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Research Article

Stock structure analysis of Yellow striped goatfish, *Upeneus vittatus* (Forsskal, 1775) based on truss morphometric analysis along the Indian coast

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Abstract

In the present study, 347 specimens of Yellow striped goatfish, *Upeneus vittatus* were collected from the three locations along the Indian Coast from October 2018 to March 2019. The truss matrix was developed by interconnecting the 13 morphological landmarks, which form different triangles and rectangles to form 26 truss variables. All the transformed truss measurements data were subjected to factor analysis and discriminant function analysis. The factor analysis indicated first three factors together, showing 73.43% of the total variations. The first factor exhibited meaningful loading on the straight and oblique depth measurements of the anterior half and middle part of the fish body. In contrast, the second factor showed significant loadings on the fish body's posterior part (caudal peduncle region). Further, cross-validation from discriminant function analysis revealed an overall 86.69% successful classification, where the well-classified stock was from Odisha (93.93%), followed by Mumbai (82.50%) and Kakinada (82.14%). The finding indicates the existence of two separate stocks of *U. vittatus* in the west and east coast of India.

Keywords: Yellow striped goatfish, Truss matrix, Stock structure, Indian coast.

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Introduction

Stock identification is prerequisite for stock assessment and population dynamics studies. Most population models infer that the group of individuals has homogenous vital traits and a close life cycle. The knowledge of the stock structure of a particular species plays a vital role in scientific resource management and marine stock enhancement programs (Shaklee and Bentzen, 1998). The concept of stock structure is also essential for successful and scientific management of exploited fish stocks and implementing worthwhile stock rebuilding programs (Carvalho and Hauser, 1994; Begg *et al.*, 1999). Several methods (i.e., traditional morphometric, meristic, otolith shape analysis, otolith microchemistry, parasitic tags, and molecular genetics) are used for stock identification. Among all the methods, the study of morphometric traits is the most commonly adopted because of its cost-effectiveness and ease of collecting information. To overcome the inherent weaknesses of traditional morphometric methods, the truss network method is being used.

Truss network system (Strauss and Bookstein, 1982) is an anatomical landmark-based system of body morphometric, without any restriction on the directions of variation and localization of shape changes. It is much helpful in getting information about the shape of an organism (Cavalcanti *et al.*, 1999). It can differentiate the phenotypic stock because the truss configuration covers the entire body of fish with no loss of information, and it is more sensitive to changes. Morphometry measurements based on truss network data have been used successfully for species discrimination (Palma and Andrade, 2002), ontogeny (Hard *et al.*, 1999), and functional morphology (Dean *et al.*, 2006).

Goatfishes are commercially important group of fishes belong to the family Mullidae, under the order Perciformes. They have two chemosensory chin barbells, used for searching food (Uiblein, 2007) characterize them. It contributes significantly to the food and nutritional security of fisher folk along the Indian coast, but the knowledge about the stock, distribution, and population dynamics of these groups is scanty. In addition to food value, *U. vittatus* is also an essential link in the food chain of larger predators, used as baits occasionally. Hence, knowledge of distribution and the stock structure of the species are essential for successful management of the resource. Therefore, the present study of stock structure analysis of *Upeneus vittatus* is undertaken.

Materials and methods

In the present study, 347 samples of *U. vittatus* were collected from the West and East Coast of India (Mumbai, Kakinada, and Odisha) from October 2018 to March 2019. The sampling location was selected following the regional grouping of Indian maritime states classified by Srinath (2003) (Fig. 1). The details of the samples from each location were listed (Table 1). The specimens were washed and placed on a flat platform with a graph paper of 0.1mm square as a background. The fins were erected and placed on the platform to clearly view origin and insertion points. A unique code was given to each individual to identify it. A Cyber-shot DSC-SX50HS digital camera, (canon) mounted on a leveling tripod used for capturing the digital images of each sample.

