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Geometric Morphometric Analysis of Body Shape Variation in *Glossogobius giuris* from Lake Mainit, Agusan del Norte, Philippines

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ABSTRACT

Most fish exhibit remarkable morphological diversity, which is often influenced by genetic variation and ecological pressures. Consequently, these are the outcomes of organisms' responses to their environment. Meanwhile, modern morphometrics can quantify shape variation within species of the same group. This study aims to determine the body shape variation of *Glossogobius giuris* from Lake Mainit, Agusan Del Norte, Philippines. 60 adult, uniform-sized fish samples were collected and subjected to standardized laboratory procedures. Further, the samples were digitized for 16 homologous landmark points and loaded into Symmetry Asymmetry Geometric Data (SAGE) Software. Across the tested factors—individuals, sides, and individual x sides—result shows that shape variations among individuals were highly significant ($F = 2.1045$, $p < 0.0001$), along with among males ($F = 3.2711$, $p < 0.0001$). Females exhibited higher Fluctuating Asymmetry (FA) ($F = 18.99$, $p < 0.0001$) compared to males ($F = 7.0964$, $p < 0.0001$). It suggests morphological shape differences across the sexes, and the shape variation observed could be a response to environmental perturbations. Shape variations were associated with swimming, food hunting, and predator defense. Moreover, Principal Component Analysis

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(PCA) demonstrates higher scores of FA in females (81.96%) than in males (74.76%). It was noticed that females had a high fluctuating asymmetry. It might be due to various physiological and ecological pressures compared to males. The observed levels of directional and fluctuating asymmetry in males and females, respectively, may indicate sex-linked morphological and developmental processes, which are important to consider in ecological or evolutionary contexts. Thus, utilizing geometric morphometrics can depict subtle differences across the same populations.

Keywords: Caraga Region; Ecology; Freshwater Fish; Landmarks; Limnology; Phenotypes; Shape Variation

1. Introduction

Glossogobius giuris, or "tank goby", is a widely distributed fish species in the Philippines and Asia's freshwater and estuarine ecosystems [1]. This fish is important in local fisheries as it is commercially valued while being significantly identified as predatory and interacting with other species [2]. Biologically, this fish type often inhabits sandy or muddy substrates, where it can hunt small invertebrates, crustaceans, and fish fry [3]. On the other hand, *G. giuris* is commonly found in lakes and river systems, including Lake Mainit, in the Philippines, where its population is enormous and serves both food resources and livelihood in the region [4]. Since fishes are diverse and ecologically significant, they are subject to morphological investigation because of their adaptive variations. In addition, this fish type holds economic significance in the region as a source of livelihood and serves as an essential protein resource in humans, apart from being a key element of biodiversity [5].

Studies concerning morphology assess species differentiation, environmental adaptation, and evolutionary relationships [6]. Most fish exhibit remarkable morphological diversity, which is often influenced by genetic variation and ecological pressures [7]. Relatively, fish morphology is essential in taxonomy, ecology and conservation biology [8]. Identifying species and distinguishing populations are essential for the conservation management of fishery resources [9]. Further, ecological factors influence morphological characters, making them crucial for population differentiation and species identification [10]. At the same time, this population's body shape variations may be associated with factors such as food availability, temperature, and water depth [11]. Fish exhibit greater variations in morphological traits than other vertebrates, both within and among populations, and they are more responsive to these alterations, ultimately modifying their morphology [12]. Assessing their biological forms in conservation biology, population structure, phenotypic health, and morphological integrity is necessary, especially in cryptic or endangered species where genetic differences are unavailable [13]. Additionally, taxonomists clarify species boundaries by detecting shape differences too subtle for traditional classification [14]. Besides, taxonomy holds significance for fisheries researchers for identifying fish stocks and assisting in creating balanced conservation efforts [15]. Interestingly, studies on morphological differentiation within species are crucial for addressing issues related to species recognition since it is acknowledged that inadequate data on geographic variations within species may result in misidentifying species [16].

Over the years, conventional morphometrics were utilized in fish groups and several studies [17]. Geometric morphometric analysis (GM) offers a more detailed and comprehensive method for examining shape variations [18]. GM used landmark-based techniques to quantify shape differences in organisms, allowing for a detailed comparison of morphological traits [19]. Likely, these variations often denote intraspecific differences and potential environmental influences [20]. With GM, results can be visually represented through difference vector diagrams or thin plate spline [21]. Techniques for image processing have significantly advanced morphometric analysis and have substantially enhanced stock identification and differentiation in fish [22]. In recent years, the geometric morphometric approach has been extensively utilized for morphological research [23, 24]. It can differentiate between species of fish that are closely related [25], and it reveals the relationship between shape and variations in developmental, evolutionary, functional, and ecological aspects [14]. The dimensions and form of the body in geometric morphometrics serve as essential techniques for documenting morphological differences, especially changes in size and shape [25]. It involves digitizing specific anatomical landmarks on an organism, aligning then using Procrustes superimposition, and analyzing the resulting shape variables using multivariate statistical techniques such as Canonical Variate Analysis (CVA), Principal Component Analysis and Procrustes ANOVA [26, 27]. One of the most significant advantages of geometric morphometric is its ability to visualize shape differences through deformation grids or thin-plate spline transformations [28].

