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Multivariate morphometric variability in sardine, *Amblygaster clupeoides* (Bleeker, 1849), from the Bay of Bengal coast, Bangladesh

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Abstract

Background: Sardine *Amblygaster clupeoides* is a reef-associated oceanic species having long-standing socioeconomic and ecological importance along the coast of Bay of Bengal, Bangladesh, but less is known about the morphometric variability of the species. To uncover this, morphometric variability of *A. clupeoides* based on truss network technique was employed

Results: A total number of 160 specimens from four coastal regions (Sundarbans, Kuakata, Bhola, and Cox's Bazar) of the Bay of Bengal coast were used to determine whether separate populations could be distinguished. To test the hypothesis of differentiation, each sample was subjected to morphometric measurements consisting of twenty-eight landmarks. In one way ANOVA analysis, twenty-six out of 28 morphometric measurements showed significant differences among the four populations. The principal component analysis indicated shape variation and explained 70.11% of the total variance. About 68.39% of individuals into their original group were correctly classified in discriminating space, as determined by discriminant function (DF) analysis.

Conclusion: Morphometric traits like body length, body depth, body diagonal, body height, head length, head depth, mouth length, anal fin length, dorsal fin length, and caudal length diagonal were mainly responsible for variation and discrimination of populations. The present investigation demonstrates that the population of the east coast (Cox's Bazar) is morphometrically different from other populations. Future stock assessment of *A. clupeoides* should be considered especially on the east coast (Cox's Bazar) while formulating management action plans.

Keywords: Stock assessment, Truss network system, Population, Conservation

Background

Measuring stock status of a fish species is crucial for fisheries management, as stocks with different life history traits are essential to enhance yield as well as for stock management program (Siddik, Hanif, Chaklader, Nahar, & Fotedar, 2016). Morphometry is a cost-effective technique frequently employed for describing fish body shape which is required to identify fish stocks, to delineate stock status, to discriminate between fish populations, and to link

ontogeny with functional morphology of a species (Hanif et al., 2019; Torres, Gonzalez, & Pena, 2010). It is also imperative to collect actual biological information of fish such as ecology, evolution, behavior, and stock assessment (Hanif, Siddik, Chaklader, Pham, & Kleindienst, 2017; Islam et al., 2017; Silva, 2003; Yakubu & Okunsebor, 2011) linked with diverse species, subspecies, and races (Chaklader et al., 2016). The truss network system is considered superior to traditional morphometrics that use morphometric traits to represent the complete shape of fish, which has been commonly used in the field of fish taxonomy and fisheries management (Francoy, Franco, & Roubik, 2012; Sen et al., 2011; Turan, 2004). A number of

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studies has been conducted based on truss network system worldwide including Caspian lamprey (*Caspiomyzon wagneri*), black stripe minnow (*Alosa pseudoharengus*), Alewife (*Alosa pseudoharengus*), roho labeo (*Labeo rohita*), and so on (Cronin-Fine et al., 2015; Galeotti, Castalanelli, Groth, McCullough, & Lund, 2015; Mir, Sarkar, Dwivedi, Gusain, & Jena, 2012; Solomon, Okomoda, & Ogbenyikwu, 2015; Vatandoust, Mousavi-Sabet, Razeghi-Mansour, AnvariFar, & Heidari, 2015), but its application in the coast of Bangladesh is still scarce.

The southern coastal belt of Bangladesh is prosperous in fish and fisheries resources (Hanif, Siddik, Chaklader, Nahar, & Mahmud, 2015; Hanif, Siddik, Nahar, Chaklader, & Fotedar, 2017; Siddik, Chaklader, Hanif, Islam, & Fotedar, 2016; Siddik et al., 2016; Siddik, Hanif, Chaklader, Nahar, & Mahmud, 2015), where the Bay of Bengal solely provides a large number of marine fisheries resources to Bangladesh (Hussain & Hoq, 2010). The genus *Amblygaster* includes three species, one being the Bleeker smoothbelly sardinella, *Amblygaster clupeoides* (Culpiformes: Clupeidae), the focus of this study. *A. clupeoides* is a reef-associated oceanic species, distributed in marine waters along the Indo-West Pacific regions including the coast of the Bay of Bengal, Indonesia, eastward to Fiji, and is also reported from Tonga and New Caledonia (Randall et al., 2004; Wantiez, 1993). Morphologically, the body is moderately cylindrical, the belly is rather rounded, and scutes are not prominent. A similar species *Amblygaster sirm* is distinguished from *A. clupeoides* by the presence of round black spots along the flank. *A. clupeoides* is a pelagic fish and generally found in large schools.

In Bangladesh, a large proportion of fish species in the coastal region remain unassessed due to insufficient scientific study. There is no stock structure information available for *A. clupeoides* population in the Bay of Bengal. The present research is therefore designed to examine the morphometric differences of *A. clupeoides* in their natural habitats, four coastal regions (Sundarbans, Kuakata, Bhola, and Cox's Bazar), of the Bay of Bengal.

