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Population variability of the Golden rabbit fish (*Siganus guttatus* Bloch) (*Pisces: Siganidae*) in Northern Mindanao, Philippines

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Abstract. Variability within, between and among *Siganus guttatus* population in Bacolod-Kauswagan, Lopez Jaena-Plaridel, Ozamis and MSU at Naawan was investigated based on selected morphological characters. The morphological characters investigated included 15 conventional morphometric characters, 23 landmark distances, six (6) meristic characters and five (5) gut morphomeristic characters. Analysis was done based on descriptive statistics, coefficient of variation, discriminant function analysis. Results indicate all 49 morphological characters classify individuals at 96.3% accuracy. Implications to fishery management based on results of morphological variations are discussed.
Key Words: Variability, landmark distances, meristic, morphometric.

Introduction. The golden rabbit fish or the orange–spotted spine foot, *Siganus guttatus* (Bloch), locally known, as "kitong", is a highly esteemed food fish in the Philippines and in the Indo-West Pacific region. Rabbit fishes or siganids are an export item of the Philippines and they are considered high value food fish. The local demand for siganids as food fish is ever increasing with the growing population and the unabated degradation, as a result of anthropogenic activities, of natural habitats such as coral reefs and sea grass beds. Aside from economic and fishery considerations, siganids are aquaculturally efficient as they occupy a low trophic level specifically *S. guttatus* which is relatively fast growing.

Rabbit fishes or siganids are generally littoral to sublittoral fishes and inhabit coral reefs, seaweed and sea grass beds, mangrove swamps, estuaries, river mouths and lagoons to a depth of 6 meters (Froese & Pauly 1998). Proper management of this valuable fishery resource is needed in order to maximize their potential. A proper understanding of their genetic pool expressed in morphological features is therefore important.

Family Siganidae is represented by 27 species (FishBase 1999) of which 15 species are schooling and the rest occur in pairs and are coral dwellers. These coral dwelling species are brightly colored, fragile, and sensitive to physico-chemical changes and usually show interspecific aggressive behavior. The schooling species of siganids, colored gray or drab, are sturdy and apparently resistant to considerable variations in salinity and temperature. These schooling species are important food fishes and currently the subject of mariculture studies such as *S. argenteus, S. canaliculatus, S. rivulatus, S. vermiculatus and S. guttatus*. Growth is faster in *S. vermiculatus* and *S. guttatus* compared to *S. canaliculatus* in ponds and in cages. The golden rabbit fish (*S. guttatus)*, however, attain the highest maximum size observed at about 42 cm (Rau & Rau 1980).

The current morphological study of *S. guttatus* natural populations in Iligan Bay and in Panguil Bay and the farmed population in Naawan will help expand the understanding of the siganid biology and may help improve fishery management and aquaculture of the golden rabbit fish. The morphology of organisms has been the primary source of information for taxonomic and evolutionary studies. Notwithstanding the value and availability of genetic, physiological, behavioral, and ecological data for such studies, systematists continue to depend heavily on morphology for taxonomic characters. In fishes, species have characteristic shapes, sizes, pigmentation patterns, disposition of fins, and other external and internal features that aid in recognition, identification and classification. Information on the external morphology of fishes used in this study can be found in many references including Lagler et al (1977), Bond (1979) Moyle & Cech (1981), Cailliet et al (1986) and Strauss & Bond (1990).

The study of biological populations within species concerns geographic variations and its meaning. Distinguishing valid species from geographical populations begins by studying variability of morphological characters. Character variability often describes changes in sample means of characters over a geographical range. Genetically based characters reflect an evolutionary response, by means of natural selection, to geographically varying environmental factors such as temperature, water quality and food.

Proper exploitation of the gene pool of the golden rabbit fish for commercial purposes and stock improvement requires an understanding of the extent of its morphological variability. Identification of the structure of the wild and farmed population is important as the presence of subpopulations of *S. guttatus* indicate distinct breeding units, which may display different morphological and physiological characteristics. These differences require their management as separate breeding stocks and can be utilized for the production of improved strains, and hence, higher productivity (Capuli 1991).

The study therefore aimed to investigate the morphological and biochemical variability in *S. guttatus* populations in Iligan Bay and Panguil Bay and in the farmed population in Naawan, Misamis Oriental.