Moreover, previous studies on *G. guiris* also focused on body shape variations [29–31]. However, no studies have been conducted on the fish using geometric morphometric techniques within the region or even in the country as of 2025. Monitoring through spatial and temporal dynamics also constitutes significant input to fish stocks regarding development and growth. Hence, the present study aimed to differentiate *Glossogobius giuris* through body shape variations and to assess the variations among sexes of *G. giuris* from Lake Mainit, Agusan Del Norte, Philippines.

2. Materials and Methods

2.1. Study Area, Collection of Fish Samples and Laboratory Procedures

The collection of fish samples was done with the aid of local fishermen in the area (**Figure 1**). A total of 60 individuals consisting of 30 males and 30 females of mature and uniform size were collected. Afterward, laboratory procedures were done following the standardized methods. Each of the samples was positioned on the top of the Styrofoam using the pins to stretch out the fins through 10% formalin application. Next, each of the samples was photographed using the digital camera on its left and right sides three times to minimize the error. Later, each sample underwent an exterior examination to look at the genitalia for sex determination. Females were identified by their granular textures ranging from yellow to orange. While the male samples were identified through smooth, white, granular-free testes.

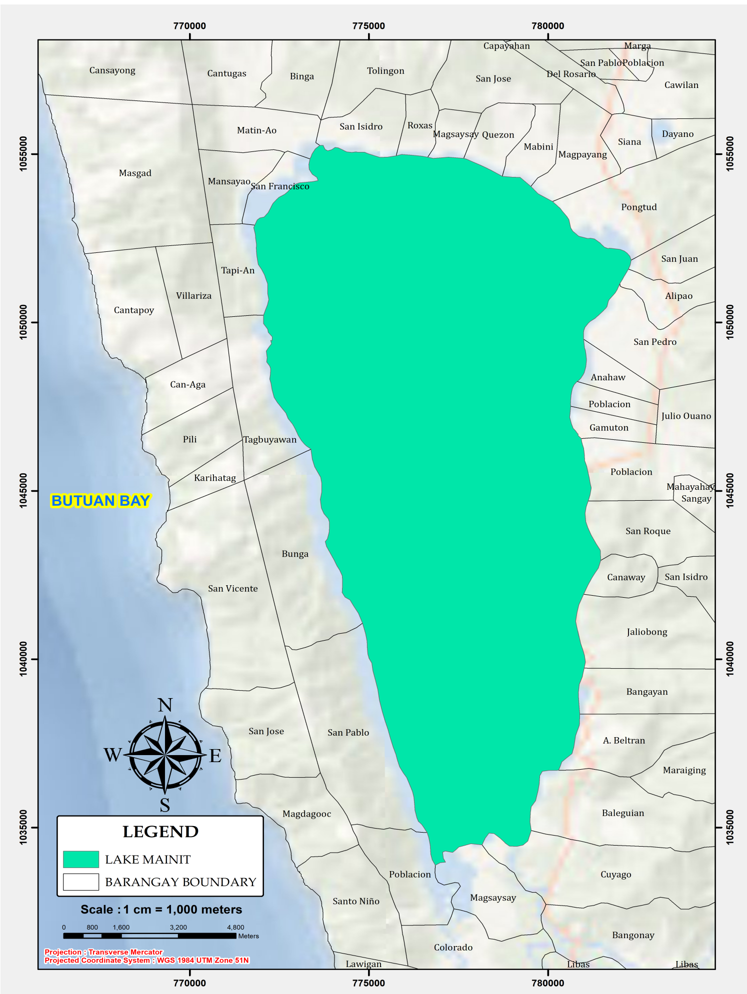

Figure 1. Map of the Study Area, Lake Mainit, Agusan del Norte, Philippines.

