent cover by vegetation, percent filamentous algae, percent detritus, and percent submerged vegetation (Table 5). Significant correlations also occur with the substrate factors, percent rubble and percent boulders; thus DCCA 3 could be interpreted as a vegetation/substrate gradient. The species-environment correlation is 0.777. The multiple regression model for scores on DCCA 3 incorporates eight vegetation/substrate factors: percent cover by detritus, percent substrate comprised of stone, number of vegetation types, percent filamentous algae, percent mud, percent submerged vegetation, percent cover by vegetation, and percent sand (Table 6).

Species loading highest on DCCA 3 are *Labeo dero*, *Tor tor*, and *Pseudecheneis sulcatus*. Fishes with highest negative loadings include *Glyptothorax telchitta*, *Clupisoma garua*, and *Osteobrama cotio*.

## Ordination without mountain samples

### Axis 1

As with indirect gradient analysis, I removed the distinctive mountain collections and reordinated the remaining samples in an attempt to better differentiate fish assemblage composition and its environmental basis in the high hills, low hills, and lowlands (Fig. 7). The overall ordination and DCCA 1 are both highly significant

($P < 0.001$). DCCA 1 maintains extremely high correlations with all geographic variables and concomitant correlations with water quality, substrate, and vegetation variables (Table 7). The species-environment correlation is 0.959.

The strength of the relationship between geographic factors and DCCA 1 scores is indicated by the arrows in Fig. 7. DCCA 1 explains 28.5% of the variation in species data. Multiple regression analysis shows that three geographic factors (river kilometer, stream order, and natural region) explain the greatest portion of variance in a model predicting DCCA 1 scores (Table 8).

Fishes with highest scores on DCCA 1 without mountain samples include _Euchiloglanis_ _hodgarti_, _Schizothorax_ _richardsoni_, _S_. _progastus_, _Acrossocheilus_ _hexagonolepis_, _Noemacheilus_ _shebbearei_, _Glyptothorax_ _kashmirensis_, and _Pseudecheneis_ _sulcatus_. Highest negative loadings are for _Rasbora_ _daniconius_, _Mastacembelus_ _armatus_, _Osteobrama_ _cotio_, _Puntius_ _guganio_, _Channa_ _punctatus_, and _Barilius_ _tileo_ (Fig. 7).

### Axis 2

DCCA 2 is highly significant ($P < 0.01$) and scores are most variable in the lowlands (Fig. 7). Highest correlations between axis 2 scores and environmental variables are with season, water temperature, dissolved oxygen, current speed and water clarity (Table 7), again suggesting a seasonal interpretation for axis 2. The species-environment correlation is 0.884.

DCCA 2 explains 10.7% of the variance in species data. Arrows of environmental factors on Fig. 7 highlight the seasonal component. A multiple regression model predicting DCCA 2 scores includes stream width, stream depth, percent substrate comprised by sand, percent mud, percent stone, season, and current speed as variables explaining the greatest portion of variance in fish assemblage composition along DCCA 2 (Table 8).

Species scoring high on DCCA 2 include Glyptothorax telchitta, Labeo dero, Botia lohachata, Chanda baculis, Clupisoma garua, Crossocheilus latius, Pseudecheneis sulcatus and Barilius barila. Fishes with highest negative loadings on DCCA 2 are Semiplotus semiplotus, Rasbora daniconius, Esomus danricus, and Puntius sophore (Fig. 7).

## Axis 3

DCCA 3 is also statistically significant ($P < 0.05$) and explains 5.1% of the variation in the species data. The species-environment correlation is 0.790, but plots of DCCA 3 scores showed no obvious patterns in samples or species. DCCA 3 is most highly correlated with vegetation factors, including percent cover by detritus, number of vegetation types, and percent cover by vegetation (Table 7). Multiple regression analysis further supports the association between DCCA scores and percent detritus and number of vegetation types (Table 8).

Fishes having highest scores on DCCA 3 are _Tor tor_, _Semiplotus semiplotus_, _Acrossocheilus hexagonolepis_, and _Tor putitora_. Species with highest negative loadings on DCCA 3 include _Clupisoma garua_, _Osteobrama cotio_, and _Glyptothorax telchitta_.

## Comparison of DCA and DCCA

Indirect and direct gradient methods lead to similar results and interpretations in the analysis of fish assemblage data and environmental gradients in the Kali Gandaki/Narayani River. Plots of the ordination of species and site scores are similar for the two methods. The relative importance and statistical significance of correlation coefficients between environmental variables and ordination axes are also similar for indirect and direct methods for data sets with and for those without mountain samples, though magnitudes differ for some variables. Comparison of multiple regression analyses of environmental variables on ordination scores also shows the similarity of the two techniques for these data.

Eigenvalues of the first three axes are similar for DCA and DCCA in analyses both with and without mountain samples. Species-environment correlations of the first three axes are all high for both data sets (Table 9). The fraction of variance accounted for by the axes is nearly the same for DCA and DCCA both with and without mountains (Table 9). Such similarity between the results of direct and indirect gradient analyses indicates that the measured environmental variables are sufficient to explain a major portion of the variation in fish assemblage composition (Ter Braak 1986).

## Analysis of seasonal and stream order effects

Indirect and direct gradient analyses both show a seasonal component for axis 2. Extended periods of heavy rains during the monsoon season (June - September) result in greatly increased river discharge and turbidity (Sharma 1977b). For example, mean monthly discharges for the Kali Gandaki River at Setibeni in 1976 ranged from 45 $m^3/s$ in March to 904 $m^3/s$ in August (Anonymous 1984). Such increases in discharge coincide with increased movement and upriver spawning migrations of many adult fishes (personal observation, personal communication with local fishermen). Similar spawning migrations occur with increased discharge of rivers in Africa and South America (Lowe-McConnell 1975, and references therein).

The seasonality hypothesis just described predicts that the abundance of individual species loading heavily on axis 2 should show an added variance component attributable to season. To test this hypothesis, I subjected the coded abundances of the ten species having the highest absolute scores for DCCA 2 to a two-way analysis of variance (ANOVA -- Sokal and Rohlf 1981) in which the independent variables were biogeographic zone (mountains, high hills, low hills, and lowlands) and season (hot, wet monsoon; cool, dry; and hot, dry). The intent of this analysis was to assess temporal effects independently of spatial variation (c.f., Lewis 1978, Matthews 1989 - manuscript submitted).

Five of the 10 species -- *Barilius barila*, *Crossocheilus latius*, *Danio devario*, *Puntius guganio*, and *Rasbora daniconius* -- exhibited statistically significant temporal variation ($.01 < P < .04$; $3.39 < F < 6.30$, 2 df). (Three of those five were among the six species having the highest scores on DCA 2.) Thus, as predicted, the abundances of individual species loading heavily on DCCA 2 are associated with seasonality.

I also examined the distribution of fishes in the Kali Gandaki/Narayani for "faunal breaks" (sensu Matthews 1986), or distinct areas of faunal change. Presenceabsence data for species in each collection were used to compare species similarity among sites and to investigate the correspondence between faunal change and stream order. Morisita's index (Morisita 1959) was employed to test for sharp differences in species composition between adjacent sites. Calculated values of Morisita's index indicate that as much variation exists within zones and even at given sites over different seasons as occurs between sites where stream order increases. Thus, while stream order was highly significantly correlated with scores on the first ordination axis (Tables 1, 3, 5, 7) and was often retained as a significant independent variable in regression models for ordination scores (Tables 2, 4, 6, 8), it alone does not sufficiently explain a high proportion of the variance in fish assemblage composition in the Kali Gandaki/Narayani. Rather, my results indicate that a combination of synergistic and related physiochemical parameters, mainly components of "stream hydraulics" (Statzner and Higler 1986), are the abiotic factors that best predict longitudinal zonation in fish assemblage structure in the Kali Gandaki/Narayani River.

## Mesohabitat patterns of assemblage composition

Insight into fish assemblage structure along the length of the Kali Gandaki/Narayani is provided by an examination of "mesohabitat" trends (sensu Meffe & Sheldon 1988); i.e., the relative abundance of species in riffles, pools and runs from region to region. To investigate such possible trends, I performed separate DCA ordinations on species captured in riffles, pools and runs throughout the river. I included only those sites at which separate samples were made in all three mesohabitats, i.e., in riffle(s), pool(s), and run(s).

To further increase the validity of comparisons among such divergent macrohabitat types, I eliminated all sites where gill netting or electrofishing sampling methods were employed, and used only those sites where seining (hauls or riffle kicks) and cast netting were used for sampling. (See Edds (1986) for a more qualitative treatment of assemblage composition that includes all sites and species. Pool and run assemblages at sites were found to be very similar throughout the river. Thus, I later combined individuals from these two mesohabitats at each site for comparison with the distinctive riffle fish assemblages.

Longitudinal patterns in riffle DCA 1 scores are evident along the length of the Kali Gandaki/Narayani (Fig. 8). Scores for collections made in mountain riffles are particularly distinctive compared with those of other zones. On average, scores for riffle collections made in the high hills are intermediate between those made in the mountains and those made in the low hills and lowlands. Riffle collections from the low hills and lowlands exhibit similar scores on DCA 1. A parallel pattern exists for the collections from pool/run assemblages (Fig. 9). The small differences in DCA 1 scores between low hills and lowlands for both riffles and pool/runs is in part due to inclusion of the highly divergent data for mountain samples, and is not entirely indicative of the degree of similarity in species composition between low hills and lowlands. Some of the overlap between zones is also due to seasonal effects, since species composition at a given site may vary greatly among seasons.

Along the length of the Kali Gandaki/Narayani, riffle-dwelling fishes are mainly cyprinids, homalopterid loaches and sisorid sucker catfishes, with the loaches and sucker catfishes becoming the most common fishes in the riffles of the hill and lowland zones. The cyprinid Schizothorax richardsoni is dominant in mountain riffles while the loach Noemacheilus shebbearei is the most common riffle-dweller in the high hills. The loaches N. scaturigina, N. rupecula, and the sucker catfishes Glyptothorax pectinopterus and G. kashmirensis are the most common riffle-dwellers in the low hills. In the lowlands, the loaches N. scaturigina, N. rupecula, N. corica, N. beavani and Botia lohachata form a major portion of the fish assemblage in riffles.

Pool/run assemblage composition is dominated by *Schizothorax richardsoni* in the mountain zone, but the congeneric species *S. progastus* and other cyprinids dominate in the high hills. Cyprinids and homalopterids are important members of the pool/run mesohabitat in the high hills, low hills and lowlands. The greatest number of species inhabits the lowland pool/runs, where, in addition to the cyprinids and homalopterids that are most abundant, two cobitid loaches, two chandid glassfishes, two mastacembelid spiny eels, one schilbeid catfish, one belonid needlefish, and one gobiid goby are important members of the pool/run assemblage of fishes.

## Mountains

In the mountain zone, riffles and pool/runs are both dominated by the cyprinid *Schizothorax richardsoni* (Table 10). The sisorid catfish *Euchiloglanis hodgarti* also is a major component of the fish assemblage in mountain riffles. The homalopterid loach *Noemacheilus rupecula* also occurs in both riffles and pool/run mesohabitats in the mountains (Table 10).

## High hills

The riffle fish-assemblage in the high hills comprises cyprinids (5 species), homalopterids (3), and sisorids (2), the most common being the homalopterid loaches *Noemacheilus shebbearei* and *N. rupecula*, the cyprinids *Barilius bendelisis*, *B. vagra*, and *Schizothorax progastus*, and the sisorid *Euchiloglanis hodgarti* (Table 11).

Pool/run habitats are dominated by cyprinids (10), with one homalopterid and one sisorid also occurring periodically. *Schizothorax progastus* is the most common fish in high hills pool/runs, along with *Barilius bendelisis* and *B. vagra*. The cyprinids *B. shacra*, *Schizothorax richardsoni* and *Acrossocheilus hexagonolepis* also occur in many pool/run collections in this zone (35-53%). Less abundant members of this assemblage include the cyprinids *Tor putitora*, *Crossocheilus latius*, and *Garra gotyla* and the loach *Noemacheilus corica* (Table 12).

## Low hills

The riffle fish-assemblage in the low hills comprises mainly cyprinids (8), homalopterids (4), and sisorids (4), one cobitid loach, one amblycipitid catfish, and one mastacembelid spiny eel (Table 12). The major components are the cyprinids *Barilius vagra* and *B. bendelisis*, the sisorid *Glyptothorax pectinopterus*, and the homalopterid *Noemacheilus scaturugina*, all of which occur in 38-50% of the collections. The cobitid loach *Botia lohachata* and the sisorids *Glyptothorax kashmirensis* and *Pseudecheneis sulcatus* are also present at many sites (19%).

Pool/run assemblages are dominated by cyprinids (18) and homalopterid loaches (5), with one cobitid loach, one schilbeid catfish, two sisorids, and one belonid also occurring (Table 13). The cyprinid *Barilius vagra* occurred in all 25 pool/run collections from the low hills. The cyprinids *B. bendelisis*, *B. shacra*, *B. barna* and *Schizothorax progastus* are also common, and the loaches *Noemacheilus corica* and *Noemacheilus scaturigina* form another major component of pools and runs in the low hills (Table 12).

## Lowlands

Lowland riffles had 13 species of cyprinids, six homalopterid loaches, five sisorid catfishes, two cobitid loaches, one amblycipitid catfish, one chandid glassfish and one mastacembelid spiny eel (Table 13). The most common species are the homalopterids *Noemacheilus scaturigina*, *N. rupecula*, *N. corica*, *N. beavani*, *N. botia* and *N. shebbearei*, the cyprinids *Barilius bendelisis*, *B. vagra*, and *Garra gotyla*, the cobitid *Botia lohachata*, the amblycipitid *Amblyceps mangois*, and the sisorid *Glyptothorax pectinopterus*.

Lowland pool/runs are inhabited by 28 cyprinid species, five homalopterids, two cobitids, two sisorids, two chandids, two mastacembelids, one schilbeid, one amblycipitid, one belonid, one chandid glassfish, and one gobiid goby (Table 14). The most common fishes in lowland pool/runs are the cyprinids *Barilius barna*, *B. bendelisis*, *B. shacra*, *B. vagra*, *B. barila*, *Puntius conchonius*, *P. ticto*, *Chagunius chagunio*, *Aspidoparia jaya*, *A. morar* and *Danio devario*, the homalopterids *Noemacheilus corica* and *N. botia*, the needlefish *Xenentodon cancila* and the glassfish *Chanda baculis* (Table 13).

## Intra-generic zonation

Patterns of longitudinal zonation are evident among species of four different genera. *Schizothorax richardsoni* dominates in the mountains, but is replaced by *S. progastus* in the high hills. Species of another cyprinid genus, *Barilius*, also demonstrate a longitudinal progression of occurrence in the Kali Gandaki/Narayani: 1) *B. bendelisis* is widespread, occurring from the high hills to the lowlands; 2) *B. bendelisis* and a second species, *B. vagra* dominate the high hill and low hill portions of the river; 3) *B. shacra* and *B. barna* become more common downstream in the low hills and lowlands; 4) these four species are joined by *B. bola* and *B. tileo* in the lowlands.

*Noemacheilus rupecula* is the most wide ranging of all the fishes of the Kali Gandaki/Narayani. It occurs from the mountains to the lowlands, and is the only loach in the mountains. *N. shebbearei* is the most common loach in the high hills, whereas *N. scaturigina* and *N. corica* are the most common members of the genus in the low hills and lowlands. Among the Sisoridae, *Euchiloglanis hodgarti* is the only species of the family in the mountains and is the most abundant sisorid in high hills riffles. In the low hills, *E. hodgarti* is replaced other sisorids, including *Glyptothorax pectinopterus*, *G. kashmirensis*, and *Pseudecheneis sulcatus*; these are joined in lowland riffles by *G. telchitta* and *G. trilineatus*.

## DISCUSSION

### Longitudinal zonation and distribution of Himalayan fishes

The general distribution pattern of fishes throughout the Himalaya mountain range has been addressed by Hora (1951, 1952) and Menon (1954, 1962, 1974). These accounts were based primarily on ichthyofauna surveys done in India in the Eastern Himalaya (e.g., Hora 1921b, 1935, Shaw and Shebbeare 1937) and the Western Himalaya (e.g., Silas 1960, Sehgal 1971). However, relatively little information has been published on the distribution of fishes in the Central Himalaya, i.e., between about 80 and 87 degrees east longitude in Nepal.

G.E. Hutchinson outlined a scheme of fish species zonation in his 1939 monograph on fishes of the extreme northwestern Himalaya. His zones included: 1) headwater streams inhabited by rheophilic species of *Noemacheilus*; 2) large streams with schizothoracines and *Noemacheilus* species; 3) rapid, turbid rivers with rheophilic species of *Schizothorax* and *Noemacheilus*; and 4) slow rivers and lacustrine swamps inhabited by limnadophil species of *Schizothorax*.

Jhingran and Sehgal (1978) designated three fish zones in torrential Himalayan streams: 1) the "loach" or "headwater zone", inhabited by noemacheiline loaches and the sucker catfish *Glyptosternum*; 2) the "snow trout" (Cyprinidae, Schizothoracinae) or "rapid clear water zone", the most torrential reaches of which are inhabited by one schizothoracine species (less rapid reaches of this zone are frequented by other schizothoracines); and 3) the "rapid turbid water zone", inhabited mainly by rheophilic schizothoracines and loaches.