Material and Method

Study area. Wild sourced *S. guttatus* were collected in three study sites in Panguil Bay and Iligan Bay (Figure 1) namely: Malaubang, Ozamis City; Lopez Jaena – Plaridel, Misamis Occidental, and Kauswagan-Bacolod, Lanao Del Norte. The hatchery bred *S. guttatus* were collected from the fishponds and fish hatchery of MSU-Naawan, Naawan, Misamis Oriental and MSU experimental fish cages in Lopez-Jaena, Misamis Occidental.

The climate regime over Ozamis City and Lopez Jaena- Plaridel belong to type II of the Modified Corona's classification where the area experience no dry season and a pronounced maximum rain period during December to January. Rainfall is about 2-3000 mm. The climate regime over Bacolod – Kauswagan, Lanao Del Norte belongs to type IV where rainfall is more or less evenly distributed throughout the year. Rainfall is also about 2-3000 mm.

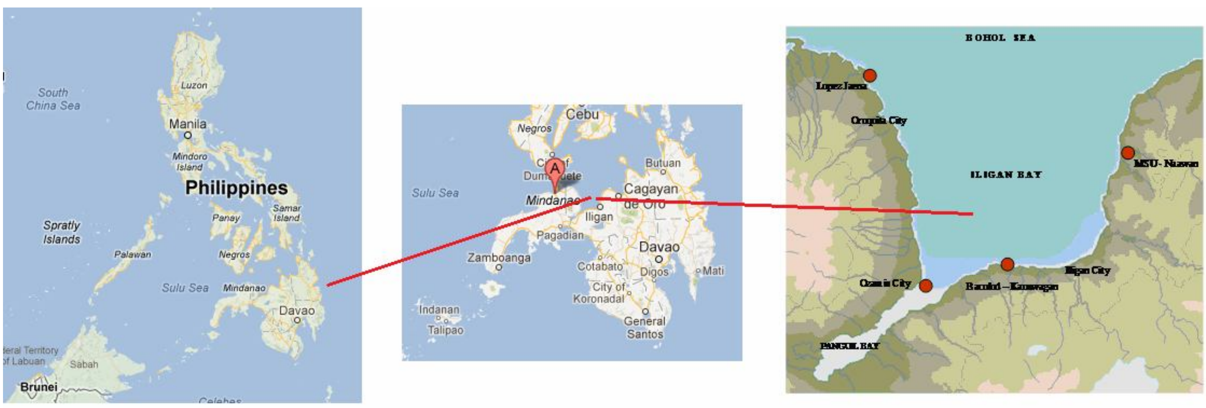

Figure 1. Sampling sites for *S. guttatus* in Iligan Bay and Panguil Bay, Northern Mindanao, Philippines.

Morphological characters. Attributes of body form and structure among populations are usually described as contrasts in overall body form or in particular, anatomical features.

The morphological characters used in this study to characterize *S. guttatus* in four geographical locations in Northern Mindanao, Philippines include about 15 conventional morphometric characters, Six (6) meristic characters, 23 landmark distances and five (5) gut morphomeristic characters.

Secondary sexual dimorphism both qualitative and quantitative (T-test, $P > 0.05$) in *S. guttatus* was not observed in all samples in concurrence with Duray (1998).

Morphometric characters. Morphometric (mensural) characters are characteristics of form that can be measured in millimeters on the body. Mensural traits change continuously with size and age because of continuous growth in fishes (Lagler et al 1977; Strauss & Bond 1990).

The morphometric characters (Figure 3) used in this study include the following: head length, total length, standard length, pectoral fin length, eye diameter, pre-dorsal length, snout length, upper jaw length, head width, body depth, caudal peduncle length, caudal peduncle depth, sub orbital width, caudal fin length and ventral (pelvic) fin length. Descriptions and definitions of the morphometric characters are of Lagler et al (1977), Cailliet et al (1986) and Strauss & Bond (1990).