Methodology
Sample collection and identification
A total of 160 *A. clupeoides* were collected directly from fishermen immediately after catch. Methods of capture included gill net (mesh size 6.5 cm) and coastal set bag net (mouth mesh size 12 cm, middle 4 cm, and cod end 0.5 cm). The study occurred over a 6-month period from March 2015 to August 2015 from four coastal regions (Sundarbans, Kuakata, Bhola, and Cox's Bazar) of the Bay of Bengal coast. The fish were transported to the laboratory in chilled polystyrene boxes for further identification and morphometric measurements. Phenotypic characteristics were used to identify fish species. Sampling sites locations, dates, number of samples analyzed, and the GPS coordinates (latitude and longitude) are displayed in Table 1 and Fig. 1.

Laboratory work
In the present study, truss-based technique was used for *A. clupeoides* where a truss box for each sample was created by joining 13 points to make a total of 28 measurements (Table 2 and Fig. 2) for representing the outline of fish (Strauss & Bookstein 1982). Total length and standard length (SL) were also collected which had been removed by allometric transformation to avoid size effect and were not used for further analysis. All measurements were taken to the nearest 0.1 cm by the same person from the left side of each de-frozen samples within 1 month time to ensure similar period between death and freezing, which might have impact on the results of the study. We employed a manual method where morphometric data were collected by placing the fish on water-resistant graph paper and measured by piercing the paper with a needle, corresponding to the anatomical landmarks.

Statistical analysis
To minimize size-related dissimilarity, all morphometric variables were amended by adjusting an allometric approach as proposed by Elliott, Haskard, and Koslow (1995):

$$M_{\text{adj}} = M \, (\text{Ls}/\text{Lo})^b$$

where M is the original measurement, M_{adj} is the size-corrected measurement, Ls is the overall mean of standard length for all samples in each analysis, Lo is the standard length, and b is the slope of the regression of log M on log Lo using all fish from each group. Significance test of correlating coefficient was applied between transformed variables and standard length to check if the transformation was successful in eliminating the size effects from the entire dataset. One way ANOVA for 28 morphometric traits was performed to estimate the significant variation among the four locations. For the current study, principal component (PC) analysis, discriminant function (DF) analyses, and cluster analysis (CA) were performed to differentiate the four populations. For decreasing redundancy among the morphometric variables and removing plentiful autonomous variables for population distinction (Samaee, Patzner, & Mansour, 2009; Veasey, Schammass, Vencovsky, Martins, & Bandel, 2001), principal component analysis was used. The Wilks' lambda (λ) was used to assimilate the variation between and among the entire populations. To compute correctly classified percentage of fish samples, the discriminate function (DF) analysis was used. The

Table 1 Summary of *A. clupeoides* samples (sampling sites, dates, geographical locations, and numbers of the collected fish sample) used in morphometric analysis

Sample	Collection site	Date	Latitude	Longitude	Collected sample			
					F_1	F_2	F_3	Total
1	Cox's Bazar	12 April 2015	21° 82′ N	89° 50′ E	17	9	14	40
2	Kuakata	26 July 2015	21° 83′ N	90° 25′ E	40	–	–	40
3	Bhola	03 August 2015	21° 90′ N	90° 60′ E	40	–	–	40
4	Sundarbans	17 September 2015	21° 50′ N	92° 00′ E	13	27	–	40

F_1, F_2, and F_3 indicate fishermen by whom fish samples were collected

probable errors of the classification functions were calculated through cross-validation. The StatSoft STATISTICA (version 11.50), SPSS (version 16.1.0), Minitab (version 15.1.30), and Excel (Microsoft Office 2007) were used for statistical analyses.

