Significance of Traditional and Advanced Morphometry to Fishery Science

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Received 24 May 2020; Revised 03 August 2020; Accepted 17 August 2020; Published 01 September 2020

Abstract

Morphometric characters of fishes are measurable or metric characters. Morphometrics is a more or less interwoven set of large statistical procedures to analyze variability in the size and shape of organisms. Morphometrics and phylogenetics of a species are combined to utilize existing phylogeny which addresses hypotheses of shape change through evolutionary time. Morphometric differences among stocks of a species are recognized as important to evaluate population structure and form a basis to identify stocks. Advancements in morphometrics used powerful tools for testing and displaying differences in shape, isolated shape from size variation and identifying stocks of species with unique morphological characteristics enabling better management of the species. Traditional or standard morphometry has been improvised from time to time with advanced methods by technological advancements like geometric morphometrics, image analysis, principal component analysis, truss network analysis and multivariate analysis as well as many more to update knowledge and get more accurate information. These advanced methods have strengthened earlier technologies to improve upgrade fishery research throughout the globe.

Keywords: Morphometry; Truss Network; Image Analysis; Multivariate Analysis; Principal Component Analysis.

1. Introduction

An organism expresses its phenotypic characters as a result of its genetic constituents as well as environmental influences. Morphometrics was defined as a more or less interwoven set of large statistical procedures to analyze variability in size and shape of organs and organisms. Nayman [1] described morphological systematic as measurement of morphometric characters and meristic account which was considered as authentic and easiest method to identify a specimen. According to Talwar and Jhingran [2], morphometry is the external measurement of body parts of an organism whereas meristic characters are countable characters. Most of those characters with significance to economic traits in fish and fisheries are measurable (metric) or quantitative showing individual variations within a population and their magnitudes depend on a large number of factors as well as number of genes and various environmental parameters [3, 4]. In comparison to any other vertebrate, fishes show greater differences in morphological traits in between the populations and within species [5, 6]. Random fluctuations in these traits in an organism are desirable to destabilize development governed by endogenous factors or exogenous environmental perturbations [7]. Avsar [8] reported that, animals with same morphometric characteristics were believed to belong to the same species. Kováč and Copp [9], morphometric study is a fundamental tool to know growth and development of organisms, their systematic, variations

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http://dx.doi.org/10.28991/HEF-2020-01-03-05

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and structure of population characteristics. Interactive effect of environment, selection and heredity on body shape and size of a species can be studied by this tool [10]. Morphometric differences among stocks of a species are recognized as important method to evaluate population structure and identify stocks [11, 12]. Turan [12] informed that, such analyses were commonly used to identify stocks of fish and to establish evolutionary linkages between ancient and modern fish fauna. Different fish population exhibit differences in their morphometric characters [13] hence, there exists variations among different populations of a species in their body shape and size due to external environmental conditions and various factors. Therefore, study of morphometric character is an important tool used by the fishery scientists globally for identification of stocks and various other purposes.

Murta [14] and Pinheiro et al. [15], morphometric variations between stocks provide basis for stock structure which could be applied to study short term, environmentally induced variation geared towards successful fishery management. Such studies in fishes have mostly used classical dimensions [16-19]. Such analyses were used to identify different stocks of fish species, populations and races [20]. Smith and Jamieson [21] and Randall and Pyle [22] informed that, morphometric differences among stocks of a species are recognized as important tool to evaluate population structure and form basis to identify stocks. According to Hossain et al. [23], fishes quickly adapt themselves by changing necessary morphometrics as they are very sensitive to environmental changes. Morphometric trait proves to be the most frequently employed and cost effective method for identification of a species [24]. The field of fishery science has employed many tools such as genetics and morphometric to differentiate fish population [25]. Information on the biology and population structure of any species is a pre requisite to develop proper strategies for their conservation and management [26]. As stated by Chaklader et al. [27], by detecting changes in the shape, morphometric characters could be used to quantify trait of evolutionary significance. As per Chakravorty et al. [28], morphometry is an essential tool to provide a concept of size and shape of the specimens making identification of species taxonomically significant and also as an essential tool to determine variations among them. Begum et al. [29], Mekkawy and Mohammad [30] and Satyanarayana and Ratnakumari [31] morphometric variations or biometric analysis is employed to identify and find out variations in different fish stocks at species level. Batubara et al. [32] summarized that, morphometric characters are part of morphological characters to analyze quantitative measurements like size and shape. Traditional or standard morphometry has been improvised from time to time with advanced technologies like image analysis, principal component analysis, truss network analysis and multivariate analysis as well as many more to update knowledge and get more accurate information. Keeping the availability of an array of earlier references on application of morphometry in fishes in view, this review was done stating its significance to fishery research throughout the globe. The aim of this article is to emphasize the significance of morphometry in genetics, evolution, systematic and taxonomy of fishes as well as applied aspects like stock management and identification.

