Population variability in *Poecilia reticulata* based on morphological character measurements, length-weight and length-length relationships

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Abstract. Fishes are susceptible to different changes in the environment, and they adapt quickly by modifying certain morphometric characters. These intraspecific morphological changes are associated with ecological variables and other factors of the environment, both abiotic and biotic, which serve as selective pressures. However, it is also suggested that, while morphometric characters respond to these disturbances, their responses are different in some situations. These characters may differ based on separate sexes of species occupying other geographical locations; thus, this study investigated this aspect in the guppy, *Poecilia reticulata*. To determine whether there were variations in morphological characteristics, including length-weight relationships and condition factors, morphometric indices such as total length (TL), standard length (SL), and body weight (BW) were assessed using standard methods. The length-weight relationship (LWR) and length-length relationship (LLR) determined their growth patterns and physiological well-being. The fish samples were collected for 6 months, from September 2015 to March 2016. A total of 180 specimens from 3 rivers show that females were significantly larger and heavier than males in terms of body size. The regression coefficient for the LWR in females, males, and both sexes shows a negative allometric growth pattern for the Alegria guppies. Females exhibited positive allometry for Tubod and Tambulig populations, while the males indicated negative allometry. Results from the regression coefficient for combined sexes indicate allometric growth. Only the females, however, showed a definite allometric growth pattern. LLR varies, but the standard length is directly proportional to the total length for all populations. The mean condition factors individually and for combined sexes are all below one, indicating that the fish samples collected were not in a good condition in the studied habitats. However, some individuals are showing good health.

Key Words: guppy, length-weight relationship, growth patterns, morphometric, regression, *Poeciliidae*.

Introduction. The guppy, *Poecilia reticulata* (Peters, 1859), is a popular aquarium fish (Mousavi-Sabet et al 2012) widely distributed in freshwater habitats (Lucinda 2003; Nelson 2006; Araujo et al 2009), especially in the watercourses of the Philippines (Lacorte et al 2015; Solis et al 2015). Guppies are not native species in the Philippines, but were introduced to many regions of the country as ornamental fish and a biological agent to control mosquito larvae (COPESCAL 1996; Lucinda 2003; Rojas et al 2004). This species can reproduce and spread in various environments (Vitousek et al 1997), having broad environmental tolerance. They can withstand high salinity (Chervinski 1984) and very low (12^{o}C) and high temperature (40^{o}C) (Chung 2001). Reports show that this species can survive in relatively polluted water, reproducing often and giving birth to fast-growing live-young. Thus, this species is considered an indicator of poor water conditions (Araujo et al 2009). Likewise, *P. reticulata* thrives in a very harsh environment by responding rapidly to altered selective regimes, rendering this species' invasive potential (Deacon et al 2011).

In Mindanao, Philippines, guppies are widespread and are abundant in freshwater habitats like lakes, streams, ponds, canals, and rivers. Studies show morphometric variations in body shapes in different fish populations (Solis et al 2015; Lacorte et al 2015; Gelsano & Demayo 2019). This species exhibits fluctuating asymmetry, indicating developmental instability in the species attributed to variations in environmental conditions (Solis et al 2015; Lacorte et al 2015). Since fishes are susceptible to different changes in the environment, it is argued that they adapt quickly by modifying certain morphometric characters to survive (Cabral et al 2003; Hossain et al 2010). Although morphometric characters respond to disturbances, their responses are different in some situations and may differ based on sex. For these reasons, the present study was conducted to assess changes in the morphological characters of the species, including length-length relationships and condition factors. It is argued that the study could be helpful for the management of this invasive species and assess the habitat quality in different aquatic environments where the species thrive. Since the morphology of fishes is a significant source of information for taxonomic and evolutionary studies (Ambily 2016), measurable structures such as total length, standard length, fin length, head length, body depth, eye diameter, snout length, and other structures are being used as an important parameter in studying morphological variations in fishes (Ferreira et al 2008; Gonzalez et al 2016). Despite the recent advances in biochemical or molecular techniques in studying variation, the morphometric method is used to delineate fish stocks (Petrakis & Stergiou 1995; Santos et al 2002; Cadrin & Silva 2005). Morphometric analysis continues to have a significant role in stock identification. It can differentiate taxonomic units and detect differences within and between populations of the same species (King 1996; Goncalves et al 1997).

Industrialization, especially the disposal of large quantities of sewage, chemical, and industrial wastes into rivers and drainage systems, has affected the water quality of surrounding aquatic habitats (Paranhos et al 2006). These anthropogenic activities eventually influence fish species' breeding patterns and growth rates (Martin-Smith 1998; Cunico et al 2006; Sih et al 2011). These negative changes occur on a larger scale and at a higher speed due to human activities that affect the habitats of the species. These changes can place organisms into new environmental conditions that arise more rapidly than organisms have experienced in their evolutionary past (Sih et al 2011). Human-induced ecological changes have different effects on different species as a matter of interest. While some species may respond poorly to these environmental changes, resulting in declining populations, others may cope well or tolerate high levels of habitat disturbances and survive, guppies being one of these species.

Material and Method

Study area and sample collection. Mindanao, or Southern Philippines, is the second-largest island in the Philippines and is located in the southern region of the archipelago. The present study was carried out from September 2015 to March 2016, in three river ecosystems, namely: Tambulig, Zamboanga del Sur (804’23”N; 123032’39”E), Alegria, Surigao del Norte (9029’42”N; 125034’47”E) and Tubod, Iligan City (8013’15”N; 124013’29”E) (Figure 1).

