Journal of Applied Ichthyology

J. Appl. Ichthyol. 29 (2013), 1097–1103

ISSN 0175–8659

Received: July 18, 2012
Accepted: October 11, 2012
doi: 10.1111/jai.12141

Stock structure analysis of *Labeo rohita* (Hamilton, 1822) across the Ganga basin (India) using a truss network system

By J. I. Mir[1], U. K. Sarkar[1], A. K. Dwivedi[1], O. P. Gusain[2] and J. K. Jena[1]

[1]*National Bureau of Fish Genetic Resources, Lucknow, India;* [2]*Department of Zoology and Biotechnology, Hemwati Nandan Bahuguna Garhwal University, Srinagar Garhwal, Uttarakhand, India*

Summary

In this study the intraspecific variation of wild *Labeo rohita* was investigated on the basis of morphometric characters using the truss network system constructed from the fish body. Altogether 435 fish samples were collected from six drainages of the Ganga basin in India. Data were subjected to principal component analysis, discriminant function analysis and univariate analysis of variance. The first principal component (PC1) explained 47.88% of the total variation, while PC2 and PC3 explained 17.22 and 8.33%, respectively. The step-wise discriminant function analysis retained three variables that significantly discriminated the populations. Using these variables, 62.3% of the original groups were classified into their correct samples and 53.1% of the cross-validated groups omitting one procedure were classified into their correct samples. Misclassification was higher for samples from the River Gomti (28.6%). Of the total of 31 transformed truss measurements, 30 exhibited significant differences among populations. These findings indicate the presence of six different stocks of *L. rohita* in the Ganga basin.

Introduction

The study of morphological characters, with the aim of defining or characterizing fish stock units, has for some time been of strong interest in ichthyology (Cadrin, 2000). In general, a 'fish stock' is a local population adapted to a particular environment, and having genetic differences from other stocks (MacLean and Evans, 1981). Although genetic differences among stocks are a condition of this definition, phenotypic variations still continue to have an important role in stock identification among groups of fish (Costa et al., 2003). Usage of phenotypic characters is particularly important where the differences are mostly attributable to environmental influences rather than to genetic differentiation (Pinheiro et al., 2005).

Various tools, such as meristics and morphometrics, traditional tags, parasites as natural tags, otolith chemistry, molecular genetics and electronic tags have been used for the purpose of stock identification, among which the study of morphometric traits is one of the most frequently employed and cost-effective methods. To overcome the inherent weaknesses of traditional morphometric methods, a system of morphometric measurements entitled 'the truss network system' (Strauss and Bookstein, 1982) has been increasingly employed for purposes of stock identification, which essentially discriminates 'phenotypic stocks' that are groups of individuals with similar growth, mortality and reproductive rates (Booke, 1981). The methodology is predicated on the measurement of across-body distances connecting two morphological landmarks from a sequential series of connected polygons. This type of landmark-based technique using geometric morphometrics imposes no restrictions on the direction of variation and localization of shape changes and is highly effective in capturing information regarding the shape of an organism (Cavalcanti et al., 1999).

The Indian major carp, *Labeo rohita* (commonly known as *Roho labeo*), family Cyprinidae, is a warm-water teleost in rivers, reservoirs, lakes, and pools. It has been suggested that *L. rohita* undergo local migration that may result in the formation of the stock units based on environmental conditions. A column feeder herbivore showing rapid growth in terms of flesh, *L. rohita* are the most choice and prestigious culturable fishery in India and constitute a main capture fishery of the Ganga, especially in the upper and lower stretches and tributaries. The major source of *Roho labeo* seed in India is contributed via the Ganga basin (Chondar, 1999). The fish grows to a maximum size of 200 cm (Frimodt, 1995). This species is categorized as LC (Least Concern) as per IUCN (2012), but some species in the *Labeo* genus in India (Talwar and Jhingran, 1992) and Bangladesh (Hussain and Mazid, 2004) are categorized as endangered. To thwart this drop in *Roho labeo* catch across the Ganga basin, a study of the stock structure is a prerequisite that has yet to be done. In India the National Bureau of Fish Genetic Resources has been running a flagship network programme on stock identification of *L. rohita* using biological and molecular tools (Lakra and Sarkar, 2010). The present study is a part of this programme which aims to explore the stock structure of this species based on morphometric characteristics using the truss network system for successful development and management of *Roho labeo* across the Ganga Basin.

