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Stock structure analysis of *Decapterus russelli* (Ruppell, 1830) from east and west coast of India using truss network analysis

Swatipriyanka Sen[a,*], Shrinivas Jahageerdar[a], A.K. Jaiswar[a], S.K. Chakraborty[a], A.M. Sajina[b], G.R. Dash[c]

[a] *Fisheries Resource Harvest and Post Harvest Management Division, Central Institute of Fisheries Education, Panchmarg, Versova, Mumbai 400 061, Maharashtra, India*[1]
[b] *Fisheries Resource and Environment Management Division, CIFRI, Barrackpore, Kolkata 700120, West Bengal, India*
[c] *Crustacean Fisheries Division, Mumbai Research Centre of Central Marine Fisheries Research Institute, Versova, Mumbai 400 061, Maharashtra, India*

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ABSTRACT

Decapterus russelli (Indian Scad) is an important pelagic carangid distributed on both east and west coast of India. Despite its wide distribution, the stock structure of the species is not well known. The present study was conducted to investigate stock structure of *D. russelli*, based on body shape morphometrics using truss network system. A total number of 360 samples of the species were collected from two centres, Digha and Visakhapatnam in Bay of Bengal from east coast and on the west coast from Mumbai and Cochin in Arabian Sea. A truss network was constructed by interconnecting 11 landmarks to form a total of 23 distance variables extracted from digital images of samples using tps Dig2 and PAST software platforms. The transformed truss measurements were subjected to factor analysis and classification by cross-validation of discriminant analysis. Factor analysis showed meaningful loading of the middle portion, the portion below the second dorsal fin, above anal fin, and the caudal portion on first and second factor, respectively. The factor analysis revealed the existence of two morphologically different stocks of *D. russelli* between east and west coast of India. The discriminant analysis was conducted by the combination of the truss distances that loaded on Factor-1 and Factor-2. The measurements that belonged to the middle portion and caudal portion of the body produced minimum misclassification rate of 5% between the coasts; whereas, the misclassification was 28% for all the four stocks. The misclassification was higher between the stocks within the coast. The high rate of misclassification observed within the coast is probably the result of no demarcation in fishing area. The occurrence of a separate stock on each coast may be the result of different physical and ecological condition of Bay of Bengal and Arabian Sea.

1. Introduction

Morphometric variation between stocks can provide a basis for stock structure, and may be more applicable for studying short-term, environmentally induced variation; perhaps more applicable for fisheries management (Begg et al., 1999). In order to manage a fishery effectively, it is important to know the identity of stock structure of the species, as each stock must be managed separately to optimise their yield (Grimes et al., 1987). Studies of morphological variations between populations continue to have an important role to play in stock identification. Studies have demonstrated that stable differences in shape between groups of fish may reveal different growth, mortality or reproductive rates, and are relevant for the definition of stocks (Swain and Foote, 1999; Cadrin, 2000). The study of morphometrics using truss network system (Strauss and Bookstein, 1982) is a quantitative method to represent the complete shape of fish. This representation uses well defined morphological landmarks that extend across the entire fish. Such approaches represent geometric morphometrics which poses no restriction on the directions of variation and localization of shape changes. Truss morphometrics approach is an effective method for capturing information about the shape of an organism (Cavalcanti et al., 1999). The extension of a truss network in a uniform network across a fish is referred to as a trussed box (Strauss and Bookstein, 1982). In theory, the trussed box captures the shape of the fish and thereby increases the likelihood of extracting morphometric differences between specimens (Turan, 1999). Therefore, this quantitative method has been increasingly used for discrimination of within population allometry and between population shape differences (Strauss and Bookstein, 1982; Bookstein et al., 1985).

The Indian scad, *Decapterus russelli* (Ruppell, 1830), family Carangidae, is a benthopelagic, marine shoaling fish found at a depth of 40–300 m. The distribution of fish was traced to 200 m depth along west coast and 300 m depth along the east coast of India (Tamhane, 1996). The pelagic fin fishes form 52% of the total

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* Corresponding author. Tel.: +91 9322097152.
E-mail address: swatipriyank1a@gmail.com (S. Sen).

[1] The http://www.cife.edu.in.