2.2. Landmarks Digitization & Geometric Morphometric Analysis

The photographs were sorted according to the sex (male and female) samples. Then they were converted to tps format using the tpsUtil. Moreover, digitization of the samples was done using tpsDig2 [32]. A total of sixteen anatomical landmarks were used on the body shape of *G. guiris* (**Figure 2**). The sixteen landmarks points used were the standard meristic in evaluating shape variations in this type of fish.1-Snout tip, 2- Posterior ends of nuchal spine, 3- Anterior insertion of dorsal fin, 4- Posterior insertion of dorsal fin, 5- Dorsal insertion of caudal, 6- Midpoint of caudal border of hypural plate, 7- Ventral insertion of caudal fin, 8- Posterior insertion of anal fin, 9- Anterior insertion of anal fin, 10- Dorsal bases of pelvic fin, 11- Ventral end of lower jaw articulation, 12- Posterior ends of maxilla, 13- Anterior margins through midline of orbit, 14- Posterior margins through midline of orbit, 15- Dorsal ends of operculum. 16- Dorsal bases of pectoral fin [33]. Procrustes ANOVA was used in the study to identify the variation in fish sample body shapes (individual, sides, and individual x sides). This was the basis of the analysis at ($p < 0.0001$), the significance level. The examination of directional asymmetry and the differences between the sides were also measured. In addition, the percentage of fluctuating asymmetric (FA) in the samples of males and females was studied and compared [34]. Principal component analysis (PCA) was performed to define the highest levels (5% and above) of variations in body shape and estimate species differentiation between sexes. The collected coordinates were then subjected to (SAGE) Symmetry and Asymmetry in Geometric Data Software Application version 1.04 [35].

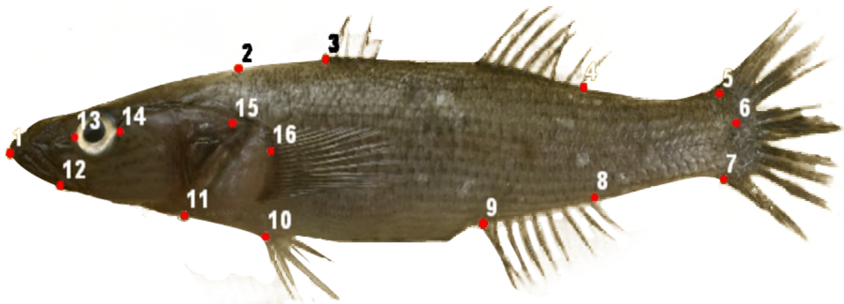

Figure 2. 16 Anatomical Landmark Points on the Body Shape of *G. giuris*.

3. Results and Discussion

Procrustes ANOVA on the body shape of *Glossogobius giuris* in terms of sex was presented in **Table 1**. It was revealed that body shape variations were highly significant ($p < 0.0001$) across the tested factors (individuals, sides, and individual x sides). The significance level denoted individual fish differed significantly in shape, while the sides showed strong evidence of directional asymmetry. This means consistent shape differences between the left and right sides. Further, individual x sides also indicated a random deviation from symmetry at the individual level. It implies a significant fluctuating asymmetry among fish samples. Shape variations among individuals were highly significant ($F = 2.1045$, $p < 0.0001$), along with among males ($F = 3.2711$, $p < 0.0001$). This substantial inter-individual variation suggests the presence of notable morphological diversity within each sex. Such variation is commonly attributed to genetic differences, ontogenetic changes, or environmental influences and is a foundational assumption in morphometric analyses [27]. Directional Asymmetry or consistent shape differences between the body's left and right sides were also significant in both sexes. Females had an F-value of 21.86 ($p < 0.0001$), while males had a higher F-value of 32.95 ($p < 0.0001$). This indicates the presence of systematic Asymmetry across individuals, which may reflect underlying functional or behavioral asymmetries, possibly linked to sex-specific ecological roles or developmental pathways [36].

The interaction between individuals and sides represents fluctuating Asymmetry (FA), a random deviation from perfect bilateral symmetry, and was significant in both groups. Females exhibited higher FA ($F = 18.99$, $p < 0.0001$) compared to males ($F = 7.0964$, $p < 0.0001$). Fluctuating Asymmetry is widely used as a proxy for developmental instability and environmental stress, suggesting that females may be more sensitive to such stressors or experience more remarkable plasticity during development[37]. The mean squares for measurement error were very low in females and males (MS = 0.0001), indicating minimal digitization or landmarking error. This supports the reliability and reproducibility of the data acquisition process[26]. This reinforces that the observed shape variation is primarily biological rather than technical[27]. The significant individual variation and Asymmetry observed in this study are consistent with the patterns revealed by PCA, highlighting individual differences as the main contributors to total shape variance. The higher levels of directional and fluctuating Asymmetry in males and females may indicate se-linked morphological and developmental processes, which are important to consider in ecological or evolutionary contexts[27].

Table 1. Procrustes ANOVA on the Body Shape of *Glossogobius giuris* in Terms of Sexes.