Materials and methods

Study areas

The Ganga River basin is located 70–88°30′E and 22°–31°N. With a total drainage area exceeding 1 060 000 km^2 the basin is the fifth largest in the world. The length of the main channel from the traditional source of the Gangotri Glacier in India is some 2550 km. The annual volume of water discharged by the Ganga is the fifth highest in the world, with a mean discharge rate of 18.7×10^3 m^3 s^{-1} (Welcomme, 1985). The main sources of water in the basin are direct seasonal rainfall mainly from the southwest, and glacial and snowmelt during the summer (Chapman, 1995). The main

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channel of the Ganga begins at the confluence of the Bhagirathi and Alaknanda, which descend from the upper Himalayas to Devprayag (520 masl) and receives a number of major tributaries. The northern tributaries that enter on the left bank principally include the Ghagra, Gomti, Buri Gandak and Kosi; the southern tributaries include Yamuna (Ken, Betwa), Son, Chambal, Tons, Kalisindh, Sharda and Damodar. Most of these tributaries are controlled by irrigation barrages, with two major barrages across the main channel: one at Haridwar which abstracts much of the water at this point to irrigate the Doab region, and one at Farakka which diverts water down to Calcutta. All of these structures modify the flow of the river and may have a considerable influence on fish distribution. Fish and fisheries are both important resources and activities in their own right but also provide indicators of the overall impact of anthropogenic changes throughout the basin.

Sampling

A total of 435 *Roho labeo* were randomly collected from six drainages of the Ganga basin from January 2009 to June 2012 and analyzed for morphometric variations. Sampling site locations, land use patterns, the number of samples analyzed per river as well as the GPS coordinates are presented in Table 1.

On-site procedure

Digitization of samples. Sampled specimens were first cleansed in running water, drained and placed on a flat platform with graph paper as a background, which was used for calibrating the coordinates of the digital images. Each individual was labeled with a specific code for identification. A Cyber shot DSC-W300 digital camera (Sony, Japan) was used to capture the digital images, which provided a complete archive of body shape and allowed a repeat of the measurements when necessary (Cadrin and Friedland, 1999). After image capture, each fish was dissected for sex determination by macroscopic examination of the gonads. The gender was used as the class variable in ANOVA to test for significant differences in morphometric characters, if any, between male and female *L. rohita*.

Laboratory Procedure

The truss protocol used for *L. rohita* in the present study was based on 14 landmarks whereby the truss network was constructed by interconnecting the landmarks to form a total of 31 measurements (Fig. 1). The extraction of truss distances from the digital images of specimens was conducted using a linear combination of three software platforms: tpsutil, tpsDig2 v2.1 (Rohlf, 2006) and Paleontological Statistics (PAST) (Hammer et al., 2001). A box truss of 31 lines connecting these landmarks was generated for each fish to represent the basic shape of the fish (Strauss and Bookstein, 1982). All measurements were transferred to a spreadsheet file (Excel 2007), and the X-Y coordinate data transformed into linear distances by computer (using the Pythagorean Theorem) for subsequent analysis (Turan, 1999).

Multivariate Data analysis

Size-dependent variation was corrected by adapting an allometric method as suggested by Elliott et al. (1995):

$$M_{adj} = M(L_s/L_0)^b$$

where M is the original measurement, M_{adj} the size adjusted measurement, L_0 the standard length of the fish, L_s the overall mean of standard length for all fish from all samples in each analysis, and b estimated for each character from the observed data as the slope of the regression of log M on log L_0 using all fish from each group. The results derived from the allometric method were confirmed by testing the significance of the correlation between the transformed variables and standard length (Turan, 1999). Univariate analysis of variance (ANOVA) was performed for 31 morphometric characters to evaluate the significant difference among the six locations. In the present study, linear discriminant function analyses (DFA) and principal component analysis (PCA) were employed to discriminate the six populations. Principal component analysis helps in morphometric data reduction (Veasey et al., 2001), in decreasing redundancy among the variables (Samaee et al., 2006) and in extracting a number of independent variables for population differentiation (Samaee et al., 2009). The Wilks' λ was used to compare the differences between and among all groups. The DFA was used to calculate the percentage of correctly classified (PCC) fish. A cross-validation using PCC was done to estimate the expected actual error rates of the classification functions. Statistical analyses for morphometric data were performed using the SPSS version 16.1.0 software package and Excel (Microsoft Office 2007).