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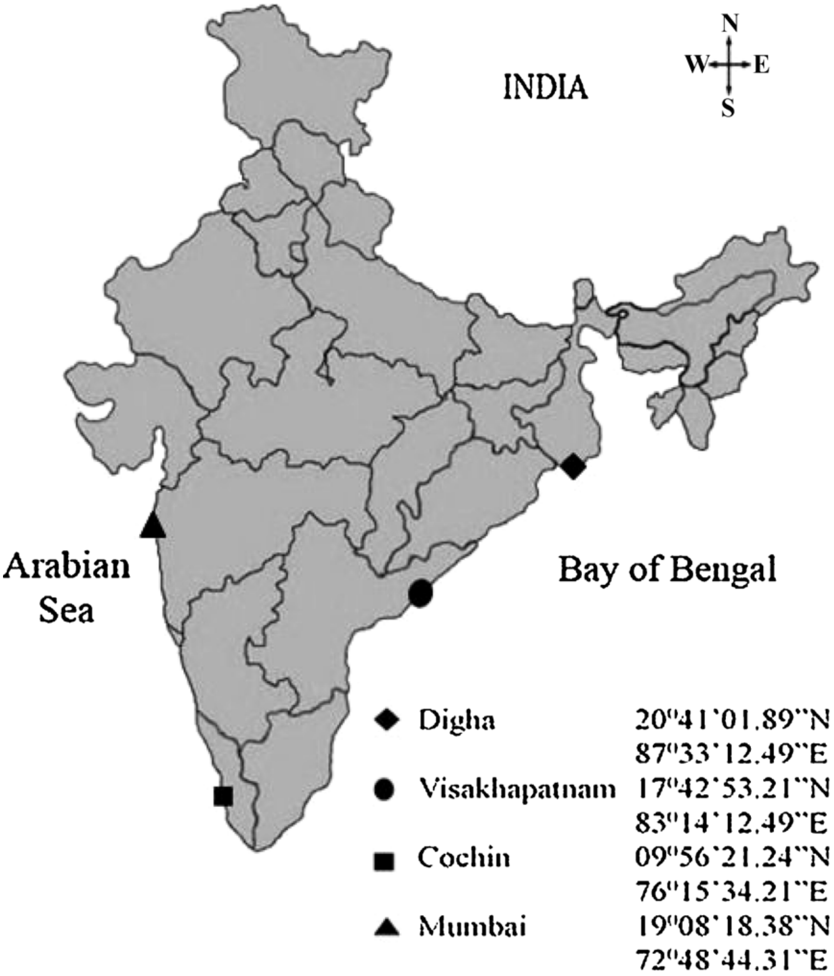

Fig. 1. India map showing sampling locations.

marine landings of India, out of which, carangids contribute 11%, and *D. russelli* contributes 31% to the landed carangid in India (Anon, 2009). It is an important species used as food and bait occasionally; the species is also an important link in food chain of larger predators. To date, there is no report on stock structure of *D. russelli* along the Indian waters. Therefore, the present study aims to investigate stock structure of *D. russelli* based on morphometric characteristics using truss network system throughout east and west coast of India.

2. Materials and methods

2.1. Sample collection

A total of 360 intact specimens of *D. russelli* were collected from the West Bengal (Digha) and Andhra Pradesh (Visakhapatnam) of east coast and Maharashtra (Mumbai) and Kerala (Cochin) of west coast of India (Fig. 1) between November 2009 and March 2010. These specimens were contributed mainly by commercial catches of trawlers, but were kept in good condition. The details of the samples from each location are listed in Table 1. The collected fish specimens were placed in insulated box with ice packs and transported to the laboratory. In the laboratory, the collected fish samples were frozen at −20 °C for 1 h.

2.2. Digitization of samples

The digitization of the image of samples was done after thawing the fish under running tap water, wiped well and placed on a flat platform with vertical and horizontal grids (Fig. 2). The distances between the vertical as well as the horizontal grids were fixed such that, one square unit covered an area of 1 cm^2 and used in calibrating the coordinates of digital images. The fins were erected and placed on a platform in such a position that it makes the origin and insertion points readily visible. Each specimen was labeled with a specific code to identify it in the image. For digitizing images of fishes, a cyber shot DSC-W300 digital camera was mounted on a leveling tripod with a bubble level as an indicator of the

Table 1
Details of samples of *Decapterus russelli* collected from various locations of east and west coast of India.