Variation of morphometric characters of *S. guttatus* within geographic location was determined by descriptive statistics. Within species, the characters with lowest Coefficient of Variation (C.V.) are the ones that can best characterize a particular species. Morphometric characters are distance measurements that vary continuously with body size. A conventional technique for assessing shape differences is to use ratios as measurements of characters. Ratios are generally assumed to remove the effects of body size by dividing out with standard length (Strauss & Bond 1990; Cailliet et al 1986).

Morphometric characters were arcsine transformed and subjected to analysis of variance (ANOVA) to test for differences between and among geographic population. Prior to ANOVA, normality test was conducted on the arcsine transformed data. Homogeneity test was also determined using Levene's test.

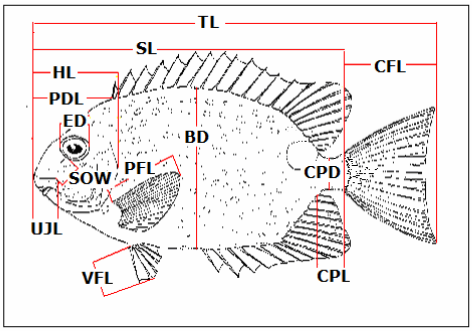

Figure 2. Conventional morphometric characters considered in *S. guttatus* samples for morphological analysis.

Meristic and other enumerable characters. Meristic characters are the body segments primarily fin rays, which once, in evolutionary history, corresponded to the body segmentations. Other characters that can be counted such as coloration spots and pyloric caeca tips are referred to as meristic characters even though they have no correspondence with the myomeres. However, these countable characters may vary within and among species. Meristic characters usually become stable in number after a threshold body size has been attained (Strauss & Bond 1990) such that in this study only adult stage *S. guttatus* were considered.

Meristic characters can be influenced substantially by environmental factors especially by temperature during early development. Variation of this nature has been noted by Taning (1952). The variation in late-determined meristic characters, e.g.

number of rays, dorsal and pectoral fins seem to be determined by metabolism, whereas the early determined characters, e.g. number of vertebra is to a greater extent controlled genetically (Taning 1952).

In systematic ichthyology the numbers of fin rays and other numerical characters have always played an important part in the description and definition of species and subspecies.

In this study, the meristic and other countable characters considered are the ff: dorsal fin spine, dorsal fin rays, anal fin spine, anal fin rays, left pectoral fin rays and caudal peduncle spots.

Landmark distances measurements. Landmark distance measurements are based on the truss protocol described in detail by Strauss & Bookstein (1982) and Strauss & Bond (1990). The truss consists of systematically arranged set of distances measured among preselected anatomical landmarks which are points identified on the basis of local morphological features and chosen to divide the body into functional parts. Typical landmarks include bases of fin spines and rays, articulation points between bones and points where edges of bones cross the midsagittal plane of the body (Strauss & Bond 1990).

Landmarks are chosen to be evolutionarily or functionally comparable in position to corresponding landmarks on other species and are explicitly assumed to be homologous (Strauss & Bond 1990). In this study about 23 landmark distances based on 11 anatomical landmarks were considered (Figure 4).

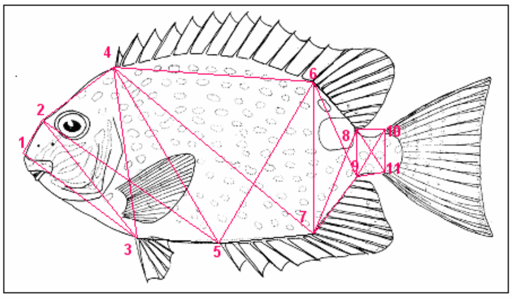

Figure 3. Schematic diagram of the 23 landmark distances measured on each specimen. Numbered points indicate midsaggital anatomical landmarks: 1. upper tip of premaxilla at symphysis; 2. anterior edge of frontal bone; 3. anterior base of the first ventral fin spine; 4. anterior base of the first dorsal fin spine; 5. anterior base of the first anal fin spine; 6. anterior base of the first dorsal fin ray; 7. anterior base of the first anal fin ray; 8. posterior base of the last dorsal fin ray; 9. posterior base of the last anal fin ray; 10. anterior base of the first dorsal procurrent caudal fin ray; and 11. anterior base of the first ventral procurrent caudal fin ray.