Results

The length ranges and means with standard errors of length for specimens collected from four locations of the Bay of Bengal coast are shown in Table 3 separately. The population of each stock was more or less similar in size range from 17.8–23.4 cm, 17.2–23.7 cm, 17.5–23.2 cm, and 17.3–23.4 cm with mean value 20.6, 20.1, 20.2, and 20.3 for Sundarbans, Kuakata, Bhola, and Cox's Bazar, respectively (Fig. 3). Although their average size is much close to each other, their average weight showed significant difference which may be due to their morphometric difference. Among the morphometric measurements, one-way ANOVA test showed that 26 truss measurements out
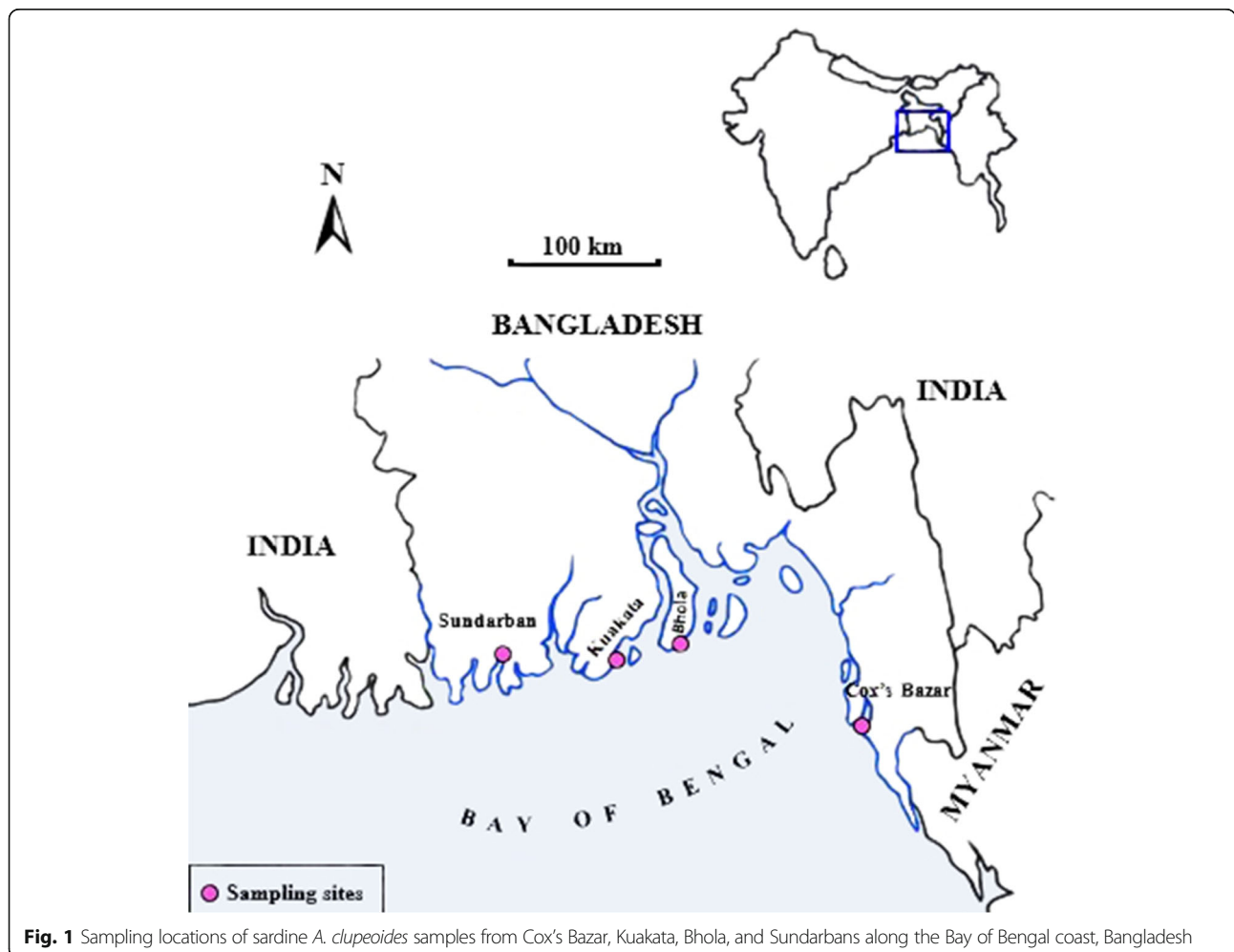

Fig. 1 Sampling locations of sardine *A. clupeoides* samples from Cox's Bazar, Kuakata, Bhola, and Sundarbans along the Bay of Bengal coast, Bangladesh

Table 2 Morphometric measurements made for each sample of *A. clupeoides* collected from the Bay of Bengal coast, Bangladesh

Measurement number	Distance code	Distance	Landmarks
1	HL 1	Head length 1	1–2
2	ML	Mouth length	1–12
3	BL 1	Body length 1	2–3
4	BD 1	Body diagonal 1	2–9
5	HH 1	Head height 1	2–11
6	HD 1	Head diagonal 1	2–12
7	HD 2	Head diagonal 2	2–13
8	DFL	Dorsal fin length	3–4
9	BD 2	Body diagonal 2	3–9
10	BH 1	Body height 1	3–10
11	BD 3	Body diagonal 3	3–13
12	BL 2	Body length 2	4–5
13	BD 4	Body diagonal 4	4–7
14	BD 5	Body diagonal 5	4–9
15	BD 6	Body diagonal 6	4–10
16	BD 7	Body diagonal 7	4–11
17	CL 1	Caudal length 1	5–6
18	BH 2	Body height 2	5–7
19	CLD	Caudal length diagonal	5–8
20	BD 8	Body diagonal 8	5–10
21	CL 2	Caudal length 2	6–7
22	BL 3	Body length 3	7–8
23	AFL	Anal fin length	8–9
24	BL 4	Body length 4	9–10
25	BL 5	Body length 5	10–11
26	BD 9	Body diagonal 9	10–13
27	HL 2	Head length 2	11–12
28	HD 3	Head diagonal 3	11–13

of 28 were highly significant ($p < 0.001$) (Table 4). All measurements were further tested using PCA and DFA. These characteristics significantly varied among the four collection areas and were used in DF and PC analyses; hence, the data was pooled for all subsequent analyses.