Figure 1. Location of sampling sites used for the present study.

Specimens of *P. reticulata* were gathered using a hand net, and males were sorted out from females by identifying observable physical attributes like gonopodium. Only mature individuals were considered in the study. A total of 170 specimens were obtained from the study area. Each sample was placed in a vial containing 100% ethanol for preservation. The fish samples were transported first to Iligan Medical Center College (IMCC) for length measurement. Then the weight was determined at the science laboratory of Mindanao State University - Iligan Institute of Technology (MSU-IIT).

Morphological analysis. Linear morphometric measurements were carried out from the left lateral side of the fish. The fish were measured using digital venire calipers (0.01 mm accuracy) using the horizontal and vertical distances between identified landmark points. In each specimen, 12 morphological distances were identified as landmark distances (Figure 2), and most of the morphometric characters were measured following the conventional method described by Gonzalez et al (2016) and Herath et al (2014).

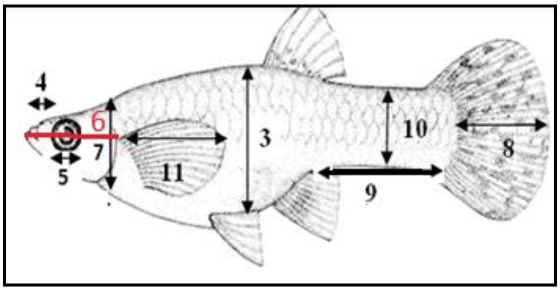

Figure 2. Schematic diagram representing the 11 morphometric measurement of *Poecillia reticulata*.

The 12 traditional characters measured on each specimen included: (1) total length (TL), (2) standard length (SL), (3) body depth (BD), (4) pre-orbital length (PreOL), (5) orbital diameter (OD), (6) head length (HL), (7) head depth (HD), (8) caudal fin length (CFL), (9) caudal peduncle length (CPL), (10) caudal peduncle depth (CPD) and (11) pectoral fin length (PFL) (Table 1).

Table 1

Body measurements obtained for *Poecillia reticulata*

Distance	*Character*	*Abbreviation*	*Description*
1	Total Length	TL	Measured from the middle of the upper lip of the mouth to the caudal end of the caudal fin
2	Standard Length	SL	Measured between the central portion of the upper lip of the mouth and the base of the caudal fin
3	Body depth	BD	The maximum vertical distance of the body
4	Snout Length	SnoutL	Tip of the snout to the anterior part orbit
5	Eye diameter	ED	Distance between the anterior and posterior part of the orbit
6	Head length	HL	Distance between the most cranial point of the upper lip of the mouth and the rear end of the operculum
7	Head depth	HD	The vertical distance along the opercula margin in between the dorsal head margin and ventral head margin
8	Caudal fin length	CFL	Distance between the midpoint of the caudal fin to the posterior end of the caudal fin
9	Caudal peduncle length	CPL	Distance between the perpendicular line from the insertion of the last spine of the anal fin to the base of the caudal fin.
10	Caudal peduncle depth	CPD	Distance from the dorsal to the ventral surface of the caudal peduncle
11	Pectoral fin length	PFL	Distance from the insertion to the caudal end of the pectoral fin

Statistical analysis. The variation in morphometric characters of fish should be attributable to body shape differences and not correlated to the relative size of the fish (Mollah et al 2012). To remove the correlation of morphometric character measurement with the body size and standardization of data was done by using the following equation (Claytor & Maccrimon 1987):

$$ACi=\log OCi-\{\beta*(\log TLi-\log MTL)\}$$

Where: ACi is the adjusted logarithmic character measurement for ith fish; OCi is the observed character measurement for the ith fish; β is standard within-group regression coefficient of that character and total length after both measurements were converted to a logarithmic value; MTL is the mean total length of fish, using all fish in all groups. The formula was applied for all morphometric characters. Correlation analysis was done against the total length of the fish to remove size dependence. A one-way ANOVA was carried out to examine statistical differences of each morphometric character for sexual and population effects. In addition, multivariate analysis of variance (MANOVA) was performed to evaluate statistically significant differences between sex and among populations of guppies. Stepwise Discriminant Function Analysis (DFA) was conducted to standardized characters to describe the correct assignment of the individual with their a priori geographical location based on their morphometric features. The significance of the derived discriminant functions was determined by the Chi-square test and Wilks lambda statistics. DFA was also used to identify the most important characters that can differentiate fish populations using the F value criterion. All statistical analyses were performed by using the PAST software statistical package.

Length-weight ratio. TL, SL, and BW of *P. reticulata* were taken and recorded. Length is measured in centimeters (cm) using a digital vernier caliper to the nearest 0.01 cm and weight in grams (g) using a digital closed air balance to an accuracy of 0.0001 g. The relationship between the length and weight of the specimen was determined by a simple linear regression using PAST software. Length-weight correlations were calculated using the equation by Ricker (1973).

$$W=aL^b$$

Where: W is the weight of fish (g), L is the length of fish (cm), coefficient 'a' is the intercept in the y-axis, and the regression coefficient b is an exponent indicating isometric growth when equal to 3. The statistical significance level of r^2 was estimated, and the parameters *a* and *b* were estimated by linear regressions on the transformed equation described by Zar (1984):

$$Log_{10}W = log_{10}a + blog_{10} L$$

Moreover, the length-length relationship (LLR), TL vs. SL was estimated as:

$$TL = aSL^b$$

The logarithmic form of the previous equation is:

$$log\ (TL) = log\ (a) + b\ log\ (SL)$$

To test for possible significant differences in both slope and intercept, we followed the analysis of covariance. All statistical analyses were considered significant at $p<0.05$.