Gut morphomeristic characters. The gut morphomeristic characters considered in this study for morphological analysis include five (5) notable characters which may describe further *S. guttatus*. These characters include the ff: digestive tract length, pyloric caeca tips, pyloric caeca tip longest length, pyloric caeca shortest tip and gall bladder position in the visceral cavity.

The gut of the *S. guttatus* starts to develop later in age during the onset of the exogenous feeding of the larval stage of the fish and completes differentiation at juvenile stage thus samples used in this study were required to be in the adult stage.

Results and Discussion. Comparison of *S. guttatus* samples from four locations based on morphometric, meristic, landmark distances and gut morphomeristic characters are presented in Table 1 and based on box plots of the raw data are presented in Figures 4-6. Mensural traits (morphometric and landmark distances) are heavily influenced by sizes of *S. guttatus* samples. Outstanding difference between samples is the mean total length of fishes. The total lengths of samples from Bacolod–Kauswagan have bigger sizes compared to Ozamis City, MSU Naawan and Lopez Jaena–Plaridel. Smallest mean total lengths are samples from Lopez Jaena–Plaridel. Noteworthy among the morphometric characters is the small head length of *S. guttatus* from the pond in MSU Naawan when compared to wild populations from Bacolod–Kauswagan, Ozamis City and Lopez Jaena–Plaridel.

Table 1

Descriptive statistical description of phenotypic variability within populations of *S. guttatus*

Characteres	*Bacolod*	*Lopez-Jaena*	*Ozamis City*	*MSU-Naawan*
		Morphological characters		
Caudal fin length	50.639	43.445	51.0733	43.579
Caudal peduncle length	13.976	10.3567	11.5217	9.872
Eye diameter	15.417	13.991	13.9267	12.287
Snout length	18.613	16.215	17.5433	14.856
Pre-dorsal length	52.155	45.38	48.005	45.518
Suborbital width	14.087	12.28	13.1817	12.787
Head width	25.312	34.2117	24.745	23.313
Upper jaw length	11.627	10.533	11.3883	9.675
Caudal peduncle depth	15.065	10.3567	14.9333	14.097
Total length	243.626	207.7833	232.09	217.926
Body depth	95.118	81.3267	91.005	88.716
Standard length	192.987	164.3383	181.0167	174.347
Head length	49.971	44.3717	47.1417	42.412
Ventral fin length	33.032	28.17	33.15	29.213
Pectoral finlength	43.95	36.9283	41.3573	34.566
		Meristic characters		
Caudal peduncle spots	6	4.3367	5.8	3.9118
Anal rays	8.976	9.0333	9	9.2941
Pectoral rays	16.098	15.7	16	15.9412
Anal spines	7.024	6.9	7	7.0588
Dorsal spines	13.049	13	13.067	13
Dorsal rays	10	9.667	10.033	10.3529
		Landmark distances		
T7-8	51.285	41.4183	48.6783	46.7044
T5-7	51.022	43.355	49.8917	49.3029
T8-10	13.607	11.6517	11.7783	11.2676
T9-11	13.883	10.325	11.755	11.2676
T4-5	102.423	88.7917	99.2433	96.4368
T6-9	57.545	48.3283	54.535	52.5544
T2-4	30.282	26.485	28.8267	30.7382
T8-11	22.955	19.1133	22.105	21.4103
T10-11	20.105	16.1433	18.6033	16.6773
T3-5	46.026	40.8433	41.2083	43.2235
T1-2	36.824	30.2517	33.12	27.8005
T6-7	75.118	62.955	72.2083	68.4044
T8-9	18.348	14.95	17.7733	16.8324
T4-6	100.52	85.6383	98.0533	93.2544
T4-7	130.862	111.72	124.7033	121.5412
T5-6	97.659	81.8083	94.605	90.8353
T1-3	67.533	58.4517	64.9533	60.4779