Sea	Location	Sample size	Sex ratio (M:F)	MSL ± S.E.
Bay of Bengal (east coast)	Digha	100	1:1.56	126.05 ± 1.44
	Visakhapatnam	83	1:0.89	142.53 ± 1.53
Arabian sea (west coast)	Cochin	96	1:1	137.11 ± 1.31
	Mumbai	81	1:1.08	157.62 ± 1.50
Total		360	1:1.14	140.82 ± 0.82

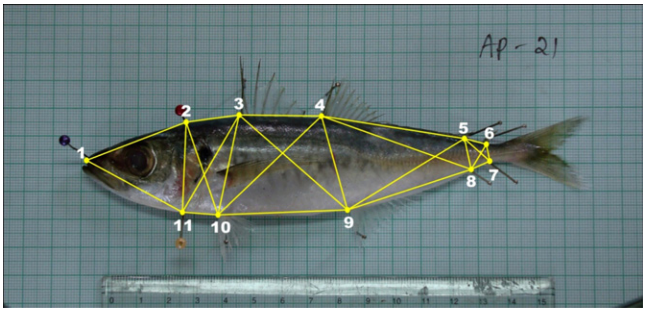

Fig. 2. Truss network of *Decapterus russelli* showing the twenty three variables extracted from 11 point truss.

inclination, and the image was taken. After digitization of the samples, the fishes were dissected to know the sex of the fish as there is no sexual dimorphism known in this fish (Balasubramanian and Natarajan, 2000). The sex ratio was found to be 1:1.14 (male:female).

2.3. Measurement of truss morphometric data

The extraction of truss distances from the digital images of specimens was done with the help of tpsDig2 V2.1 (Rohlf, 2006) and Paleontological Statistics (PAST) software (Hammer et al., 2001). A truss network was constructed by interconnecting the eleven landmarks to form a total of 23 truss points. The network extended across the entire fish to represent the full dimensions of the morphology (Fig. 2).

2.4. Analysis of truss morphometric data

All the truss measurements were log transformed and the log transformed data were tested for normality using the SAS PROC UNIVARIATE procedure (SAS, 2008) and 21 outliers were removed before further analysis. The analysis was carried out to differentiate the stocks based on coasts and within a coast. There were significant correlations between body size and truss measurements; therefore, the size dependent variation was removed using an allometric approach of Reist (1985) with some modification i.e., location wise $\mathrm{SL}_{\mathrm{mean}}$ was taken in the place of overall mean.

$$M_{\mathrm{trans}} = \log M - \beta(\log \mathrm{SL} - \log\ \mathrm{SL}_{\mathrm{mean}})$$

where M_{trans} is the transformed measurement, $\log M$ is the natural log transform of the original measurement, β is the within-group slope regressions of the $\log M$ vs $\log \mathrm{SL}$, SL is the standard length of the fish, and $\mathrm{SL}_{\mathrm{mean}}$ is the location-wise mean of the standard length.

Correlation coefficients between the transformed variables and the standard length of the fish were calculated to check whether the data transformation was effective in removing the size effect in the data. Multivariate analysis of variance (MANOVA) was performed to test for significant differences between the populations of different locations.

The 23 size corrected truss measurements were subjected to FACTOR analysis using PROC FACTOR procedure of SAS (Hatcher, 2003). The factor analysis of truss measurements was carried out in two ways *viz.* in the first case, the factors were extracted for coasts and in the second case, factors were extracted for locations within a coast. A Maximum likelihood method was used to extract the factors. Only retained factors were subjected for rotation procedure by varimax (orthogonal) rotation (SAS, 2008). For identifying the variables that demonstrate high loadings for a given component, the rotated factors were subjected to scratching procedure as described by Hatcher (2003). The PROC DISCRIM procedure (SAS, 2008) was then used to carry out the classification of individuals by cross-validation of the discriminant analysis.

Table 2
Variable loadings for the truss data from rotated factor.

