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Article

Sexual shape dimorphism in the monomorphic fish *Decapterus macrosoma* (Teleostei: Carangidae)

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Abstract

Monomorphism is prevalent among fishes consequently sexually dimorphic traits are unknown. Discrimination between sexes is often achieved through direct examination of the gonads. However, at present, patterns of sexual dimorphism are known through the analysis of body shapes. Thus, this study used landmark-based geometric morphometrics to investigate and describe sexual dimorphism in the body shape of *Decapterus macrosoma*. Fourteen landmarks from images of 60 individuals (25 males and 35 females) were subjected to geometric morphometric analysis. Variability in body shapes between sexes was visualized by generating thine-plate spline expansion plots. Results showed that females exhibited a deeper body depth, broader belly region, bigger head, and wider caudal fin while males exhibited a narrow body depth, smaller head, and wider dorsal and caudal fins. Multivariate analysis of variance and discriminant function analysis showed significant difference in the body shapes between sexes of this fish species ($p<0.05$). The results were discussed as results of sexual and natural selection in fishes.

Keywords morphology; relative warps; landmark-based morphometrics; sexual selection.

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1 Introduction

Sexual shape dimorphism is a phenomenon where the shape of males and females of the same species differs. Although information regarding the shape of an organism contributes meaningfully to various functions such as feeding, mating, parental care, and other life history characteristics, patterns of sexual shape dimorphism are least studied (Gidaszewski et. al., 2009; Berns and Adams, 2012). It has been primarily attributed to sexual selection, that is, the influence of the differences in reproductive roles in patterns of selection that could lead to sex differences in morphological attributes such as the body shape (Casselman and Schulte-Hostedde, 2004). Moreover, natural selection (Kuo et al., 2009), niche differentiation (Temeles et al., 2000; Herrel et al., 2010; Temeles et al., 2010), environmental conditions (Willemsen and Hailey, 2003; Hendry et al., 2006), and even allometry (Gidaszewski et al., 2009) have been hypothesized to drive evolution of different shapes between sexes.

Often, the adult shape of an organism is retained (Rohlf, 1990; Rohlf and Marcus, 1993; Adams et al., 2004) throughout spatial (Kelly et al., 2013; Lima Filho et al., 2017) and temporal scales (Walker and Bell, 2000). Moreover, describing the subtle differences in shape within and among populations have been improved with the advent of geometric morphometrics which provided statistically powerful and visual methods for the analysis of shape (Rohlf and Marcus, 1993).

The shortfin scad, *Decapterus macrosoma* (Bleeker, 1851) is a small pelagic and schooling fish which is widely distributed in the Indo - West Pacific region, inhabiting insular habitats. At present, sexually dimorphic traits in *D. macrosoma* have not been established as it appears to be monomorphic, that is, there are no apparent observable differences in form between sexes. Consequently, discrimination between sexes can only be accomplished by direct examination of the gonads. In this regard, a geometric morphometric analysis was employed to investigate sexual shape dimorphism in *D. macrosoma*. It was hypothesized that sexual and natural selection influenced the evolution of sexually dimorphic body shapes in *D. macrosoma*.

2 Materials and Methods

2.1 Sample collection

A total of 60 samples (25 males and 35 females) of *D. macrosoma* were collected from the catch of purse seine in the northern Sulu Sea, Philippines (Fig. 1). Only sexually mature and injury-free individuals were collected and used in the study to reduce the amount of intrapopulation variation. The samples were transported in a styropore box with ice to the laboratory and fixed for photography. The sexes of the fish were determined by direct examination of the gonads.

Fig. 1 Map showing the location of the sampling site.

2.2 Fixation and digitization

The fish were fixed using a 10% seawater-buffered formalin solution to tease the fins. Then the fish were oriented on a flat, white board, with a ruler as a reference, in standard position with fins teased so as to show their natural swimming position. High definition images of the left lateral side of the fish samples were taken using a Canon EOS 700D Digital SLR camera (18 megapixels).