Major differences in morphological measurements of *A. clupeoides* from the four distinct regions were uncovered by principal component analysis (PCA). The PC analysis of 28 morphometric measurements yielded five principal components explaining 84.75% of the total variance (60.42% for PC1, 9.61% for PC2, 5.61% for PC3,
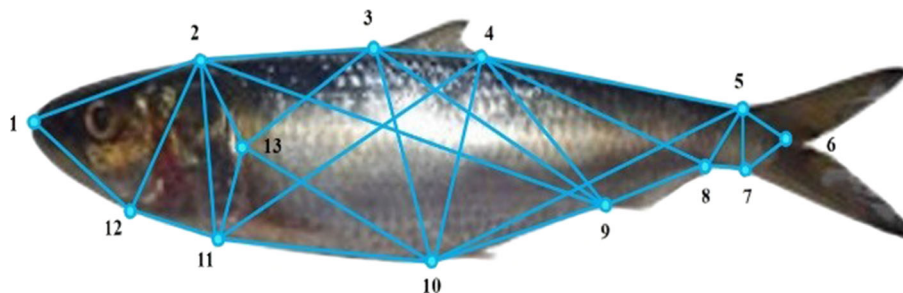

Fig. 2 Location of 13 landmarks and scheme of the truss network used in *A. clupeoides* morphometric analysis

Table 3 Descriptive data of sardine *A. clupeoides* samples from the Bay of Bengal coast, Bangladesh

Population	Sample size (*n*)	Length (SL)		Body weight
		Length range (cm)	Mean ± SE	Mean ± SE
Sundarbans	40	13.20–18.10	16.52 ± 0.42	72.10 ± 4.92
Kuakata	40	12.80–16.70	14.60 ± 0.13	52.29 ± 1.24
Bhola	40	13.20–16.90	14.49 ± 0.14	55.26 ± 0.98
Cox's Bazar	40	11.50–17.30	14.91 ± 0.20	49.29 ± 1.69

5.01% for PC4, and 4.02% for PC5) in the entire dataset, with eigenvalues of 16.92, 2.71, 1.57, 1.40, and 1.13, respectively (Table 5). PC1 and PC2 explained total 70.11% variance, and a closer investigation on these components was undertaken. In five PCAs, the mean loadings for the selected four regions differed remarkably in body morphology and also head morphology.

The PC1 was essentially a divergence between the measurements of fish head and fish body (Table 6 and Fig. 4a) except head length 1, head diagonal 1, dorsal fin length, body height 1, body diagonal 5, body diagonal 6, body height 2, caudal length 2, anal fin length, body length 4, and head length 2 which were dominated by PC2, PC3, PC4, and PC5. *A. clupeoides* from Cox's Bazar were found to possess a smaller body dimensions and larger head than the other populations, while the samples collected from Sundarbans had increased body height and diagonal body dimensions, which clearly distinguished the two distinct populations (Fig. 4b).

PC1 (first principal component) detailed the differences in all parts except HL1, HD1, DFL, BH1, BD5, BD6, BH2, AFL, BL4, and HL2 (Fig. 5). PC1 score means ($p < 0.001$) indicated a highly significant difference among the regions. Comparatively similar PC1 were found in fish from Kuakata and Bhola regions but had a significant difference in fish from both Sundarbans and Cox's Bazar regions ($p < 0.001$). The fish from the Sundarbans region had comparatively larger heads, body,

Table 4 ANOVA of morphometric characters for *A. clupeoides* samples collected from the Bay of Bengal coast, Bangladesh

Distance code	Wilks' lambda	*F* value	*p* value
HL 1	0.229	175.203	0.00*
ML	0.524	47.200	0.00*
BL 1	0.728	19.400	0.00*
BD 1	0.671	25.550	0.00*
HH 1	0.552	42.279	0.00*
HD 1	0.602	34.354	0.00*
HD 2	0.692	23.191	0.00*
DFL	0.627	30.952	0.00*
BD 2	0.743	17.973	0.00*
BH 1	0.739	18.412	0.00*
BD 3	0.695	22.771	0.00*
BL 2	0.577	38.145	0.00*
BD 4	0.605	33.943	0.00*
BD 5	0.626	31.093	0.00*
BD 6	0.654	27.554	0.00*
BD 7	0.504	51.238	0.00*
CL 1	0.568	39.514	0.00*
BH 2	0.555	41.631	0.00*
CLD	0.867	7.957	0.00*
BD 8	0.700	22.298	0.00*
CL 2	0.945	3.018	0.03
BL 3	0.935	3.618	0.02
AFL	0.854	8.924	0.00*
BL 4	0.850	9.158	0.00*
BL 5	0.676	24.876	0.00*
BD 9	0.755	16.829	0.00*
HL 2	0.678	24.666	0.00*
HD 3	0.728	19.475	0.00*

All abbreviations as in Table 2
*Significance level *p* < 0.001

and tail. Significantly different PC1 was also found among Cox's Bazar, Kuakata, and Bhola regions ($p < 0.001$). Fish samples from Kuakata and Bhola regions had a comparatively larger body form than the samples collected from Cox's Bazar.