2. Morphometry

Morphometric analysis is an age old traditional practice in fisheries research since 1980’s, hence there exists a vast array of literature to enrich pertinent knowledge in this regard. Balon [33] suggested all morphological measurements need to be converted to percentage of standard length to analyze body parts accurately calculating standard error of mean. Various fish populations were recognized by using such measurements [34-36]. The analysis helps to know the origin of stock, separation of stocks or identification of commercially important species of fishes [37-39]. Carpenter et al. [40] reported that, such study plays important role to estimate relationship between various parts of body. Two types of morphological characters like morphometrics and meristics were frequently employed to represent the stocks of a variety of exploited fish species [12, 14, 41, 42]. It is assumed that, characters are independent of each other and some of the controversy about the use of morphometric data in phylogenetics relates to no common underlying causes [43-45] however, shape variables extracted from a morphological structure jointly make up the shape as a whole and normally cannot be assumed to be independent of each other [46]. According to Naem and Salam [47], morphometric and meristic studies are dynamic tools to measure discreteness of same species. According to Sarder and Simonsen [48], taxonomists carefully count meristic characters and measure multiple morphometric variables of body shape to examine external body features; however Eklov and Svanback [49] stated that, freshwater fishes display a range of morphological adaptations. According to them, though there is a risk of misidentification during visual assessment, it is employed to discriminate fishes [48]. As reported by King [50] the morphometric relationships among different body parts of the fish could be used to determine possible differences between separated populations of the same species. Morphometric measurements were widely used to identify differences between fish populations [51-53].

On the utilities of morphometric characters in fishes it was reported by Cadrin and Silva [54], Chaklader et al. [55] and Siddik et al. [56] that, it was one of the simplest, most cost effective and most commonly used tools to identify and characterize fish stocks to determine the structure of fish assemblages [51] and distinguish fish populations [51, 57]. The degree of homoplasy in morphometric data was expected to be negatively associated with the strength of phylogenetic signal [46] and there occurred across a wide variety of physiological states and environmental conditions randomly approximating to event(s) shaping a normal distribution pattern as a result of genetic divergence and phenotypic plasticity. Poulet et al. (2004), Turan et al. (2006) and Akbarzadeh et al. (2009) [58-60] realized the
importance of both genetic and environmental factors on morphometry and morphological characters of fishes. Poulet et al. [58] recommended that these two factors and their interaction influence morphological characteristics where the environmental factors might be availability of food, distance of migration, temperature and salinity with potentiality to determine morphometric discrimination of fishes [59]. Akbarzadeh et al. [60] reported significance of these factors on morphological differentiation in fish. Morphometrics and phylogenetics could be combined to utilize existing phylogeny addressing hypotheses of shape change through evolutionary time [61]. On the utility of morphometry, Mojekwu and Annumudu [26] reported that, it allows more rigorous comparisons of metric characters adding quantitative elements which enable rigorous description of complex shapes permitting numerical comparison between different body forms. Usually, conversion of morphometric measurements in percentage of standard length, head length and caudal peduncle length or parts of thousands of standard length in fishes are described to establish phenotype of a species/variety depicting expected inheritance. Morphometric characters respond to changes in environmental factors which differ from species to species [62].