The images were then sorted according to sex and converted to tps files using TpsUtil version 1.44 (Rohlf, 2009). Before landmarking, photographs were scaled using the TpsDig version 2.12 (Rohlf, 2008a) to remove variations in the distance between the lens and the specimen. This was done by inserting a scale adjustment into the tps file. After which, the tps file was landmarked with 14 homologous anatomical landmark points located along the outline of the body of the fish (Fig. 2) which were established to represent the shape of the specimen using TpsDig version 2.12 (Rohlf, 2008a). The selection of landmarks considered both evolutionary and functional significance. The plotting of the landmarks was done in triplicate to minimize errors and/or biases.

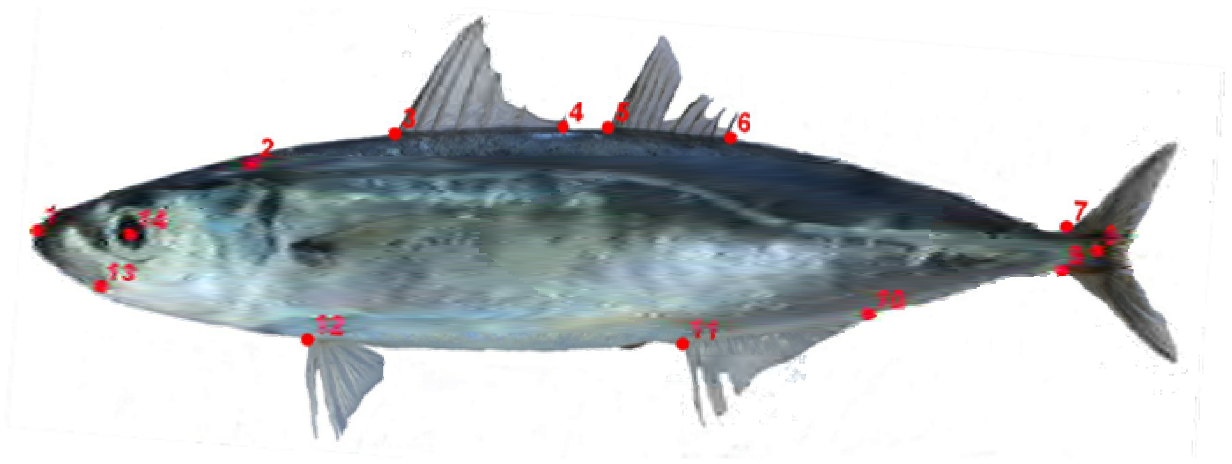

Fig. 2 An image of *Decapterus macrosoma* digitized with the 14 landmarks as follows: (1) anterior tip of the snout on the upper jaw; (2) posterior edge of supra occipital bone; (3) origin of first dorsal fin; (4) insertion point of the last dorsal fin ray of first dorsal fin; (5) origin of the second dorsal fin; (6) insertion point of the second dorsal fin; (7) dorsal origin of the caudal fin; (8) posterior end of the vertebrae column; (9) ventral origin of the caudal fin; (10) insertion point of the anal fin; (11) origin of the anal fin; (12) origin of the pectoral fin; (13) posterior most portion of maxillary and; (14) center of the eye.

2.3 Shape analysis

The raw coordinate configuration of all specimens was aligned (i.e. translated, rotated and scaled to match one another) through the generalized procrustes analysis (GPA) procedure using the tpsRelw version 1.46 (Rohlf, 2008b) in order to eliminate variations due to differences in scale and orientation which established an average configuration by minimizing the sum of squared distances between homologous landmarks from different specimens (Rohlf and Slice, 1990). After the GPA, the relative warps, which are the principal components of the covariance matrix of the partial warp scores, were computed using the unit centroid size as the alignment-scaling method (Adams et al., 2004) using tpsRelw version 1.46 (Rohlf, 2008b). Thin-plate spline expansion plots were generated in order to visualize and analyze the direction of shape differences between sexes.

To assess whether there were significant differences in body shapes between sexes of *D. macrosoma*, the relative warp scores were subjected to multivariate analysis of variance (MANOVA) and discriminant function analysis (DFA) using Paleontological Statistics (PAST) software version 3.18 software (Hammer et al., 2001).