Factors	SS	DF	MS	F	p-Value
			Female		
Individuals	0.2553	812	0.0003	2.1045	0.0001
Sides	0.0915	28	0.0030	21.8645	0.0001
Individual x sides	0.1213	812	0.0001	18.99	0.0001
Measurement error	0.0264	3360	0.0001	–	–
			Male		
Individuals	0.262	812	0.0003	3.2711	0.0001
Sides	0.0883	28	0.0032	32.9532	0.0001
Individual x sides	0.0801	812	0.0001	7.0964	0.0001
Measurement error	0.0467	3360	0.0001	–	–

Considerably, genetic and environmental influences might cause the observed shape variations in the fish body shape. Comparable results also indicated significant variations in the body shape of *G. giuris*[29–31]. This finding may be attributed ecosystem is vital in developing an organism's shape and form[9]. In addition, a fish's swimming activity may be enhanced by water moving quickly compared to stagnant water, which could lead to a change in shape due to greater mobility[38]. Study revealed that changes in metabolism caused by maintaining homeostasis and the reproductive state are expected to cause female fish to have an exceptionally high level of Fluctuating Asymmetry[39]. However, swimming patterns, food habits, actions, and water temperature increase all contribute to fish form variation[40]. Relatively, Lake Mainit is the second largest lake in Mindanao and the fourth largest in the Philippines, with an average depth of 223 meters; it is expected that water depth will account for a large portion of shape variation. This lake offers a distinctive ecological environment that most probably strongly impacts *G. giuris* body shape variation. It has a wide variety of microhabitats at different depths, substrates, and vegetation types. These environmental gradients and localized hydrological conditions, water chemistry, and resource availability can impose differential selective pressures on resident fish populations. In addition, anthropogenic factors like fishing pressure, land-use modification, and potential pollution inputs may exert developmental stress, which is commonly discernible by fluctuating asymmetry in body shape. Hence, the morphometric variation of *G. giuris* from Lake Mainit is probably due to the intricate interaction between natural environmental fluctuation and habitat changes caused by human activities.

Freshwater fishes that live in lakes tend to have significant shape differences based on environmental heterogeneity, ecological specialization, and geographic isolation. In lentic habitats such as lakes, fish populations are determined by water depth, temperature, substrate, and food gradients, resulting in divergent morphological adaptations[41]. Shape variations can reflect functional demands such as swimming efficiency, predator avoidance, or foraging strategies, resulting in distinct body shapes within the same species[13]. In the case of *G. giuris*, a widespread goby species in Southeast Asia, is known to show phenotypic plasticity in response to local environmental pressures[42]. This species occupies various habitats, from rivers to estuarine and lake systems, and demonstrates variation in body depth, fin length, and head morphology depending on habitat conditions[41]. In Lake Mainit, preliminary geometric morphometric analyses have indicated population-level differences in the fish suggesting possible ecological divergence influenced by depth and substrate type[43].

Geometric morphometrics provides a robust framework for studying these shape differences by capturing landmark-based data and analyzing variation while accounting for size and orientation [19]. In Lake Mainit, such tools have been used to assess shape variation among multiple freshwater fish species, including *G. giuris*, revealing distinct morphological groups that may be associated with specific microhabitats or environmental gradients [43]. These results have important implications for understanding adaptive variation and potential cryptic speciation in freshwater systems. Generally, body shape variation in *G. giuris* and other lake-dwelling fishes reflects the influence of ecological pressures and habitat differentiation, which can be effectively assessed through geometric morphometric techniques [34]. Furthermore, kinematics of predator obtaining have been linked to changes in specific fish body components [44]. Besides feeding habits, the interaction between prey and predator, mobility, and the aging process were linked to the observed variations in body morphologies [45]. Likewise, form dissimilarities have evolved to mitigate environmental effects, resulting in phenotypic variance contained within the geographic range. Larger abdomens are more common in female populations, and this is associated with sexual development [46]. Studies have shown a correlation between physiological characteristics, including growth, development, and reproductive stage, and variances in body shape [47]. Geographic location influences the development of unique morphological traits among fish populations, likely due to the interplay of genetics, environment, and selection that creates morphometric variations within a species [48]. The geometric morphometrics research carried out by Imtiaz and Md Naim [25] on the Genus Nemipterus also highlighted the significant role of body shape in differentiating between the genera. Overall, numerous factors significantly contribute to morphological variations, such as environmental influences, genetic influences, and habitat diversity [49], along with abiotic and biotic elements like food availability, salinity, radiation, temperature, current flow, and water depth [50].