Menon (1954) recognized six categories of Himalayan fishes according to their various morphological and behavioral adaptations to the types of waters they inhabit: 1) fishes that live at the bottom of deep, swift waters, cylindrical in form and possessing powerful muscular bodies like *Schizothorax*, *Tor* and *Semiplotus*; 2) fishes that attach themselves to bare rocks in torrential waters, including *Euchiloglanis* and *Pseudecheneis*; 3) fishes that live among the stones at the bottom of shallower, less forceful waters, including *Noemacheilus*, *Botia* and *Amblyceps*; 4) fishes having ventrally placed adhesive disks that are used to attach the fish to bare rocks in comparatively slower waters, (e.g., *Glyptothorax* and *Garra*); 5) fishes modified for a burrowing habit and which bury themselves in the substrate to avoid the force of rushing waters, (e.g., *Mastacembelus* and *Psilorhynchus*); and 6) fishes inhabiting shallow, clear waters at the base of hills, "without any striking adaptive characters" for high current speeds, (e.g., *Bagarius* and *Gagata*). Sehgal (1983) also includes *Barilius* and *Puntius* in the latter group.

My study is the first to document fish species distribution from first-order streams to lower mainstream in a major Himalayan river. The fish assemblage of the Kali Gandaki/Narayani exhibits a pattern of macrohabitat zonation from the trans-Himalaya plateau, through the mountains into the high hills, low hills and finally the lowland plains. Although zonal boundaries are not sharply defined, certain fishes dominate each region, and can be considered indicator species in the following description of fish assemblage zonation in central Nepal.

1. *Schizothorax richardsoni* zone: In the trans-Himalaya region, up to and including fourth-order waters, I collected only one species, namely *Schizothorax richardsoni*, a stenothermal cyprinid having a ventral mouth surrounded by a sucker-like disk used to cling to the substrate in torrential waters (Edds 1986). In the mountains, *S. richardsoni* remained by far the most common fish species, both in terms of frequency of occurrence and number of individuals. However, I also found *Euchiloglanis hodgarti* and *Noemacheilus rupecula*, both of which possess anatomical and behavioral adaptations to torrents. Thus, the stretch of the river upstream from the fifth-order portion, and including both the mountain and trans-Himalayan regions, can be called the *Schizothorax richardsoni* zone, after its most common member, which dominates both riffle and pool/run mesohabitats.

2. *Schizothorax progastus* zone: In the fifth-order portion of the Kali Gandaki/Narayani, *S. richardsoni* is gradually replaced by its congener *S. progastus*, a species having a suckerless, terminal mouth and a terete, streamlined body which aids in exploitation of the water column in the less torrential waters it inhabits. *S. progastus* inhabits both pool/run and riffle mesohabitats,

and is the most frequently encountered species in the high hills (Table 11). The cyprinids Barilius bendelisis and B. vagra also commonly occur in pools and runs of this zone, as well as in the riffle mesohabitat with Noemacheilus shebbearei, N. rupecula, and Euchiloglanis hodgarti.

3. Barilius vagra zone: The low hills fish assemblage is dominated by several laterally compressed species of cyprinids whose body shape presumably facilitates swimming in deeper, slower waters. B. vagra is by far the most common fish in the low hills, and the only species that occurred in every collection I made in a region. It is the most common species in the pool/run mesohabitat, along with B. bendelisis, B. shacra and the loach Noemacheilus corica. B. vagra is also the most common fish species in low hill riffles, along with Glyptothorax pectinopterus, B bendelisis, Noemacheilus scaturigina and N. rupecula.

4. Barilius barna zone: Barilius barna is the most abundant fish species in the lowlands, along with its congeners B. bendelisis, B. shacra and B. vagra. However, many other fishes are also common in this area of broad slow waters and diverse microhabitats. Besides these four barils, this zone is also characterized by the following fishes all of which occurred in at least 50% of my lowland collections: two cyprinid detritivores Aspidoparia jaya

and *A. morar*, two omnivorous cyprinids, *Chagunius chagunio* and *Puntius conchonius*, the carnivorous homalopterid *Noemacheilus corica* and the belonid predator *Xenentodon cancila*. The lowland riffle mesohabitat also supports a great number of species, including *Barilius bendelisis*, and the loaches *Botia lohachata*, *Noemacheilus scaturigina*, *N. corica* and *N. rupecula*.

## Comparison with studies from other areas

Fish species distribution in the Kali Gandaki/Narayani differs somewhat from that reported in the other Himalayan studies mentioned above. Both Hutchinson (1939) and Jhingran and Sehgal (1978) noted that headwaters on the southern slopes of the Western Himalaya were inhabited by rheophilic noemacheiline loaches. In contrast, my extensive sampling revealed no loaches above the fourth-order mountain region of the Kali Gandaki. The longitudinal pattern of fish species distribution in the Kali Gandaki River roughly corresponds to the morphological/behavioral categories described by Menon (1954). Although Menon's classification was not necessarily meant to describe zonation, his general categories parallel many of the fish assemblages in this river. Dominance of upstream areas by a schizothoracine rather than by noemacheiline rheophiles may be due in part to zoogeographic factors. While the great majority of Himalayan fish genera dispersed from the Oriental realm after the early Tertiary upheavals that created these mountains, many Central Asiatic Schizothoracinae were able to populate trans-Himalayan rivers like the Kali Gandaki during interglacial periods of the Pleistocene (Menon 1954, 1955).

Moyle and Herbold (1987) concluded that Pleistocene events also played a large role in structuring fish assemblages in Europe and eastern and western North America. These investigators found the fish faunas of Europe and western North America more similar to each other than to those of eastern North America in terms of various life history characteristics, and attributed this in part to the harsh conditions of the Ice Age. In northern parts of Europe and western North America, drainages were covered with continental glaciers, and southern portions of these areas experienced extremely adverse conditions. However, in eastern North America, fishes found refuge in the vast Mississippi-Missouri River drainage. For the fishes of Nepal, the extensive Ganges River drainage could have provided similar refuge, resulting in the present-day fish fauna which is more similar to that of eastern North America than to western North America or Europe in terms of species richness, body size, reproductive traits, migratory patterns and trophic specialization.

The structure of headwater fish assemblages is much the same in Europe, northern Asia, eastern North America, and western North America (Moyle and Herbold 1987). This is the "Trout Zone" of Huet (1949, 1959), the exact composition of which varies from place to place. Assemblage structure in the Schizothorax richardsoni zone of the Kali Gandaki bears some resemblance to that of other mountain fish communities (Hutchinson 1939, Burton and Odum 1945, Moyle and Herbold 1987). In North America, this zone is generally inhabited by trout (Salmonidae), sculpins (Cottidae), suckers (Catostomidae) and dace (Cyprinidae); in northern Europe by trout, sculpins, loaches, (Homalopteridae, mainly Noemacheilus) and minnows (Cyprinidae). In this zone of the Central Himalaya, comparable ecological equivalents can be found, including the "snow trout" Schizothorax (Cyprinidae), Euchiloglanis (Sisoridae, morphologically similar in general aspect to sculpins), Noemacheilus and drift-feeding cyprinids (Barilius).

While humans have long recognized that fishes inhabit different zones along the length of rivers and streams, the search for a universal classification scheme has proved unfruitful, perhaps sometimes even misguided. The general scheme proposed by Illies (1961) is, however, the most widely applicable, and can be compared to the zones described in the Kali Gandaki/Narayani. The rhithron, or the portion from the headwaters downstream to the point where mean monthly temperature reaches 20 degrees Celsius (Illies 1961) is represented in the Kali Gandaki from first-order streams down to where it changes to a sixth-order stream (Ridi Bazar); downstream from that point, the river can be characterized as potamon. Such a division of the Kali Gandaki/Narayani corresponds to the break between high hills and low hills and between the *Schizothorax progastus* and *Barilius vagra* zones as well as between fifth-order and sixth-order portions.

Illies and Botosaneanu (1963) added a headwater zone, the crenon, and further divided the rhithron and potamon into epi-, meta-, and hypo- zones. In the Kali Gandaki/Narayani the crenon consists of the fishless first- and second-order headwater streams, while the epirhithron corresponds to the trans-Himalaya region, the metarhithron to the remainder of the *Schizothorax richardsoni* mountain zone, and the hyporhithron to the fifth-order *Schizothorax progastus* zone. The epipotamon is the sixth-order *Barilius vagra* zone, the metapotamon is the seventh-order lowland composite zone, and the hypopotamon likely lies in northern India, upstream from the river's confluence with the Ganges.

## Comparison of analytical methods

The ordinations produced by direct and indirect gradient analyses yielded essentially the same interpretations and conclusions. That is, geographic, water quality, and factors of stream hydraulics such as current speed, stream depth and substrate type are the major abiotic factors influencing fish assemblage structure in the Kali Gandaki/Narayani River. Seasonal changes have a substantial, but secondary effect.

Exclusion of the distinctive mountain samples does not fundamentally alter the main patterns of correspondence between measured environmental parameters and fish species distribution. Rather, it allows a closer examination of the overlap of ordination scores between high hills, low hills and lowland zones. Removal of mountain samples leads to minor differences in correlations between ordination scores and environmental parameters as well as the regressions predicting axis scores, but does not change interpretation of the major abiotic factors affecting fish assemblage structure in the Kali Gandaki/Narayani.

DCCA performed as well or better than DCA in obtaining an effective ordination. The DCCA species-environment biplot simultaneously displays environmental vectors on the ordinations along with sites and species. This provides a diagrammatic view of associations between species abundances and environmental variables. The biplot provides not only an indication of how community composition changes, but also how selected species vary along the environmental gradients. Thus, direct gradient analysis simplifies interpretation of species-environment relationships, compared to the two-step process of indirect gradient analysis which requires an initial ordination and subsequent correlation and multiple regression analyses.

CANOCO also facilitates significance testing. The Monte Carlo test expedites analysis of the cumulative effects of measured environmental variables on assemblage structure by testing overall significance of the ordination. CANOCO also performs Monte Carlo tests of significance on individual axes. The program allows the investigator to partial out the effects of particular environmental variables (including extracted axes) to consider the residual variation in the species data.

DCA from DECORANA, which uses a detrending by segments algorithm, produced a systematic relation between axes 1 and 3, 1 and 4, and 3 and 4. Though the correlation coefficient between axes was small (absolute value of $r$ = 0.206 - 0.273), it was nevertheless significant ($P$ = 0.0007 - 0.0116). CANOCO's DCA, with the detrending by polynomials option produced uncorrelated axes; thus this method rectifies at least some of the suggested imperfections of DCA (c.f., Wartenberg et al. 1987, Peet et al. 1988).

Comparison of the results of direct and indirect gradient analysis allows further examination of the effects of measured environmental variables on assemblage composition. If conclusions drawn from the two techniques are divergent, then the measured environmental parameters account for less conspicuous directions of variation in the assemblage data or they account for no variation at all. However, if conclusions are in agreement then the measured environmental variables are sufficient to explain much of the variation in assemblage structure (Ter Braak 1986). The high degree of similarity between results of the two methods in my analysis probably would not occur in analyses of regions showing less extreme physiographic differences from headwaters to tailwaters. Such congruence testifies to the profound influence exhibited on the fish assemblage of the Kali Gandaki/Narayani by the physiochemical factors associated with the extreme environmental gradients in a river system draining the highest mountain range on Earth.

# TABLES

## TABLE 1

### CORRELATION COEFFICIENTS (r) BETWEEN ENVIRONMENTAL FACTORS AND DCA AXES (n = 148). EIGENVALUES OF AXES ARE GIVEN IN PARENTHESES[a].

| Environmental Factor | DCA 1 (.761) | DCA 2 (.221) | DCA 3 (.186) |
|---|---|---|---|
| Geography | | | |
| Altitude | .853**** | .000 | -.124 |
| Stream gradient | .875**** | .081 | .022 |
| River kilometer | -.786**** | -.052 | .097 |
| Stream order | -.867**** | -.074 | .015 |
| Stream width | -.662**** | -.077 | -.123 |
| Natural region | -.832**** | -.050 | .080 |
| Geology | -.787**** | .054 | .037 |
| Water Quality | | | |
| Dissolved oxygen | -.290*** | .321**** | -.065 |
| Dissolved $CO_2$ | .097 | -.026 | .107 |
| pH | -.134 | .157 | .121 |
| Total acidity | .174* | .040 | .028 |
| Total alkalinity | .471**** | .044 | .067 |
| Total hardness | .657**** | .067 | .000 |
| Temperature | -.452**** | -.369**** | .106 |
| Water clarity | -.430**** | .410**** | .050 |
| Current speed | .375**** | -.137 | .272*** |
| Stream depth | -.536**** | .025 | .122 |
| Seasonal | | | |
| Season | .304*** | -.481**** | .062 |

TABLE 1 (continued)

| Environmental Factor | DCA 1 (.761) | DCA 2 (.221) | DCA 3 (.186) |
|---|---|---|---|
| Substrate | | | |
| Dominant substrate | .404**** | .025 | .191* |
| Number types substrate | .224** | .012 | −.122 |
| Percent mud | −.410**** | .239** | .033 |
| Percent sand | −.334**** | −.121 | −.174* |
| Percent gravel | .460**** | −.130 | .010 |
| Percent stone | .332**** | −.091 | −.019 |
| Percent rubble | .145 | .069 | −.146 |
| Percent boulder | .559**** | .134 | −.161* |
| Vegetation (veg.) | | | |
| Dominant vegetation | .129 | −.039 | −.043 |
| Number vegetation types | .004 | .130 | .189* |
| Percent cover by veg. | −.121 | .195* | .171* |
| Percent detritus | −.090 | .092 | −.081 |
| Percent filamentous algae | .167* | .268*** | .179* |
| Percent submerged veg. | −.171* | .196* | .100 |
| Percent emergent veg. | .030 | −.193* | −.080 |
| Percent debris | .275*** | .230** | .153 |

[a] Correlation coefficient significant at * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$.

## TABLE 2

## RESULTS OF STEPWISE MULTIPLE REGRESSION ANALYSIS OF ENVIRONMENTAL VARIABLES ON DCA AXES (n = 148).

| Variables in Model | Partial $R^2$ | P | Model $R^2$ |
|---|---|---|---|
| DCA 1 | | | |
| Stream gradient | .766 | .0001 | .766 |
| Geology | .109 | .0001 | .875 |
| River kilometer | .027 | .0001 | .902 |
| Stream width | .013 | .0001 | .915 |
| Total hardness | .006 | .0047 | .921 |
| Altitude | .005 | .0071 | .926 |
| Percent debris | .003 | .0094 | .929 |
| DCA 2 | | | |
| Season | .231 | .0001 | .231 |
| Submerged vegetation | .051 | .0016 | .282 |
| Stream width | .031 | .0046 | .313 |
| Percent boulder | .027 | .0122 | .340 |
| Number vegetation types | .024 | .0098 | .364 |
| Percent debris | .023 | .0235 | .387 |
| Water clarity | .018 | .0378 | .405 |
| Total hardness | .018 | .0372 | .423 |
| Stream order | .018 | .0359 | .441 |
| Percent filamentous algae | .014 | .0546 | .455 |
| Percent mud | .008 | .1269 | .463 |

TABLE 2 (continued)

| Variables in Model | Partial $R^2$ | P | Model $R^2$ |
|---|---|---|---|
| | DCA 3 | | |
| Stream width | .079 | .0002 | .079 |
| Current speed | .074 | .0008 | .153 |
| Altitude | .062 | .0015 | .215 |
| Geology | .050 | .0019 | .265 |
| Percent debris | .035 | .0039 | .300 |
| Stream depth | .034 | .0053 | .334 |
| Percent sand | .034 | .0119 | .368 |
| Percent stone | .032 | .0100 | .400 |
| Percent mud | .030 | .0110 | .430 |
| Percent boulder | .016 | .0692 | .446 |

# TABLE 3

CORRELATION COEFFICIENTS BETWEEN ENVIRONMENTAL FACTORS AND DCA AXES WITHOUT MOUNTAIN SAMPLES (n=120). EIGENVALUES OF AXES ARE GIVEN IN PARENTHESES[a].

| Environmental Factor | DCA 1 (.423) | DCA 2 (.197) | DCA 3 (.135) |
|---|---|---|---|
| Geography | | | |
| Altitude | .817**** | -.233* | .029 |
| Stream gradient | .790**** | -.020 | -.016 |
| River kilometer | -.868**** | .182* | -.048 |
| Stream order | -.864**** | .059 | -.077 |
| Stream width | -.672**** | -.065 | -.055 |
| Natural region | -.706**** | .208* | -.069 |
| Geology | -.811**** | .029 | -.009 |
| Water Quality | | | |
| Dissolved oxygen | .010 | -.233* | -.202* |
| Dissolved $CO_2$ | .023 | .094 | .132 |
| pH | -.110 | .042 | .001 |
| Total acidity | .097 | -.017 | -.136 |
| Total alkalinity | .284** | .002 | .079 |
| Total hardness | .149 | -.095 | .119 |
| Temperature | -.593**** | .297*** | .207* |
| Water clarity | -.139 | -.195* | .043 |
| Current speed | .330*** | .346**** | .206* |
| Stream depth | -.174 | .169 | -.114 |
| Seasonal | | | |
| Season | -.115 | .332*** | .022 |

TABLE 3 (continued)

| Environmental Factors | DCA 1 (.423) | DCA 2 (.197) | DCA 3 (.135) |
|---|---|---|---|
| Substrate | | | |
| Dominant substrate | .443**** | .141 | .098 |
| Number types substrate | .303*** | -.159 | .072 |
| Percent mud | -.348**** | -.064 | -.004 |
| Percent sand | -.128 | -.099 | -.155 |
| Percent gravel | .316*** | .073 | .189* |
| Percent stone | .220* | -.025 | .071 |
| Percent rubble | .346**** | .111 | .145 |
| Percent boulder | .401**** | -.282** | -.065 |
| Vegetation (veg.) | | | |
| Dominant vegetation | -.080 | .031 | .098 |
| Number vegetation types | -.362**** | .132 | .283 ** |
| Percent cover by veg. | -.445**** | .062 | .193* |
| Percent detritus | -.064 | -.138 | .401**** |
| Percent filamentous algae | -.255** | -.002 | .103 |
| Percent submerged veg. | -.451**** | .032 | .081 |
| Percent emergent veg. | -.160 | .062 | .048 |
| Percent debris | -.157 | .117 | .117 |

[a] Correlation coefficient (r) is significant at * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$.