3 Results and Discussion

The thin-plate spline expansion plots of both sexes of *D. macrosoma* revealed regions of expansion and compression in parts of the body as shown in Fig. 3. It can be observed that there was an expansion in the head, between the insertion of the first dorsal fin and the origin of second dorsal fin, belly region, and caudal fin in females. In addition, compression was observed in the dorsal portions particularly in the first dorsal fin and the second dorsal fin. Generally, the female body exhibited expansion which resulted in a wider and bigger body**.**

On the other hand, compressions were prevalent in the male body shape specifically in the maxilla, first and second dorsal fin, belly region, and in the anal fin. However, expansions were observed on the anterodorsal region, particularly in the head and between the insertion of the first dorsal fin and the origin of the second dorsal fin. Also, a slight expansion was observed on the caudal fin. Generally, the male body exhibited compressions which resulted in a narrower and shorter body compared to females.

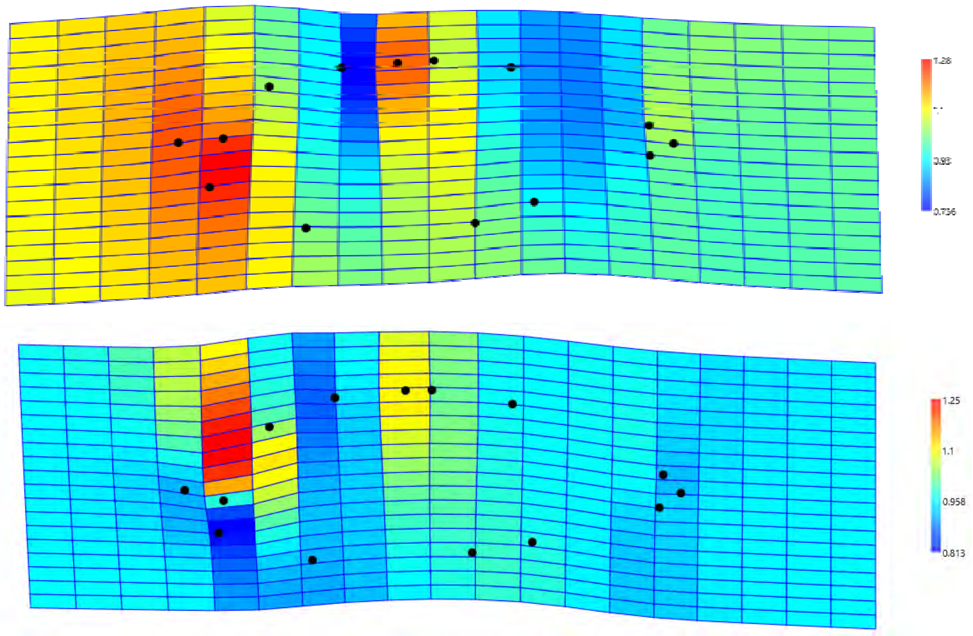

Fig. 3 Thin-plate spline expansion plots showing the expansion and compression of the body shapes of female (top) and male (bottom) *Decapterus macrosoma*. Color hues represent relative proportional variation in areas of the body (yellow to red: expansions and green to blue: compression).

Moreover, the DFA plot in Fig. 4 summarized the extent of body shape variation between sexes of *D. macrosoma*. It revealed a significant difference in the body shapes between sexes (p<0.05). Furthermore, it highlighted the overlap of some body shapes, as indicated by the overlapping bars. This implied that both sexes had similarities in their body shapes, but the variation was high enough to distinguish them. In addition, the results of the MANOVA shown in Table 1 revealed significant differences in the body shapes of female and male *D. macrosoma* (p<0.05).

It was observed that the variations in the body shapes between sexes of *D. macrosoma* were geared towards a body shape that will support reproductive success. Accordingly, the different reproductive roles performed by each sex results to dimorphism in body shape wherein females should be under selection to acquire, process and store energy to facilitate the production of offspring while males should have adaptations that increase the probability of acquiring mates and of success in male to male competition (Casselman and Schulte-Hostedde, 2004).