3. Advancements in Technology

During early investigation of morphology, the measurements were limited to selected body structures like locations of fins with poor or no ability to quantify body shape [63]. Traditional morphometrics mostly relied upon measurements of shape indicators like lengths, areas, angles and their ratios [64, 65]. Combination of multivariate and geometric methods as per Silva [41] increased the chance of detecting small differences in morphometry as anticipated at an intra-specific level since geometric methods took into account of geometry of configurations providing additional information on shape differences which is not available from multivariate methods [66]. It focused on aspects of selected shape only; as a consequence the original shape could not be reconstructed from the measured indicators. Different Mathematical models with few homologous points converted outline geometry into quantitative variables for multivariate framework. RWA was essentially a morphometric principal component analysis of relative landmark positions using variance/covariance matrix producing a series of orthogonal axes ranked by the amount of shape variation explained and all shape axes were retained for analyses [67]. Those measurements were concentrated along the body axis with sampling from depth and breadth only, where most of the measurements were from the head.

3.1. Land Mark Based Morphometry

Modern morphometry as per Rohlf [68] and Bonhomme et al. [69] considered entire shape through approaches like configuration of landmarks and outline analysis. The power of landmark based morphometry is to separate fish based on varying body form supporting the enhancement of this technique for field based diagnosis [70]. Obtaining traditional morphometric measurements is laborious and slow process as taxonomists manually generate data from numerous specimens [71]. But later on, various methods have been developed for estimating phylogenetic signal from morphometric data [46]. Mojekwu and Annumudu [26], the techniques of morphometry measurement emerged with various advancements to analyze fish population which included truss network measurement, image analysis, univariate, bivariate and multivariate analysis as well as principal component analysis (PCA). These methods quantified variations in shape of anatomical objects using the Cartesian coordinates of anatomical landmarks, keeping the effects of non-shape variations constant mathematically. Advancements in morphometrics used powerful tools for testing and displaying differences in shape, isolate shape from size variation and identifying stocks of species with unique morphological characteristics [26]. This enabled a better management of species subunits and ensured better management of the fishery resources [26]. Caillon et al. [72] modern morphometrics encompasses an array of mathematical approaches that turn shapes into quantitative variables.

3.2. Geometric Morphometrics

Bookstein [73], reported about Geometric Morphometrics as a statistical method of analyzing shape variation and its covariance with other variables. According to Adams et al. [61], Cavalcanti et al. [74], Parson et al. [75] and Toscano et al. [76], this was considered to be the most rigorous, cost effective and user friendly technique. It captures information on the shape of an organism from digital images with more powerful statistical analyses for species differentiation. Toscano et al. [76] revealed morphometric variations between the hybrids of roach (Rutilus rutilus L.) and bream (Abramis brama L.) and their parental species inhabiting an Irish lake using Geometric Morphometrics. Echem [77] reported, geometric morphometric analysis to generate shape variation of Sardinella lemuru and revealed that, shape variation could be accounted to their genetics and evolutionary adaption where phenotypic plasticity allowed to respond and adapt to environmental change by modifying their morphology and behaviour leading to changes in morphology, reproduction or survival that alleviate the effects of such environmental change.

3.3. Truss Network Analysis

According to Strauss and Bookstein [78], the conventional morphometric measurements are redundant and most are along the longitudinal axis, having no geometric properties, whereas the truss network provides measurements that cover the entire body representing the shape of the animal. The truss is a system of vertical, horizontal and oblique distances
measured between preselected anatomical landmarks which are points, chosen to divide the body into functional units identified on the basis of local morphological features [79]. This method has advantages over conventional morphometric character sets that usually comprise length, depth, and width measurements. Many authors concord that, truss dimensions measurements including components of body depth and length along the longitudinal axis having theoretical advantages over classical morphometric characters to discriminate among groups [17, 18, 63, 78, 80, 81]. This system [78] has been increasingly used for stock identification from time to time [3, 12, 63, 82-87] covering entire fish in a uniform network theoretically increasing the likelihood of extracting morphometric differences between stocks. Preliminary investigations on populations of anchovies in Turkish terrestrial waters [88] used truss network system for morphometric characters to reveal high degree of dissimilarity and indicated that the anchovies in each sea represent different aggregations. Truss networks of distances between landmarks coordinates have greater discriminating power providing more comprehensive coverage of form [89, 90]. Dwivedi and Dubey [91], it is a more useful and effective strategy to describe shape with better data collection and diversified analytical tools in comparison to traditional morphometric method. According to Mojekwu and Anumudu [26], some arbitrarily selected points on a fish body are known as landmarks which help to analyze individual fish shape. A landmark is a point of correspondence on an object that matches between and within populations. Park et al. [92] analyzed classical and truss dimensions to discriminate different species of dark banded rockfish, black rockfish, striped shiner and the slender shiner. Suryaningsih et al. [93] reported application of truss morphometrics technique in silver barb (*Barbonymus gonionotus*) to distinguish male and female stating that, male fish had a more elongated body size than female.