Truss distances	Factor-1	Factor-2	Factor-3
01-02	0.34027	0.33874	0.03003
01-11	0.12581	0.34293	0.07470
02-03	0.13192	0.15640	0.35278
02-10	0.19688	0.29745	0.31633
02-11	0.13925	0.26641	0.12892
03-04	0.45183	0.27985	0.24320
03-09	0.40431	0.16543	−0.04694
03-10	0.74277	0.19532	−0.06597
03-11	0.11132	0.13228	0.81344
04-05	0.82278	0.08248	0.10629
04-08	0.80768	0.04090	0.21158
04-09	0.75956	0.31887	0.03390
04-10	0.53196	0.09756	0.27712
05-06	0.02952	0.38883	0.06947
05-07	0.01947	0.56409	0.19982
05-08	0.23859	0.74702	0.23031
05-09	0.78956	0.12245	0.11905
06-07	0.22645	0.26257	0.26764
06-08	0.11813	0.40397	0.24507
07-08	0.10363	0.52675	−0.04015
08-09	0.83034	0.19646	0.01411
09-10	−0.11892	0.11338	0.48695
10-11	0.19912	0.03302	0.14807

3. Results

None of the standardized truss measurements showed a significant correlation with the standard length of the fish, indicating that the effects of the body length had been successfully removed by the allometric transformation.

A multivariate analysis of variance (MANOVA) found significant differences between the four stocks for the morphometric traits studied (Wilk's Lambda = 0.019, $F = 37.18$, $p < 0.0001$). The univariate comparisons between these fishes were highly significant for the standard length and also for other morphometric traits.

The result of the factor analysis for the coasts indicated that the first three factors together explained 89.23% of the total morphometric variation, with eigen-values of 66.15, 15.74 and 7.35, respectively (Table 2). Variables 3–4, 3–9, 3–10, 4–5, 4–8, 4–9, 4–10, 5–9, 8–9 had the highest loadings on the first factor (Table 2, Fig. 3); while the variables 5–7, 5–8, 6–8, 7–8 loaded on second factor (Table 2, Fig. 3) and the highest loadings for the third factor occurred with variables 3–11, 9–10 (Table 2). These three factors were concentrated on the middle and posterior part of the body including the caudal portion. Factor loadings are correlation between the variables and the factors. In the present study the variables loaded on first, second and third factors were all positive indicating the positive correlation between the variables within a factor. This relationship is expected as the variables loading on first factor belonged to the middle portion of the body and these traits grow proportionately with one another. Similarly, the traits loading on second factor are also positively correlated with one another. Another reason for positive loadings of variables may be, due to the rotation of the factors which helps to reduce the number of negative loadings to a minimum. To represent these relationships, bivariate plots were used and the plot of Factor-1 and Factor-2 revealed that the east and west coast stocks are separate (Fig. 4a).

Given the long geographical distance between the landing centres within a coast, a possibility of distinct morphometry was expected between them; therefore locations within the coasts were analyzed separately. The factor analysis for the locations within east coast revealed that the first three factors together explained

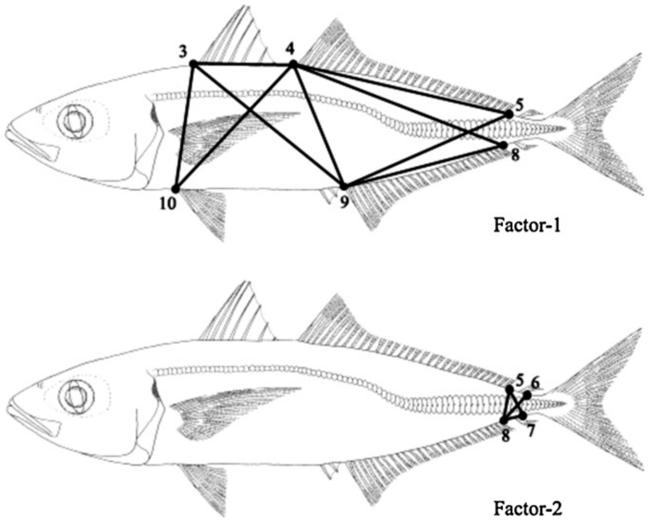

Fig. 3. Truss variables with meaningful loadings on first two factors of truss network analysis of *Decapterus russelli*.