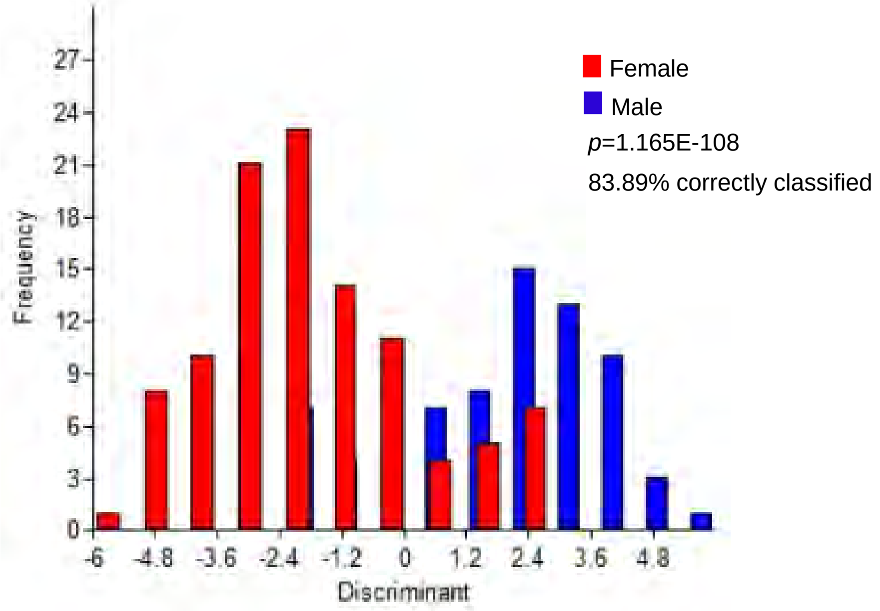

Fig. 4 Discriminant function analysis plot of warp scores of body shape variation between female and male *Decapterus macrosoma* with significant difference between sexes ($p<0.05$).

Table 1 Results of the MANOVA revealing significant variation in the body shapes between female and male *Decapterus macrosoma*.

Source of variation	Wilk's lambda (Λ)	df1	df2	F	*p* value
Body shape	0.02344	28	151	224.7	8.21E-109*

Asterisk indicates significant difference.

The influence of sexual selection in sexual shape dimorphism was supported by the results of the present study. Females were found to have a large body with a distended belly region. This is advantageous to the fish as larger females tend to have higher chances of successful reproduction due to the production of a large number of eggs and they are mostly chosen by courting males (Kitano et al., 2007). On the other hand, males were found to have slender body. This is advantageous since males mature and start breeding earlier than females which increases their chances of reproductive success as compared to larger males. In addition, males tend to have higher reproductive success when they allocate more energy into territoriality, nesting, and parental care, than spending energy to their own growth (Kitano et al, 2007).

Previous studies have found similar patterns in shape dimorphism between sexes ascribed to sexual selection in Three-Spotted Gourami, *Trichogaster trichopterus* (Dorado et al., 2010), White Goby, *Glossogobius guiris* (Dorado et al., 2012), Sardines, *Sardinella lemuru* (Luceño et al., 2014), and Bigtooth Pomfret, *Bramaorcini* (Cantabaco et al., 2015). However, Cabuga et al. (2016) reported no significant difference in body shapes of *Glossogobius guiris* between sexes and noted the importance of this adaptation towards the survival of the species. In aquatic invertebrates, sexually dimorphic traits were also detected using geometric morphometric methods. Cabuga et al. (2017) reported sexual dimorphism in Golden Apple snail (*Pomacea caniculata*) and argued that sexually dimorphic traits are primarily influenced by geographic isolation, predation and nutrient component of the gastropods. The same was reported by Presilda et al. (2018) and Castrence-Gonzales et al. (2017) in the Mangrove crab, *Scylla serrata* and Uba et al. (2019) in the marine mytilid *Modiolus metcalfei*.