## TABLE 4

## RESULTS OF STEPWISE MULTIPLE REGRESSION ANALYSIS OF ENVIRONMENTAL VARIABLES ON DCA AXES WITHOUT MOUNTAIN SAMPLES (n = 120).

| Variables in Model | Partial $R^2$ | P | Model $R^2$ |
|---|---|---|---|
| DCA 1 | | | |
| River kilometer | .754 | .0001 | .754 |
| Stream order | .055 | .0001 | .809 |
| Natural region | .032 | .0001 | .841 |
| Percent submerged vegetation | .019 | .0001 | .860 |
| Percent filamentous algae | .007 | .0124 | .867 |
| Temperature | .007 | .0183 | .874 |
| Percent debris | .006 | .0272 | .880 |
| Percent boulder | .005 | .0276 | .885 |
| DCA 2 | | | |
| Season | .120 | .0001 | .120 |
| Current speed | .120 | .0001 | .240 |
| Altitude | .119 | .0001 | .359 |
| Stream width | .054 | .0037 | .413 |
| Percent mud | .050 | .0008 | .463 |
| Percent stone | .038 | .0022 | .501 |
| Stream depth | .036 | .0060 | .537 |
| Percent sand | .036 | .0071 | .573 |
| Percent boulder | .022 | .0155 | .595 |
| Geology | .021 | .0171 | .616 |

TABLE 4 (continued)

| Variables in Model | Partial $R^2$ | P | Model $R^2$ |
|---|---|---|---|
| DCA 3 | | | |
| Percent detritus | .161 | .0001 | .161 |
| Current speed | .087 | .0003 | .248 |
| Number vegetation types | .049 | .0054 | .297 |
| Percent gravel | .039 | .0111 | .336 |
| Season | .027 | .0270 | .363 |
| Temperature | .026 | .0347 | .389 |

## TABLE 5

## INTRA-SET CORRELATION COEFFICIENTS (r) BETWEEN ENVIRONMENTAL VARIABLES AND DCCA AXES (n = 148). EIGENVALUES OF AXES ARE GIVEN IN PARENTHESES[a].

| Environmental Factor | DCCA 1 (.684) | DCCA 2 (.153) | DCCA 3 (.084) |
|---|---|---|---|
| Geography | | | |
| Altitude | .733**** | −.118 | .097 |
| Stream gradient | .945**** | −.030 | −.007 |
| River kilometer | −.686**** | .119 | −.097 |
| Stream order | −.805**** | .045 | .036 |
| Stream width | −.519**** | −.085 | −.197* |
| Natural region | −.691**** | .126 | −.084 |
| Geology | −.700**** | −.061 | −.023 |
| Water Quality | | | |
| Dissolved oxygen | −.129 | −.528**** | −.202* |
| Dissolved $CO_2$ | .100 | .138 | .103 |
| pH | −.102 | −.066 | .104 |
| Total acidity | .228** | −.098 | −.052 |
| Total alkalinity | .329**** | −.103 | .223** |
| Total hardness | .448**** | −.137 | .145 |
| Temperature | −.372**** | .619**** | .166* |
| Water clarity | −.251** | −.459**** | .073 |
| Current speed | .305*** | .388**** | .045 |
| Stream depth | −.428**** | .133 | −.252** |
| Seasonal | | | |
| Season | .124 | .641**** | −.142 |

TABLE 5 (continued)

| Environmental Factor | DCCA 1 (.684) | DCCA 2 (.153) | DCCA 3 (.084) |
|---|---|---|---|
| Substrate | | | |
| Dominant substrate | .357**** | .116 | .079 |
| Number types substrate | .180* | -.211** | -.103 |
| Percent mud | -.299*** | -.308*** | -.028 |
| Percent sand | -.258** | .125 | -.069 |
| Percent gravel | .349**** | .086 | .022 |
| Percent stone | .244** | -.071 | -.090 |
| Percent rubble | .141 | .148 | .281*** |
| Percent boulder | .515**** | -.237** | -.225** |
| Vegetation (veg.) | | | |
| Dominant vegetation | .027 | .013 | .061 |
| Number vegetation types | -.063 | .039 | .573**** |
| Percent cover by veg. | -.152 | -.094 | .442**** |
| Percent detritus | -.055 | -.185* | .351**** |
| Percent filamentous algae | -.121 | -.171* | .430**** |
| Percent submerged veg. | -.190* | -.057 | .339**** |
| Percent emergent veg. | -.011 | .177* | -.122 |
| Percent debris | .127 | -.205* | .265** |

[a] Correlation coefficient significant at * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$.

# TABLE 6

RESULTS OF WEIGHTED MULTIPLE REGRESSION ANALYSIS SHOWING ENVIRONMENTAL VARIABLES EXPLAINING THE GREATEST PORTION OF VARIANCE IN THE SPECIES DATA, ORDINATED BY DCCA, WITH STUDENT'S t-VALUE FOR SIGNIFICANCE TESTS OF CANONICAL COEFFICIENTS (TER BRAAK 1988a) (n = 148).

| Variables in Model | t | P < |
|---|---|---|
| DCCA 1 | | |
| Stream gradient | 9.55 | .0001 |
| River kilometer | 5.11 | .0001 |
| Altitude | 4.38 | .0001 |
| Geology | 2.20 | .025 |
| DCCA 2 | | |
| Stream width | 4.38 | .0001 |
| Percent submerged vegetation | 3.97 | .0001 |
| Temperature | 3.05 | .005 |
| Geology | 2.88 | .005 |
| River kilometer | 2.79 | .005 |
| Percent filamentous algae | 2.72 | .005 |
| Season | 2.55 | .01 |
| Stream order | 2.55 | .01 |
| Dissolved $CO_2$ | 2.50 | .01 |
| Stream gradient | 2.32 | .025 |
| Percent debris | 2.24 | .025 |

TABLE 6 (continued)

| Variables in Model | t | P < |
|---|---|---|
| DCCA 3 | | |
| Percent detritus | 4.27 | .0001 |
| Percent stone | 3.55 | .0005 |
| Number vegetation types | 3.46 | .0005 |
| Percent filamentous algae | 3.37 | .0005 |
| Temperature | 3.15 | .005 |
| Percent mud | 3.02 | .005 |
| Percent submerged vegetation | 2.89 | .005 |
| Stream order | 2.87 | .005 |
| Season | 2.83 | .005 |
| Natural region | 2.39 | .01 |
| Percent cover by vegetation | 2.30 | .025 |
| Percent sand | 2.21 | .025 |

# TABLE 7

## INTRA-SET CORRELATION COEFFICIENTS (r) BETWEEN ENVIRONMENTAL VARIABLES AND DCCA AXES, WITHOUT MOUNTAIN SAMPLES (n = 120). EIGENVALUES OF AXES ARE GIVEN IN PARENTHESES[a].

| Environmental Factor | DCCA 1 (.386) | DCCA 2 (.145) | DCCA 3 (.068) |
|---|---|---|---|
| Geography | | | |
| Altitude | .784**** | -.205* | -.012 |
| Stream gradient | .818**** | .037 | -.051 |
| River kilometer | -.866**** | .144 | -.023 |
| Stream order | -.881**** | -.027 | -.055 |
| Stream width | -.620**** | -.184* | -.278** |
| Natural region | -.711**** | .161 | .021 |
| Geology | -.805**** | -.087 | -.006 |
| Water Quality | | | |
| Dissolved oxygen | -.001 | -.493**** | -.166 |
| Dissolved $CO_2$ | .027 | .014 | .112 |
| pH | -.103 | .212* | .179* |
| Total acidity | .096 | -.069 | -.070 |
| Total alkalinity | .301*** | -.086 | .074 |
| Total hardness | .145 | -.162 | .270** |
| Temperature | -.551**** | .529**** | .138 |
| Water clarity | -.151 | -.365**** | .196** |
| Current speed | .434**** | .410**** | -.056 |
| Stream depth | .221**** | .156 | -.242** |
| Seasonal | | | |
| Season | -.100 | .541**** | -.236** |

TABLE 7 (continued)

| Environmental factor | DCCA 1 (.386) | DCCA 2 (.145) | DCCA 3 (.068) |
|---|---|---|---|
| Substrate | | | |
| Dominant substrate | .450**** | .148 | .065 |
| Number types substrate | .278** | -.259** | -.044 |
| Percent mud | -.326*** | -.235** | .089 |
| Percent sand | -.237** | .092 | .005 |
| Percent gravel | .353**** | .087 | .055 |
| Percent stone | .251** | -.132 | -.097 |
| Percent rubble | .380**** | .134 | .199* |
| Percent boulder | .378**** | -.352**** | -.256** |
| Vegetation (veg.) | | | |
| Dominant vegetation | -.143 | -.008 | .132 |
| Number vegetation types | -.386**** | .114 | .446**** |
| Percent cover by veg. | -.435**** | -.001 | .374**** |
| Percent detritus | -.019 | -.183* | .677**** |
| Percent filamentous algae | -.206* | -.062 | .196* |
| Percent submerged veg. | -.461**** | .083 | .148 |
| Percent emergent veg. | -.166 | .090 | -.049 |
| Percent debris | -.160 | -.027 | .107 |

[a] Correlation coefficient significant at * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, **** $P < 0.0001$.

## TABLE 8

## RESULTS OF WEIGHTED MULTIPLE REGRESSION ANALYSIS SHOWING ENVIRONMENTAL VARIABLES EXPLAINING THE GREATEST PORTION OF VARIANCE IN THE SPECIES DATA WITHOUT MOUNTAIN SAMPLES, ORDINATED BY DCCA, WITH STUDENT'S t-VALUE FOR SIGNIFICANCE TESTS OF CANONICAL COEFFICIENTS (TER BRAAK 1988a) (n = 120).

| Variables in Model | t | P < |
|---|---|---|
| DCCA 1 | | |
| River kilometer | 5.07 | .0005 |
| Stream order | 4.65 | .0005 |
| Natural region | 3.23 | .001 |
| Percent submerged vegetation | 2.46 | .01 |
| Temperature | 2.37 | .01 |
| Dominant substrate | 2.36 | .01 |
| Geology | 2.18 | .025 |
| DCCA 2 | | |
| Stream width | 4.33 | .0005 |
| Stream depth | 3.43 | .0005 |
| Percent sand | 3.20 | .001 |
| Percent mud | 2.70 | .005 |
| Percent stone | 2.64 | .005 |
| Season | 2.44 | .01 |
| Current speed | 2.23 | .025 |

TABLE 8 (continued)

| Variables in Model | t | P < |
|---|---|---|
| DCCA 3 | | |
| Percent detritus | 5.54 | .0005 |
| Number vegetation types | 3.63 | .0005 |
| Temperature | 3.34 | .001 |
| Season | 2.93 | .005 |

# TABLE 9

RESULTS OF DCA AND DCCA FOR FISH SPECIES AND ENVIRONMENTAL DATA INCLUDING AND EXCLUDING MOUNTAIN SAMPLES: EIGENVALUES, SPECIES-ENVIRONMENT CORRELATION COEFFICIENTS, AND FRACTION OF TOTAL VARIANCE ACCOUNTED FOR BY THE FIRST s AXES, WHERE s = 1,2,3. SUM OF ALL CANONICAL EIGENVALUES (TRACE) = 2.015 FOR WITH AND 1.352 FOR WITHOUT MOUNTAINS.

| | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| | | <u>With mountains</u> | |
| | | Eigenvalues | |
| DCA | 0.761 | 0.221 | 0.186 |
| DCAA | 0.684 | 0.153 | 0.084 |
| | | Correlation coefficients | |
| DCA | 0.944 | 0.827 | 0.786 |
| DCCA | 0.951 | 0.874 | 0.777 |
| | | Fraction of variance accounted for | |
| DCA | 0.336 | 0.412 | 0.469 |
| DCCA | 0.339 | 0.416 | 0.457 |

TABLE 9 (continued)

| | Axis 1 | Axis 2 | Axis 3 |
|---|---|---|---|
| | Without mountains | | |
| | Eigenvalues | | |
| DCA | 0.423 | 0.197 | 0.135 |
| DCAA | 0.386 | 0.145 | 0.068 |
| | Correlation coefficients | | |
| DCA | 0.948 | 0.829 | 0.712 |
| DCCA | 0.959 | 0.884 | 0.790 |
| | Fraction of variance accounted for | | |
| DCA | 0.282 | 0.382 | 0.432 |
| DCCA | 0.285 | 0.392 | 0.443 |

## TABLE 10

MOUNTAIN FISH SPECIES DISTRIBUTION IN RIFFLE (n = 17) AND POOL/RUN (n = 11) HABITATS, SHOWING PERCENT FREQUENCY OF OCCURRENCE, RANGE (IN PARENTHESES) AND MEAN ± 1 SD OF CODED ABUNDANCE OF SPECIES OCCURRING IN AT LEAST 5% OF ALL COLLECTIONS, WHERE 0 = NONE, 1 = 1-5, 2 = 6-10, 3 = 11-20, AND 4 = > 20 INDIVIDUALS.

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Cyprinidae | | |
| <u>Schizothorax</u> <u>progastus</u> | 6 (0-1)<br>0.1 ± 0.2 | --- |
| <u>S.</u> <u>richardsoni</u> | 82 (0-4)<br>2.2 ± 1.5 | 100 (1-4)<br>3.3 ± 1.2 |
| Homalopteridae | | |
| <u>Noemacheilus</u> <u>rupecula</u> | 35 (0-4)<br>0.5 ± 0.8 | 9 (0-2)<br>0.2 ± 0.6 |
| Sisoridae | | |
| <u>Euchiloglanis</u> <u>hodgarti</u> | 71 (0-4)<br>1.5 ± 1.5 | --- |

## TABLE 11

HIGH HILLS FISH SPECIES DISTRIBUTION IN RIFFLE (n = 13) AND POOL/RUN (n = 17) HABITATS, SHOWING PERCENT FREQUENCY OF OCCURRENCE, RANGE (IN PARENTHESES) AND MEAN ± 1 SD OF CODED ABUNDANCE, AS IN TABLE 10.

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Cyprinidae | | |
| *Acrossocheilus hexagonolepis* | --- | 53 (0-3)<br>0.8 ± 1.0 |
| *Barilius bendelisis* | 38 (0-4)<br>0.8 ± 1.2 | 82 (0-4)<br>2.9 ± 1.6 |
| *B. shacra* | --- | 35 (0-4)<br>0.7 ± 1.2 |
| *B. vagra* | 31 (0-2)<br>0.4 ± 0.6 | 82 (0-4)<br>2.5 ± 1.6 |
| *Crossocheilus latius* | --- | 12 (0-1)<br>0.1 ± 0.3 |
| *Garra gotyla* | 8 (0-1)<br>0.1 ± 0.3 | 12 (0-1)<br>0.1 ± 0.3 |
| *Schizothorax progastus* | 31 (0-3)<br>0.5 ± 1.0 | 88 (0-4)<br>2.6 ± 1.5 |
| *S. richardsoni* | 8 (0-1)<br>0.1 ± 0.3 | 47 (0-3)<br>0.8 ± 1.0 |
| *Tor putitora* | --- | 18 (0-2)<br>0.2 ± 0.6 |
| *T. tor* | --- | 6 (0-1)<br>0.1 ± 0.2 |
| Homalopteridae | | |
| *Noemacheilus corica* | 8 (0-1)<br>0.1 ± 0.3 | 23 (0-1)<br>0.2 ± 0.4 |
| *N. rupecula* | 31 (0-1)<br>0.3 ± 0.5 | --- |
| *N. shebbearei* | 46 (0-4)<br>1.4 ± 1.7 | 6 (0-1)<br>0.1 ± 0.2 |

TABLE 11 (continued)

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Sisoridae | | |
| *Euchiloglanis hodgarti* | 38 (0-1)<br>0.4 ± 0.5 | --- |
| *Glyptothorax kashmirensis* | 8 (0-1)<br>0.1 ± 0.3 | 6 (0-1)<br>0.1 ± 0.2 |

# TABLE 12

LOW HILLS FISH SPECIES DISTRIBUTION IN RIFFLE (n = 16) AND POOL/RUN (n = 25) HABITATS, SHOWING PERCENT FREQUENCY OF OF OCCURRENCE, RANGE (IN PARENTHESES) AND MEAN ± 1 SD OF CODED ABUNDANCE, AS IN TABLE 10.