The condition factor was calculated for each fish by the formula (Pauly 1983):

$$K = 100W/L^3$$

Where:

K is the condition factor, W is the weight (g), and L is the total length (cm).

All statistical analyses were considered at a significance level of 5% ($p<0.05$). PAST Software and Microsoft Office Excel were used in this study. Tables and graphs were plotted with the use of MS Words and Excel 2007. This study also used a canonical correlation analysis to identify and measure the associations among two sets of variables.

Results and Discussion. The total number of specimens collected and morphometric characters, like total length and mean total length, are presented in Table 2. Tubod and Tambulig rivers have an equal number of fish sampled, comprising 30 females and 30 males, while 50 specimens (20 females and 30 males) were collected from the Alegria river.

Table 2

Collection sites, sample size, and size ranges of adult *Poecilia reticulata*

Location	*Abbreviation*	*N*	*TL range (mm)*	*Mean TL (mm)*	*SD*
Alegria, Surigao	A-Females	20	20.53-27.08	22.82	1.62
	A-Males	30	17.65-25.3	19.99	1.65
Tubod, Iligan	T-Females	30	22.11-38.51	28.91	4.34
	T-Males	30	18.56-24.79	21.57	1.58
Tambulig, Zamboanga	Z-Females	30	27.82-42.53	37.44	2.88
	Z-Males	30	23.9-30.25	26.57	1.57

Morphological analysis. The range of variations of the ten morphometric characters between sexes of *P. reticulata* collected from each river location after size standardization is presented in Table 3. One-way ANOVA shows that the mean (±SD) for each morphometric character as a percentage of mean TL for each group shows significant differences between sexes.

Table 3

Morphometric characters after size standardization against the total length

Character abbreviation	*Alegria*		*Tubod*		*Zamboanga*	
	Females (n=20)	*Males (n=30)*	*Females (n=30)*	*Males (n=30)*	*Females (n=30)*	*Males (n=30)*
SL	73.83±1.33*	73.05±1.05*	72.58±3.56*	75.48±1.16*	78.70±2.33*	72.33±1.41*
HL	21.65±0.37*	21.64±0.62*	19.27±0.86*	18.71±0.43*	19.61±0.59*	19.42±0.38*
HD	15.70±0.27	16.88±0.76	13.09±0.90*	15.65±0.52*	14.56±0.54*	14.19±0.34*
ED	9.09±0.24	9.69±0.23	8.61±0.24*	7.44±0.19*	6.85±0.22*	8.07±0.29*
SnoutL	6.16±0.15	6.77±0.22	5.52±0.38*	5.64±0.13*	5.99±0.25*	4.66±0.21*
CPD	11.05±0.29*	13.45±0.32*	13.84±0.66*	13.23±0.38*	13.04±0.40*	14.26±0.36*
CPL	28.30±0.93	34.33±0.82	33.93±1.07	25.80±0.79	25.04±1.08	35.32±0.93
CFL	26.18±1.22	26.95±1.42	27.42±0.93*	24.52±0.85 *	21.42±2.55	27.67±1.87
PFL	19.73±0.35*	25.06±0.58*	19.15±0.72*	19.57±0.56*	19.02±0.54*	18.7±0.39*
BD	18.19±0.48*	24.18±0.41*	18.70±1.02*	19.88±0.37*	21.79±0.75*	18.19±0.41*

Note: asterisks indicated One-Way ANOVA results for size-adjusted characters showing that males and females were significantly different ($p<0.05$).

CVA analysis determining the relationships of the 11 morphometric variables showed significant variations between populations (Wilks' lambda 0.001208; $p<0.001$). The association is presented in Figure 3. Discriminant classification results for each group as percent correctly classified (%) are presented in Table 4. It can be seen from the results that the Tambulig female guppies and Tubod male river guppies were different from all other populations based on all morphometric measurements. The Alegria male guppies were different from the three populations based on four characters (HD, BD, PFL, and snoutL) (Figure 3).