Furthermore, natural selection may have an influence on the body shapes of female and male *D. macrosoma*. Females exhibited bigger heads, in both dorsal and ventral regions, than males, which only exhibited expansion in the dorsal region. Bigger head region would maximize buccal volume and suction velocity as an adaptation for feeding macro benthos (Caldecutt and Adams, 1998). Smith-Vaniz and Williams (2016) reported that this species feeds primarily on small invertebrates. For a zooplankton feeder like *D. macrosoma*, this adaptation gives them advantage in easily capturing their food, as zooplankton, which are suspended in the water, can only be effectively captured through suction feeding. Moreover, the bigger head of females compared to the males suggests that females need to acquire more energy from food than males due to the high nutritional requirements of producing eggs for reproduction.

Moreover, females had wide caudal and anal fin but had narrow first and second dorsal fins while males had wide dorsal and caudal fins. These adaptations allow individuals to adjust their swimming behavior and maneuver to foraging, predator-prey interactions, antagonistic interactions, or courtship (Walker and Bell, 2000). As a small pelagic species, its wide dorsal and caudal fin suggests an adaptation for rapid acceleration and maneuvering since the dorsal fins in fishes have been shown to act as stabilizers by inhibiting roll movements during steady swimming and turning, and at the same time contribute to thrust production of the caudal fin (Drucker and Lauder, 2001; Lauder and Drucker, 2004; Standen and Lauder, 2005). In addition, it is suggested that the wider caudal fin and anal fin of the females may be an adaptation in order not to sacrifice speed due to its bigger body size.

The same results were reported by Nacua et al. (2011) in Mozambique Tilapia, *Oreochromis mossambicus* from Lake Lanao, Philippines wherein significant differences in body shapes were attributed to the size of the head and the elongation of dorsal and anal fins. Similarly, Nacua et al. (2012) found out that male *Hypseleotris agilis* from the same location exhibited bigger head, along with elongated dorsal and anal fin bases. In addition, Echem and Catubay (2017) have found out significant differences in body shapes between sexes of Mackerel Tuna, *Euthynnus affinis* landed in Zamboanga City, Philippines, particularly in the snout tip, the dorsal extremity of the caudal fin, and interior of the anal fin.

4 Conclusion

The landmark-based geometric morphometric analysis coupled with multivariate statistical tools revealed sexual shape dimorphism in the monomorphic fish, *D. macrosoma*, where females exhibited a deeper body depth, broader belly region, bigger head, and wider caudal fin while males exhibited a narrow body depth, smaller head, and wider dorsal and caudal fins. Sexual dimorphism in the body shapes of *D. macrosoma* was argued to support sexual selection and natural selection. These adaptations were necessary to increase the fitness of the species.

The knowledge generated by this study improved our understanding that sexual dimorphism in a monomorphic fish may be inferred from the analysis of its body shape. Furthermore, it broadened our understanding on the influence of sexual selection, natural selection, and niche differentiation on the body shapes of sexes of a monomorphic fish. As the first investigation on the sexually dimorphic traits of the monomorphic fish, *D. macrosoma*, through shape analysis, this study will serve as a baseline for future investigations.

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References

Adams DC, Rohlf FJ, Slice DE. 2004. Geometric morphometrics: ten years of progress following the revolution. Italian Journal of Zoology, 7(1): 5-16

Berns CM, Adams DC. 2012. Becoming different but staying alike: patterns of sexual size and shape dimorphism in bills of hummingbirds. Evolutionary Biology, 40(2): 246-260

Cabuga, CC, Masendo CBE, Hernando BJH, Joseph CCD, Velasco JPB, Angco MKA, Ayaton MA, Obenza OLP, Jumawan JH, Jumawan JC, Requieron EA, Torres MAJ, Havana HC. 2016. Relative warp analysis in determining morphological variation and sexual dimorphism between sexes of flathead goby (*Glossogobius giuris*). Computational Ecology and Software, 6(3): 95-105

Cabuga CC, Sularte RP, Acob MCO, Eleazar MMP, Tiempo CMT, Joseph CCD, Angco MKA, Calub AMN,Havana HC, Dominguito JD, Budlayan MLM, Colon RMA, Guilleno JR, Arriza SM. 2017. Describingshell shape variations and sexual dimorphism of Golden Apple Snail, *Pomacea caniculata* (Lamarck, 1822)using geometric morphometric analysis. Computational Ecology and Software, 7(3): 123-139