PC2 described mainly body form morphology with a single part of the head (HL1), body height (BH1), body diagonal (BD5 and BD6), and anal fin length (AFL) (Fig. 5). PC1 score means ($p < 0.001$) indicated a significant difference among the regions. Fish from the Cox's Bazar region had a comparatively compressed body form compared to the other regions, while fishes from Sundarbans region possessed a longer and stiffen body form. PC2 scores differed significantly from the Kuakata and Bhola as in these two regions more or less similar body

Fig. 3 Size frequency distribution of sardine, *Amblygaster clupeoides*, in four different stocks

Table 5 Eigenvalues, percentage of variance, and percentage of cumulative variance for the five factors of *A. clupeoides* for truss morphometric measurements

Factors	Eigenvalues	Percentage of variance	Percentage of cumulative variance
PC1	16.92	60.42	60.42
PC2	2.71	9.69	70.11
PC3	1.57	5.61	75.72
PC4	1.40	5.01	80.73
PC5	1.13	4.02	84.75

Table 6 Results of factors extraction in PC analysis after varimax normalized rotation in *A. clupeoides* from the Bay of Bengal coast, Bangladesh

Landmark distance code	PC1	PC2	PC3	PC4	PC5
HL 1	0.571	− 0.659			
ML	− 0.724				
BL 1	0.639			0.448	− 0.478
BD 1	− 0.868				
HH 1	− 0.810				
HD 1	0.511			0.673	
HD 2	0.655			0.573	
DFL	− 0.589				0.789
BD 2	0.447		0.897		
BH 1	0.547	− 0.672			
BD 3	− 0.934				
BL 2	− 0.942				
BD 4	0.876				
BD 5	0.508	0.617			
BD 6	0.584	0.647			
BD 7	− 0.749		− 0.403		
CL 1	0.625			0.444	
BH 2	0.517				0.817
CLD	0.454		0.627		
BD 8	0.855				
CL 2	0.594			0.401	− 0.496
BL 3					0.431
AFL	0.509	0.724			
BL 4	0.490			0.690	
BL 5	0.839				
BD 9	0.616		0.406		
HL 2	− 0.535			− 0.835	
HD 3	0.852				

Significant loadings > 0.60

shape were observed than two other regions, Sundarbans and Cox's Bazar ($p < 0.001$).
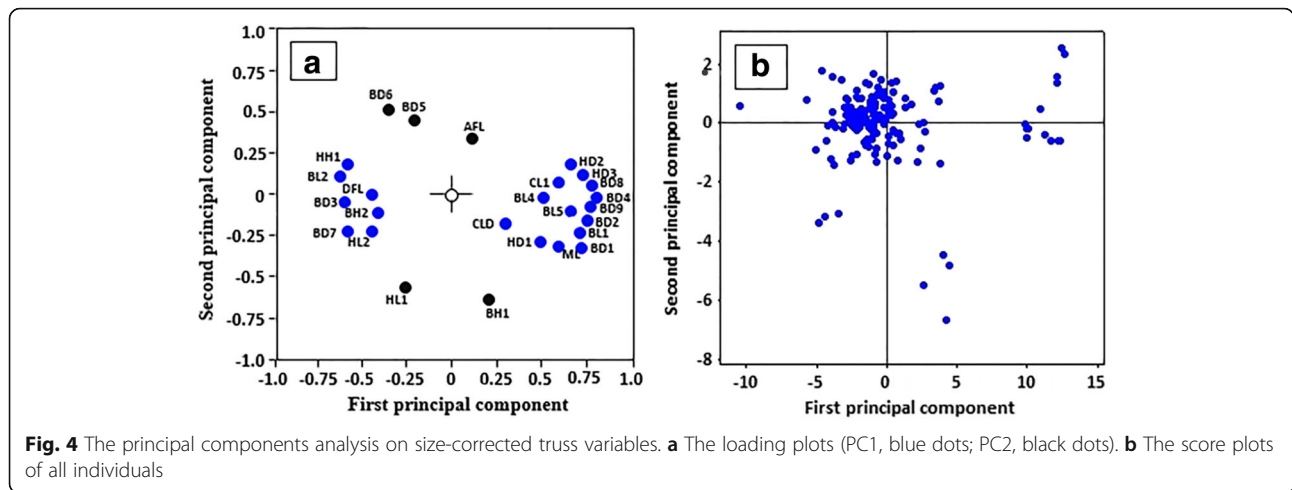
The discriminant function (DF) analysis shows three morphological indices defining 93.9% (DF1), 5.8% (DF2), and 0.3% (DF3) of the morphological difference (Table 7) . The truss distances with important loading on DF1 were shown in Table 7 with total variance of 93.9%. All of these distances were described as morphometric measurements cover the whole body of the fish. The DF2 elucidated 5.8% of the total variation, and four measurements in the tail region showed important loading. The DF3 elucidated 0.3% of the total variance, and four measurements in the body and head region loaded heavily. The DF1 and DF2 plot elucidated 99.7% of the total difference among the measurements and presented assortment among the stocks of *A. clupeoides* (Fig. 6).