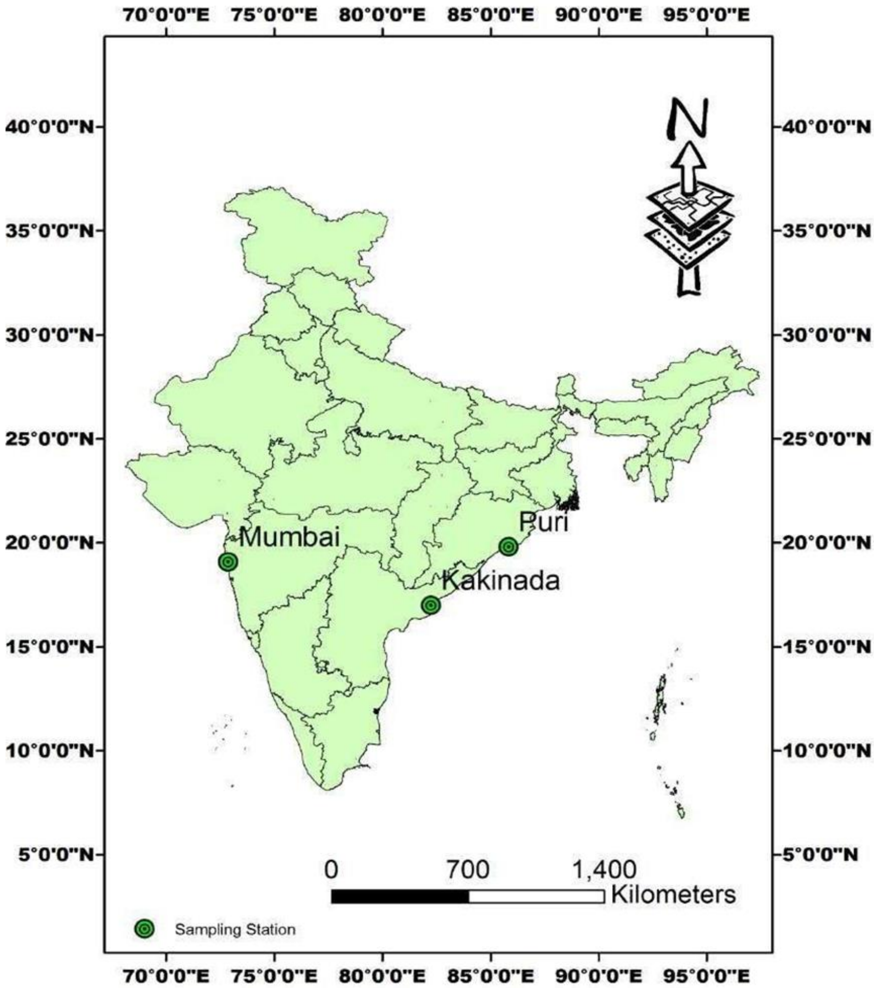

Figure 1: Location selected for the sampling of *U. Vittatus.*

Table1: Descriptive data of *Upeneus vittatus* samples collected from three sampling locations.

Coast	**East coast (Bay of Bengal)**		**West coast (Arabian Sea)**
State	Andhra Pradesh	Odisha	Maharashtra
Sampling date	October 2018 to March 2019	November 2018	October. 2018
Sampling center	Kakinada	Odisha	Mumbai
Sampling location	16°57'N, 82°15'E	19°81N, 85°83'E	18°54'N, 72°49'E
Length range (cm)	12.21-17.52	11.41-16.5	10.95-21.44
Sampling size(n)	130	100	117
Total		**347**	

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The truss matrix was developed by interconnecting the thirteen landmarks (Fig. 2; Table 2), which formed 26 truss measurements (Fig3). The morphometric data was extracted from each digital image of specimens by a linear combination of two software, tps Dig2 V2.1 (Rohlf, 2006) and Paleontological Statistics (PAST) (Hammer *et al.*, 2001). All the images were first converted from JPEG (*.jpeg) to TPS (*.tps) format by using a utility program called tpsUtil V1.38 (Rohlf, 2006). The landmarks for truss analysis were digitized on the image using the 'Digitized landmarks' mode of the software. The landmark data was encrypted into the tps files as X-Y coordinates. The data encrypted tps format image files were used as input sources in the PAST. The data on distances between the landmarks were extracted using the 'all distances from landmarks' and '2-dimensional' options of the 'Geomet' menu.