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Cyprinidae | | |
| *Acrossocheilus hexagonolepis* | --- | 16 (0-3)<br>0.2 ± 0.7 |
| *Aspidoparia jaya* | --- | 8 (0-1)<br>0.1 ± 0.3 |
| *A. morar* | --- | 8 (0-1)<br>0.1 ± 0.3 |
| *Barilius barila* | --- | tr*(0-4)<br>0.2 ± 0.8 |
| *B. barna* | 12 (0-3)<br>0.2 ± 0.8 | 44 (0-4)<br>1.0 ± 1.5 |
| *B. bendelisis* | 38 (0-2)<br>0.5 ± 0.7 | 88 (0-4)<br>2.5 ± 1.6 |
| *B. bola* | --- | 12 (0-1)<br>0.1 ± 0.3 |
| *B. shacra* | 12 (0-1)<br>0.1 ± 0.3 | 80 (0-4)<br>2.0 ± 1.5 |
| *B. vagra* | 50 (0-3)<br>0.6 ± 0.8 | 100 (1-4)<br>2.8 ± 1.3 |
| *Chagunius chagunio* | --- | 24 (0-4)<br>0.4 ± 0.9 |
| *Crossocheilus latius* | 19 (0-1)<br>0.2 ± 0.4 | 20 (0-2)<br>0.3 ± 0.7 |
| *Garra gotyla* | 12 (0-1)<br>0.1 ± 0.3 | 16 (0-3)<br>0.2 ± 0.7 |
| *Puntius conchonius* | --- | 12 (0-2)<br>0.2 ± 0.5 |

TABLE 12 (continued)

| | SPECIES | RIFFLE | POOL/RUN |
|---|---|---|---|
| | *Schizothorax progastus* | 6 (0-1)<br>0.1 ± 0.2 | 32 (0-4)<br>0.8 ± 1.5 |
| | *S. richardsoni* | 6 (0-1)<br>0.1 ± 0.2 | 8 (0-1)<br>0.1 ± 0.3 |
| | *Semiplotus semiplotus* | --- | 20 (0-3)<br>0.3 ± 0.7 |
| | *Tor putitora* | --- | 20 (0-4)<br>0.5 ± 1.0 |
| | *T. tor* | --- | 20 (0-3)<br>0.4 ± 0.9 |
| Cobitidae | | | |
| | *Botia lohachata* | 19 (0-1)<br>0.2 ± 0.4 | 8 (0-1)<br>0.1 ± 0.3 |
| Homalopteridae | | | |
| | *Noemacheilus beavani* | --- | 20 (0-3)<br>0.3 ± 0.7 |
| | *N. corica* | 12 (0-4)<br>0.5 ± 1.4 | 64 (0-4)<br>1.3 ± 1.4 |
| | *N. rupecula* | 31 (0-1)<br>0.3 ± 0.5 | 4 (0-1)<br>tr* ± 0.2 |
| | *N. scaturigina* | 38 (0-4)<br>0.6 ± 1.1 | 28 (0-3)<br>0.5 ± 0.9 |
| | *N. shebbearei* | 12 (0-3)<br>0.2 ± 0.8 | 8 (0-1)<br>0.1 ± 0.3 |
| Schilbeidae | | | |
| | *Clupisoma garua* | --- | 8 (0-1)<br>0.1 ± 0.3 |
| Amblycipitidae | | | |
| | *Amblyceps mangois* | 6 (0-1)<br>0.1 ± 0.2 | --- |

TABLE 12 (continued)

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Sisoridae | | |
| *Glyptothorax kashmirensis* | 19 (0-1)<br>0.2 ± 0.4 | --- |
| *G. pectinopterus* | 50 (0-2)<br>0.6 ± 0.6 | 4 (0-1)<br>tr* ± 0.2 |
| *G. trilineatus* | 6 (0-1)<br>0.1 ± 0.2 | 4 (0-1)<br>tr* ± 0.2 |
| *Pseudecheneis sulcatus* | 19 (0-1)<br>0.2 ± 0.4 | --- |
| Belonidae | | |
| *Xenentodon cancila* | --- | 4 (0-1)<br>tr* ± 0.2 |
| Mastacembelidae | | |
| *Mastacembelus armatus* | 6 (0-1)<br>0.1 ± 0.2 | --- |

tr* = trace = < 0.5%

# TABLE 13

LOWLAND FISH SPECIES DISTRIBUTION IN RIFFLE (n = 26) AND POOL/RUN (n = 62) HABITATS, SHOWING PERCENT FREQUENCY OF OCCURRENCE, RANGE (IN PARENTHESES) AND MEAN ± 1 SD OF CODED ABUNDANCE, AS IN TABLE 10.

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Cyprinidae | | |
| *Acrossocheilus hexagonolepis* | --- | 3 (0-1)<br>tr* ± 0.2 |
| *Aspidoparia jaya* | --- | 55 (0-4)<br>1.5 ± 1.7 |
| *A. morar* | 8 (0-1)<br>0.1 ± 0.3 | 56 (0-4)<br>1.1 ± 1.3 |
| *Barilius barila* | 8 (0-3)<br>0.2 ± 0.6 | 45 (0-4)<br>0.9 ± 1.3 |
| *B. barna* | 12 (0-1)<br>0.1 ± 0.3 | 84 (0-4)<br>2.6 ± 1.6 |
| *B. bendelisis* | 38 (0-3)<br>0.7 ± 1.0 | 85 (0-4)<br>2.1 ± 1.5 |
| *B. bola* | --- | 40 (0-3)<br>0.5 ± 0.7 |
| *B. shacra* | 12 (0-2)<br>0.2 ± 0.5 | 81 (0-4)<br>2.2 ± 1.5 |
| *B. tileo* | --- | 16 (0-3)<br>0.2 ± 0.5 |
| *B. vagra* | 23 (0-1)<br>0.2 ± 0.4 | 73 (0-4)<br>1.8 ± 1.6 |
| *Chagunius chagunio* | 4 (0-1)<br>tr* ± 0.2 | 69 (0-4)<br>1.8 ± 1.6 |
| *Chela cachius* | --- | 18 (0-4)<br>0.4 ± 1.0 |
| *Crossocheilus latius* | 8 (0-1)<br>0.1 ± 0.3 | 24 (0-4)<br>0.3 ± 0.7 |

TABLE 13 (continued)

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| *Danio devario* | --- | 31 (0-4)<br>0.7 ± 1.3 |
| *Esomus danricus* | --- | 16 (0-4)<br>0.4 ± 1.0 |
| *Garra gotyla* | 19 (0-4)<br>0.3 ± 0.8 | 13 (0-4)<br>0.2 ± 0.6 |
| *Labeo dero* | --- | 3 (0-1)<br>tr* ± 0.2 |
| *Osteobrama cotio* | --- | 13 (0-4)<br>0.2 ± 0.7 |
| *Puntius conchonius* | 8 (0-1)<br>0.1 ± 0.3 | 69 (0-4)<br>1.9 ± 1.7 |
| *P. guganio* | --- | 26 (0-4)<br>0.5 ± 1.1 |
| *P. sophore* | --- | 18 (0-4)<br>0.3 ± 0.7 |
| *P. ticto* | 4 (0-1)<br>tr* ± 0.2 | 35 (0-4)<br>0.7 ± 1.2 |
| *Rasbora daniconius* | --- | 19 (0-4)<br>0.4 ± 0.9 |
| *Salmostoma bacaila* | --- | 15 (0-3)<br>0.2 ± 0.5 |
| *Schizothorax progastus* | 8 (0-1)<br>0.1 ± 0.3 | 5 (0-4)<br>0.1 ± 0.5 |
| *Semiplotus semiplotus* | 4 (0-1)<br>tr* ± 0.2 | 5 (0-1)<br>tr* ± 0.2 |
| *Tor putitora* | --- | 15 (0-3)<br>0.2 ± 0.5 |
| *T. tor* | --- | 11 (0-4)<br>0.2 ± 0.7 |

TABLE 13 (continued)

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Cobitidae | | |
| *Botia lohachata* | 35 (0-4)<br>0.5 ± 0.9 | 11 (0-4)<br>0.3 ± 0.9 |
| *Lepidocephalus guntea* | 8 (0-2)<br>0.1 ± 0.4 | 19 (0-3)<br>0.3 ± 0.6 |
| Homalopteridae | | |
| *Noemacheilus beavani* | 27 (0-3)<br>0.3 ± 0.7 | 15 (0-4)<br>0.2 ± 0.6 |
| *N. botia* | 19 (0-3)<br>0.3 ± 0.7 | 35 (0-2)<br>0.4 ± 0.5 |
| *N. corica* | 35 (0-1)<br>0.3 ± 0.5 | 55 (0-4)<br>1.2 ± 1.5 |
| *N. rupecula* | 35 (0-2)<br>0.4 ± 0.6 | 3 (0-2)<br>tr* ± 0.3 |
| *N. shebbearei* | 15 (0-1)<br>0.2 ± 0.4 | --- |
| *N. scaturigina* | 42 (0-4)<br>0.7 ± 1.0 | 15 (0-4)<br>0.2 ± 0.6 |
| Schilbeidae | | |
| *Clupisoma garua* | --- | 10 (0-4)<br>0.1 ± 0.6 |
| Amblycipitidae | | |
| *Amblyceps mangois* | 19 (0-2)<br>0.2 ± 0.5 | 5 (0-1)<br>tr* ± 0.2 |

TABLE 13 (continued)

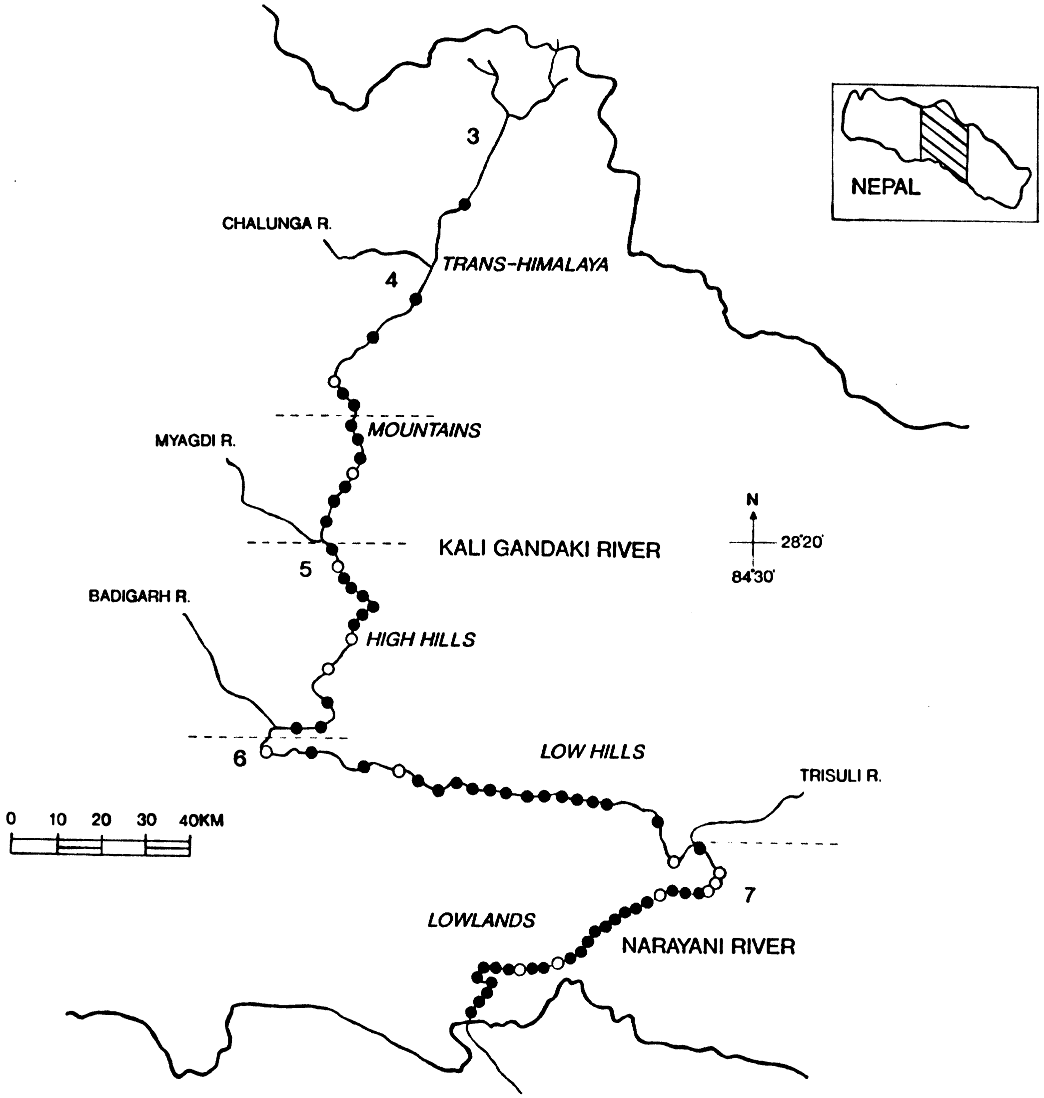
| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Sisoridae | | |
| *Glyptothorax kashmirensis* | 8 (0-1)<br>0.1 ± 0.3 | --- |
| *G. pectinopterus* | 15 (0-1)<br>0.2 ± 0.4 | --- |
| *G. telchitta* | 8 (0-1)<br>0.1 ± 0.3 | 3 (0-2)<br>tr* ± 0.3 |
| *G. trilineatus* | 12 (0-1)<br>0.1 ± 0.3 | 2 (0-1)<br>tr* ± 0.1 |
| *Pseudecheneis sulcatus* | 8 (0-1)<br>0.1 ± 0.3) | --- |
| Belonidae | | |
| *Xenentodon cancila* | --- | 50 (0-4)<br>1.0 ± 1.3 |
| Channidae | | |
| *Channa punctatus* | --- | 11 (0-1)<br>0.1 ± 0.3 |
| Chandidae | | |
| *Chanda baculis* | 4 (0-1)<br>tr* ± 0.2 | 29 (0-4)<br>0.7 ± 1.3 |
| *C. ranga* | --- | 13 (0-4)<br>0.2 ± 0.7 |
| Gobiidae | | |
| *Glossogobius giuris* | --- | 23 (0-2)<br>0.2 ± 0.5 |