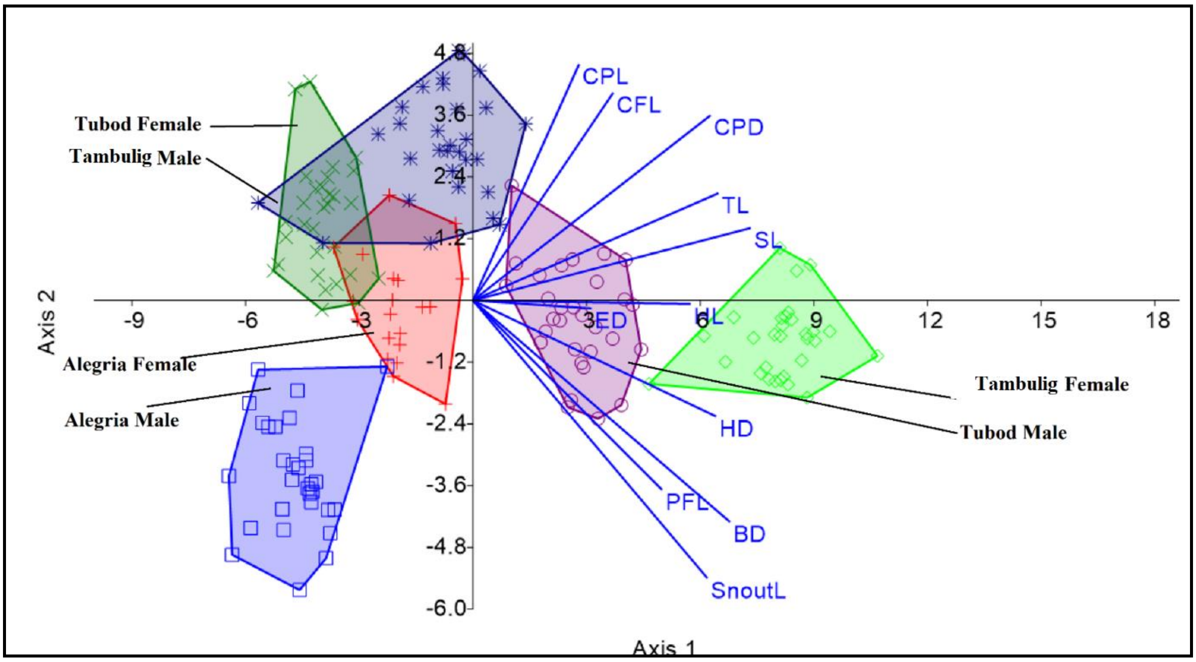

Figure 3. CVA scatter plot showing the difference between sexes and populations of the guppies.

Table 4

Discriminant classification results for each group as percent correctly classified (%)

	Alegria		*Tubod*		*Tambulig*		*N*
	Females (n=20)	*Males (n=30)*	*Females (n=30)*	*Males (n=30)*	*Females (n=30)*	*Males (n=30)*	
Alegria F	19 (95)	0	1	0	0	0	20
Alegria M	0	30 (100)	0	0	0	0	30
Tubod F	0	0	29 (96.67)	0	0	1 (3.33)	30
Tubod M	0	0	0	29 (96.67)	0	1 (3.33)	30
Tambulig F	0	0	0	0	30 (100)	0	30
Tambulig M	0	0	2	0	0	28 (93.33)	30

The morphometric analysis revealed that morphological variation exists within and between populations of guppies. Endler (1995) and Reznick et al (1997) reported that sexual dimorphism is highly pronounced in this species. A significant variation was found between males' and females' TL and SL in three areas. The females are larger than males in the three areas studied in terms of TL. At the same time, the SL of guppies may vary in different locations. Females have a higher SL than males in Tambulig, while the SL of males in Tubod is larger than females. In Alegria area, both sexes have almost the same SL. Jacobs (1971) emphasized that the degree of size dimorphism in this species is variable, ranging from a species in which the maximum length of females is more than twice the maximum length of males to a species in which the length of both sexes is about the same. Darwin (1874) suggested that larger size in females is primarily the product of selection for producing more offspring. The larger size in males is related to intrasexual competition for access to mates.

The proportion of each body part to TL carried out to understand the relationship between body parts of separate sexes shows that guppies from Alegra significantly differ from each other in the SL, HL, CPD, PFL, and BD characters. For Tubod and Tambulig guppies, almost all the morphometric characters measured were significantly different based on the mean TL percentage, which indicates that these morphometric characters may grow symmetrically as the fish grow.

As to body sizes and the posterior parts of the body, measured by CPD, CPL, and CFL, significant differences were observed among all the populations. The degree of variations of these traits in three locations shows that Tambulig guppy populations exhibited a larger size (SL) and a deeper caudal peduncle (CPD) than Alegria and Tubod populations. Guppies from the Alegria river also had a longer CPL and CFL than Tambulig and Tubod.

Length-weight ratio analysis. The results for the length-weight analysis are presented in Tables 5 and 6. Table 5 shows the number of specimens from each sampling area, the maximum and minimum SL and the TL, and the mean of SL and TL. The largest females were recorded in Tambulig Zamboanga del Sur, with a maximum SL and TL of 33.72mm and 42.53mm, respectively. The smallest females were obtained from Alegria and Tubod, with a minimum SL and TL of 14.01 mm and 18.38 mm, respectively. Meanwhile, the size of size varied from a minimum SL of 13.34 mm taken from the Tubod river to a maximum of 19.85 mm in three populations. Most of the guppies from Alegria were smaller than in the other rivers. The observed body weights for different sexes are shown in Table 6. It can be seen from the results that females were heavier than males.

Table 5

Total length and standard length (mm) distribution of guppies from Alegria, Tubod, and Zamboanga

Sex	*N*	*Total Length*			*Standard Length*		
		Minimum	*Maximum*	*Mean±SD*	*Minimum*	*Maximum*	*Mean±SD*
				Alegria, Surigao del Norte			
Males	30	17.65	25.3	20±1.66	13.36	18.69	14.67±1.11
Females	30	19.14	27.08	21.97±1.88	14.01	20.03	16.32±1.4
Combined Sex	60	17.65	27.08	20.98±2.02	13.36	20.03	15.49±1.5
				Tubod, Iligan City, Lanao del Norte			
Males	30	18.88	24.65	21.34±1.47	13.34	19.85	16.4±1.37
Females	30	18.38	35.15	27.09±3.92	14.35	28.28	20.73±3.16
Combined	30	18.38	35.15	24.22±4.12	13.34	28.28	18.56±3.25
				Tambulig, Zamboanga del Sur			
Males	30	19.65	25.99	22.26±1.65	14.87	19.59	16.41±1.14
Females	30	22.8	42.53	34.96±5.3	16.47	33.72	27.31±4.42
Combined	60	19.65	42.53	28.61±7.5	14.87	33.72	21.86±6.36