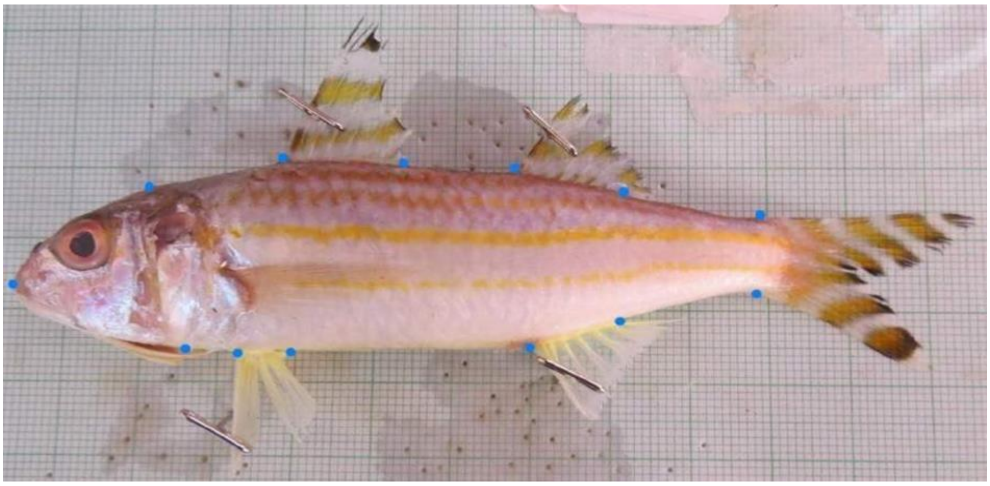

Figure 2: Image of *U. vittatus* showing thirteen anatomical landmarks.

Table 2: Anatomical landmarks selected for Truss Network Analysis of *Upeneus vittatus.*

Landmark Number	Landmark Position
01	The anterior tip of the snout on the upper jaw
02	Posterior edge of supra occipital bone
03	Origin of the first dorsal fin
04	The insertion point of the first dorsal fin
05	The origin point of the second dorsal fin
06	The insertion point of the second dorsal fin
07	Dorsal origin of the caudal fin
08	Ventral origin of the caudal fin
09	The insertion point of anal fin
10	Origin of anal fin
11	The insertion point of pelvic fin
12	Origin of pelvic fin
13	The insertion point of operculum and ventral contour of the body

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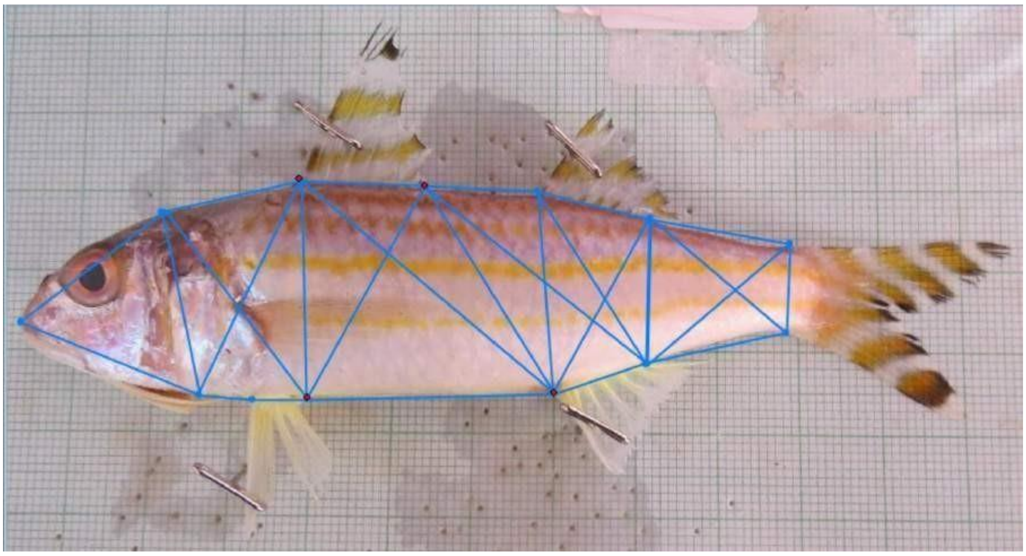

Figure 3: Truss Network of *U. vittatus* showing different landmarks with a specific code.

The landmarks and truss network distances were subjected to be descriptive statistical analysis for outlier detection, to assess normality and to inspect the linearity of correlations. Multivariate analysis of variance (MANOVA) was carried out for the transformed truss morphometric variables to find a significant difference among the populations. All the truss morphometric measurements were log-transformed using an allometric approach (Elliott *et al.*, 1995). Data were transformed using the following formula:

$Mtrans=M * (SL\ mean / SL)^{b}$

Where, 'Madj' is transformed morphometric measurement, 'M' is original morphometric measurement, 'SL' is standard length of fish, 'mean' is combined mean, standard length for species and 'b' is within-group slope of the mean regression of log M against log SL.