Wilk's lambda (λ) test of discriminant function (DF) analysis showed significant variation among morphometric traits of all stocks except the third function because the p value ($p > 0.001$) of the third function is not significant (Table 8).

Discriminant function analysis presented 68.39% correctly classified individuals into their original populations. The percentage of correctly classified group results were analogous with the result of cross-validation test. The highest proportion of reclassification rate was registered for the Cox's Bazar (85.0%), followed by the Sundarbans, Kuakata, and Bhola in reducing order (80%, 77.5%, and 70%). Almost similar proportionate were found in the cross validation test, where Cox's Bazar contributed maximum amount (75.0%) following Sundarban (72.5%), Kuakata (52.5%) and Bhola (52.5%). The maximum intermingling was detected among sampling sites, viz. Kuakata and Bhola, Sundarbans and Kuakata, Sundarbans, Kuakata and Bhola, and Cox's Bazar and Bhola (Table 9).The unweighted pair group method with arithmetic mean (UPGMA) analysis resulted in two main clades: the first one includes Bhola, Kuakata, and Sundarbans populations and the second clade consists of Cox's Bazar population (Fig. 7). Similar to the DF analysis results, dendrogram indicated a clear of isolation of Cox's Bazar populations, while high degree of overlapping was found between Kuakata and Bhola, suggesting that the variables were adequate to clearly differentiate Cox's Bazar.

Discussion

Morphological variation is common within and between populations due to the segregation of a population within the surroundings of native territory. The present study assessed the morphometric variability of *A. Clupeoides*, and at least three morphologically distinguishable stocks were identified in the coast of the Bay of Bengal, Bangladesh. Phenotypic plasticity could be due

Fig. 4 The principal components analysis on size-corrected truss variables. **a** The loading plots (PC1, blue dots; PC2, black dots). **b** The score plots of all individuals

to genetic variations among the stocks (Robinson & Wilson, 1996), which would be associated with unusual aquatic circumstances, i.e., temperatures, salinity, turbidity, current pattern, and alkalinity (Hanif et al., 2019; Mir et al., 2012). However, similarities between stocks may be the consequence of homogenous environmental factors and habitat characteristics.

The results of DFA analysis demonstrated that except for Bhola and Kuakata specimens, the morphometric variability was relatively higher between different populations. PC analysis demonstrated that the difference in morphometric traits was apparent in the head, body, and caudal region among the populations of *A. clupeoides.* Sundarbans and Cox's Bazar populations were well separated which may be ascribed to the geographic distances between the rivers and limited migration in these waters. The strong phenotypic discreteness of the Sundarbans and Cox's Bazar samples may also indicate resident populations or subspecies of *A. Clupeoides* in these rivers.

The intermingling relationship was highest in Kuakata and Bhola regions which may be attributed to the similar geographical positions and climatic conditions of the two rivers and probable unintended sampling of migratory *A. Clupeoides* from the Kuakata to the Bhola region; it may also indicate some temporal and spatial residence of individuals from the Kuakata population in the Bhola river. Multivariate analysis (DF and PC) was applied by Hossain (2010) to three populations of *L. calbasu* from two Bangladeshi rivers (Jamuna and Halda) and a hatchery to describe the morphological variation between them. In their study, the possible causes of the variations were local fish migration and environmental factors.