3.4. Principal Components Analysis

PCA is a multivariate statistical technique that uses orthogonal transformation to convert a set of correlated variables into a set of orthogonal uncorrelated axes called principal components [94, 95]. According to Silva [41], principal components analysis on size corrected truss variables and cluster analysis of mean fish shape using landmark data indicated that the shape of sardine off southern Iberia and Morocco is distinct from the shape of sardine in the rest of the area. Multivariate techniques like principal components (PCA) and discriminate analyses quantified morphometric variables receiving increased attention in stock identification [96-100].

3.5. Multivariate Analysis

As per Cadrin [10], morphometric methods were developed and applied to discriminate stocks like univariate comparisons, bivariate analyses of relative growth pattern and a series of multivariate methods. It enabled condensation of data on a multivariate phenomenon into its main, representative features by projection of data into a two dimensional presentation. Hard et al. [101] analyzed in Coho Salmon by multivariate analysis of shape variation through procrustes coordinates, visualized by thin plate spines indicating adults reared in captivity and differentiated from the wild fish showing sharply reduced sexual dimorphism as well as smaller heads and less hooked snouts, increased trunk depth, larger caudal peduncles, shorter dorsal fins, larger hind bodies and a reduction in body streamlining. Martinez et al. [102] analyzed morpho-structural model of *Dormitator latifrons* through multivariant techniques evaluating effects of sex and production system and reported that, they exhibited sexual dimorphism with insignificant differences in morphometric measurements. Vatandoust et al. [103] compared morphometric characteristics of two groups of *Caspiomyzon wagneri* noting some ranges of overlapping in multivariate analysis.

3.6. Image Processing Analysis

Cadrin and Friedland [11] assessed the enhanced use of image processing techniques but reported that it was not applied frequently to morphometric analyses in fisheries research. But later on, the image analysis systems played a major role to develop morphometric techniques boosting the utility of research. The characteristics were more applicable to study short term, environmentally induced disparities, stock identification [89, 90], species differences, practical morphology and improved fisheries management [88]. Costa et al. [104], this form of morphometric analysis offered more efficient and powerful techniques like image analysis to detect differences among groups differentiating between species of similar shape.

4. Application in Global Fisheries

Shubinkova [105] analyzed morphometric characteristics to report variability in silver carps whereas Ihssen et al. [106] reported utility of morphometry in fisheries to solve problem of stock differentiation and life cycle. According to Ihssen et al. [106], morphometric analysis was one of many tools available for identification of fish stocks which had been applied to many stock differentiation and life history problems [3, 63, 107-111]. It was reported in rainbow trout by Leary et al. [112] from morphometric analysis that there were some asymmetry in morphotype expression and development with low variability. Spanakis et al. [113], found significant genetic and morphometric differences between the Aegean and Ionian Sea populations of Azov Anchovis. Reist et al. [114] detected hybrids among coregonid fishes based on morphological variations. Beeman et al. [110] proposed the utility of morphometric indices in salmonids as a non-lethal measure of smoltification assessment replacing other contemporary methods like physiological, biochemical
and endocrinal requiring killing of animals. Measuring the morphometric characters and calculating the canonical variate is a relatively simple procedure and can be performed with little harm to the fish [110]. As stated by Carvalho and Hauser [115], stock identification is an integral component of modern fisheries stock assessment studies for efficient fisheries management. Balon [33] stated that, a body depth in carps reflected condition, sex and possible lotic or lentic environment. Large body depth in common carp was an indicator of domestication reflecting the probable habitat status and conscious selection [33]. Baranyi et al. [116] conventional morphometric analysis used external measurements to reveal considerable morphological variations within samples involving body depth and fin size but did not allow adaptive eco-morphological interpretation with insignificant correlation limited by the narrow range of heterozygosity estimates. Rosenfield [117] realized the importance of meristic characterization augmented with morphological and color evidence to detect natural hybridization between pink salmon (Onchorhyncus gorbuscha) and Chinook salmon (O. tshawytscha). Cavalcanti et al. [74] studied morphometric variations among six species of serranid fishes and observed non-uniform changes in body shape.