Table 6

The weight (g) distribution of *P. reticulata* from Alegria, Tubod and Tambulig rivers

Sex	*Alegria*			*Tubod*			*Tambulig*		
	Min	*Max*	*Mean±SD*	*Min*	*Max*	*Mean±SD*	*Min*	*Max*	*Mean±SD*
Males	0.0463	0.0781	0.11±0.14	0.0583	0.1265	0.08±0.02	0.0549	0.133	0.08±0.02
Females	0.0536	0.0956	0.07±0.01	0.058	0.4318	0.20±0.10	0.074	0.7647	0.41±0.19
Combined	0.0463	0.4901	0.09±0.10	0.058	0.4318	0.14±0.09	0.0549	0.7647	0.24±0.21

The estimates of the regression parameters (Table 7, Figure 4) show that the Alegria guppies indicated a negative allometric growth (b<3) for separate and combined sexes and were observed slimmer in shapes. For the Tubod guppies, a negative allometric increase was observed with a slimmer appearance for males (<3) but not for females (>3). The ideal shape and isometric growth can only happen if the observed b value equals 3 (Olurin & Aderibigbe 2006). Male guppies from Tambulig had an isometric growth indicated by the b value close to 3. This observation is similar to those of a study by Garcia et al (2008). They reported that the allometric index of guppy from the pond of Santa Maria, Colombia, was close to 3. Only guppies from both sexes of Alegria and the male guppies of Tubod showed negative allometric growth, indicating that the body length increases faster than weight (Sandon 1950; Montag et al 2011). Positive allometric changes were observed in females of Tambulig and Tubod guppies, indicating that the weight increases faster than body length, thus showing the fish becomes fatter (Ibrahim 1984; Ayo-Olalusi 2014). The observed results of the female guppies in the Tambulig and Tubod river populations were similar to those from two lakes in the Kashmir, Himalayas (Zargar et al 2012). All guppy populations had a length that was directly proportional to their weight.

Table 7
The regression coefficient for length-weight relationships of *P. reticulata* from three rivers in Mindanao, Philippines

Sex	*A*	*b*	*sb*	r^2	*p-value (p<0.05)*	*GP*
			Alegria			
Males	-1.7709	1.7543	0.18168	0.76906	0.00*	NA
Females	-1.6492	1.4405	0.14216	0.78573	0.004*	NA
Combined Sex	-1.7535	1.7232	0.10342	0.8272	0.00*	NA
			Tubod			
Males	-1.6118	1.6213	0.45098	0.3158	0.179	NA
Females	-2.1818	3.3477	0.15987	0.93998	0.00*	PA
Combined Sex	-2.1174	3.1818	0.13203	0.9092	0.00*	PA
			Tambulig			
Males	-2.0831	2.7948	0.27265	0.78959	0.00*	NA
Females	-2.3225	3.4868	0.15019	0.95062	0.00*	PA
Combined Sex	-2.3109	3.4603	0.063257	0.98099	0.00*	PA

Note: b - the slope of the regression line; a - intercept of the regression line; r^2 - coefficient of determination; GP - growth pattern; PA - positive allometric, NA - negative allometric.