In the present study, in line with the DFA plot, UPGMA cluster also differs the Sundarbans region and Cox's Bazar region from Kuakata and Bhola regions which may be related to geographic distance because it is well known that geographical isolation produces morphological changes (Yamamoto et al., 2006). The
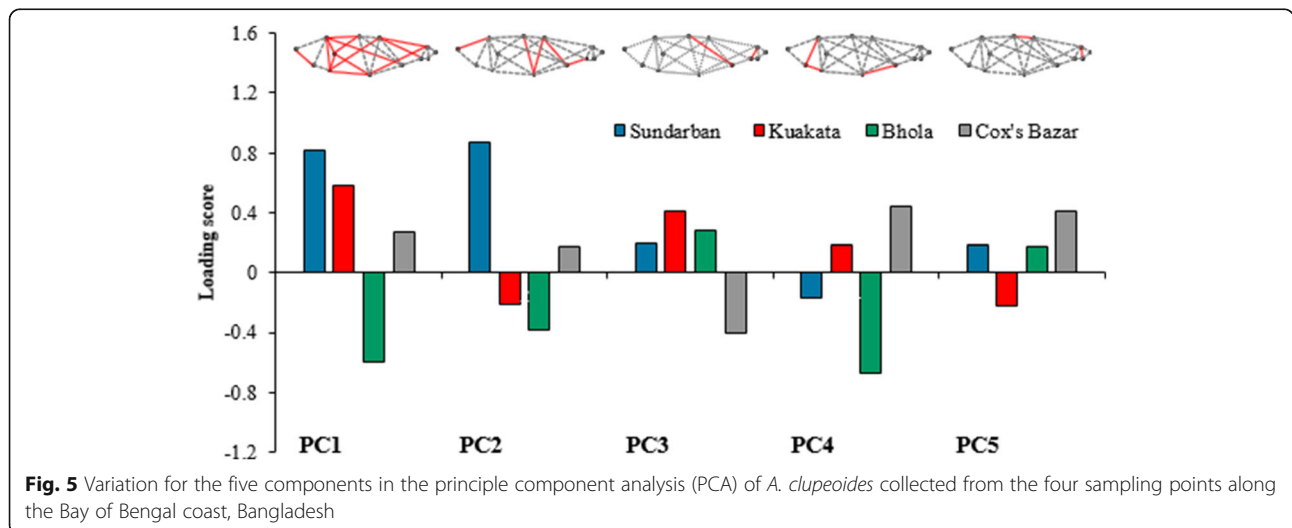

Fig. 5 Variation for the five components in the principle component analysis (PCA) of *A. clupeoides* collected from the four sampling points along the Bay of Bengal coast, Bangladesh

Table 7 Contribution of morphometric measurements to discriminant functions (DF) of *A. clupeoides* collected from the four sampling sites along the Bay of Bengal coast, Bangladesh

Landmark distance code	DF1 (93.9%)	DF2 (5.8%)	DF3 (0.3%)
HL 1	0.940*	− 0.010	0.018
ML	0.482*	0.294	0.290
BL 1	0.465*	0.304	0.257
BD 1	0.449*	0.249	0.183
HH 1	0.417*	0.194	0.317
HD 1	0.379*	0.308	0.262
HD 2	0.371*	0.347	0.199
DFL	0.364*	0.281	0.270
BD 2	0.354*	0.079	0.251
BH 1	0.349*	0.142	0.193
BD 3	0.343*	0.062	0.311
BL 2	0.326*	0.250	0.154
BD 4	0.325*	0.300	0.240
BD 5	0.315*	0.000	0.127
BD 6	0.308*	0.213	0.263
BD 7	0.305*	0.279	0.205
CL 1	0.277*	0.109	0.271
BH 2	0.235*	0.103	0.223
CLD	0.156*	− 0.041	0.114
BD 8	0.126*	− 0.007	0.072
CL 2	0.378	0.467*	0.361
BL 3	0.275	0.415*	0.163
AFL	0.242	0.304*	0.259
BL 4	− 0.091	0.170*	0.003
BL 5	0.278	− 0.555	0.703*
BD 9	0.429	0.472	0.657*
HL 2	0.362	0.089	0.377*
HD 3	0.183	0.100	0.269*

All abbreviations as in Table 2
*Largest correlation between each variable and DF

Sundarbans region is situated in the southwestern coast of Bangladesh, while the Kuakata and Bhola regions are in the middle coast and the Cox's Bazar region is situated in the southeastern coast of the country. The distance between Sundarbans to Kuakata is about 81.17 km, Kuakata to Bhola 52.22 km, and Bhola to Cox's Bazar 141.73 km.

Morphological differences in factor 1 of *A. Clupeoides* could be due to its feeding behavior as for predator evasiveness and foraging adeptness, high locomotory performance is crucial (Chipps, Dunbar, & Wahl, 2004; Swain, Hutchings, Foote, Cadrin, & Friedland, 2005). For taking the optimum amount of food, body depth adaptations are essential for transient and topical swimmers (Pazhayamadom et al., 2014). It is reported that the deep
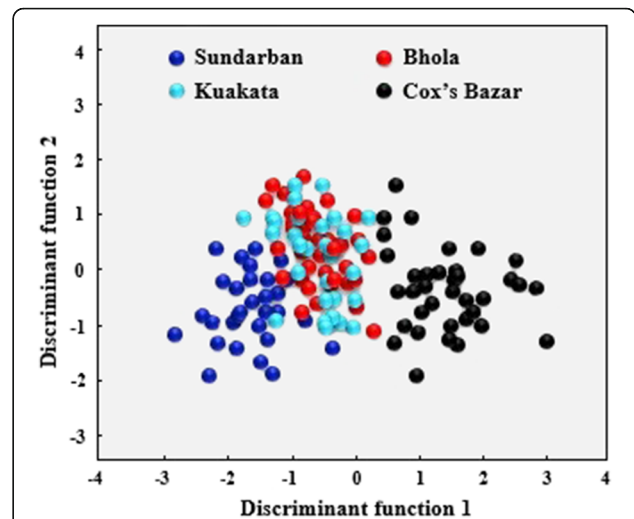