Caldecutt WJ and Adams DC. 1998. Morphometrics of trophic osteology in the threespine stickleback, *Gasterosteus aculeatus*. Copeia, (4): 827-838

Cantabaco JK, Celedio SF, Gubalani CMB, Sialana RJ, Torres MAJ, Requieron EA, Martin TTB. 2015. Determining sexual dimorphism in Bigtooth Pomfret, *Brama orcini*, in Tuka Bay, Kiamba, Sarangani Province. AACL Bioflux, 8(6): 1009-1018

Casselman SJ, Schulte-Hostedde AI. 2004. Reproductive roles predict sexual dimorphism in internal and external morphology of Lake Whitefish, *Coregonus clupeaformis*. Ecology of Freshwater Fish, 13(3): 217-222

Castrence-Gonzales R, Gorospe JG. Torres MAJ, Vicente HJ, Roa EC, Demayo CG. 2017. Asymmetry in the shape of the carapace of *Scylla serrata* (Forsskål, 1755) collected from Lingayen Gulf in Luzon, Philippines.Proceedings of the International Academy of Ecology and Environmental Sciences, 7(3): 55-66

Dorado EL, Torres MAJ, Barrion AA, Amparado RF, Gorospe JG, Demayo CG. 2010. Sexual dimorphism in body shapes of the Three-Spotted Gourami, *Trichogaster trichopterus* (Pallas, 1770) of Lake Buluan, Mindanao, Philippines. Research Journalof Fisheries and Hydrobiology, 5(2): 111-118

Dorado E, Torres MAJ,Demayo CG. 2012. Describing body shapes of the White Goby, *Glossogobius giuris* of Lake Buluan in Mindanao, Philippines using landmark-based geometric morphometric analysis. International Research Journal of Biological Sciences, 1(7): 33-37

Drucker EG, Lauder GV. 2001. Wake dynamics and fluid forces of turning maneuvers in sunfish. Journal of

Experimental Biology, 204: 431-442

Echem RT, Catubay IJ. 2017. Describing shape variations of *Euthynnus affinis* (Mackerel Tuna) using landmark-based geometric morphometric analysis. Advance Research Journal of Multi-Disciplinary Discoveries, 9: 9-19

Gidaszewski NA, Baylac M, Klingenberg CP. 2009. Evolution of sexual dimorphism of wing shape in the *Drosophila melanogaster* subgroup. BMC Evolutionary Biology, 9(110): 1-11

Hammer Ø, Harper DAT, Ryan PD. 2001. PAST: Paleontological software package for education and data analysis. Paleontologia Electronica, 4(1): 1-9

Hendry A, Kelly ML, Kinnison MT,Reznick DN. 2006. Parallel evolution of the sexes? Effects of predation and habitat features on the size and shape of wild guppies. Journal of Evolutionary Biology, 19(3): 741-754

Herrel A, Moore JA, BredewegEM, Nelson NJ. 2010. Sexual dimorphism, body size, bite force and male mating success in tuatara. Biological Journal of the Linnean Society, 100(2): 287-292

Kelly CD, Folinsbee KE, Adams DC, Jennions MD. 2013. Intraspecific sexual size and shape dimorphism in an Australian freshwater fish differs with respect to a biogeographic barrier and latitude. Evolutionary Biology, 40: 408-419

Kitano J, Mori S, Peichel CL. 2007. Sexual dimorphism in the external morphology of the Threespine Stickleback (*Gasterosteus aculeatus*). Copeia, 2: 336-349

Kuo C-Y, Lin Y-T, Lin Y-S. 2009. Sexual size and shape dimorphism in an Agamid lizard, *Japalura swinhonis* (Squamata: Lacertilia: Agamidae). Zoological Studies, 48(3): 351-361

Lauder GV, Drucker EG. 2004. Morphology and experimental hydrodynamics of fish fin control surfaces. IEEE Journal of Oceanic Engineering, 29(3): 556-571