Bronte et al. [4] correlated the genetic basis with whole body morphology of Baikal omul (Coregonius autumnalis, Georgii) with some meristic and classical morphometric measures for stock differentiation whereas Hockaady et al. [118] gave various mathematical models and methods of analyzing morphometry. Katoh and Tokimura [119] compared measurements among different catfishes. Zafar et al. [120] reported in Mahseer (Tor putitora) that, all the meristic characters remained constant whereas morphometric characters gradually increased with increasing body length showing isometric growth pattern. Parsons et al. [75] revealed high morphometric variations in two cichlid fish species. Morphometric data of Sardines through truss variables and landmark were reported by Silva [41] from north eastern Atlantic and western Mediterranean by multivariate and geometric methods. Park et al. [16] investigated eye traits as measurements of head clarifying width between two eyes/distances between head length and premaxilla in catfish. Chakrabarty and Ng [121] identified Mystus cavasius in Myanmar employing morphometric analysis. According to Analaura et al. [122], morphometric or biometric studies were used to estimate the percentage of fish harvested from length-weight data, determining the effects of environmental improvement to regulate fisheries.

Katselis et al. [123] studied morphometric variation among four grey mullet species of Mediterranean revealing high classification of species into their respective groups. Sakai et al. [124] studied morphological variation among three crucian carps from Ob River system Kazakhstan, revealing high morphometric variation among species based on landmark based morphometry. Hossain et al. [23] examined morphometrics along with truss network measurements and meristic counts of Labeo calbasu based on landmark analysis to evaluate their population status reporting some significant differences in four morphometric measurements, revealing high isolation of stocks. Engdaw [125] studied morphometric parameters of Labeo barbus intermedius in Ethiopia finding significant linear relation between total length and standard length and between total length and total weight whereas Makmur et al. [126] estimated morphometric parameters of Hampala macrolepidota from Indonesia observing all measurements with significant positive correlation. According to Solomon et al. [127], farming of a particular fish species for several years could dilute initial gene pool to drive genetic variations manifested in morphological differences between cultured and wild Clarias gariepinus (Burchell). Jacquemin and Pyron [128] studied morphological variation in Cyprinidae from lentic and lotic systems to gain insight into long term patterns in morphology. Siddik et al. [129] studied morphometric characters of Sillaginopsis panijus to delineate stock structure and results showed different stocks in various rivers of Bangladesh.

Morphometric measurements were widely used to identify differences between populations of fishes (51-53, 130). References for morphometry studies in fishes [3, 4, 33, 63, 105-112, 116-118] largely stressed upon importance of morphometric analysis as significant tool for stock identification in fishes. Turan [12], Corti et al. [82], Haddon and Willis [131], Turan [132], Pakkasmaa and Piironen [133] and Turan et al. [134] reported well documented morphometric studies providing evidence for stock discrimination in fishes. Martinez et al. [102] reported regarding requirement of morphological and meristic characterization of chame (Dormitator latifrons) whose characterization was in an advanced stage as compared to other native species [135, 136], as all of which were reported to be interesting to conservationists. Olopade et al. [137] conducted research to study the morphological characteristics of Coptodon guineensis using morphometric measurements and meristic counts and showed that almost all the values of the external morphometric parameters were higher in the river population than those of from creek and revealed that freshwater population could be phenotypically separable from the brackish water population.