Results

None of the standardized truss measurements showed a significant correlation with the standard length of the fish,

Table 1
Sample size and GPS coordinates of *Labeo rohita* samplings sites and the patterns of land use, Ganga basin, India

Rivers (Sites)	Sample size	Latitude (°N)	Longitude (°E)	Land-use pattern
Ganga (Narora)	68	28°12′12″	78°23′33″	Atomic power plant, dams, temples, semi-urban, agriculture, domestic sewage
Ghaghara (Faizabad)	58	25°45′55″	84°38′14″	Semi-urban, agriculture, domestic sewage
Betwa (Bhojpur)	69	24°8′54″	76°30′35″	Small dams, water lifting pumps, new road construction activities, industrial discharge, temples, rural, agriculture
Sharda (Palia)	64	22°49′47″	75°47′59″	Rural area, new road construction activities, agriculture activities, forests
Ken (Patan)	92	23°17′4″	79°41′27″	Rural area, buffer zone (PA) agriculture activities, forest
Gomti (Lucknow)	84	26°52′24″	80°55′42″	Urban, barrage, domestic sewage, beverage, distillery industry, temple on the river bank

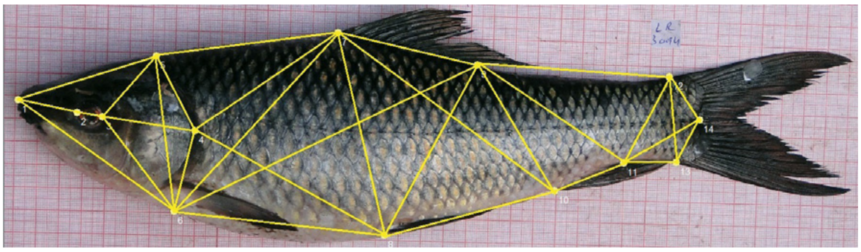

Fig. 1. Schematic image of *L. rohita* depicting 14 landmarks and associated box truss to infer morphological differences among *Labeo rohita* populations. 1. Tip of snout; 2. end of eye towards mouth; 3. end of eye towards tail; 4. end of operculum; 5. forehead (end of frontal bone); 6. dorsal origin of pectoral fin; 7. origin of dorsal fin; 8. origin of pelvic fin; 9. termination of dorsal fin; 10. origin of anal fin; 11. termination of anal fin; 12. dorsal side of caudal peduncle, at the nadir; 13. ventral side of caudal peduncle, at the nadir; 14. end of lateral line (Adapted from truss box, after Strauss and Bookstein, 1982 and Bookstein, 1991)

indicating that the effects of the body length had been successfully removed by the allometric transformation. Among six drainages of *Roho labeo*, means of 30 of 31 truss measurements were found to be significantly ($P < 0.01$) different in univariate analysis of variance. The one remaining truss measurement, viz. 10–11, was found to be insignificantly different ($P > 0.05$). The morphometric characters between both sexes did not differ significantly ($P > 0.05$), hence the data for both sexes were pooled for all subsequent analyses.

A common problem with many fish morphology studies that use multivariate analysis is potentially an inadequate sample size. For decades, authors of theoretical works on PCA and DFA recommended that the ratio of the number of organisms measured (N) relative to the parameters included (P) in the analysis be at least 3–3.5 (Kocovsky et al., 2009). Small N values may fail to adequately capture covariance or morphological variation, which may lead to false conclusions regarding differences among groups (McGarigal et al., 2000). In this analysis all 31 characters were retained and under these circumstance the N: P ratio was 14.03 for all 31 truss measurements.

In order to determine which morphometric measurement most effectively differentiates populations, the contributions of the variables to principle components (PC) were examined. To examine the suitability of the data for PCA, Bartlett's Test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure was performed. The Bartlett's Test of sphericity tests the hypothesis that the values of the correlation matrix equal to zero (small significance levels support the hypothesis that there are real correlations between the variables), and the KMO measure of sampling adequacy tests whether the partial correlation among variables is sufficiently high (Nimalathasan, 2009). The KMO statistics varies between 0 and 1. Kaiser (1974) recommends that values greater than 0.5 are acceptable. Between 0.5 and 0.7 are mediocre, between 0.7 and 0.8 are good, and between 0.8 and 0.9 are superb (Field, 2000). In this study, the value of KMO for the overall matrix is 0.75 and the Bartlett's Test of sphericity is significant ($P \leq 0.01$). The results (KMO and Bartlett's) suggest that the sampled data are appropriate to proceed with a factor analysis procedure.