On the other hand, principal component analysis (PCA) was used to identify the affected landmarks among the fish samples (**Table 2**). The study examined four principal components (PCs) in samples of males and females population. In female samples, there were four principal components PC1 (49.95%), PC2 (15.20%), PC3 (12:48) and PC4 (6.20%) accounting to (83.83.%) with a total interaction/fluctuating asymmetry (81.96%) of the combined variations. Across the four principal component scores, landmarks were the most affected in the female samples along with PC1 were: 1 (Snout tip), 2 (Posterior ends of nuchal spine), 3 (Anterior insertion of dorsal fin), 4 (Posterior insertion of dorsal fin), 5 (Dorsal insertion of caudal), 6 (Midpoint of caudal border of hypural plate), 7 (Ventral insertion of caudal fin), 8 (Posterior insertion of anal fin), 9 (Anterior insertion of anal fin), 10 (Dorsal bases of pelvic fin), 11 (Ventral end of lower jaw articulation), 12 (Posterior ends of maxilla), 13 (Anterior margins through midline of orbit), 14 (Posterior margins through midline of orbit), 15 (Dorsal ends of operculum), 16 (Dorsal bases of pectoral fin). In PC2 were 1 (Snout tip), 2 (Posterior ends of nuchal spine), 7 (Ventral insertion of caudal fin), 8 (Posterior insertion of anal fin), 9 (Anterior insertion of anal fin), 10 (Dorsal bases of pelvic fin), 11 (Ventral end of lower jaw articulation), 13 (Anterior margins through midline of orbit). In PC3 were (Snout tip), 4 (Posterior insertion of dorsal fin), 5 (Dorsal insertion of caudal), 6 (Midpoint of caudal border of hypural plate), 7 (Ventral insertion of caudal fin), 8 (Posterior insertion of anal fin), 12 (Posterior ends of maxilla), 13 (Anterior margins through midline of orbit), 14 (Posterior margins through midline of orbit). In PC4 were 1(Snout tip), 4 (Posterior insertion of dorsal fin) and 9 (Anterior insertion of anal fin). Eventually, the most common affected landmarks across the four PCs were 1 snout tip.

In male samples, the four principal components PC1 (44.61%), PC2 (13.86%), PC3 (12.43%) and PC4 (9.85%) also contributed to (80.76%) with the total interactions/fluctuating asymmetry (74.76%) of the combined variations. Across the four principal component scores, landmarks were the most affected in the female samples along with PC1 were 1(Snout tip), 2 (Posterior ends of nuchal spine), 3 (Anterior insertion of dorsal fin), 4 (Posterior insertion of dorsal fin), 5 (Dorsal insertion of caudal), 6 (Midpoint of caudal border of hypural plate), 7 (Ventral insertion of caudal fin), 8 (Posterior insertion of anal fin), 9 (Anterior insertion of anal fin), 10 (Dorsal bases of pelvic fin), 11 (Ventral end of lower jaw articulation), 12 (Posterior ends of maxilla), 13 (Anterior margins through midline of orbit), 14 (Posterior margins through midline of orbit), 15 (Dorsal ends of operculum), 16 (Dorsal bases of pectoral fin). In PC2 were 1(Snout tip), 3 (Anterior insertion of dorsal fin), 4 (Posterior insertion of dorsal fin), 5 (Dorsal insertion of caudal), 6 (Midpoint of caudal border of hypural plate), 7 (Ventral insertion of caudal fin), 8(Posterior insertion of anal fin), 9 (Anterior insertion of anal fin), 10 (Dorsal bases of pelvic fin), 12 (Posterior ends of maxilla), 15 (Dorsal ends of opercula), 16 (Dorsal bases of pectoral fin). In PC3 were 1 (Snout tip), 2 (Posterior ends of nuchal spine), 3 (Anterior insertion of dorsal fin), 4 (Posterior insertion of dorsal fin), 6 (Midpoint of caudal border of hypural plate), 7 (Ventral insertion of caudal fin), 8 (Posterior insertion of anal fin), 9 (Anterior insertion of anal fin), 15 (Dorsal ends of operculum), 16 (Dorsal bases of pectoral fin). In PC4 were 1(Snout tip), 4 (Posterior insertion of dorsal fin), and 9 (Anterior insertion of anal fin). The commonly affected landmarks in male samples for the four PC scores were landmarks 1 and 4. These were the portion of the snout tip and the posterior insertion of the dorsal fin. In comparison female *Glossogobius giuris* were observed to reveal higher fluctuating asymmetry (FA) when compared in males. The affected landmarks among male and female fish may generally be ascribed to their movement and interactions with their surroundings. However, all evidence suggests that a distinct increase in body form elongation may be more notable than the ontogenetic phase, even with the limitations of geometric morphometric study [51].

Table 2. Principal Component Analysis Showing the Values of Symmetry and Asymmetry Scores with the Summary of the Affected Landmarks Between Sexes of *Glossogobius giuris*.

PCA	Individual	Sides	Interactions (FA)	Affected Landmarks
			Female	
PC1	49.95%	100%	39.50%	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
PC2	15.20%		21.21%	1, 2, 7, 8, 9, 10, 11, 13
PC3	12.48%		11.92%	1, 4, 5, 6, 7, 8, 12, 13, 14
PC4	6.20%		9.33%	1, 4, 9
Total	83.83%		81.96%	
			Male	
PC1	44.61%	100%	31.22%	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
PC2	13.86%		17.39%	1, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 16
PC3	12.43%		14.26%	1, 2, 3, 4, 6,7, 8, 9, 15, 16
PC4	9.85%		11.89%	1, 4, 9, 10, 11
Total	**80.76%**		**74.76%**	

A prior study also indicates that stream-dwelling fish often exhibit more elongated bodies and streamlined shapes to reduce drag and maintain stability in fast-flowing waters. In contrast, fish inhabiting lentic or still water environments tend to have deeper bodies and enhanced maneuverability for navigating complex habitats like submerged vegetation or rocky substrates [41]. In comparison, a study in *Channa gachua* in different freshwater habitats in Southeast Asia revealed significant shape differences likely driven by habitat isolation and environmental pressures [52]. Similarly, a study on the investigation of craniofacial variation in cichlid fishes linked the morphological traits to feeding specialization and ecological divergence [53].