TABLE 13 (continued)

| SPECIES | RIFFLE | POOL/RUN |
|---|---|---|
| Mastacembelidae | | |
| *Mastacembelus armatus* | 12 (0-2)<br>0.2 ± 0.5 | 8 (0-1)<br>0.1 ± 0.3 |
| *M. pancalus* | --- | 10 (0-2)<br>0.1 ± 0.4 |

tr* = trace = < 0.5%

# FIGURES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CHALUNGA R.
TRANS-HIMALAYA
4
MOUNTAINS
MYAGDI R.
KALI GANDAKI RIVER
N
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84°30'
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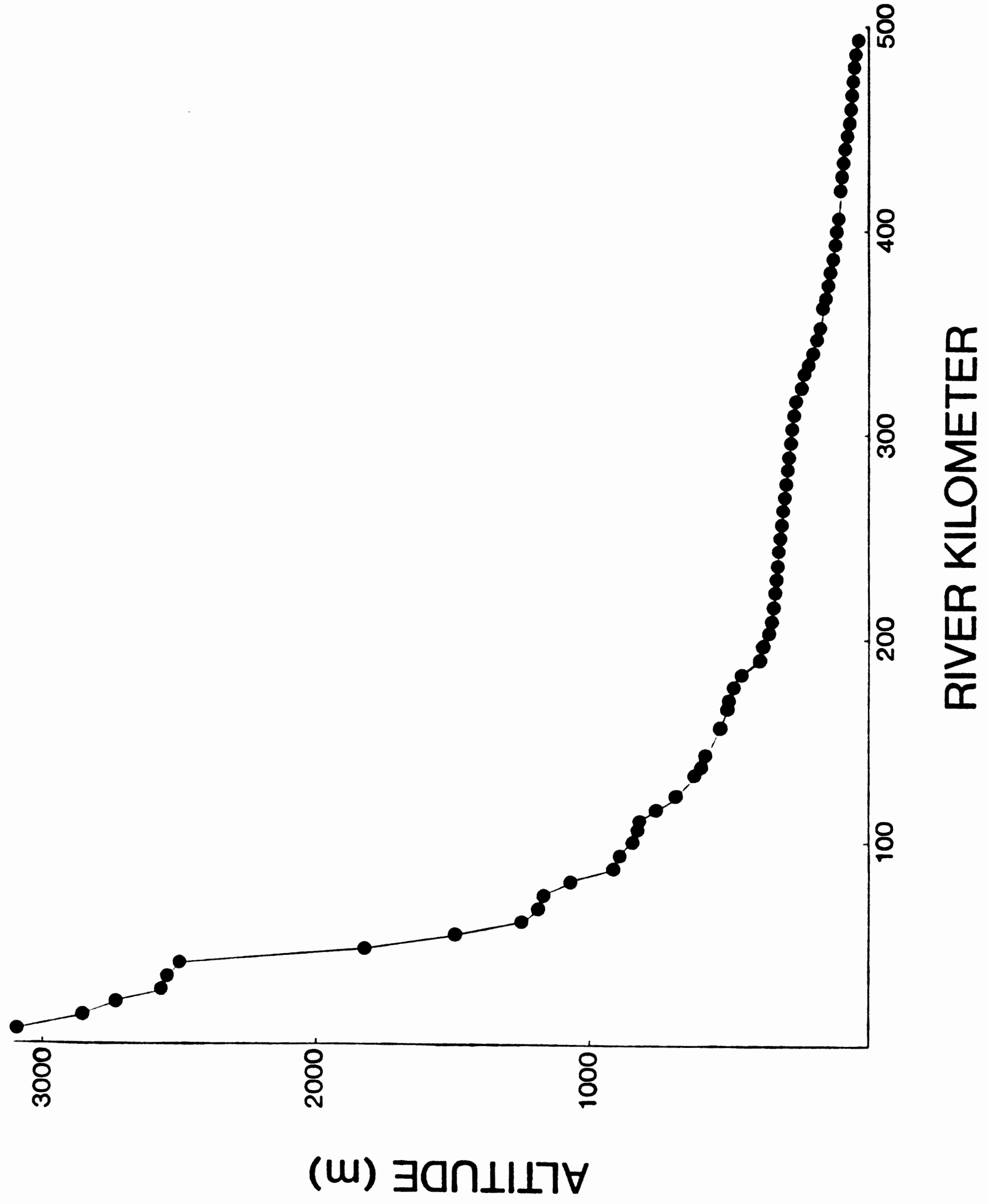
BADIGARH R.
HIGH HILLS
6
LOW HILLS
TRISULI R.
0 10 20 30 40KM
7
LOWLANDS
NARAYANI RIVER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100
200
300
400
500
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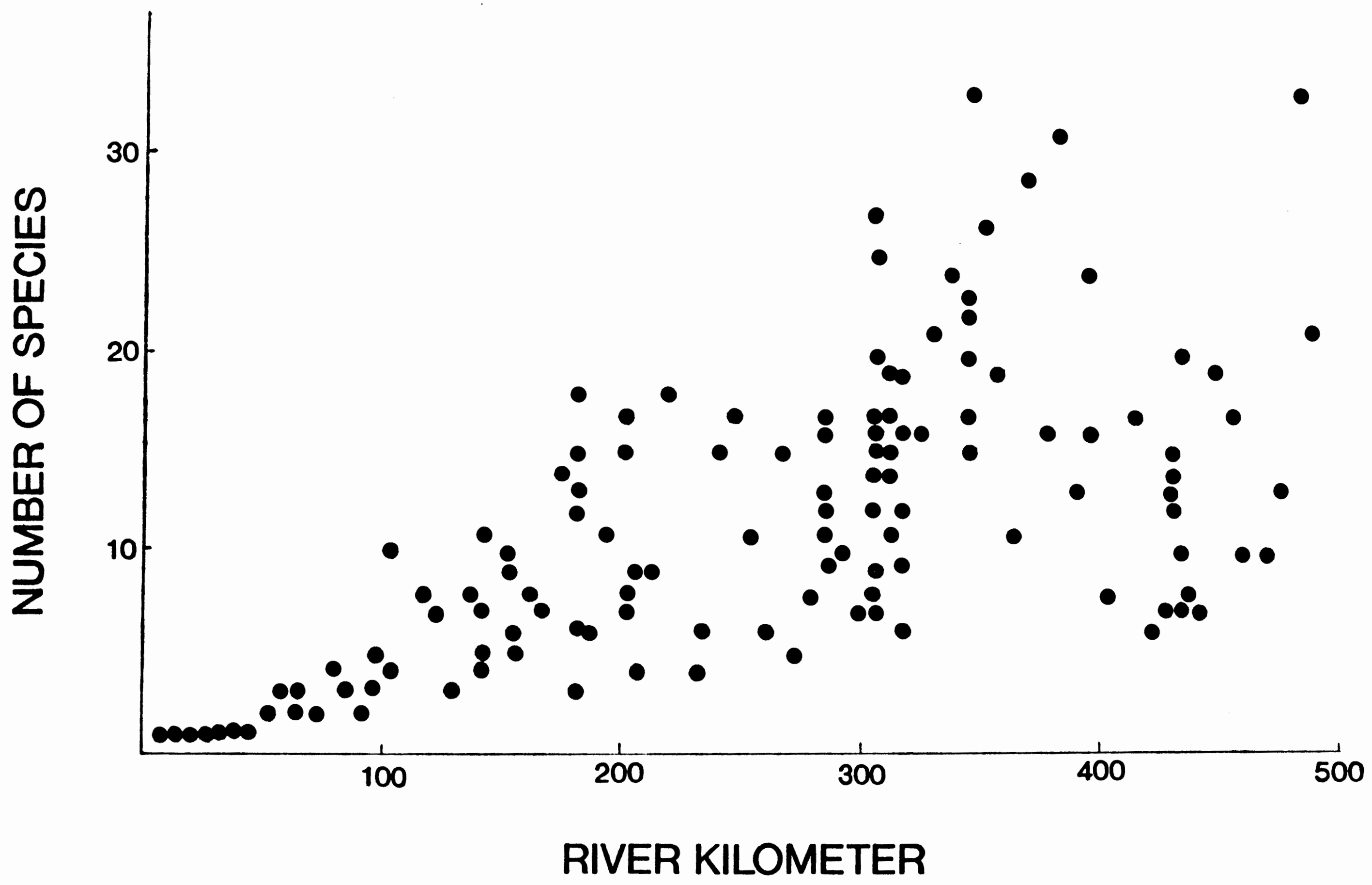
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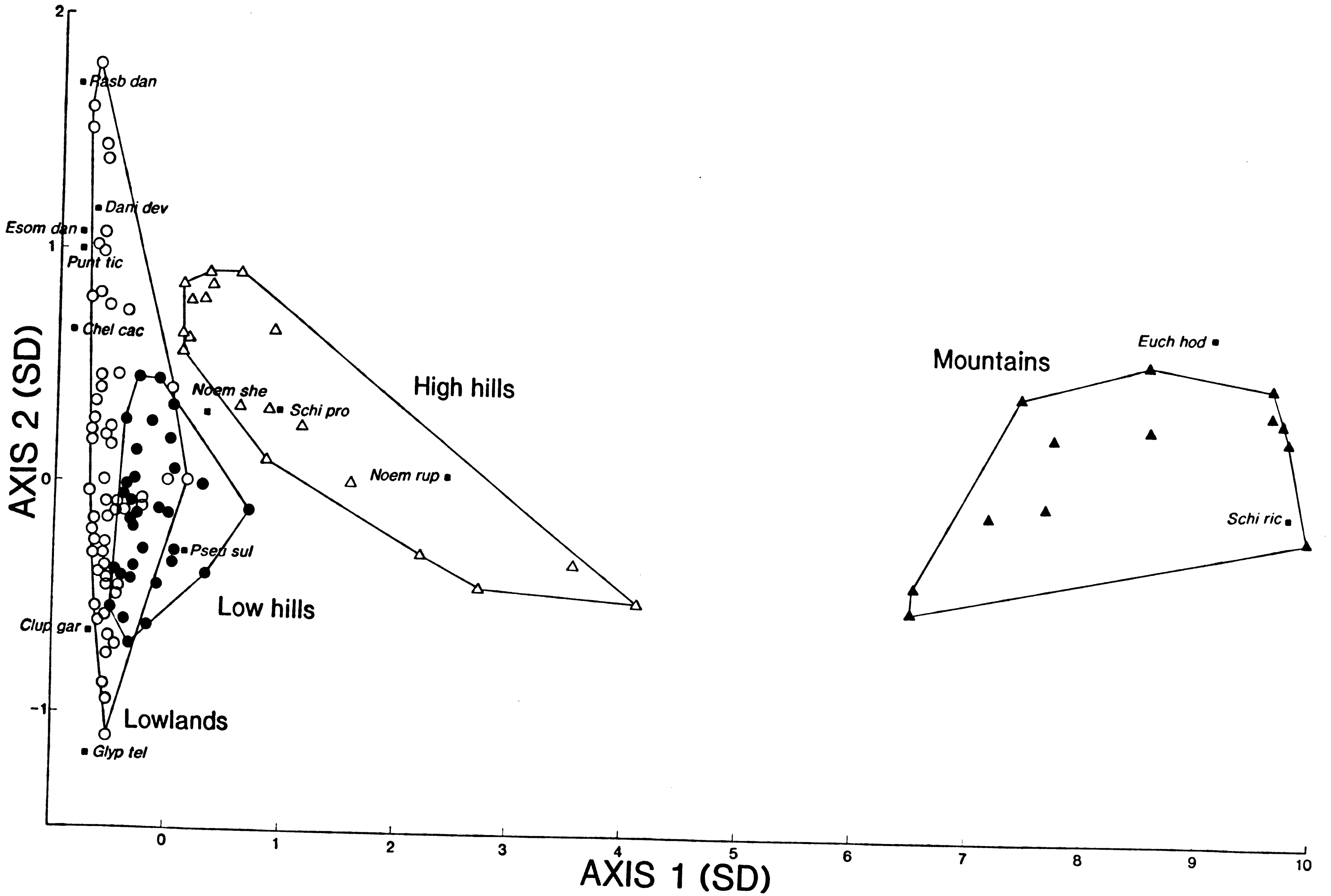
RIVER KILOMETER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AXIS 1 (SD)
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1
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1
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3
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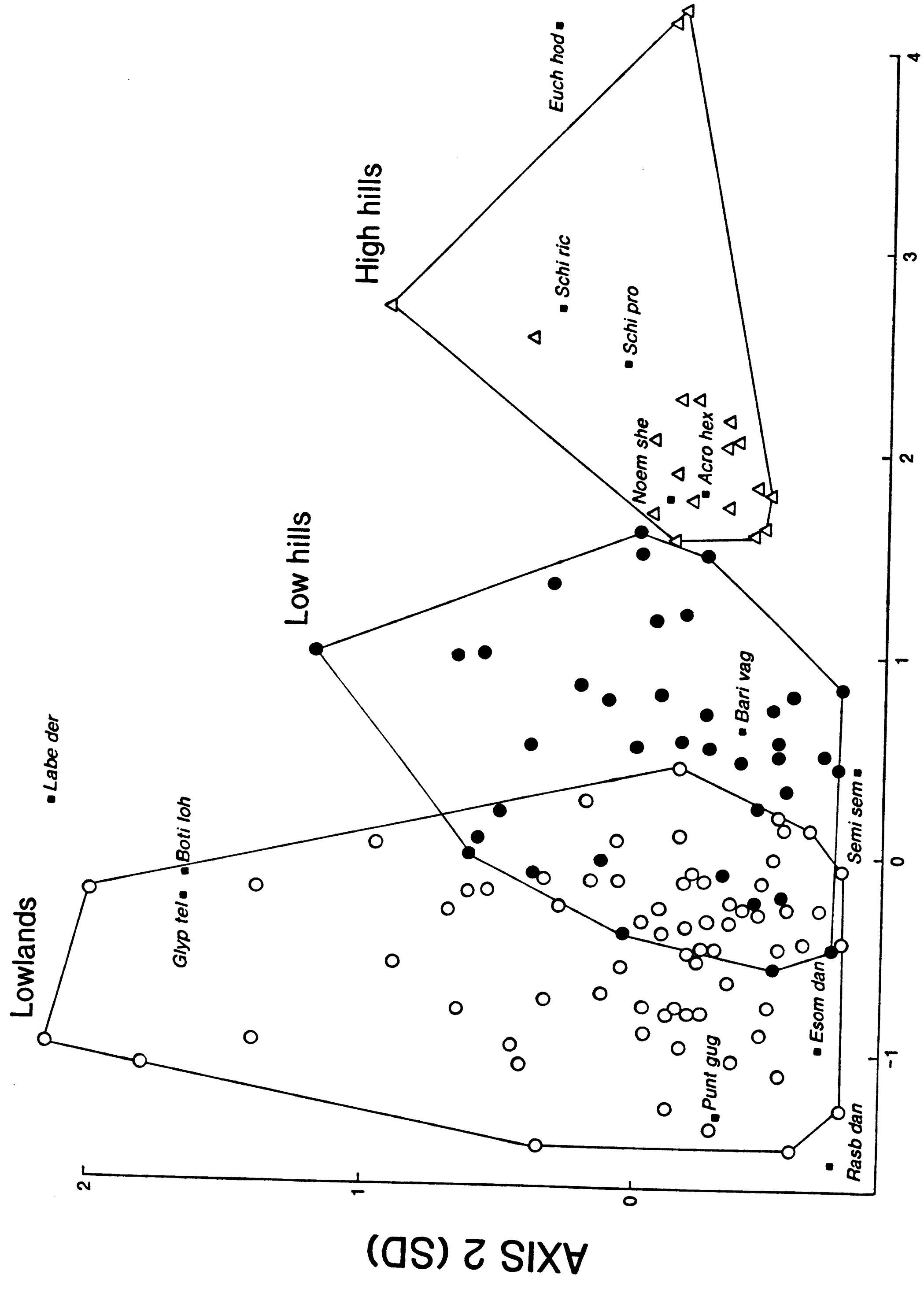
9
10
Rasb dan
Dani dev
Esom dan
Punt tic
Chel cac
Noem she
Schi pro
Noem rup
Pseu sul
Clup gar
Glyp tel
Euch hod
Schi ric
Lowlands
Low hills
High hills
Mountains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Low hills
High hills
Labe der
Boti loh
Glyp tel
Punt gug
Esom dan
Rasb dan
Semi sem
Bari vag
Noem she
Acro hex
Schi pro
Schi ric
Euch hod
AXIS 1 (SD)
AXIS 2 (SD)
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3
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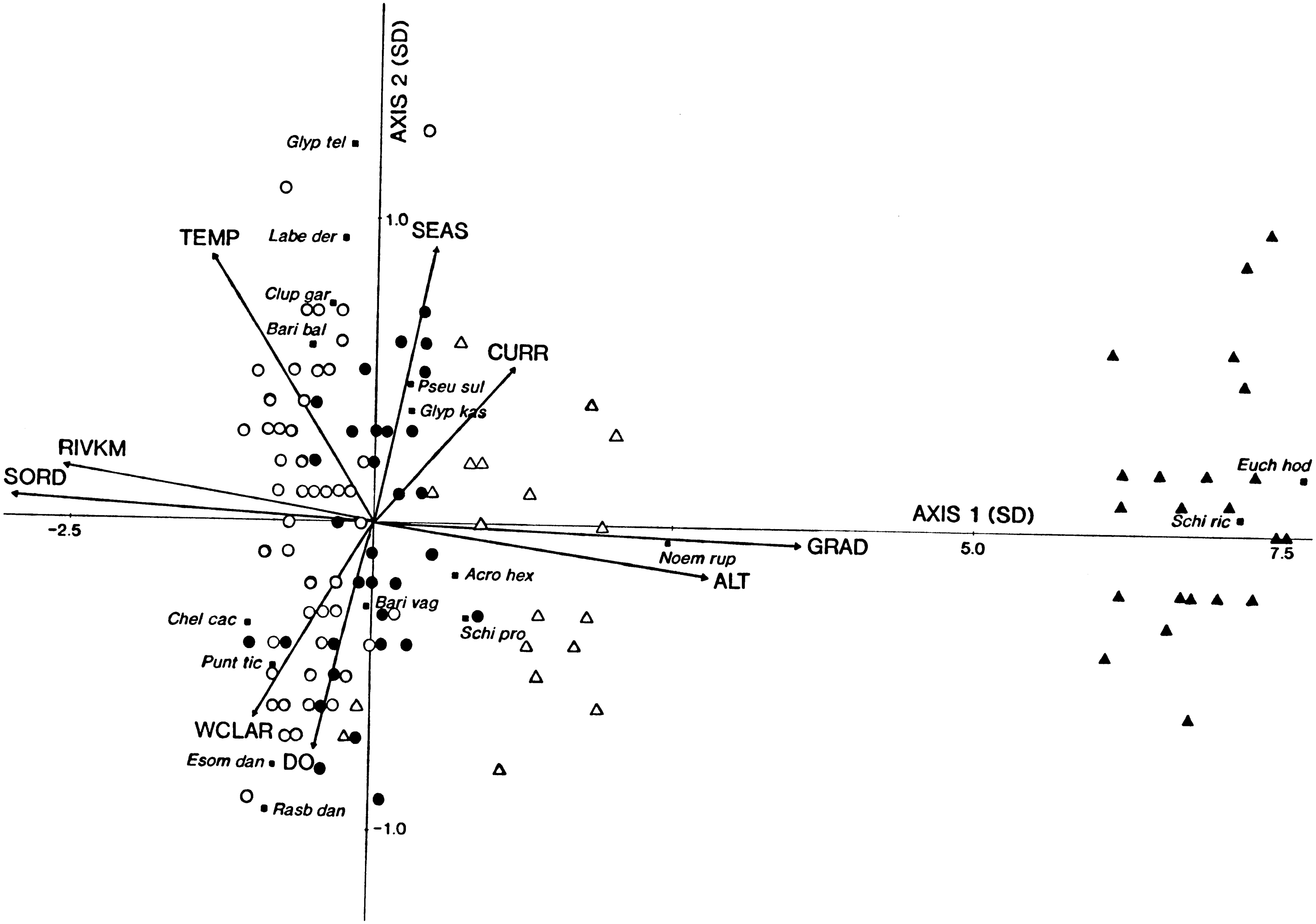
1
2