Principal component analysis of 31 morphometric measurements extracted six factors with eigen-values > 1, explaining 86.89% of the variance (Fig. 2). The first principal component (PC1) accounted for 47.88% of the variation, second (PC2), third (PC3), fourth (PC4), fifth (PC5) and the sixth (PC6) for 17.22%, 8.93, 4.92, 4.60 and 3.32 respectively (Table 2), the most significant loadings on PC1 were 3–5, 3–6, 4–6, 4–7, 4–8, 5–6, 5–7, 6–7, 6–9, 7–10, 8–9, 8–10, 9–11, 10–11, 10–12, 11–14 and 12–14 (Table 3). In this analysis, the characteristics with an eigen-values exceeding 1 were included and others discarded.

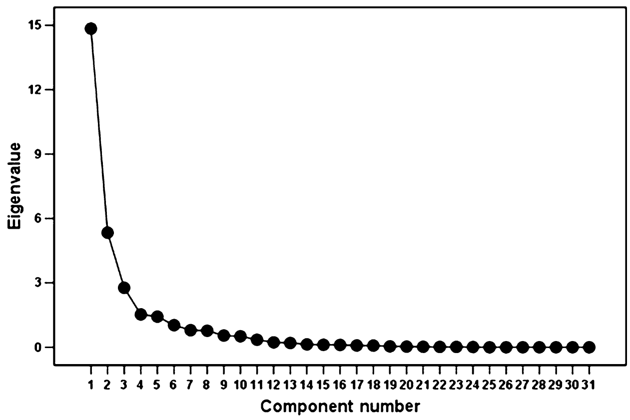

Fig. 2. Scree plot of principal component in morphometric measurements for *Labeo rohita* in six Ganga basin drainages

Table 2
Eigen values, percentage of variance and percentage of cumulative variance for 6 PC in *Labeo rohita* morphometric measurements

Factor	Eigen-values	% of Variance	Cumulative%
PC 1	14.844	47.884	47.884
PC 2	5.339	17.222	65.106
PC 3	2.770	8.935	74.041
PC 4	1.527	4.925	78.966
PC 5	1.426	4.601	83.566
PC 6	1.031	3.327	86.893

One method to reduce the number of factors to something below that found by using the 'eigen-value greater than unity' rule is to apply the scree test (Cattell, 1966). In this test, eigen-values are plotted against the factors arranged in descending order along the *X*-axis. The number of factors that correspond to the point at which the function so produced appears to change slope is deemed to be the number of useful factors extracted. This is a somewhat arbitrary procedure. Its application to this dataset led to the conclusion that the first four factors should be accepted. Worth mentioning here is that factor loading greater than 0.30 is considered significant, 0.40 more important, and 0.50 or greater is very significant (Nimalathasan, 2009). For parsimony, in this study only those factors with loadings above 0.40 were considered significant.

Table 3
Results of factors extraction in PCA after Varimax normalized rotation

	Components					
Truss measurement	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
1–2		0.682				
1–5		0.961				
1–6		0.968				
2–3			0.841			
3–4		0.704				0.559
3–5	0.407	0.600		0.528		
3–6	0.860					
4–5				0.811		
4–6	0.908					
4–7	0.905			0.258		
4–8	0.413		0.652		0.503	
5–6	0.830			0.426		
5–7	0.901					
6–7	0.665			0.616		
6–8				0.616		0.464
6–9	0.763					
7–8	0.682			0.620		
7–9	0.434	0.712		0.439		
7–10	0.767				0.430	
8–9	0.819					
8–10	0.698				0.509	
9–10		0.846				
9–11	0.665		0.502			
9–12		0.838				
10–11	0.635		0.665			
11–12	0.660				0.493	
11–13					0.778	
11–14	0.561				0.535	
12–13			0.896			
12–14	0.434	0.712		0.439		
13–14						0.664

Table 5
Morphometric measurement contributions to discriminant functions of *Labeo rohita* collected from six drainages of Ganga basin. Character descriptions given in Fig 1