This condition also indicates that changes in morphometric characteristics were influenced by external elements like water quality and food availability [54]. Moreover, variations in the morphology of the head pattern are also a result of utilizing different environmental niches, food availability, and prey type [55, 56]. Environmental and genetic variations could have been responsible for population differences [12]. Furthermore, how much energy is used for swimming may impact the species' physical characteristics [57]. According to the study, the affected anatomical regions were important for body movement while swimming and needed a lot of oxygen and protein [58]. For instance, the axial muscle growth and was linked to increased swimming activity due to evading predators. Fish undergo this transition, changing their body shape to deeper and more laterally compressed, better suited for fast swimming [59, 60].

The present data is similar to the previous findings in fish morphometric studies, where intraspecific variations are often attributed to genetic background, phenotypic plasticity, ontogenetic stages, and environmental heterogeneity [27, 61]. Fish usually exhibit shape differences influenced by habitat complexity, current velocity, feeding activities, and predator presence [35]. For example, in riverine systems, individuals may develop deeper bodies and shorter caudal peduncles in slower waters for better maneuverability, while those in faster currents may have more streamlined shapes [41]. These shape differences within the same populations may reflect local microhabitat adaptations [21]. Subsequently, ontogenetic variations (differences associated with growth and development) significantly affect shape diversification among individuals [14]. As fish grow, changes in muscle mass, fin positions, and body proportions occur, contributing to shape variation that is detectable using landmark-based geometric morphometrics [19]. Therefore, the individual level of variation serves as a basis for assessing population structure, local adaptation, and evolutionary potential [62]. In many teleost fishes, directional asymmetry can be associated with functional morphology, such as preferred turning direction during escape responses, feeding asymmetry, e.g., scale-eating cichlids) or uneven organ development [63]. As well as, certain benthic or ambush predator fish display jaw asymmetry to enhance prey capture success from a particular side [64]. Accordingly, the various environments are frequently considered as a foundation for strong divergent selection in morphology among fish population [34]. A link exists between morphological characters and their roles concerning the environment [65]. Spatial seclusion has resulted in significant morphological diversity [66]. Additionally, several studies indicate variations in the whole fish body are directly attributed to fish inhibiting in different flow regimes [52].

As a result, patterns can be used to visualize the significance of distinguishing shape dissimilarities within fish species (**Figures 3** and **4**). Principal Component Analysis (PCA) is a tool used to visualize dimensionality and explore variation in shape based on landmark data [18, 19]. It helps to identify significant trends in morphological variation across a sample. Principal Component 1 among the population represents the largest source of shape variation, female (49.95%) and male (44.61%). These figures are commonly used in geometric morphometrics to analyze biological shape variation, especially in studies of fish, insects, skulls, or other anatomical features [67]. PC1 shows the most substantial variation. The deformation grid suggests a dorsoventral bending or warping of the structure. It may correspond to body depth or curvature. This shape variation is likely associated with environmental adaptation, such as habitat preference or differences in swimming ability [68]. PC2 appears to reflect lateral compression or expansion in specific body regions. This may indicate functional differences in feeding, locomotion, or niche specialization [20]. PC3 and PC4 represent subtler variations. These might include asymmetry or regional differences that, while less dominant, could still be biologically important regarding development stability or sexual dimorphism [68].