Lima Filho PA, Bidau CJ, Alencar CERD, Molina WF. 2017. Latitudinal influence on the sexual dimorphism of the marine fish *Bathygobiussoporator* (Gobiidae: Teleostei). Evolutionary Biology, 44(3): 374-385

Luceño AJM, Torres MAJ, Tabugo SRM, Demayo CG. 2014. Describing the body shapes of three populations of *Sardinella lemuru* (Bleeker, 1853) from Mindanao Island, Philippines using relative warp analysis. International Research Journal of Biological Sciences, 3(6): 6-17

Nacua SS, Torres MAJ, Demayo CG. 2011. Sexual dimorphism in Tilapia, *Oreochromis mossambicus* (Peters, 1852) from Lake Lanao, Philippines. Research Journal of Fisheries and Hydrobiology, 6(2): 92-99

Nacua SS, Torres MAJ,Demayo CG. 2012. Sexual dimorphism in body shape of *Hypseleotris agilis* (Herre, 1927) from Lake Lanao, Philippines. ISCA Journal of Biological Science, 1(2): 25-31

Presilda CJ, Salcedo MA, Moreno MJ, Cogenera J, Japitana RA, Jumawan JH, Jumawan JC, Presilda J,Presilda CJR, Requieron EA, Torres MAJ. 2018. Sexual dimorphism in the carapace of mud crab (*Scyllaserrate*, Forsskål, 1775) in Magallanes, Agusandel Norte using geometric morphometric analysis. Computational Ecology and Software, 8(4): 88-97

Rohlf FJ. 1990. Morphometrics. Annual Review of Ecological Systematics, 21: 299-316

Rohlf FJ. 2008a. TpsDig version 2.12. Department of Ecology and Evolution, State University of New York at Stony Brook, New York, USA

Rohlf FJ. 2008b. TpsRelw version 1.46. Department of Ecology and Evolution, State University of New York at Stony Brook, New York, USA

Rohlf FJ. 2009. TpsUtil version 1.44. Department of Ecology and Evolution, State University of New York at Stony Brook, New York, USA

Rohlf FJ, Slice DE. 1990. Extensions of the procrustes method for the optimal superimposition of landmarks. Systematic Zoology, 39(1): 40-59

Rohlf FJ, Marcus LF. 1993. A revolution in morphometrics. Trends Ecology and Evolution, 8(4): 129-132

Smith-VanizWF, Williams I. 2016. *Decapterus macrosoma*. The IUCN Red List of Threatened Species 2016: e.T20431518A115379160. http://www.iucnredlist.org/details/20431518/0 Retrieved 7 May 2018

Standen EM, Lauder GV. 2005. Dorsal and anal fin function in bluegill sunfish *Lepomis macrochirus*: three-dimensional kinematics during propulsion and maneuvering. Journal of Experimental Biology, 208: 2753-2763

Temeles EJ, Pan IL, Brennan JL,Horwitt JN. 2000. Evidence for ecological causation of sexual dimorphism in a hummingbird. Science, 289(5478): 441-443

Temeles EJ, Miller JS, Rifkin JL. 2010. Evolution of sexual dimorphism in bill size and shape of hermit hummingbirds (Phaethornithinae): a role for ecological causation. Philosophical Transactions of the Royal Society of London B Biological Sciences, 365(1543): 1053-1063

Uba KIN, Monteclaro HM, Noblezada-Payne MMP, Quinitio GF. 2019. Sexual dimorphism, asymmetry, and allometry in the shell shape of *Modiolus metcalfei* (Hanley, 1843) collected from Dumangas, Iloilo, Philippines: A geometric morphometric approach. Computational Ecology and Software, 9(3): 107-120

Walker JA, Bell MA. 2000. Net evolutionary trajectories of body shape evolution within a microgeographic radiation of three spine sticklebacks (*Gasterosteus aculeatus*). Journal of Zoology, 252: 293-302

Willemsen RE, Hailey A. 2003. Sexual dimorphism of body size and shell shape in European tortoises. Journal of Zoology, 260(4): 353-365