To check the effective data transformation in removing the effect of size in the data, Correlation coefficients between transformed variables and standard length were estimated. All the transformed truss measurements data were subjected to Factor analysis to evaluate interrelationships among the variables and explain them in terms of their standard underlying dimensions. Among all the morphometric variables, those showing the threshold value of above 0.7 were selected for stepwise discriminant analysis. Stepwise Discriminant Function analysis selects the quantitative variables to discriminate among the stocks. All the statistical analysis was performed by using Statistica 12 software.

Results

There was no significant correlation between the standard length of the fish and transformed truss morphometric measurements indicating that the allometric transformation had successfully removed effects of the body length. The multivariate analysis of variance (MANOVA) found significant differences among the three stocks of *U.*

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vittatus for truss morphometric traits (Wilk's Lambda=0.1870, F=14.034, *p*<0.0001). In the factor analysis, the first three factors together showed 73.43% of total variation with eigenvalue of 15.61, 2.106, 1.371 (Table 3). The truss distance with meaningful loading on factor 1 were 2-11, 2-13, 3-4, 3-10, 3-11, 3-13, 4-11, 5-9, 5-10, 6-10 and 7-8 which explained 60.05 % of total variance (Table 4; Fig. 4).

Table 3: Eigenvalues and proportion of variance contribution to the total variance of truss distance.

No.	Eigenvalue	% Total - variance	Cumulative - Eigenvalue	Cumulative (%)
1	15.61489	60.05726	15.61489	60.05726
2	2.10660	8.10229	17.72148	68.15955
3	1.37149	5.27498	19.09298	73.43453

Table 4: Variables Loadings of first two factors for the truss morphometric data in *U. vittatus* (Marked loadings are >.700000).

Truss distance	Factor 1	Factor 2
(1-2)	0.69691	0.267678
(1-13)	0.69976	0.157060
(2-3)	0.62268	0.157525
(2-11)	0.88683	0.266554
(2-13)	0.75116	0.127093
(3-4)	0.70627	0.012494
(3-10)	0.81474	0.448823
(3-11)	0.88238	0.261668
(3-13)	0.89749	0.293512
(4-5)	0.05506	0.673065
(4-9)	0.53377	0.728956
(4-10)	0.65552	0.666882
(4-11)	0.81678	0.312683
(5-6)	0.57919	0.317610
(5-9)	0.73856	0.574433
(5-10)	0.78501	0.502947
(6-7)	0.19666	0.780972
(6-8)	0.30912	0.796341
(6-9)	0.65347	0.644113
(6-10)	0.73829	0.564587
(7-8)	0.70504	0.541037
(7-9)	0.41012	0.765373
(8-9)	0.18323	0.764590
(9-10)	0.55306	0.452997
(10-11)	0.47928	0.479447
(11-13)	0.57974	0.222611
Expl.Var	11.03501	6.704148
Prp.Totl	0.40870	0.248302

All these eleven measurements were characterized by the straight and oblique depth measurements of the anterior half of the fish body. The second factor showed 8.10% of the total variation and showed significant loadings on the variables are 4-9, 6-7, 6-8, 7-9, and 8-9 (Table 4; Fig. 5). All these variables showed significant loadings on the fish body's posterior part (caudal peduncle region). The stepwise discriminant function analysis of sorted 16 variables out of 26 truss distances showed 86.69% of correct cross-validation classification

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and 13.31% of miss classification. The well classified group was Odisha with 93.93% correct classification followed by Mumbai population with 82.5% correct classification. The least defined group was the Kakinada population, with 17.86% of miss-classification (Table 5). The bivariate plot of factors 1 and factor 2 revealed the existence of two separate stocks of *U. vittatus* in the West and East Coast of India (Fig. 6).