AXIS 2 (SD)
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SEAS
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Pseu sul
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SORD
Euch hod
AXIS 1 (SD)
Schi ric
-2.5
GRAD
5.0
7.5
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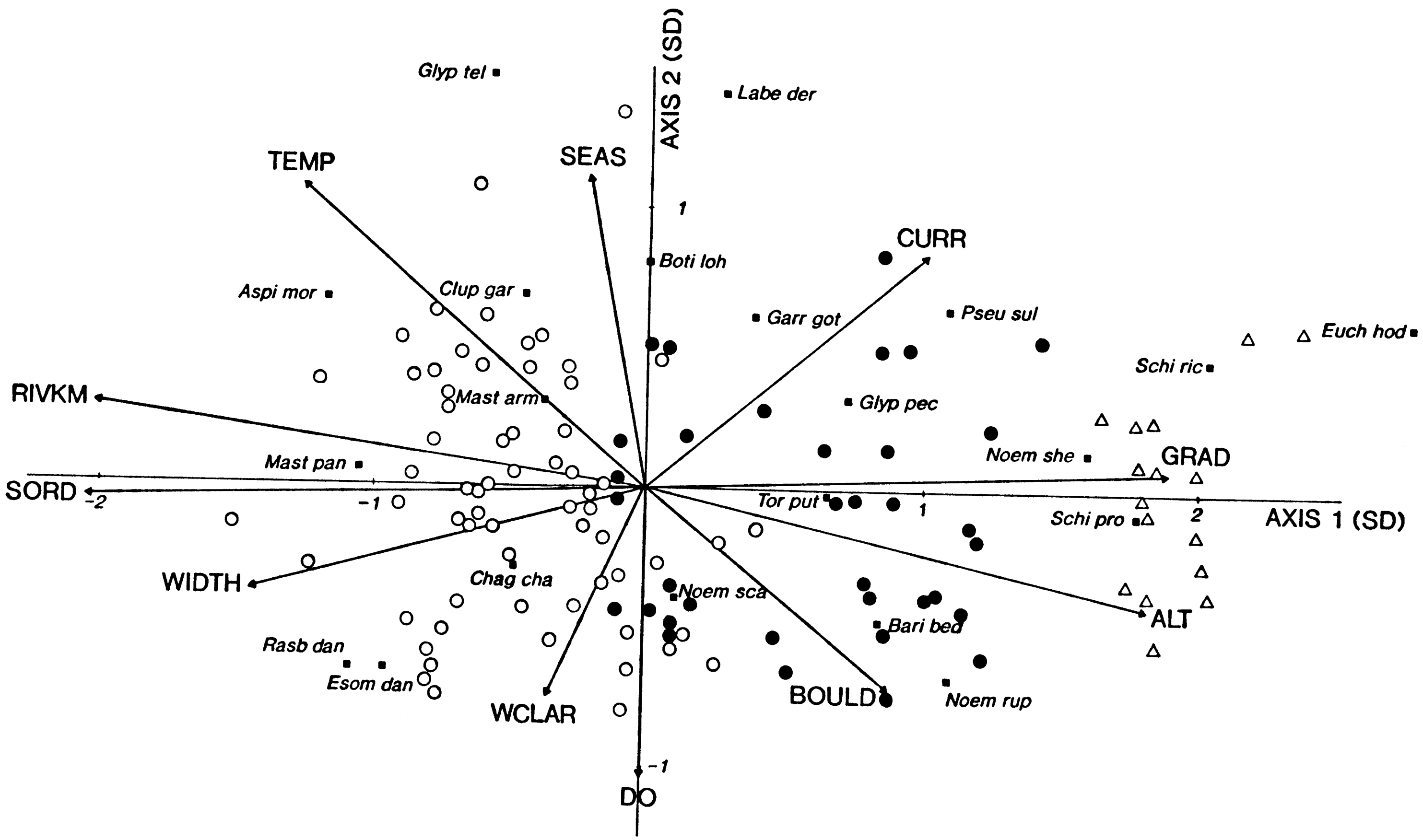
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WIDTH
ALT
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DO
Glyp tel
Labe der
Boti loh
Aspi mor
Clup gar
Garr got
Pseu sul
Euch hod
Schi ric
Mast arm
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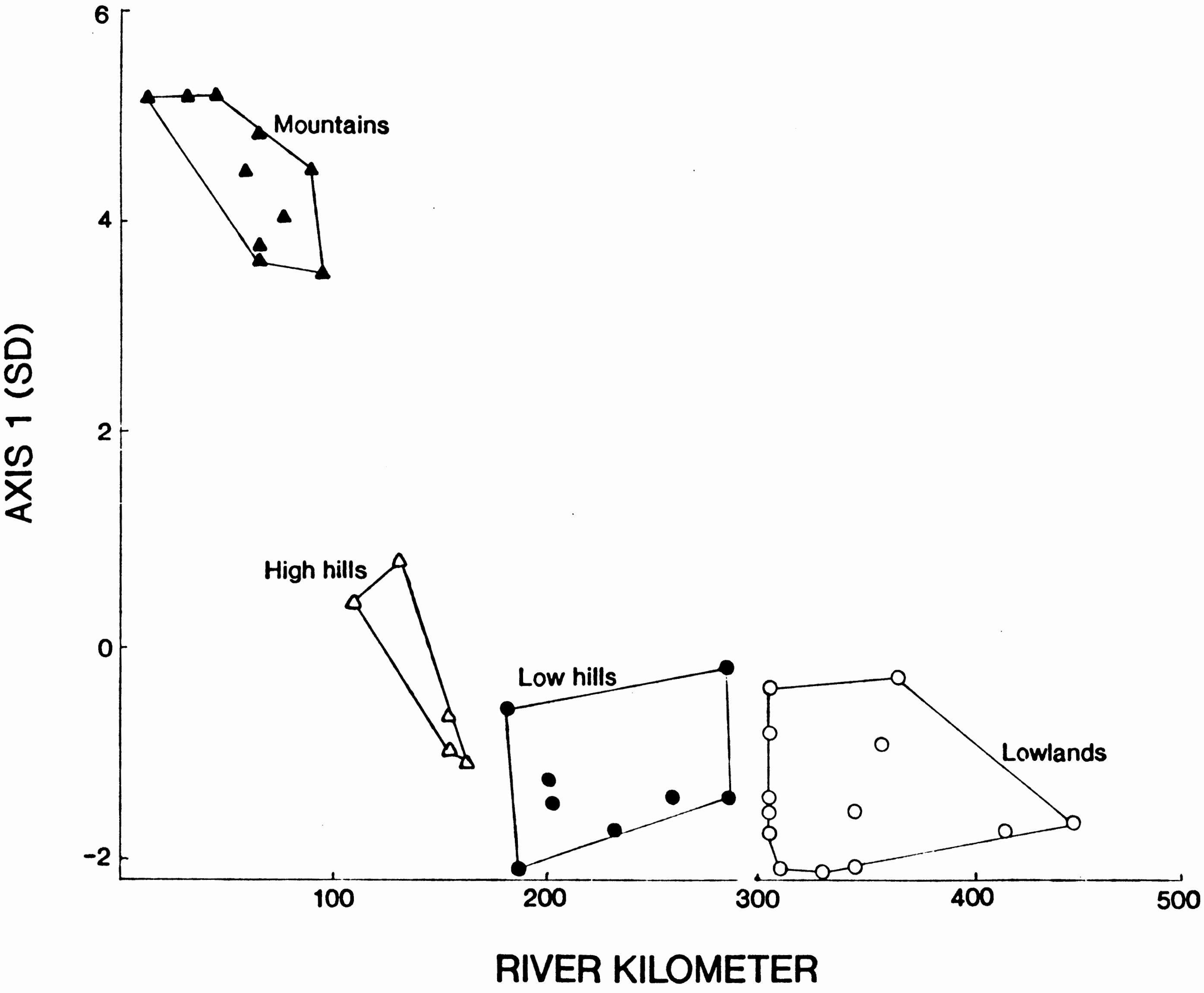
Chag cha
Noem sca
Bari bed
Rasb dan
Esom dan
Noem rup


Mountains
High hills
Low hills
Lowlands
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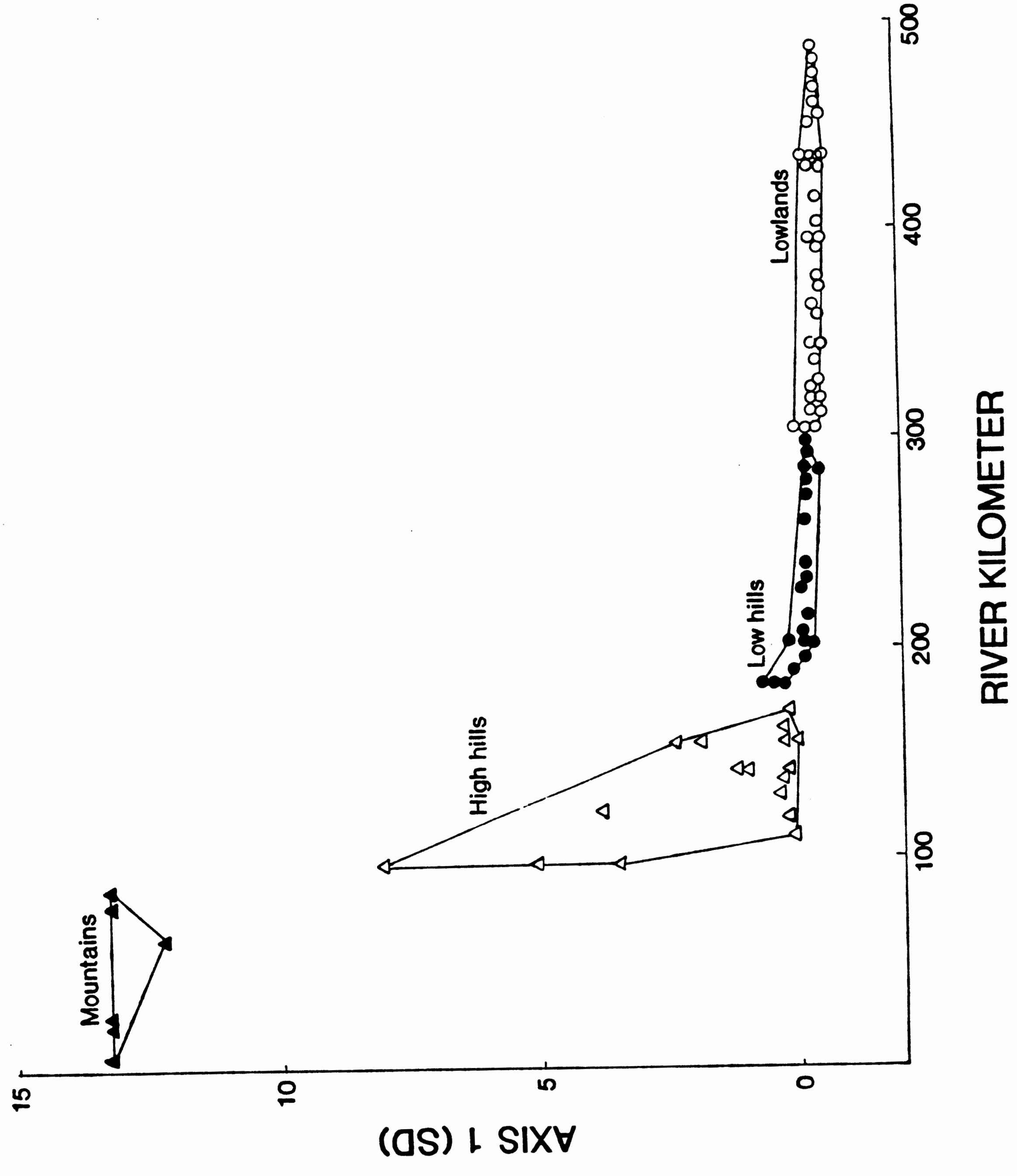
-2
100
200
300
400
500
RIVER KILOMETER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10
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0
RIVER KILOMETER
100
200
300
400
500
Mountains
High hills
Low hills
Lowlands

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# APPENDIXES

# APPENDIX A

## VALUES OF ENVIRONMENTAL PARAMETERS AT EACH SITE

collection number, number of species, longitudinal position (x 6.5 = river kilometer), water temperature (°C), water clarity (in inches), dominant substrate type (1 = mud, 2 = sand, 3 = gravel, 4 = stone, 5 = rubble, 6 = boulder), number of substrate types, dominant vegetation type (1 = filamentous algae, 2 = submerged, 3 = emergent, 4 = floating, 5 = detritus, 6 = debris), number of vegetation types, % cover by vegetation, width (1 = 0-25 m, 2 = 26-50 m, 3 = 51-75 m, 4 = 76-100 m, 5 = 101-150 m, 6 = 151-200 m, 7 = 201-300 m, 8 = 301-400 m , 9 = 401-500 m, 10 = > 500 m), altitude (m), dissolved oxygen (mg/L), pH, carbon dioxide (mg/L), total hardness (grains per gallon [gpg] $CaCO_3$), total acidity (gpg $CaCO_3$), total alkalinity (gpg $CaCO_3$), mean current velocity ( / 30 = feet per second), mean depth (inches), percent gradient, natural region (1 = trans-Himalaya, 2 = mountains, 3 = hills downstream from Beni, 4 = lowland valley downstream from Devghat, 5 = lowland plains downstream from Tribeni Barrage), stream order, season (1 = Oct.-Jan., 2 = Feb.-May, 3 = June-Sept.), geologic stratum (1 = Pleistocene-Recent, 2 = Tethysian, 3 = Arenaceous Cambrian-Precambrian, 4 = Argillaceous Cambrian-Precambrian, 5 = Calcarous Cambrian-Precambrian), % mud, % sand, % gravel, % stone, % rubble, % boulder, % detritus, % filamentous algae, % submerged vegetation, % emergent vegetation, % floating vegetation, % debris.