75.68% of the total morphometric variation with eigen-values of 43.64%, 21.81%, and 10.23%, and for the west coast they explained 78.99% of the total morphometric variation with eigen-values of 46.86%, 17.42%, and 14.71%, respectively. Bivariate plot of Factor-1 against Factor-2 showed a clear evidence for size and shape variation between stocks and within east and west coasts (Fig. 4b and c). The factor analysis involving the stocks of each location (Digha, Visakhapatnam, Cochin and Mumbai) revealed that the morphology separated the fish specimens across the horizontal and vertical axis (Fig. 4d).

The discriminant analysis conducted by considering the truss traits 3–10, 4–8, 4–9 and 5–9 which loaded on Factor-1 and Factor-2 had a misclassification rate of 5% between the coasts (Table 3). However, with the same traits the overall misclassification was 28% for all the four stocks, with the misclassification being higher between the stocks within the coast (Table 4).

Table 3
Percentage of fish from each coast (in rows) classified in each coast (in columns) in the cross-validation of the discriminant analysis.

Coasts	East	West
East	98.89	01.11
West	04.83	95.17
Total rate of classification (%)	95.00	
Total rate of misclassification (%)	05.00	

The factor analysis showed the separation of the stocks within the coast but the discriminant analysis showed a high percent of misclassification of 28% indicating the intermix of the population.

4. Discussion

In general, fishes show higher degree 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, 2004). Such differentiation can occur through different processes. For example, reproductive isolation

Table 4
Percentage of fish from each location (in rows) classified in each location (in columns) in the cross-validation of the discriminant analysis.

Location	Visakhapatnam	Digha	Cochin	Mumbai
Visakhapatnam	72	25	3	0
Cochin	5	0	62	33
Mumbai	1	0	28	71
Digha	23	77	0	0
Total rate of classification (%)	72			
Total rate of misclassification (%)	28			

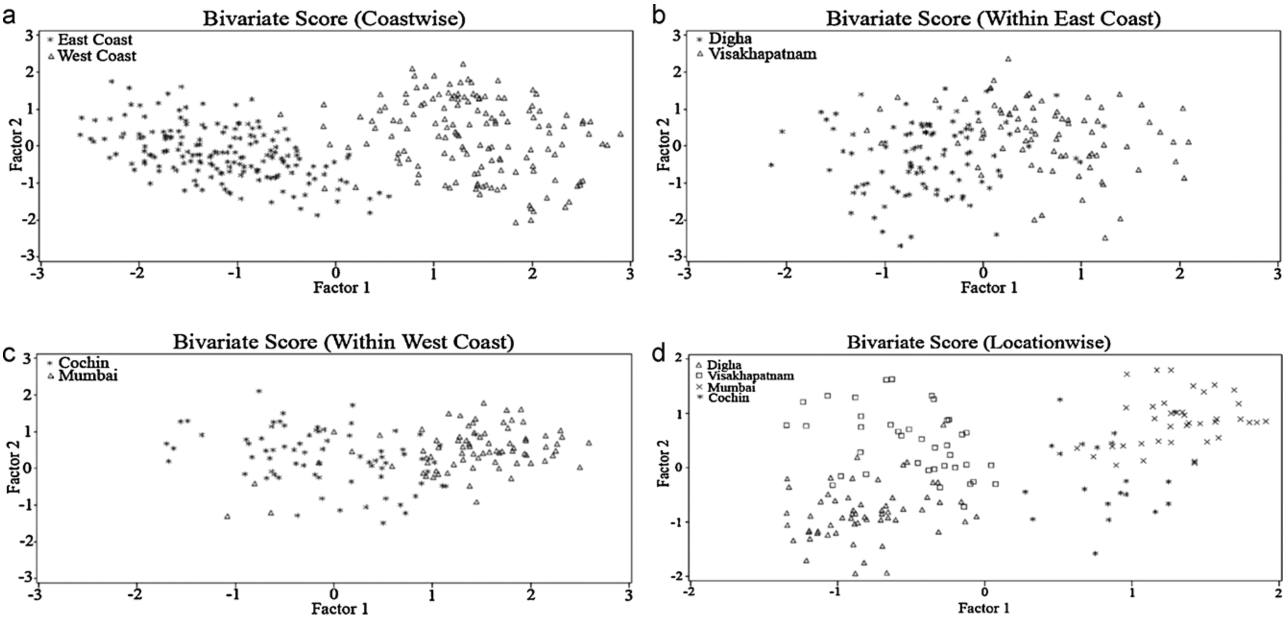

Fig. 4. Bivariate plot of scores on the two factors extracted from 11 point truss measurements of *Decapterus russelli* representing the separations. (a) Coast-wise, (b) within east coast, (c) within west coast and (d) location-wise.