	Function		
Character	d.f. 1 (61.4%)	d.f. 2 (19.1%)	d.f. 3 (12.2%)
1–2	0.166	−0.299	−0.395(*)
1–5	0.388(*)	−0.347	−0.223
1–6	0.334(*)	−0.296	−0.243
2–3	0.459(*)	−0.348	−0.014
3–4	0.212(*)	−0.167	−0.064
3–5	0.577(*)	−0.174	0.084
3–6	0.511(*)	0.093	0.365
4–5	0.495(*)	−0.015	0.156
4–6	0.411	0.180	0.458(*)
4–7	0.537(*)	0.067	0.316
4–8	0.436(*)	−0.166	0.370
5–6	0.536(*)	0.146	0.426
5–7	0.532(*)	0.092	0.313
6–7	0.448(*)	0.054	0.274
6–8	0.286(*)	0.092	0.281
6–9	0.628(*)	−0.011	0.486
7–8	0.385	0.205	0.457(*)
7–9	0.579(*)	−0.152	0.098
7–10	0.310	0.260	0.661(*)
8–9	0.514(*)	−0.020	0.406
8–10	0.414(*)	−0.014	0.379
9–10	0.415(*)	−0.163	0.003
9–11	0.460(*)	0.030	0.379
9–12	0.364(*)	−0.177	−0.117
10–11	0.572(*)	−0.147	0.183
11–12	0.474(*)	0.089	0.406
11–13	0.281	0.073	0.320(*)
11–14	0.543(*)	−0.226	0.271
12–13	0.476(*)	−0.393	0.072
12–14	0.579(*)	−0.152	0.098
13–14	−0.259	−0.593(*)	0.437

* indicates significance level ($P < 0.01$).

Wilk's λ tests of discriminant analysis indicated significant differences in morphometric characters of all populations except the fifth function, which were non-significant ($P > 0.05$), whereas the first three functions showed highly significant differences ($P < 0.001$) (Table 4).

The DFA revealed five morphological indices describing 61.4, 19.1, 12.2, 5 and 2.3% of the morphological variation in the sample (Table 5). We considered the first three of these for further interpretations. The truss distances with meaningful loading on first factor (DF1) were 1–5, 1–6, 2–3, 3–4, 3–5, 3–6, 4–5, 4–7, 4–8, 5–6, 5–7, 6–7, 6–8, 6–9, 7–9, 8–9, 8–10, 9–10, 9–11, 9–12, 10–11, 11–12, 11–14, 12–13 and 12–14, with this factor explaining 61.4% of the total variance. All of these 25 distances characterize the measurements covering the entire body of the fish. The second factor (DF2) explained 19.1% of total variation, and 1 distance variable (13–14) showed significant loading belonging to the tail region. Five distances (1–2, 4–6, 7–8, 7–10 and 11–13) loaded heavily on Factor 3 (DF3), which explained 12.2% of the total variance. These were concentrated in the head region, across the body and the anal region. The DF1 vs DF2 plot explained 80.5% of total variance among the samples and showed intermingling among some *L. rohita* stocks from the Ganga basin (Fig. 3). Discriminant function analysis showed 62.3% correct classification of individuals into their original populations, and the cross-validation test results were com-

Table 4
Results of Wilks' lambda tests (functions 1 through 5) for verifying differences among six stocks of *Labeo rohita* with morphometric characters separately compared using discriminant function analysis

Functions	Wilks' λ	χ^2	d.f.	P
1 through 5	0.130	847.199	150	0.000
2 through 5	0.374	409.278	116	0.000
3 through 5	0.591	218.805	84	0.000
4 through 5	0.809	87.964	54	0.002
5	0.934	28.602	26	0.329

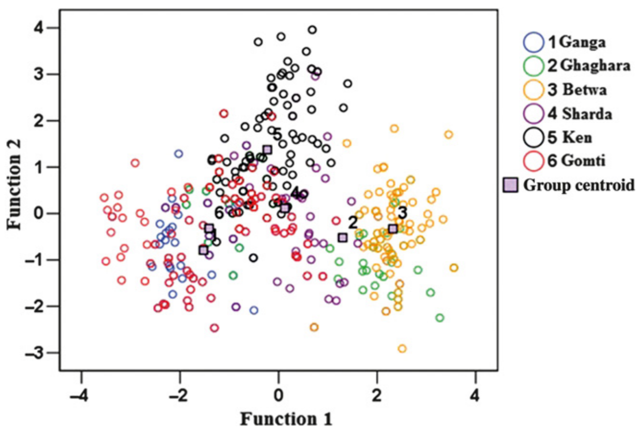

Fig. 3. Discriminant analysis plot with 31 morphometric variables for *L. rohita* in six drainages of Ganges basin, India