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 1  1  1 14  5 3 5 3 1  5  5 3100  8 8.00  5 21 1 10 30 15 1.00 1 3 3 1
   0 20 40 30  5  5  0  0  5  0  0  0
 2  1  2 15  1 4 4 0 0  0  2 2854  8 7.75  5 14 1 19 99 11 1.00 1 4 3 1
   0  5 20 70  5  0  0  0  0  0  0  0
 3  1  3 18  2 2 5 0 0  0  2 2743  8 7.75  5 16 1 16  9  9 1.00 1 4 3 1
   0 50 20 15  5 10  0  0  0  0  0  0
 4  1  3 18  2 4 5 3 1  5  5 2743 10 8.00  5 16 1 12 34  7 1.00 1 4 3 1
   0 20 25 40  5 10  0  0  5  0  0  0
 5  1  4 16  4 5 6 6 3 25  1 2560  9 8.25  5 16 1 13 12  6 1.00 1 4 3 2
  35  5  5  5 45  5  0 10  0 10  0 20
 6  1  4 14  1 2 5 6 4 35  2 2560  8 8.00 10 16 2 17 28  6 1.00 1 4 3 2
   0 50 20  5 20  5  0  5  5  5  0 20
 7  1  4 15 13 3 6 6 3 25  1 2560 10 8.50  5 17 1 19 11  8 1.00 1 4 2 2
  20 25 30 10 10  5  0 10  0  2  0 13
 8  1  4 14  3 2 5 2 3 50  3 2560  9 8.00  5 13 1 20 19  5 1.00 1 4 2 2
   0 50 10 15 20  5  0 35  0  5  0 10
 9  1  4 18  2 4 5 3 1  2  4 2560  8 8.00  5 12 1 10 24 13 1.00 1 4 3 2
   0 12 30 32 10 15  0  0  2  0  0  0
10  1  4 11  7 3 6 6 1 15  4 2560 13 8.50  5 14 1 13 35  5 1.00 1 4 2 2
   5 20 35 20 10 10  0  0  0  0  0 15
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11  1  5 16  5 2 5 6 2 20  2 2550  7 7.75  5 13 1 23 36 19 1.00 1 4 2 2
   5 30 15 30 20  0  0  5  0  0  0 15
12  1  6 16  1 2 5 6 1  5  1 2500  9 8.00  5 15 1 16 50 16 1.00 1 4 2 2
   0 40  5 15 30 10  0  0  0  0  0  5
13  1  7 15  6 3 5 0 0  0  2 1830  9 8.00  5  9 1  7 50  9 6.60 2 4 3 5
   0 25 30 10 10 25  0  0  0  0  0  0
14  2  8 17  3 6 4 2 2  9  1 1500 11 8.00  5 12 1 13 45  8 2.50 2 4 2 5
   0  0 10 10 30 50  0  5  0  0  0  4
15  3  9 16  3 6 5 2 2 11  2 1250 11 8.00  5 12 1 13 45  8 2.50 2 4 2 5
   5 10 20 10 15 40  0  6  0  0  0  5
16  3 10 19  4 6 4 2 1  5  2 1189 10 8.25  5 13 1 12 96 10 2.50 2 4 3 4
   0  0 10 15 25 50  0  5  0  0  0  0
17  2 10 12 13 5 6 2 2 30  2 1189 13 8.00  5 14 1 18 37  8 2.50 2 4 2 4
   5  5  5 10 43 32  0 20  0  0  0 10
18  3 10 19  4 5 6 2 3 35  2 1189 10 8.00  5 16 1 18 34  4 2.50 2 4 2 4
   5 10 15 24 26 20  0 20  0  5  0 10
19  2 10 19  2 4 5 4 1 10  2 1189 10 8.00  5 11 1 11 55  7 2.50 2 4 3 4
   0  5 15 30 25 25  0  0  0 10  0  0
20  2 10 13 13 4 5 6 2 10  2 1189 14 8.00  5  9 1 16 40  5 2.50 2 4 2 4
   0  1 30 30 19 20  0  0  0  5  0  5
21  3 10 18  4 5 6 2 3 30  2 1189 10 8.00  5 16 1 17 32  4 2.50 2 4 2 4
   5 10 15 20 30 20  0 15  0  5  0 10
22  2 11 18  3 6 5 2 2 11  2 1175 10 8.00  5 11 1 12 45  8 2.50 2 4 2 4
   0 10 15 25 20 30  0  6  0  0  0  5
23  4 12 20  7 6 5 2 1  7  3 1073  9 8.00 10  7 2  9 24 13 2.50 2 4 3 4
   0 13 15 12 15 45  0  7  0  0  0  0
24  3 13 19  8 3 5 2 2  9  2  920 11 8.00  5 12 1 13 45  8 2.50 2 4 2 4
   0 15 40 30 10  5  0  5  0  0  0  4
25  2 14 10 12 5 6 2 2 10  2  900 15 8.00  5 14 1 13 36 11 2.50 2 4 2 4
  10 15  5 10 35 25  0 10  0  0  0  5
26  3 15 10 16 4 6 2 2 21  2  850 15 8.00  5 11 1 12 37 14 0.50 3 5 2 4
  10 17 10 30 26  7  0 11  0  0  0 10
27  5 15 19  7 6 5 6 2  8  3  850 11 8.25  5 11 1 13 60 10 0.50 3 5 2 4
   0 28 22  8 12 30  0  2  0  0  0  5
29  3 15 11 16 3 6 0 0  0  4  850 14 8.00  5 10 1  8 15 14 0.50 3 5 2 4
   2 22 28 28 10 10  0  0  0  0  0  0
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   2 20  0  0 70  8  0  9  0  1  0  0
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  30 20  0  5 10 35  0 15  0  0  0  0
33  8 18 18 18 5 6 2 2 20  2  770 11 8.25  5 11 1 11 35  9 0.50 3 5 2 4
   5 24 12 23 26 10  0 15  0  0  0  5
34  7 19 18 12 3 4 6 1  5  3  700 14 8.00  5  8 1 11 19 19 0.50 3 5 2 4
   0 34 36 20 10  0  0  0  0  0  0  5
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  35 55  0  0  0 10  0  0  0  0  0  5
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  10 15 20 10 30 15  0 30  0  0  0  5
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   1 50  0 10 30  9  0  4  5  1  0  0
38  4 22 12 24 2 3 0 0  0  3  600 13 8.00  5  9 1 10  1 17 0.50 3 5 1 4
  35 60  0  0  0  5  0  0  0  0  0  0
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   20 70  0  0  2  8  0  0  0  0  0  1
40  7 22 19  1 2 5 0 0  0  8  600  8 8.00  5  7 1 11 24 18 0.50 3 5 3 4
    0 60 15 10 10  5  0  0  0  0  0  0
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   10 15 25 10 35  5  0  5  0  0  0  6
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   10 20 35 20 10  5  0  2  0  1  0  0
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    0  7 22 35 23 20  0  0  0  0  0  0
46  5 24 14 28 2 6 0 0  0  4  540 15 8.00  5  8 1  7 36 11 0.20 3 5 1 4
   13 40 17  8 15  7  0  0  0  0  0  0
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    5 10 25 20 30 10  0 10  0  0  0  5
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   15 25  5 15 35  5  0 10  0  0  0  0
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    0 15 40 10 35  0  0 15  0  0  0 10
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    5 40 20 20 15  0  0  0  0  0  0  0
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    1 31 29 18 10  4  0  0  0  0  0  0
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    0 50 20  5  5 20  0  0  0  0  0  0
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   24  8 16 22 18 12  0  0  2  2  0  0
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   82  5  3  3  4  3  0  0  0 16  0  0
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   18 29  9 28 10  6  0  0  4  1  0  6
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   44 27 10  9  5  5  0  0  1  0  0  0
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    2 19 38 29  4  1  0  0  0  0  0  0
 98  9 47 19 30 4 6 2 1  4  8  285 14 8.00  5  9 1  9 21 12 0.10 4 7 1 1
    1 10 29 42 11  7  0  4  0  0  0  0
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   27 28 12 20  8  5  0  0  7 27  0  0
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   14 49  0 10 14 14  0  5  0  0  0  0
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   44 32  2  5 16  0  0 25 40  0  0  4
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   44 46  5  5  0  0  0 10  0  0  0 30
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    5 35 35 18  8  0  0  0  0 25  0  0
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   20 30  0 25 25  0  0 20  0  0  0 10
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   12 28 28 20 10  5  0 25  0 10  0  0
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   45 30  0 15 10  0  0 70  0  5  0 10
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    0 95  0  2  3  0  0  0  0  0  0 10
135 24 61 25 30 2 4 3 2 32  7  135 12 8.25  5  8 1  9 18 19 0.10 4 7 2 1
   50 45  0  0  0  5  0  5  5  0  0  5
136  8 62 18 25 2 3 2 1 10  9  134 11 8.00  5  9 1 11 11 18 0.10 4 7 1 1
   40 50  0  0  0 10  0 10  0  0  0  0
139 13 66 24  1 1 2 4 2 55 10  125  9 7.75  5  6 1  6 15 16 0.10 4 7 3 1
   35 65  0  0  0  0  0  0  0 50  0  5
140 15 66 18 25 2 2 2 4 75 10  125 16 8.50  5  9 1 10  0 16 0.10 4 7 1 1
   35 65  0  0  0  0  0 35 20 15  0  5
141 12 66 25 30 1 2 3 3 85 10  125 12 8.50  5  8 1 11  0 16 0.10 4 7 2 1
   65 35  0  0  0  0  0 15 60  0  0 10
142 15 66 26  2 1 2 3 1 50 10  125 12 8.00  5  6 1  6  6 28 0.10 4 7 3 1
   70 30  0  0  0  0  0  0 50  0  0  0
143  7 66 18 31 1 1 3 2 25 10  125 18 8.00  5  7 1  7  0 21 0.10 4 7 1 1
  100  0  0  0  0  0  0  5 20  0  0  0
144 14 66 26 25 2 1 2 2  5 10  125 11 8.00  5  8 1  7 26 24 0.10 4 7 2 1
    1 99  0  0  0  0  0  5  0  0  0  0
146 17 64 27 30 1 1 3 4 95 10  123 12 8.25  5  8 1  9  0 12 0.10 4 7 2 1
  100  0  0  0  0  0 10 15 65  0  0  5
147  6 65 24 30 2 4 3 2 32 10  122 12 8.25  5  8 1  9 60 99 0.10 4 7 2 1
  100  0  0  0  0  0  0  5  0  0  0  5
148 19 67 24  1 2 5 6 2 11 10  120  9 8.00  5 11 1  6 30 20 0.10 5 7 3 1
   25 50  5  5 15  0  0  0  0  5  0  6
149 10 67 21 30 5 5 2 3 27  5  120 12 8.00  5 10 1 14 15 13 0.10 5 7 1 1
   30 20  5 14 31  0  0 20  5  0  0 10
```

```
150 19 67 27 30 5 4 2 1 20  6  120 12 8.50  5  7 1 11 26 11 0.10 5 7 2 1
   20 25 10 20 25  0  0 30  5  0  0  2
151  8 67 24  2 2 5 3 1  4 10  120 12 8.00  5  7 1  9 15 12 0.10 5 7 3 1
    0 56  6 26  9  3  0  0  2  0  0  0
152  7 67 19 25 2 5 0 0  0 10  120 16 8.50  5  8 1  7  0 16 0.10 5 7 1 1
    0 50  5 20 15 10  0  0  0  0  0  0
153 20 67 24  4 2 6 2 1  2 10  120  9 8.00  5  9 1  7 15  9 0.10 5 7 2 1
    2 55 18 15  8  2  0  2  0  0  0  0
154  7 68 23 30 4 3 2 2 35  5  115 15 8.50  5 10 1 11 37  6 0.10 5 7 2 1
    0  0 20 41 39  0  0 30  0  0  0  5
155 19 69 22 25 2 4 2 1 31 10  112 14 8.00  5  9 1  7 12  9 0.10 5 7 2 1
    0 80  9 10  1  0  0 31  0  0  0  0
156 17 70 25 30 2 4 3 3 45  5   95 14 8.50  5 10 1 11  2 13 0.10 5 7 2 1
   35 45  0  5 15  0  0 20 21  0  0  4
157 10 71 30 21 2 1 2 2 25 10   94 13 8.50  5  8 1  7  7 17 0.10 5 7 2 1
    1 99  0  0  0  0  0 25  0  0  0  0
158 10 72 27 18 2 2 2 1 10 10   85 10 8.00  5  8 1  7  4 13 0.10 5 7 2 1
   10 90  0  0  0  0  0 10  0  0  0  0
159 13 73 25 11 2 3 2 1  5 10   80  9 8.00  5  8 1  8 14 16 0.10 5 7 2 1
    0 70 15 15  0  0  0  5  0  0  0  0
160 33 74 28 24 2 4 2 1  5 10   75  9 8.00  5  8 1  7 15 22 0.10 5 7 2 1
    2 88  5  5  0  0  0  5  0  0  0  0
161 21 75 23 42 4 6 1 4 10  3   50  9 8.25 10  9 1  9 49 20 0.10 5 7 2 1
   30 40 10 20  0  0  0 25  5  0  0  0
```

# APPENDIX B

SAMPLE SITES, IN ORDER FROM HEADWATERS DOWNSTREAM: SAMPLE NUMBER, LOCATION, AND DATE. "KGR" = KALI GANDAKI RIVER, "NR" = NARAYANI RIVER. "*" = SITES NOT INCLUDED IN PRESENT ANALYSIS.

1 KGR AT CHUSANG, MUSTANG 14 SEPT 85
2 KGR ABOVE KAGBENI, MUSTANG 10 SEPT 84
3 KGR AT JOMSOM, MUSTANG 11 SEPT 84
4 KGR AT JOMSOM, MUSTANG 10 SEPT 85
5 KGR AT LARJUNG, MUSTANG 5 JUNE 84
6 KGR AT LARJUNG, MUSTANG 12 SEPT 84
7 KGR AT LARJUNG, MUSTANG 18 FEB 85
8 KGR AT LARJUNG, MUSTANG 30 MAY 85
9 KGR AT LARJUNG, MUSTANG 9 SEPT 85
10 KGR AT LARJUNG, MUSTANG 12 FEB 86
11 KGR BELOW BAKSHI R. CONFLUENCE, DOWNSTREAM FROM LARJUNG, MUSTANG 30 MAY 85
12 KGR AT KALAPANI, MUSTANG 30 MAY 85
13 KGR AT PAHIROTHAPLA, MUSTANG 13 SEPT 84
14 KGR AT RUPCHE CHARA, MYAGDI 28 MAY 85
15 KGR AT MRISTI R. CONFLUENCE, MYAGDI 26 MAY 85
16 KGR AT TATOPANI, MYAGDI 14 SEPT 84
17 KGR AT TATOPANI, MYAGDI 16 FEB 85
18 KGR AT TATOPANI, MYAGDI 27 MAY 85
19 KGR AT TATOPANI, MYAGDI 8 SEPT 85
20 KGR AT TATOPANI, MYAGDI 10 FEB 86
21 KGR AT TATOPANI, MYAGDI 21 MAY 86
22 KGR AT GHAR R. CONFLUENCE, 2 KM DOWNSTREAM FROM TATOPANI, MYAGDI 27 MAY 85
23 KGR AT MOHABIR, MYAGDI 15 SEPT 84
24 KGR AT BEG KHOLA, MYAGDI 25 MAY 85
25 KGR AT SANSAR R. CONFLUENCE, 3 KM DOWNSTREAM FROM BEG KHOLA, MYAGDI 15 FEB 85
26 KGR AT BENI, MYAGDI 15 FEB 85
27 KGR AT BENI, MYAGDI 24 MAY 85
28* KGR AT BENI, MYAGDI 6 SEPT 85
29 KGR AT BENI, MYAGDI 9 FEB 86
30 KGR AT SIMAA, MYAGDI 27 MAY 84

31 KGR AT AT KHANIYA GHAT, PARBAT 14 FEB 85
32* KGR AT SHASADARA, PARBAT 24 MAY 85
33 KGR AT RITHE R. CONFLUENCE, ARMADI, PARBAT 13 FEB 85
34 KGR AT MODI R. CONFLUENCE, KUSMA, PARBAT 23 MAY 85
35 KGR AT BAGLUNG BALEYA, BAGLUNG 23 JAN 85
36 KGR AT JYAMRI GHAT, BAGLUNG 22 JAN 85
37 KGR AT SUMSA GHAT (="BINAMARE"), BAGLUNG 25 MAY 84
38 KGR AT SUMSA GHAT, BAGLUNG 22 JAN 85
39 KGR AT SUMSA GHAT, BAGLUNG 23 MAY 85
40 KGR AT SUMSA GHAT, BAGLUNG 23 AUG 85
41* KGR AT SUMSA GHAT, BAGLUNG 23 JAN 86
42* KGR AT BELBAGAR, BAGLUNG 21 JAN 85
43 KGR AT GAUNDI R. CONFLUENCE (="GUMTI"), GULMI 20 JAN 85
44 KGR AT GAUNDI R. CONFLUENCE, GULMI 22 MAY 85
45 KGR AT GAUNDI R. CONFLUENCE, GULMI 22 AUG 85
46 KGR AT GAUNDI R. CONFLUENCE, GULMI 21 JAN 86
47 KGR AT SETI BENI, PARBAT 19 JAN 85
48 KGR AT PAHADI, SYANGJA 18 JAN 85
49 KGR AT BADIGARH R. CONFLUENCE AT RUDRABENI, GULMI 19 AUG 84
50 KGR AT RIDI BAZAR, GULMI 22 MAY 84
51 KGR AT RIDI BAZAR, GULMI 18 AUG 84
52 KGR AT RIDI BAZAR, GULMI 17 JAN 85
53 KGR AT RIDI BAZAR, GULMI 20 MAY 85
54 KGR AT RIDI BAZAR, GULMI 19 AUG 85
55 KGR AT RIDI BAZAR, GULMI 19 JAN 86
56 KGR AT RANI GHAT, PALPA 16 JAN 85
57 KGR AT RAMDI, PALPA 1 MAY 85
58 KGR AT NIMA, SYANGJA (5 KM FROM GYALANG) 4 MAY 84
59 KGR AT NIMA, SYANGJA 21 AUG 84
60 KGR AT NIMA, SYANGJA 6 JAN 85
61 KGR AT NIMA, SYANGJA 2 MAY 85
62 KGR AT NIMA, SYANGJA 20 AUG 85
63 KGR AT NIMA, SYANGJA 6 JAN 86
64 KGR AT NAU GAUN, PALPA 5 JAN 85
65 KGR AT KHORIYA GHAT, PALPA 4 JAN 85
66 KGR AT RAMPUR, PALPA (="RAMPUR-POKHARA") 1 MAY 84
67 KGR AT KELADI GHAT, PALPA 3 JAN 85
68 KGR AT PUTTAR GHAT, TANAHUN 2 JAN 85
69 KGR AT BAUNDI R. CONFLUENCE, DERGAON, NAWALPARASI 1 JAN 85
70 KGR AT HADAHA, NAWALPARASI 29 APRIL 84

71 KGR AT SPRING FEEDER CONFLUENCE, BULING, NAWALPARASI 31 DEC 84
72 KGR AT LADI R. CONFLUENCE, SANO TADI, NAWALPARASI 30 DEC 84
73 KGR AT KHALTE, TANAHUN 27 APRIL 84
74 KGR AT CHERANGA R. CONFLUENCE, TANAHUN 29 DEC 84
75 KGR AT BHATYARI, TANAHUN 28 DEC 84
76 KGR AT KALIKATAR, TANAHUN 25 APRIL 84
77 KGR AT KALIKATAR, TANAHUN 10 AUG 84
78 KGR AT KALIKATAR, TANAHUN 27 DEC 84
79 KGR AT KALIKATAR, TANAHUN 21 APRIL 85
80 KGR AT KALIKATAR, TANAHUN 13 AUG 85
81 KGR AT KALIKATAR, TANAHUN 28 DEC 85
82 KGR AT DEUTI R. CONFLUENCE, 2 KM N OF DEV GHAT, TANAHUN 9 DEC 84
83 NR AT DEV GHAT, CHITAWAN 9 DEC 84
84 NR AT NARAYANGARH, CHITAWAN 1 APRIL 84
85 NR AT NARAYANGARH, CHITAWAN 18 JULY 84
86 NR AT NARAYANGARH, CHITAWAN 10 DEC 84
87 NR AT NARAYANGARH, CHITAWAN 13 JAN 85
88 NR AT NARAYANGARH, CHITAWAN 10 FEB 85
89 NR AT NARAYANGARH, CHITAWAN 12 MAR 85
90 NR AT NARAYANGARH, CHITAWAN 19 APRIL 85
91 NR AT NARAYANGARH, CHITAWAN 18 MAY 85
92 NR AT NARAYANGARH, CHITAWAN 11 JUNE 85
93 NR AT NARAYANGARH, CHITAWAN 18 JULY 85
94 NR AT NARAYANGARH, CHITAWAN 14 AUG 85
95 NR AT NARAYANGARH, CHITAWAN 20 SEPT 85
96 NR AT NARAYANGARH, CHITAWAN 17 OCT 85
97 NR AT NARAYANGARH, CHITAWAN 10 NOV 85
98 NR AT NARAYANGARH, CHITAWAN 10 DEC 85
99 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 4 APRIL 84
100 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 17 JULY 84
101 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 6 DEC 84
102 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 3 APRIL 85
103 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 17 JULY 85
104 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 7 DEC 85
105 NR BELOW BRIDGE AT NARAYANGARH, CHITAWAN 3 APRIL 86
106 NR AT KHARKHARE GHAT, NAWALPARASI, 13 KM W OF NARAYANGARH 21 APRIL 84
107 NR AT KHARKHARE GHAT, NAWALPARASI 19 JULY 84
108* NR AT KHARKHARE GHAT, NAWALPARASI 10 MAY 84
109 NR AT KHARKHARE GHAT, NAWALPARASI 8 DEC 84
110 NR AT KHARKHARE GHAT, NAWALPARASI 20 APRIL 85

111 NR AT KHARKHARE GHAT, NAWALPARASI 19 JULY 85
112 NR AT KHARKHARE GHAT, NAWALPARASI 8 DEC 85
113* NR AT SIKRAULI GHAT, NAWALPARASI, 7 AUG 84
114 NR AT PIPARA (3 KM S OF RAJAHAR), NAWALPARASI
17 DEC 84
115 NR AT BHUSARE GHAT, NAWALPARASI 15 MAR 85
116 NR UPSTREAM FROM TIGER TOPS TENTED CAMP, NAWALPARASI
5 APRIL 85
117* NR AT RAPTI R. CONFLUENCE, CHITAWAN 5 MAY 86
118 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 7 APRIL 84
119 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 6 AUG 84
120 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 12 DEC 84
121* NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 12 DEC 84 - 15 FEB 85
122 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 4 APRIL 85
123 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 10 AUG 85
124* NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 11 AUG 85
125 NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 11 DEC 85
126* NR AT GHARIAL CONSERVATION PROJECT CAMP, BELOW RAPTI
R. CONFLUENCE, CHITAWAN 10 DEC 85
127 NR AT AMALTARI GHAT, CHITAWAN 5 APRIL 85
128 NR AT LAINDA GHAT, NAWALPARASI 13 DEC 84
129 NR ABOVE ARUNG R. CONFLUENCE, NAWALPARASI 13 DEC 84
130 NR AT ARUNG R. CONFLUENCE, NAWALPARASI 21 JULY 85
131 NR AT BINAI R. CONFLUENCE, NAWALPARASI 22 JULY 85
132 NR 4 KM DOWNSTREAM FROM MATYARI (= "MATERI"),
CHITAWAN 14 DEC 84
133 NR 2 KM UPSTREAM FROM KANAHA R., CHITAWAN 14 DEC 84
134 NR AT CONFLUENCE WITH KANAHA R., CHITAWAN 14 DEC 84
135 NR AT KANAHA R. CONFLUENCE, CHITAWAN 8 MAR 85
136 NR 1 KM BELOW CONFLUENCE WITH KANAHA R., CHITAWAN
14 DEC 84
137* NR AT TRIBENI, NAWALPARASI 25 - 29 MAR 85
138* NR AT TRIBENI, NAWALPARASI 25 MAR 86
139 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE)
3 AUG 84
140 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE)
15 DEC 84

141 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE) 7 MAR 85
142 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE) 7 AUG 85
143 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE) 15 DEC 85
144 NR AT TRIBENI GHAT, NAWALPARASI (ABOVE BARRAGE) 13 MAR 86
145* NR AT CONFLUENCE WITH FEEDER CREEK, TRIBENI, NAWALPARASI 9 MAR 85
146 NR AT CONFLUENCE WITH NEPALI CANAL, TRIBENI, NAWALPARASI 9 MAR 85
147 NR AT CONFLUENCE WITH GANDAK WESTERN CANAL, TRIBENI, NAWALPARASI 9 MAR 85
148 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 3 AUG 84
149 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 15 DEC 84
150 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 7 MAR 85
151 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 7 AUG 85
152 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 15 DEC 85
153 NR JUST BELOW TRIBENI BARRAGE, NAWALPARASI 13 MAR 86
154 NR BETWEEN TRIBENI AND NARSAI, AT #6 PIER, NAWALPARASI 6 MAR 85
155 NR NEAR NARSAI, NAWALPARASI, AT PIER # 10 THROUGH # 13, DOWNSTREAM FROM TRIBENI 27 FEB 86
156 NR AT NARSAI, NAWALPARASI PIER #12 6 MAR 85
157 NR ACROSS FROM NARSAI, NAWALPARASI AT PIER #13 12 APRIL 86
158 NR BELOW NARSAI, NAWALPARASI AT PIER #15 12 APRIL 86
159 NR AT SEMARI TARAINI, NAWALPARASI AT PIER #2 13 APRIL 86
160 NR 5 KM N OF TADI GHAT, NAWALPARASI AT PIER #5 13 APRIL 86
161 NR 2 KM N OF TADI GHAT, NAWALPARASI 15 MAR 84

# APPENDIX C

## CODED ABUNDANCE OF SPECIES (ROWS) AT SITES (COLUMNS) ARRANGED BY TWINSPAN (HILL 1979b). SEE APPENDIX D FOR KEY TO SPECIES' ABBREVIATIONS.