between stocks of marine fishes may arise by homing to different spawning areas (Hourston, 1982) or by hydrographic features, which 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 into a loss of genetic diversity, and other unknown ecological consequences (Begg et al., 1999).

The result obtained from the truss-based morphometrics indicated that the *D. russelli* of Bay of Bengal from east coast is morphologically different from the Arabian Sea from west coast of India. Such indications of stock structure arise from consideration of the first, second and third factors. This analysis confirmed the variation evident in the middle part of the body and the portion from origin of first dorsal fin to origin of second dorsal fin and the portion below the second dorsal fin and above anal fin was useful for the stock separation. This variation in the caudal region of specimens from the Arabian Sea and the Bay of Bengal could be a consequence of phenotypic plasticity in response to uncommon hydrological conditions like difference in salinity, current pattern and temperature between these areas. The Bay of Bengal is having more turbulent water condition (Chamarthi et al., 2008). Within this scenario, these pressures can result in more resistance on fish body during the swimming and making the body more slender, specially the caudal portion. In contrast, those fish from the Arabian Sea demonstrate an abdomen that is wider and this may reflect these habitats where the sea is calmer. These differences are likely to represent adaptations to prevailing environmental conditions. However, a detailed follow-up study is required to reveal whether it is purely environmental or result of genotype by environmental interaction. Bagherian and Rahmani (2009) also reported that high water velocity leads to slender body shape in *Chalcalburnus chalcoides*. The environment conditions such as currents or water masses play an important role in spatial distribution, movement and isolation of pelagic fish stocks (Tsujita and Kondo, 1957). Thus the different current pattern of Bay of Bengal and Arabian Sea may be playing an important role in modifying the morphometry of *D. russelli* between the east and west coast, respectively. A study by Imre et al. (2002) demonstrated morphological variation in the caudal area in brook charr (*Salvelinus fontinalis*) from microhabitats differing in water velocity. Sajina et al. (2010) have also found variation in the caudal area of *Megalaspis cordyla* from the Arabian Sea and Bay of Bengal.

The separation of the stocks within the coasts may be due to different biotic and abiotic factors such as food availability, salinity, temperature, which are affecting the morphometry of the fish in each location. Similarly, three distinct populations of *D. russelli* from Arafura Sea, Sulawesi Sea and Makassar Strait and the rest of the Indo-Malay archipelago have been reported by Rohfritsch and Borsa (2005).

Assuming that the fish stocks are distributed in space as gradients (Murta et al., 2008), it is unlikely that fish from Bay of Bengal could belong to the Arabian Sea but the possibility of the fish of one stock within the coast is much higher. The misclassification results of discriminant function clearly support this theory. The similarity between the stocks within a coast may be due to a common environment, similar genetic origin at earlier period, and the similarity may also be due to the genetic introgression of the fishes especially those in the transition zones. However, this needs to be verified through the molecular genetic studies. As in the present study, the fishes were collected only from four locations within a coast, and it is difficult to conclude the mixture of the stocks. Thus, a useful follow up study would involve more sample sites to achieve greater separation of these newly identified stocks. In the present study, the samples were collected from the catches of commercial trawlers, and it is highly likely that the fishes caught at one location may land at other location leading to the mixture of the stocks.

The truss System can be successfully used to investigate stock separation within a species, as reported for other species in marine and freshwater environments. In this study, the truss protocol revealed a clear separation of *D. russelli* stock observed from east and west coast of India suggesting a need for separate management strategy to sustain the stock for future use. The observation given 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 (Graves, 1998; Turan et al., 1998; Shaw et al., 1999) 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 implementation of appropriate mesh size in both the coasts may help to sustain this resource for the future use.

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