4.1. Application of Morphometry in Indian Fisheries

Various authors from India reported from time to time stating the utility of morphometric analysis in fish and fisheries for a systematic account. As described by Johal et al. [138], the morphometric characteristics of Tor putitora were classified into various ranges controlled characters i.e.- vast (environmental), moderate (intermediate) and narrow (genetical). Similar references from India included Bhowmick et al. [139], Chondar [140-142], Khan et al. [143], Tripathy et al. [144] and Sarangi et al. [145] and many more from time to time. Chondar [140-142] reported on systematic account of morphometric and meristic characters in hybrids of Indian major carps like catla rohu and mrigal. Sinha and Khan [146] reported about occurrence of three intra-specific populations of catla in Rihand Dam, Madhya Pradesh, based on distinct morphometry. Khan et al. [143] reported morpho meristic account of rohu, mrigal and their
inter-generic hybrids. In *Tor putitora*, meristic characters were independent of body size and there was no change with increasing body length [2]. Pandey and Nautiyal [147], evaluated some meristic and morphometric characters of taxonomic significance in differentiating *S. richardsonii* (Gray) and *S. plogiostomus* (Heckle) to reveal fin length as characters of diagnostic significance, whereas Johal et al. [148] informed about morphometric and meristic characters of age and growth of golden mahseer *Tor putitora* from Himachal Pradesh but Ujjania et al. [149] reported morphometric and meristic characters of *Tor tor* from Udaipur. Goswami and Dasgupta [150] studied morphometric and meristic characters of *Nandus nandus* (Gangetic leaf fish), as it was reported to be very much essential to record such characters of different species to solve race problem. They reported that, there was a proportional positive increase of morphometric characters with increasing in length.

Darshan et al. [151] identified *Mystus ngasep* in Manipur employing morphometry analysis. Tripathy et al. [152] reported morphometric analysis supported by generation mean analysis in various generations of catla and rohu including their F$_1$ hybrids and backcross populations following Balon [33] to study some of their hereditary trends. Braich and Akhter [153] investigated on morphometry and meristic accounts of *Crossocheilus latius latius* whereas Braich and Akhter [154] reported morphometric characters and meristic counts of *Garra gotoya gotoya* (Gray). Morphometric characters and meristic count of *Garra gotoya gotoya* (Gray) were reported by Braich and Akhter [154] from Ranjit Sagar Wetland. Chakravorty et al. [28], morphometric variations and advancements indicated adaptive capability of Mystus spp. over varied geographical, climatic and nutritive factors. Mohan and Sherly [155] reported utility of morphometric and meristic analysis to separate species, populations and races and identification of species as well as determination of sexual dimorphism in a goby fish *Oxyurichthys tentacularis*. Dwivedi [156] determined morphometric variations in Indian major carps like *rohu, mrigal* and *catla* from Ganga to detect hybrids and described it as a cost effective method. Kaur et al. [62] studied morphometric characters *Labeo rohita* (Hamilton-Buchanan) studying eighteen characters in percentage of total length from which thirteen characters were reported to be genetically controlled three characters were intermediate and two were environmentally controlled and observed a positive correlation between total length and external body parts. Priyanka et al. [157] reported that, all species of family Bagridae showed considerable variations in their morphometric and meristic characters stating the role of such studies in species identification and measuring discreteness and relationships among various taxonomic categories.

5. Conclusion

Most of the phenotypic characters with significance to economic traits in fishes are measurable or quantitative. Those exhibit individual variations within a population. Their magnitudes depend on a large number of factors like number of genes and various environmental parameters. Morphometry enables to know growth and development of organisms. It also enables to know systematic, variations and structure of population characteristics. Traditional methods have been updated from time to time with advanced technologies. Such advancements are like image analysis, principal component analysis, truss network analysis and multivariate analysis to get more accurate information upgrading knowledge and information. So, it is obvious that, morphometry is significant for genetics, evolution, systematic and taxonomy of fishes as well as applied aspects like stock management and identification. It has changed the face of fishery management and research with appropriate application to identify and classify species, races and stocks.

6. Declarations

6.1. Data Availability Statement

Data sharing is not applicable to this article.

6.2. Funding

The author received no financial support for the research, authorship, and/or publication of this article.

6.3. Declaration of Competing Interest

The author declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the author.

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