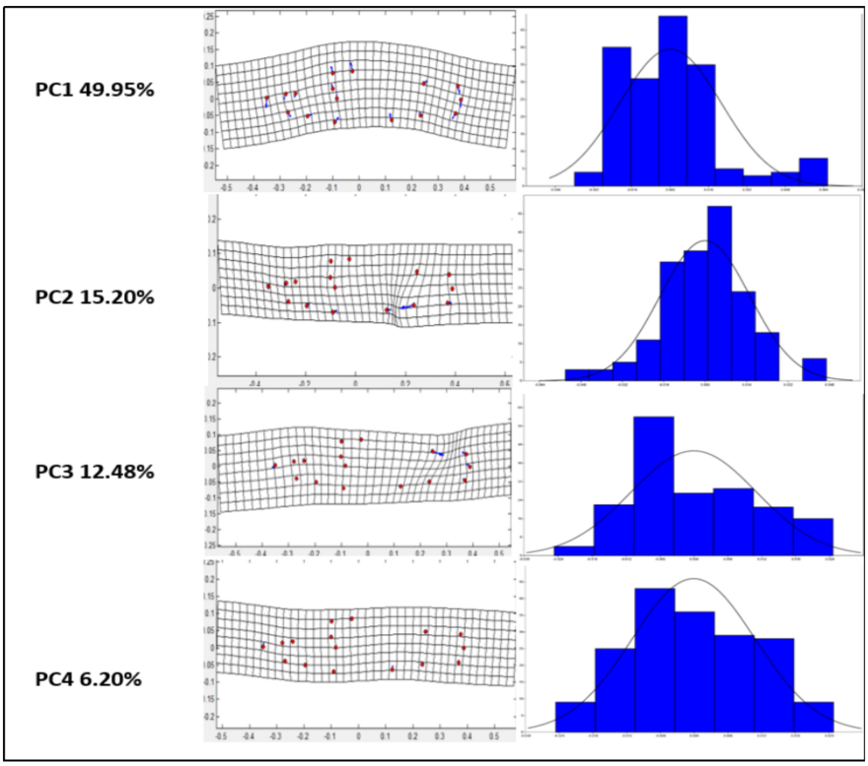

Figure 3. Principal Components Implied Deformation Grid and a Histogram of Individual (Symmetric) in Female *Glossogobius giuris.*

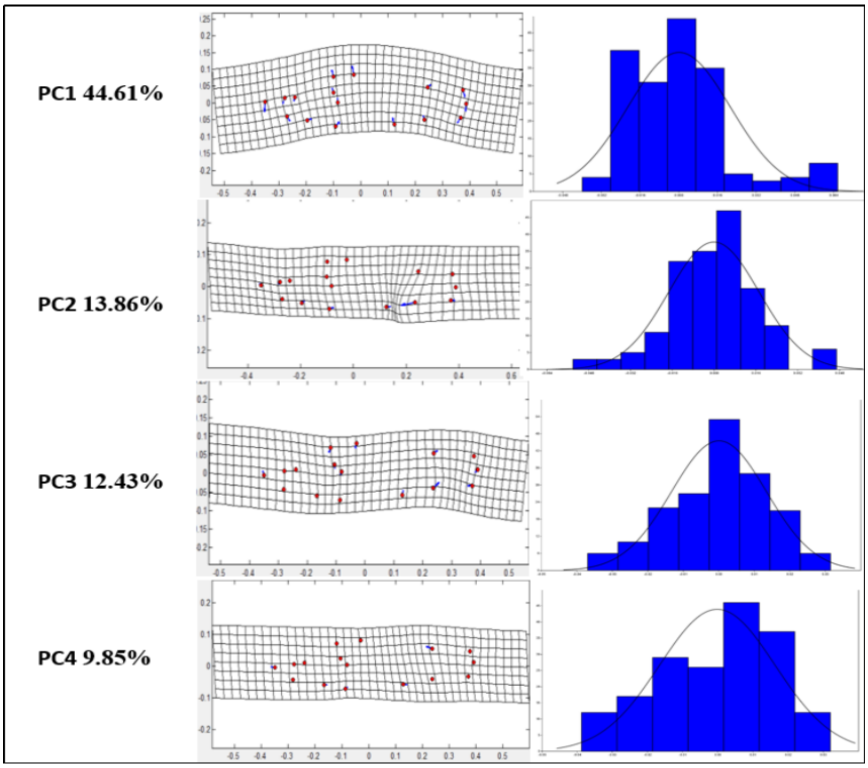

Figure 4. Principal Components (PC) Implied Deformation Grid and a Histogram of Individual (Symmetric) in Male *Glossogobius giuris.*

Moreover, the substantial variation explained by PC1 across the sexes suggests a primary axis of morphological divergence among the specimens. For instance, body depth is often associated with different ecological strategies in fish: deeper-bodied species are typically found in lentic (still water) habitats where maneuverability is more important. In contrast, streamlined bodies are advantageous in lotic (flowing water) environments for reducing drag [69]. On the other hand, PC2 and PC3 may draw morphological adaptation to more specific developmental and ecological perturbations. For example, feeding habits or reproductive roles might change eye position, fin placement, or jaw shape. These shape variations can thus provide insights into ecological specialization, sexual selection, and even the speciation process [19]. Shape differences along these components may also reflect genetic divergence among populations. Morphometric data combined with genetic analyses have often revealed congruent differentiation patterns, suggesting that morphometrics can be a valuable proxy for underlying genetic or adaptive divergence [41]. Also, shape variations across fishes in the same taxonomic group frequently results from adaptations to specialized ecological niches based on environmental drivers, including habitat structure, predation regime and food specialization [54]. Even closely related taxa may exhibit important morphological disparity in body depth, head morphology and fin locations, impacting locomotion ability and feeding modes [70]. These differences in shape represent critical markers for evolutionary processes such as adaptive radiation and ecological speciation [58]. Nonetheless, geometric morphometric methods enable researchers to measure and compare these differences in shape precisely, illustrating on phenotypic plasticity and evolutionary limitations [53]. For instance, a gobiid fish species has shown significant morphological differentiation concerning benthic and pelagic life histories even when sympatric [71]. Such variation is crucial for interpretating ecological interactions and guiding taxonomic classifications and conservation management particularly in the case of cryptic or morphologically inconspicuous species [72]. Knowledge of shape variation in taxa assists in uncovering how form and function develop under ecological pressures, further supporting the significance of combining morphometric and ecological information in biodiversity evaluations [73].