Table 6
Percentage of specimens classified in each group and after cross-validation for morphometric measurements of *Labeo rohita* from six drainages of Ganga basin (62.3% of originally grouped cases correctly classified, 53.1% cross-validated grouped cases correctly classified)

Rivers	Ganga	Ghaghara	Betwa	Sharda	Ken	Gomti	Total
Original group (%)							
Ganga	67.6	0.0	7.4	2.9	4.4	17.6	100.0
Ghaghara	6.9	53.4	17.2	5.2	12.1	5.2	100.0
Betwa	0.0	15.9	81.2	1.4	1.4	0.0	100.0
Sharda	7.8	12.5	1.6	59.4	14.1	4.7	100.0
Ken	1.1	0.0	0.0	10.9	71.7	16.3	100.0
Gomti	28.6	3.6	0.0	22.6	4.8	40.5	100.0
Cross-validated (%)							
Ganga	57.4	0.0	7.4	4.4	5.9	25.0	100.0
Ghaghara	6.9	44.8	24.1	5.2	12.1	6.9	100.0
Betwa	1.4	18.8	76.8	1.4	1.4	0.0	100.0
Sharda	9.4	25.0	3.1	45.3	14.1	3.1	100.0
Ken	1.1	0.0	1.1	12.0	65.2	20.7	100.0
Gomti	34.5	3.6	0.0	26.2	7.1	28.6	100.0

parable to the results obtained from PCC. The percentage of correctly classified fishes was highest in the Betwa River (81.2%), followed by the Ken, Ganga, Sharda, Ghaghara and Gomti rivers in decreasing order. The highest intermingling was observed between rivers, *viz*. the Ganga and Gomti, Betwa and Ghaghara, Sharda, Ken and Ghaghara, Ken and Gomti and Gomti, Ganga and Sharda (Table 6).

Discussion

In general, fishes show higher degrees of variation within and between populations than other vertebrates, and are more susceptible to environmentally-induced morphological variation (Wimberger, 1992). Such variation in morphology is commonly due to the isolation of portions of a population within local habitat conditions. A sufficient degree of isolation may result in notable phenotypic and genetic differentiation among fish populations within a species, as a basis for separation and management of distinct populations (Turan et al., 2004). Such differentiation can occur through different processes. For example, reproductive isolation between different stocks of fishes may arise by homing to different spawning areas (Hourston, 1982), or by hydrographic features that reduce or prevent migration between areas (Iles and Sinclair, 1982). Failure to recognize or to account for stock complexity in management units has led to an erosion of spawning components, resulting in a loss of genetic diversity and other unknown ecological consequences (Begg et al., 1999).

The results obtained from the truss-based morphometrics indicated that the *L. rohita* showed significant phenotypic heterogeneity among some populations and limited overlapping between others in the Ganga basin. Discriminant function analysis (DFA) could be a useful method to distinguish different stocks of the same species (Karakousis et al., 1991). In the present investigation, 62.3% of individuals were correctly classified into their respective groups by DFA, indicating intermingling among some the populations. Turan et al. (2004) studied the anchovy (*Engraulis encrasicolus*) from different areas of the Mediterranean Sea, and found significant morphometric heterogeneity among different populations by applying DFA. Turan et al. (2004) suggested four phenotypically-distinct local samples varying in degrees of differentiation and owed this to the migration of the fish. The DFA segregation was partly confirmed by PCA, where the graphs of PC1 and PC2 scores for each sample revealed that, among six populations, some showed overlapping and others were clearly distinct. The populations of the rivers Ken and Betwa showed limited overlapping with other populations, possibly due to the large distances from the remaining four drainages. The rivers Ken and Betwa are tributaries of the River Yamuna (a large tributary of the Ganga), and the morphological discreteness among these rivers may be due to the selection of the sampling sites. Samples of *L. rohita* from the River Ken were obtained from a stretch belonging to a buffer zone (Panna national park and forest area), whereas the River Betwa has human interruptions throughout. Morphological parameters of *L. rohita* showed overlapping between four other rivers, which may be attributed to the small geographic distances between these drainages and their similar environmental conditions. Such indications of stock structure arise from consideration of the first, second and third factors. This analysis confirmed that the variation in morphological measurements was evident in the head region, eye diameter, body depth and caudal peduncle, among different populations of *Roho labeo*. Hossain et al. (2010) applied DFA and PCA to three populations of *L. calbasu* from the Jamuna and Halda rivers as well as a hatchery and reported morphological discrimination among them due to environmental factors and local migration of the fish. Khan et al. (2012) noted similar observations in *Channa punctatus* from three Indian rivers, where the environmental conditions were found to play an important role in spatial distribution, movement and isolation of fish stocks.