```
          11111111111111111111111111111111111111111111      111111           11111111111         11      11
          230124434556124412223333450123345555611257889901234577889999999000001134556778888900577712685556455556347525673458233455566334433344 44  1       11  12221122122221112
          678313987491550140280234636091520567078485016701398169561234589235792664289182389014703797640319814201464572902785385903474513636723245679011836974705523466891

Esom dan  ------22----2-2-5----42553---------------------------2----------------------------------------------------------------------------------------------------------------
Rasb dan  -2----------2334-424--5222---2------222-----------------------------------------------------------------------------------------------------------------------------
Bari til  -------2----2-22--24-2---------3--2---222-----------------------------2--2-------------------------------------------------------------------------------------------
Punt gug  -2-------------32-355-55-342-2-2222--2-52---------------------------------------2-------2--------------------------------------------------------------------------
Sale bac  -2--2----------2----2---2-2--222----222-3----------------------------4------------------------------------------------------------------------------------------------
Punt tic  ----2-2--2-5522-253-3523-22--5--24-2-5-------------------------2-------------2-2-------2-----------------2-----------------------------------------------------------
Lepi gun  22--2--2-----3--22-2-2-244-2-----22-2224---------------22-----------------------------------------------------------------------------------------------------------
Mast pan  22-------------2--3---2----2---2-2223----------------------------------------------------------------------------------------------------------------------------------
Chel cac  ------52--32-2---52--52-2-----------5--2----------------------------2------------------------------------------------------------------------------------------------
Dani dev  22---2222--2454255555-2----2---------242------------------------2---2----------22------------------------------------------------------------------------------------
Glyp cav  2-----2---------------------------------------------------------------------------------------------------------------------------------------------------------------
Glos giu  22--22-2----2--2-2-2-----2---2-3-2--22-3------2------------------2---------------22------------------------------------------------------------------------------------
Chan pun  -----22----------2--2--22-2----------2-2------------------------2-------------------------------------------------------------------------------------------------------
Oste cot  --222-------------2---------4235----22-2-------22--------------------------------------------------------------------------------------------------------------------
Chad bac  -22---332-24------4-2----2245-253-525-54-------22---3-2---2---5-------------------------------------------------------------------------------------------------------
Noem bot  22-----2---2442-22-2-2--22222---22-22332-------2---------------22---42----2----2-22-32--3-2-----------------------------------------------------------------------------
Aebl man  -2-----2----23----2-----------22--2----232--2-------------2-----2-------------------22242-2-----------------------------------------------------------------------------
Punt sop  222----2-------------3-23---2-2-----222---------------------2--3-----------3252--------2-----------------------------------------------------------------------------
Late der  --2-2-2----2------------------------222--------------------------------------224--------------------------------------------------------------------------------------
Mast arm  -3-22------223---2---2----2-2-----2---32-2------2----2-----------------2--------------2223222-------------------------------------------------------------------------
Aspi mor  2223--22-22---------25--2-2452423235244-53---2-2-22-22424-22353-5-2422-335----------------2225--------------------------------------------------------------------------
Clup gar  22-----22--------------------5------------22--2--22-------22-------------------------------2---------------------------------------------------------------------------
Glyp tel  2-----2-2------------------------3------2--4--------------------------------------------------------------------------------------------------------------------------
Chad ran  3--------------2-----------2--2--2--2-2--------------------43--2----------------5------------------------------------------------------------------------------------
Bari bol  ---2--------------222-2422--2222-222-22-2-------------2--324------22-2--22332-2---------------2------------------------------------------------------------------------
Punt con  -2--2--22-255245345423---55544-255-25-5-------5----234243522-55452-25-52524-2-35522-44--225------------------------------------------------------------------------
Chag cha  222222-3--2-5-4-3525-244-4452-5-45244--4-322----------4225234223542525-24545--25-552------2-52--------------------5---------------------------------------------------
Xene can  -2--2------25-32225-222--5442-2-----2254-----22-------34--22---255-43-34-3---------2442---------2------------------------------------------------------------------------
Aspi jay  -------------4---5-5-----4-4552222--225242--------2-2-2-4-4-55452-5545-2-545-522----522--3--2245--5--------------------------------------------------------------------
Bari bal  22---2---255--2--------------222-5-5-3--2--5---4224532-3---222-422-4--3-2-2---------3---42543----------------------------------------------------------------------------
Bari ban  ----2432--2--2---2523323-5555455-52253422552555453255525555555555453545-5222-35553-4525445525-5------------------------------------------------------------------------
Tor_ tor  22--2--2----------------22----------224-----------------2-----------32----4----25-3-252---3--23-2-44-----------------------------2-----------------------------------------
Glyp tri  -----------2---2------------------------2--2--2--2----------------------------------------3---2--------------------------------------------------------------------------
Semi sem  ---2----------------------------2-2-----2------------------------42222-2-2---------2-2------------------2-----------------------------------------------------------------
Noem sca  -----------2--32--22------------2--22----5--5-22----2--422-2--235-----2--2--42--2---------------45---33-----------------2--------------------------------------------------
Boti loh  -4--2-4232-522---2---2------2---525-2223----------------------------2--------------2-2--2222224552-24------2-22--------------------------------------------------------
Tor_ put  22-22--2-----------------------22--22-2-----------------23-2-----------2----32-3--42---2----22-352-2-3--------------------------32------2-----------------------------------
Cros lat  252----3--35------2------2-3-222-2-2-4244------2--2--2-----2--2------2-2--3-----------323233535333243222------------------2-----22------------------------------------------
Garr got  -2--2--5---5----------2-------2---32--223--2--22---2-----2---2--------------22-4---2--22--423552-224-------------------------2-------2-----------------------------------
Noem bea  2-----2----2-2-2-----------2-2---2-----33-----22-2---2------2-2-5-----2------------24--45522255--222----2----------2------222----------------------------------------------
Bari sha  ---2--2--322---223-24--3553-24-35-352223-242553334255555453445555452525542-3-25522--5554555555355554--2322-55455--32-523-222-------------------------------------------
Noem cor  22--2--2--22--3-42---2-2-2--2---33--4---2223222222--2-53-5555-55522-54-4-32----43-2455-5524555-4355-------2--2222----22253-22---------------------------------------------
Bari bed  2--222-2--224-3255354425422345245-25232535225-23-445253555334552--52552535524542 2555-2455555344-22452254555-355-2232555555554-------------------------------------------
Bari vag  ------2---4-----55-4253522-22-22522---2245452-4532232425225553225255-4-22-5-54555255532235222244222255455-424-44552552-23555555-----------------2----------------------
Pseu sul  -------------------------------------------------------------------------------2-4-----2--2--5-222--23------------------2-2-------------------------------------------
Glyp kas  -3----------------------------------------------------------------------------2-2------22--25-224-2-2----2---3-------------2-----2-----------------------------------------
Acro hex  ------------2-----------------------------2---2--------------------4-------------2-22-2-------------------3-2-222322243-2-------------------------------------------------
Noem she  -----------2-----------------------------2---------------------2-----22--------23--423-2--------------------253--3553-------------------------------------------------------
Glyp pec  -------4-2-2------------------------2-----------------------------2--3-3-----2-2---4-222222----2-2-----------22---------------------------------------------------------
Schi ric  ---------------------------------------------------------------------------------------------23---23-2-------22-----------3233------222555555534442242232545544-4
Schi ann  -----------------------------2-----------------------------------32---2---2-25522-553-5--3----455525555-55355-444-55-------------542------2-----
Noem rup  -------------22------------------------222---------2-23----5---3----------22--2-2--2--4---4---22---------2-------3---------22-3-22----------------------3-222524

Euch hod  -----------------------------------------------------------------------------------------------------3---------------------22-----------------2222222223425455
```

# APPENDIX D

## ALPHABETICAL LISTING OF SPECIES' ABBREVIATIONS

Acro hex = *Acrossocheilus hexagonolepis*

Ambl man = *Amblyceps mangois*

Aspi jay = *Aspidoparia jaya*

Aspi mor = *Aspidoparia morar*

Bari bal = *Barilius barila*

Bari ban = *Barilius barna*

Bari bed = *Barilius bendelisis*

Bari bol = *Barilius bola*

Bari sha = *Barilius shacra*

Bari til = *Barilius tileo*

Bari vag = *Barilius vagra*

Boti loh = *Botia lohachata*

Chad bac = *Chanda baculis*

Chad ran = *Chanda ranga*

Chag cha = *Chagunius chagunio*

Chan pun = *Channa punctatus*

Chel cac = *Chela cachius*

Clup gar = *Clupisoma garua*

Cros lat = *Crossocheilus latius*

Dani dev = *Danio devario*

Esom dan = *Esomus danricus*

Euch hod = *Euchiloglanis hodgarti*

Garr got = *Garra gotyla*

Glos giu = *Glossogobius giuris*

Glyp kas = *Glyptothorax kashmirensis*

Glyp pec = *Glyptothorax pectinopterus*

Glyp tel = *Glyptothorax telchitta*

Glyp tri = *Glyptothorax trilineatus*

Labe der = *Labeo dero*

Lepi gun = *Lepidocephalus guntea*

Mast arm = *Mastacembelus armatus*

Mast pan = *Mastacembelus pancalus*

Noem bea = *Noemacheilus beavani*

Noem cor = *Noemacheilus corica*

Noem rup = *Noemacheilus rupecula*

Noem sca = *Noemacheilus scaturigina*

Noem she = *Noemacheilus shebbearei*

Oste cot = *Osteobrama cotio*

Pseu sul = *Pseudecheneis sulcatus*

Punt con = *Puntius conchonius*

Punt gug = *Puntius guganio*

Punt sop = *Puntius sophore*

Punt tic = *Puntius ticto*

Rasb dan = *Rasbora daniconius*

Salm bac = *Salmostoma bacaila*

Schi pro = *Schizothorax progastus*

Schi ric = *Schizothorax richardsoni*

Semi sem = *Semiplotus semiplotus*

Tor put = *Tor putitora*

Tor tor = *Tor tor*

Xene can = *Xenentodon cancila*

# VITA

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Candidate for the Degree of

Doctor of Philosophy

Thesis: MULTIVARIATE ANALYSIS OF FISH ASSEMBLAGE COMPOSITION AND ENVIRONMENTAL CORRELATES IN A HIMALAYAN RIVER - NEPAL'S KALI GANDAKI/NARAYANI

Major Field: Zoology

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