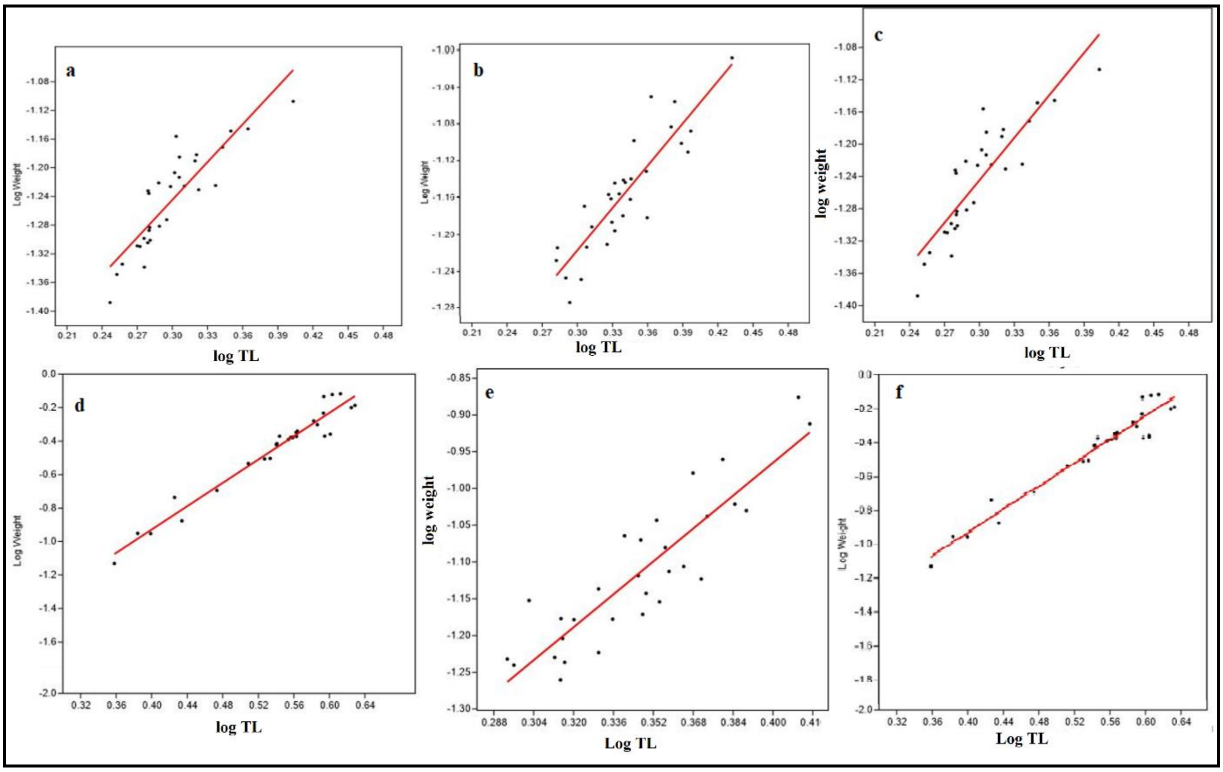

Figure 4. Length-weight relationships between sexes of *P. reticulata* from Alegria River, Surigao del Norte (a, b); Tubod River, Iligan City (c, d); Tambulig River, Zamboanga del Sur (e, f).

Length-length relationship. The TL-SL relationships (LLR) are presented in Table 8 and Figure 5. The results suggest that the populations of *P. reticulata s*how a non-isometric growth pattern. There were high correlations between females and combined sexes of guppies collected from Tubod and Tambulig (r^2>0.9; p<0.05). There is a weak correlation between male and female sexes, and when combined for Alegria guppies. Males from Tubod and Tambulig also showed a weak correlation. While all the guppies had the SL directly proportional to their TL since all the "b" values were positive, the relationship is weak because they are near zero (Figure 5).

Table 8

Length-length relationship (LLR) between total length (TL) and standard length (SL)

Sex	*a*	*b*	*sb*	r^2	*p-value (p<0.05)*
			Alegria		
Males	0.22481	0.45275	0.18953	0.1693	0.007*
Females	0.17071	0.80223	0.11607	0.63046	0.099
Combined Sex	0.18312	0.72667	0.089823	0.53016	0.003*
			Tubod		
Males	0.1749	0.71879	0.072735	0.77718	0.00*
Females	0.13065	0.95556	0.03357	0.96544	0.0079*
Combined Sex	0.12917	0.94926	0.026271	0.95747	0.0058*
			Zamboanga		
Males	0.15917	0.87376	0.12195	0.64706	0.309
Females	0.15702	0.88645	0.047928	0.92434	0.024*
Combined Sex	0.15619	0.88814	0.020421	0.97025	0.00*

Note: b - the slope of the regression line; a - intercept of the regression line; r^2 - coefficient of determination; GP - growth pattern; PA - positive allometric, NA - negative allometric.

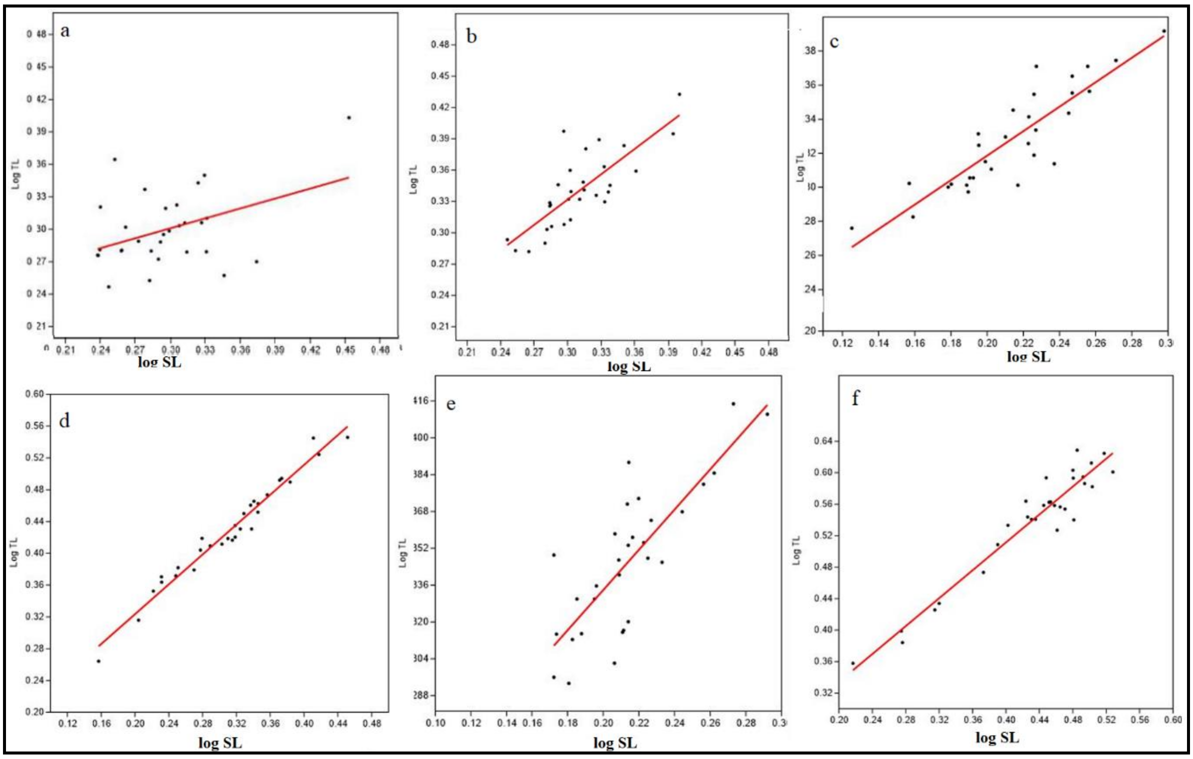

Figure 5. Length-length relationships between sexes of *P. reticulata* from Alegria River, Surigao del Norte (a, b); Tubod River, Iligan City (c, d); Tambulig River, Zamboanga del Sur (e, f).