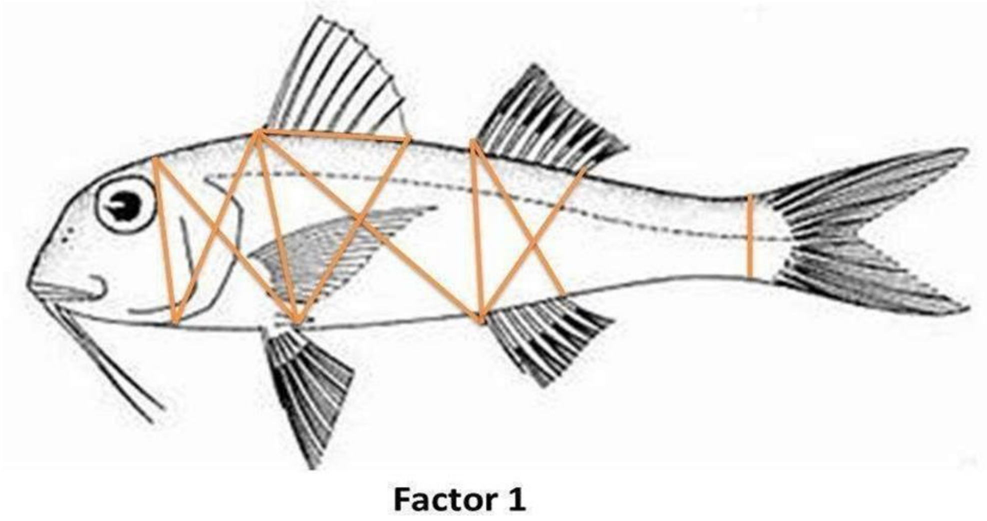

Figure 4: Truss variables with meaningful loading on the first factors in truss network analysis.

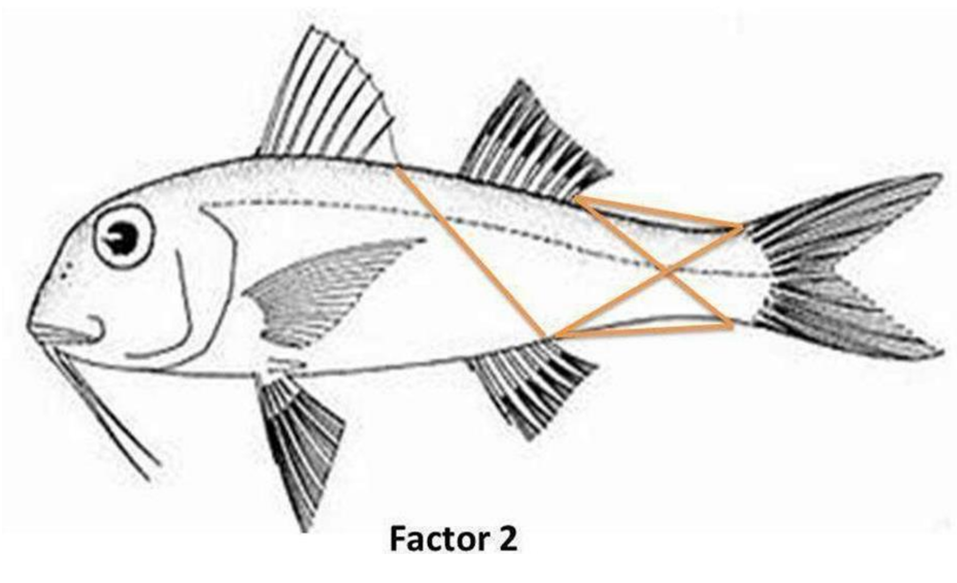

Figure 5: Truss variables with meaningful loading on the second factors in truss network analysis.

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Table 5: Classification matrix of different stocks in Stepwise (forward) Discriminant Analysis.

Location	Percent – Correct	Kakinada	Odisha	Odisha
Kakinada	82.14286	69	6	6
Odisha	93.93939	1	93	93
Mumbai	82.50000	3	11	11
Total	**86.69202**	**73**	**110**	**110**