Previous research reveals that females of different species have high fluctuating asymmetry [74]. FA is a variation from perfect bilateral symmetry brought on by developmental instability and environmental pressures during maturation [49, 50]. Studies indicate that low mass at length, slower growth rates, smaller size, and significant fluctuating asymmetry in female fish may all hurt reproductive fitness [75]. Observed asymmetry during fish growth indicates increased metabolic efficacy [76]. In this regard, research indicates that morphological variations in fish frequently influence selection and geographical barriers [10]; nonetheless, studies have indicated that environmental limitations might also contribute to this phenomenon [77]. Variations often associated with the environment might provide an understanding of the ecological approaches of a species, including dietary behaviors, locomotion patterns, and relationships with different species [78, 79].

From a developmental perspective, shape variation reflects coordinated changes among traits [?]. In comparison, studies show that integrated structures may be subject to evolutionary tradeoffs [42]. The shape variation observed here may represent an adaptive landscape where different morphologies correspond to fitness peaks. Morphological differences in PC1 might illustrate evolutionary adaptations to divergent ecological niches, a key step in ecological speciation [11].

Nevertheless, the morphological variation along multiple PCs could justify the identification of distinct morphotypes or even cryptic species, particularly if corroborated by genetic or ecological data [80]. Along with landmark-based PCA, it is valuable for distinguishing ontogenic (age-related) sexual or population-level variation. If supplementary metadata, e.g., age and location, are available, researchers could correlate PC scores with these variables to uncover patterns of sexual dimorphism or geographic variations [81]. Consequently, the biological importance of PCs depends on how consistent and accurate the landmarking is. Errors in landmarking placement can distort results, especially in small data sets. Hence, rigorous landmarking protocols and validations are critical [61]. Finally, the results presented in this study give a detailed view of shape variations among *G. guiris* with clear implications for understanding morphological diversity, ecological adaptation, development integration, and evolutionary divergence. The dominant shape variation along PC1 reflects significant structural differences tied to ecological or functional demands, while PC2 up to PC4 reveal subtler yet potentially significant shape differences. This study illustrates the efficacy of geometric morphometric analysis in determining variations in the body shape of *Glossogobius giuris* in Lake Mainit, Agusan del Norte, Philippines. These morphological variations may manifest underlying ecological environmental, or genetic factors, highlighting the significance of shape-based evaluations in fisheries management and conservation. These results add to the general knowledge of the population structure of freshwater fish and underscore the role of morphometric methods in facilitating sustainable biodiversity monitoring in Philippine aquatic ecosystems.

4. Conclusions and Recommendations

This study aims to determine the body shape variation of *Glossogobius giuris* from Lake Mainit, Agusan Del Norte, Philippines. Across the tested factors: individuals, sides, and individual x sides result shows that shape variations among individuals were highly significant ($p < 0.0001$). It suggests morphological shape differences across the sexes, and the shape variation observed could be a response to environmental perturbations. These morphological alterations are probably related to the sex-linked and genetic component. Using the geometric morphometric technique actually examines fish stock among taxa in more detail. It permits a thorough, accurate, and precise comparison of a species' morphology, even using the same coordinate system. Geometric morphometric analysis provides a solid platform to compare morphological characteristics quantitatively by retaining the geometry of anatomical structure via landmark-coordinate data. Applying the same coordinate system makes it feasible to achieve accuracy and precision while detecting minute differences in shape both within and across populations, thereby making it possible to make genuine estimations on morphological variability, developmental stability, and evolution trends. The study implied that the geometric morphometric technique is valuable for managing fisheries and efficiently examines shape variation within the same taxa. Thus, the study proposes future research in other fish types using geometric morphometric analysis for fishery policy or ecological monitoring.

The study's results suggest that future studies concerning other fish types as a subject for geometric morphometrics require more samples and include the environmental factors, i.e., Physicochemical parameters, heavy metals in the fish tissues, water, and sediments. Ultimately, the goal is to conduct a molecular/genetic identification of why shape variation occurs among fish of the same taxa.

Author Contributions

Conceptualization, methodology, formal analysis, writing—original draft preparation, review and editing, C.C.C.J.; data curation, A.M.D.E. project administration, J.M.D.P. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Ethical review and approval were waived for this study because Caraga State University Cabadbaran Campus had no institutional ethics committee during the study period. All procedures followed the ASIH Guidelines for the Use of Fishes in Research and complied with national regulations of Bureau of Fisheries and Aquatic Resources. And Department of Environment and Natural Resources.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Conflict of Interest

The authors declare no conflict of interest.

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