The variation among the stocks of six populations of Ganga basin could be a consequence of phenotypic plasticity in response to uncommon hydrological conditions such as differences in alkalinity, current pattern, temperatures, turbidity, and land-use patterns among these drainages. The closeness between stocks may be due to their similar habitat attributes and to environmental impacts. These results are similar to the findings of Boussou et al. (2010) in the *Chromidotilapia guntheri* from three coastal rivers of Africa where environmentally-induced morphological differences were found among the tributaries of the Tanoe River, which were geographically close to each other. Quilang et al. (2007) noticed similar observations in silver perch *Leiopotherapon plumbeus* from three lakes in the Philippines and attributed this to the differences in the physico-chemical characteristics of the water.

These differences were attributed to both phenotypic plasticity and genetic concerns due to the distinct environmental attributes. Akbarzadeh et al. (2009) used 32 truss morphometric measurements to determine the variation among different stocks of pikefish (*Sander lucioperca*) from the southern Caspian Sea. The Akbarzadeh et al. (2009) analyses successfully demonstrated three morphologically-distinct populations and concluded that these differences may be due solely to the body shape variation and not to size effects, giving the reason that this discrimination would be attributed to the spawning migration of this anadromous fish. Similarly in our study, morphological differences within the Ganga basin may be solely related to body shape variation, as the size effect was removed successfully by allometric transformation.

The causes of morphological differences among different populations are often quite difficult to explain. It has been suggested that the morphological characteristics of fish are determined by genetics and environment, and the interaction between them (Poulet et al., 2004). Environmental factors prevailing during the early development stages, when the individual's phenotype is more amenable to environmental influence are of particular importance (Pinheiro et al., 2005). The phenotypic variability may not necessarily reflect population differentiation at the molecular level (Ihssen et al., 1981). Apparently the fragmentation of river impoundments can lead to an enhancement of pre-existing genetic differences, providing a high interpopulation structuring (Esguicero and Arcifa, 2010). Thus, there is the possibility that the observed morphological variations in the present study might be due to genetic differences among the populations.

The truss system can be successfully used to investigate stock separation within a species, as reported for other species in freshwater and marine environments. In this study, the truss protocol revealed a clear separation of *L. rohita* wild stocks observed in six drainages of the Ganga basin, suggesting a need for separate management strategies in order to sustain the stocks for future use. The observations in the present study can further be confirmed based on molecular and biochemical methods. Application of molecular genetic markers such as microsatellite and mtDNA applications along with morphometric studies would be effective methods to further examine the genetic component of phenotypic discreteness between geographic regions and to facilitate the development of management recommendations. This additional examination would provide further confirmation of the stock structure resolved in this study with the truss analysis. However, based on this morphometric study, development of proper guidelines for the implementation of appropriate mesh sizes in all drainages of the Ganga basin may help in sustaining this resource for future use.

Acknowledgements

The authors are grateful to the Director of NBFGR, Lucknow, for providing necessary facilities. Thanks are due to the Indian Council of Agricultural Research, New Delhi for financial support to carry out this work. We would also like to especially acknowledge Professor Harald Rosenthal (Editor-in-Chief, JAI) and referees for their constructive comments for the improvement of our paper.

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Author's address: Uttam Kumar Sarkar, National Bureau of Fish Genetic Resources, Canal Ring Road, PO Dilkusha, Lucknow 226002, UP, India.
E-mail: usarkar1@rediffmail.com; uksarkar1@gmail.com