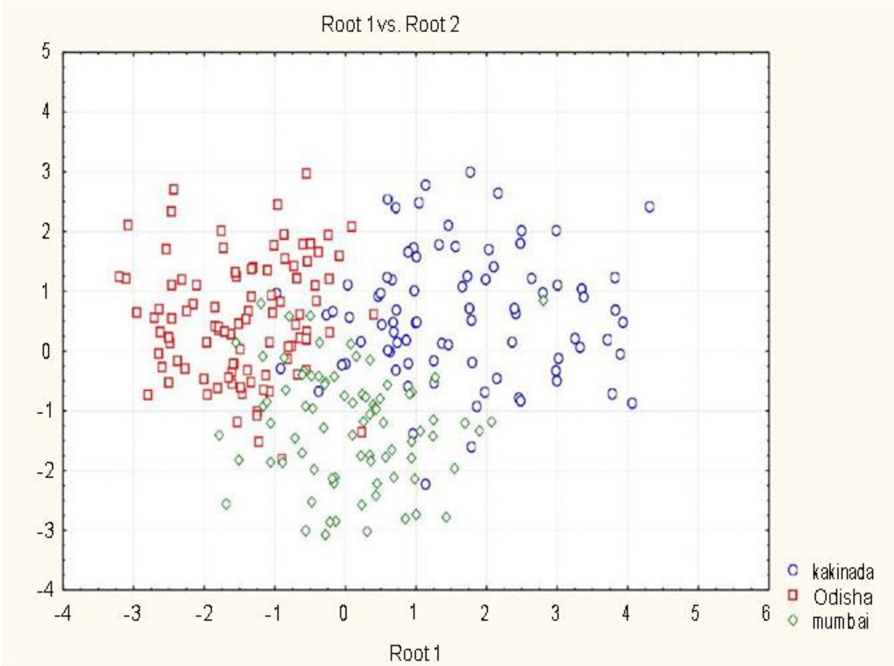

Figure 6: The location wise scatter plot of the two factors extracted from 13 points truss measurements showing separation of two stocks of *U. vittatus* along the Indian coast.

Discussion

The morphometric analysis helps analyse the variability in size and shape of fishes, evaluate the population structure of a species, and stock (Cadrin and Friedland, 1999; Turan, 2004). The morphometric analysis provides information on phenotypic stocks, individuals with similar growth, mortality, and reproductive rates (Booke, 1981). The Truss network system is being used extensively to investigate stock identification because it allows better discrimination of stocks using shape analysis. In the present study, the truss morphometric results showed significant phenotypic heterogeneity among the *U. vittatus* stocks of the Bay of Bengal from the east and the Arabian Sea from the west coast of India. This variation could be due to geographical isolation as the collective effects of different environmental parameters, selection, and genetics on individual ontogenies can develop morphometric differences within a species (Cadrin and Silva, 2005).

The traits loaded on the second factor showed significant loading in the caudal peduncle region of the fish body. Researchers have observed that the water turbulence of the Bay of Bengal is higher than the Arabian Sea (Kolla *et al.*, 1981; Chamarthi *et al.*, 2008). These differences could be the probable reason for significant variation in the caudal peduncle region of *U. vittatus*. Under this condition, fish body, especially the caudal peduncle portion, becomes slender and elongated. These differences in body morphometric are probably due to adaptations to prevalent environmental conditions. However, a comprehensive study is recommended to explain whether it is exclusively environment conditions or genotype by environmental interaction.

Environmental conditions such as oceanic currents and water masses play an essential role in fish stocks' spatial distribution, movement, and isolation (Tsujita, 1957). The different current patterns of the Arabian Sea and Bay of Bengal probably influence the morphometry of *U. vittatus* populations along the west and east coast of India. Blake (2004) opined that the broad and elongated caudal peduncle regions help better propulsion in fishes in turbulent water and control their swimming behaviour. Pazhayamadom *et al.* (2017) also observed the morphological variation in goldband goatfish *Upeneus moluccensis* from the Red Sea and the Mediterranean Sea populations, where the fishes from the Mediterranean Sea have a deeper caudal peduncle due to turbulent water. Pavlov (2018) studied the stock structure of Freckled Goatfish *Upeneus tragula* in the Coastal Zone of Vietnam. The results revealed a homogenous distribution of stocks in the coastal zones of Central and North Vietnam.

The first three factors showed 73.43% of the total variations in the factor analysis with an eigenvalue of 15.61, 2.106, and 1.371. The first, second, and third factors showed 60.05%, 8.10%, and 5.2% variations. However, only the first two factors were considered for analysis since the third factor did not contribute significantly to the separation of population structure. A similar finding by Pazhayamadom *et al.* (2017) in goldband goatfish *U. moluccensis* from the Red Sea and the Mediterranean Sea revealed that the first three factors cumulatively explain 69.22% of the total morphometric variation. Only the first and second factors were considered since the third factors did not show significant variation in population clusters.

The present work results showed clear discrimination between the Bay of Bengal and the Arabian Sea populations based on the higher classification percentage in discriminant function analysis. Separate Stock assessments need to be adopted for these populations to manage the fisheries sustainably. A further combined investigation based on molecular techniques such as mtDNA, microsatellite marker, and otolith elemental composition analysis (Cadrin *et al.,* 2013). It is recommended more sampling locations to improve the spatial resolution.

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