Fig. 6 Discriminant function (DF) analysis plot with 28 morphometric variables for *A. clupeoides* collected from the four sampling points along the Bay of Bengal coast, Bangladesh

healthy fish stocks from less turbulent waters perform faster speed with brief propulsion (Blake, 2004; Webb, 1984). The eastern coast of the Bay of Bengal is more turbid than the western coast (Chamarthi, Ram, & Josyula, 2008). Thus, the Sundarbans region is less turbulent in comparison to the Cox's Bazar region. The population of Cox's Bazar had comparatively more streamlined body which may be an adjustment toward food searching in the turbulent waters. The second factor component was loaded heavily with truss distances representing the region across the head length, body height, body diagonal, and anal fin length. The variables with high loadings (BH 1 BD 5 and BD 6) in factor 2 may not be due to shape variations that represented the distinctness of stock, but most probably linked with the feeding biology of *A. clupeoides*. The most preferred food species of *A. clupeoides* is zooplankton, predominantly copepods, which are highly abundant in the Sundarbans region (west coast). Most fish samples collected from the Sundarbans region were observed with a swollen belly that was significantly different from other sampling sites.

The morphological divergence is exclusively associated to body shape but not to size. Traits related to

Table 8 Results of Wilks' lambda test for verifying differences among populations of *A. clupeoides* collected from the four sampling sites along the Bay of Bengal coast, Bangladesh

Test of functions	Wilks' lambda	Chi-square	df	Sig.
1 through 3	0.166	278.057	12	0.000
2 through 3	0.801	34.391	6	0.000
3	0.989	1.684	2	0.431

Table 9 Percentage of specimens classified into each group and after cross-validation for morphometric data

	Original group				Total	Cross-validated group				Total
	Sundarbans	Kuakata	Bhola	Cox's Bazar		Sundarbans	Kuakata	Bhola	Cox's Bazar	
Sundarbans	*80.0*	12.5	7.5	0.0	100.0	72.5	20.0	7.5	0.0	100.0
Kuakata	5.0	*77.5*	17.5	0.0	100.0	10.0	52.5	37.5	0.0	100.0
Bhola	0.0	30.0	*70.0*	0.0	100.0	7.5	40.0	52.5	0.0	100.0
Cox's Bazar	0.0	5.0	10.0	*85.0*	100.0	0.0	15.0	10.0	75.0	100.0

size can make the result error if not removed from the data during morphometric analysis (Yakubu & Okunsebor, 2011). In the present study, morphological variation within the coast of the Bay of Bengal may be linked with head and body shape differences; as by using allometric transformation, the size effect for morphometric data was successfully removed. However, further studies need to be done through molecular genetic studies to verify the present results.

Conclusion

The truss-based technique can be effectively applied to examine the variation of stocks within a species, which has been previously described for many species in both marine and freshwater habitats. The present study based on truss morphometric technique exposed a clear variation in the wild stocks of *A. clupeoides* at the four sampling regions of the Bay of Bengal coast, Bangladesh, recommending a need for distinct management approaches to protect the stocks of *A. clupeoides* and ensure its sustainability. However, molecular distinction along with morphological attributes provides important information about a species to formulate scientifically

robust fisheries management strategies of particular species in distinct habitats (Dowling, Anderson, Marsh, & Rosenberg, 2015).
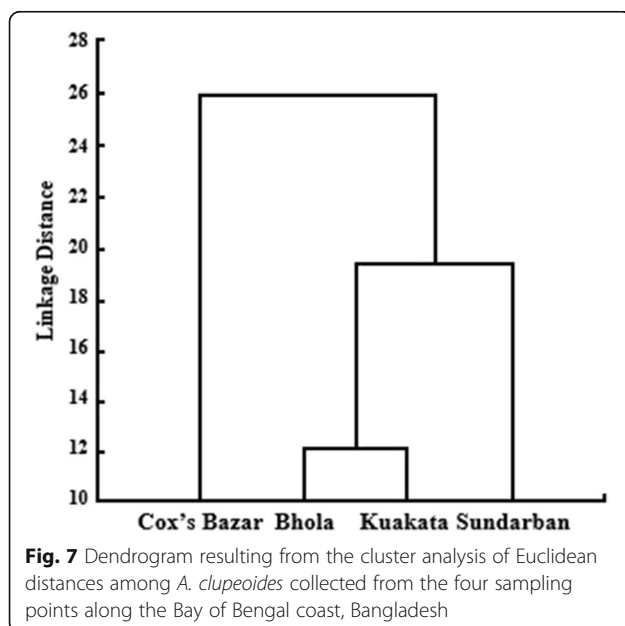
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Fig. 7 Dendrogram resulting from the cluster analysis of Euclidean distances among *A. clupeoides* collected from the four sampling points along the Bay of Bengal coast, Bangladesh

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