Condition factor. The condition factor (K) was used as an index to provide the general condition of fish, and the quality of their habitat was assessed based on the relationship between the weight of the fish and its length (Table 9, Figure 6). The condition factor 'K' results close to or above 1 indicate that fish are healthy. The guppies from the Alegria river had poor health conditions. Some fish were in good health for the Iligan River guppies since the values are close to 1. The condition factor of guppies from the Tambulig River was less than 1, implying that not all the guppies were in a better state of well-being. Some of the fish were in good health, with a condition factor above 1, but, generally, guppies examined from the river were not.

Table 9
Condition factor (K) of females and males *P. reticulata* collected from Alegria, Surigao del Norte

	Alegria, Surigao del Norte		
	Females	Males	Combined sex
Minimum	O.4814065	0.4822691	0.4814065
Maximum	0.8645379	0.8595423	0.8645379
Mean	0.6675506	0.7227897	0.6951701
	Tubod, Iligan City, Lanao del Norte		
	Females	Males	Combined sex
Minimum	0.6715475	0.5221028	0.5221028
Maximum	1.15944	1.479144	1.479144
Mean	0.9350805	0.8773079	0.9061942
	Tambulig, Zamboanga del Sur		
	Females	Males	Combined sex
Minimum	0.6243487	0.5794782	0.5794782
Maximum	1.218723	0.8734329	1.218723
Mean	0.8801091	0.7050474	0.7925782

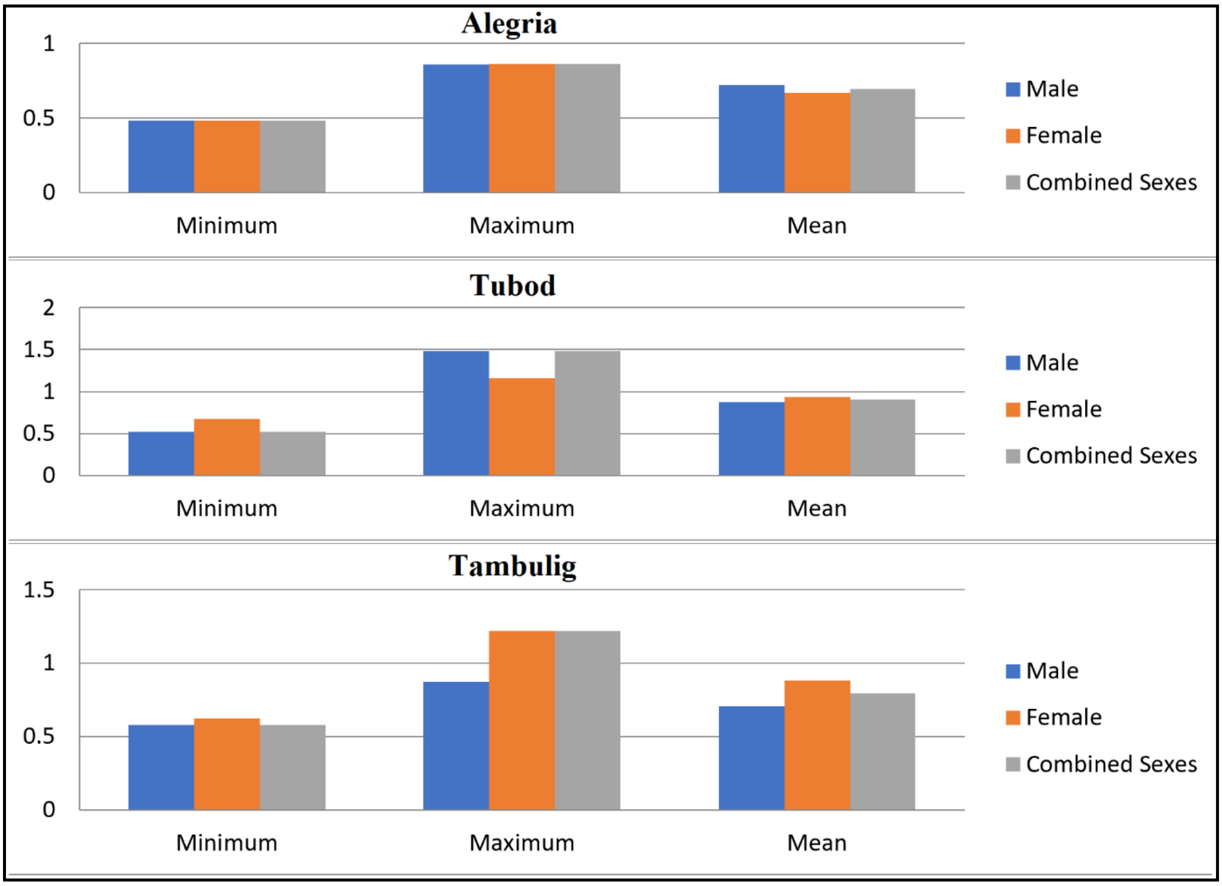

Figure 6. Condition factor of males, females and combined sex of the three populations of *P. reticulata*.

Several studies have shown that morphometric characters are suitable parameters for describing morphological variations among populations (Murta 2000; Costa et al 2003) and determining possible differences between individual unit stocks of the same species (King 2007). The present study demonstrated that there are significant phenotypic variations among the three studied populations as well as between the sexes. The weights of the two sexes vary considerably, with females heavier than males. The observed differences in the body size in this study are typical in poeciliids species, with females being larger than males (Vargas & Sostoa 1996; Machado et al 2002; Urriola et al 2004; Garcia et al 2008). Batista (1991) stated that the larger size in females is an expected trait for viviparous species, since they invest more energy in their development (i.e., gonadal production) (Angelescu et al 1958; Maguire & Mace 1993). Males require energy only for courtship and the production of secondary characters like the caudal fin (Vazzoler 1996).

Observations on morphological variations in the guppies based on LWR and LLR may be argued to be helpful for this species to cope with the different selection pressures of the habitat (Le Cren 1951; Endler 1995; Perry et al 1996; De Silva & Liyanage 2009; Montag et al 2011; Mir et al 2013; Siddik et al 2016). Studies have shown that this may have resulted in evading predation (Walker 1997). In the presence of predators, a longer caudal peduncle and caudal fin are necessary to improve swimming performance to escape predation. An increased body depth has been demonstrated to be an adaptive response to predation from gape-limited predators (Reznick et al 1997; Langerhans et al 2004; Abrahams 2006). The present study conforms to these findings. Alegria samples have a smaller body size, a longer caudal peduncle and caudal fin, and a deeper body than Tubod and Tambulig populations. A deeper caudal peduncle detected in Tambulig guppies shows a superior ability to accelerate in fast running water, and the caudal fin length is significantly related to swimming performance. The pectoral fin is associated with fish locomotion (Breda & Goulart 2005), with Alegria samples having a larger pectoral fin that indicates high swimming speed. There is also a minimal variation in sampled guppies' PFL. Reznick & Endler (1982) reported that guppies exposed to increased predation communities mature at a younger age and exhibit a smaller body size than their low predation counterparts. In this study, all the guppies coexist with other communities of predators in the three rivers. It could be that size preferences and the intensity of predation among sampling sites could influence the body size variation of this species. This result conforms to Reznick et al (1997), who noted that body size variation correlates with environmental differences, particularly with predation.

The water depth also influences the position of guppies in the water column. Regarding water depth, Noltie & Johansen (1986) reported that microhabitat selection between sexes was also observed, with male guppies commonly found in shallower water and slower moving water. The females preferred to occupy the deeper portion of the water (Croft et al 2004). Morphological variation was also found in the head region between and among populations of guppies. This variation could be attributed to the feeding behaviors (Anderson 2005; Cullen & McCarthy 2007) and the foraging performance of fish (Watson & Balon 1984). Between sexes, in each location, females had a longer head than males, while a higher HD and longer snoutL were detected in Alegria and Tubod guppies. Among populations variation, the Alegria samples presented a more extended HL and snoutL and a higher HD than the other guppy populations. Winemiller (1991) reported that the size of the head of fish is directly related to the food consumed, and a more prominent head region is an advantage, as it maximizes buccal volume and suction velocity (Caldeccut & Adams 1998).

Other environmental variables such as turbidity, flow velocity, water depth, substrate type, availability of food, and habitat structure may also contribute to the observed variation in selected morphometric characters in the guppies. A higher ED, for example, was observed in the guppies from the Alegria river, which may have resulted from adaptation to the low illumination intensity of water to perfect visualization in the water column and to help detect prey. The Alegria river was observed to have low flow, less depth, and a muddy substrate making the water more turbid. Turbidity hinders light penetration in the water layer. Thus, larger eyes may have adapted to cope with the turbid environment and improve feeding abilities, especially in detecting prey. In related previous studies, it was argued that the turbidity of the water might cause the diameter of the eye to be larger (Matthews 1988; Schliewen et al 2001; Lattuca et al 2007).

The Tambulig river guppy population shows a remarkably higher SL value than the other two populations. In a study conducted by Hockley et al (2014), the authors argue that the SL was associated with water velocity, with smaller guppies spending more time in low flow than larger ones. The current study observed that the velocity of water differs in the three areas, with Tambulig characterized by fast-flowing water compared to slow-flowing water in Alegria and Tubod. This observation may also explain the variations observed between populations of guppies.

Other environmental factors like the physicochemical factors (i.e., temperature, pH, and salinity) (Pauly 1984) and human activities (Abdullahi & Ahmad 2013; Hamid et al 2015) could have a detrimental effect on biota. Other factors like age, season, sex, stomach fullness, sampling methods, and sampling size influence LWR in fishes (Tesch 1971), but these factors were not accounted for.

Bagenal & Tesch (1978) noted the suitable condition factor (K) value range of 2.9-4.8 for matured freshwater fish. However, the condition factors of the guppies sampled in the present study revealed that the fish species had K values below the recommended value range. Furthermore, there has been no research on the physico-chemical analyses of the three locations. Hence it could not be determined whether it was caused by pollution, which is the most likely rational reason.

Conclusions. The length-weight relationship and length-length relationship in the current study helped provide us with necessary information regarding the body size, growth patterns, general condition of the fish, and the quality of the habitat where they live. It can be concluded that the body size was significantly different between males and females, with females larger and heavier than the males, which is a common trait among the Poeciliids species.

Conflict of Interest. The authors declare that there is no conflict of interest.

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Received: 28 April 2022. Accepted: 23 May 2022. Published online: 15 June 2022.

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How to cite this article:
Gelsano M. L., Demayo C. G., 2022 Population variability in *Poecilia reticulata* based on morphological character measurements, length-weight and length-length relationships. AACL Bioflux 15(3):1355-1370.