Characteres	Bacolod	Lopez-Jaena	Ozamis City	MSU-Naawan
		Landmark distances		
T9-10	23.555	18.485	21.79.17	20.7412
T3-4	84.926	72.5433	81.4267	75.9515
T7-9	36.437	29.615	34.145	32.6897
T2-5	105.726	91.2883	99.555	98.8118
T6-8	42.518	35.3733	39.51	36.875
T2-3	75.178	63.275	71.1533	67.6706
		Gut morphometric characters		
Pyloric caeca shortest tip	15.39	15.2667	12.5	12.087
Pyloric caeca longest tip	37.805	33	27,4	32.765
Digestive tract length	679.902	559.6333	553.5	573.382
Pyloric caeca tips	5.024	4.4	4.533	5.441
Gall bladder position	1.5	1.5	1.5	1.309

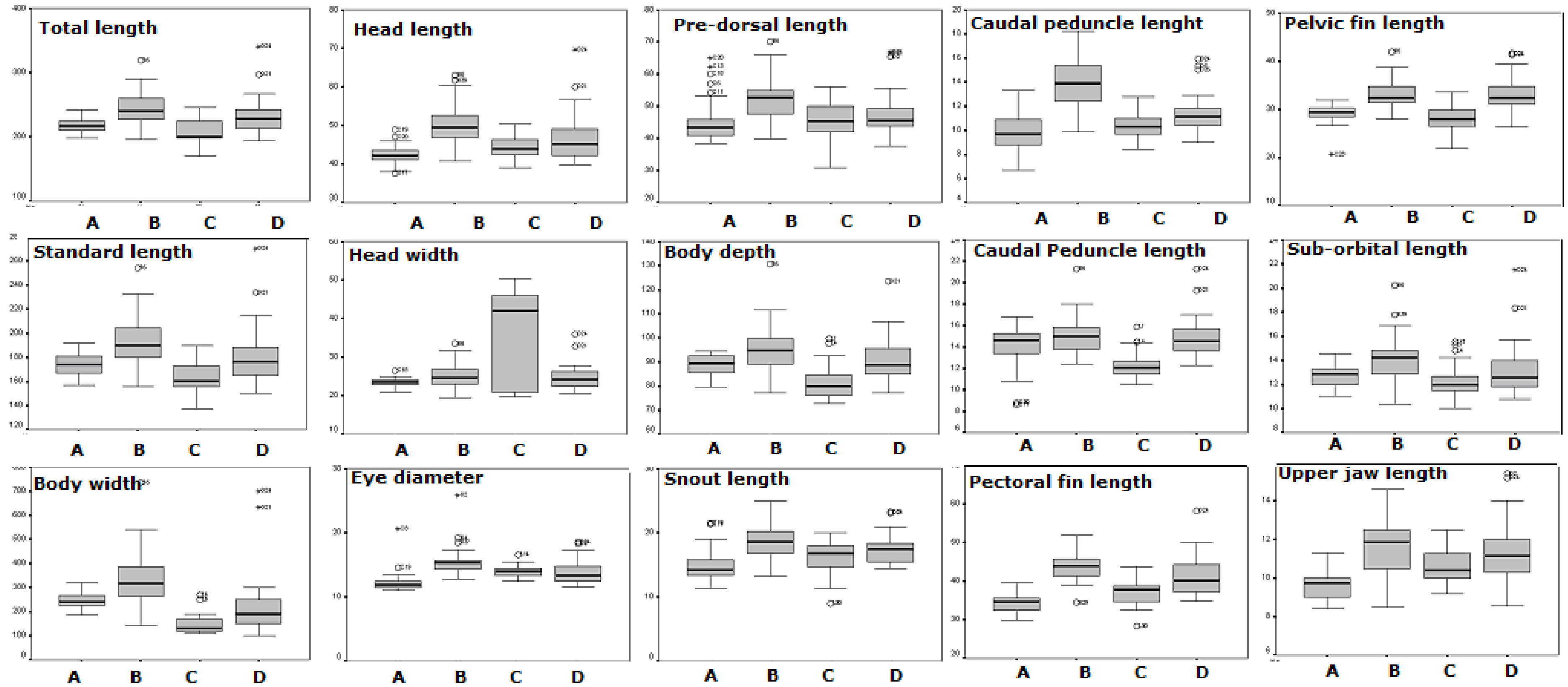

Figure 4. Boxplots for the comparison of morphometric characters in *S. guttatus* from four sampling locations (A-MSU-Naawan; B-Bacolod-Kauswagan; C- Lopez Jaena; D-Ozamis City).

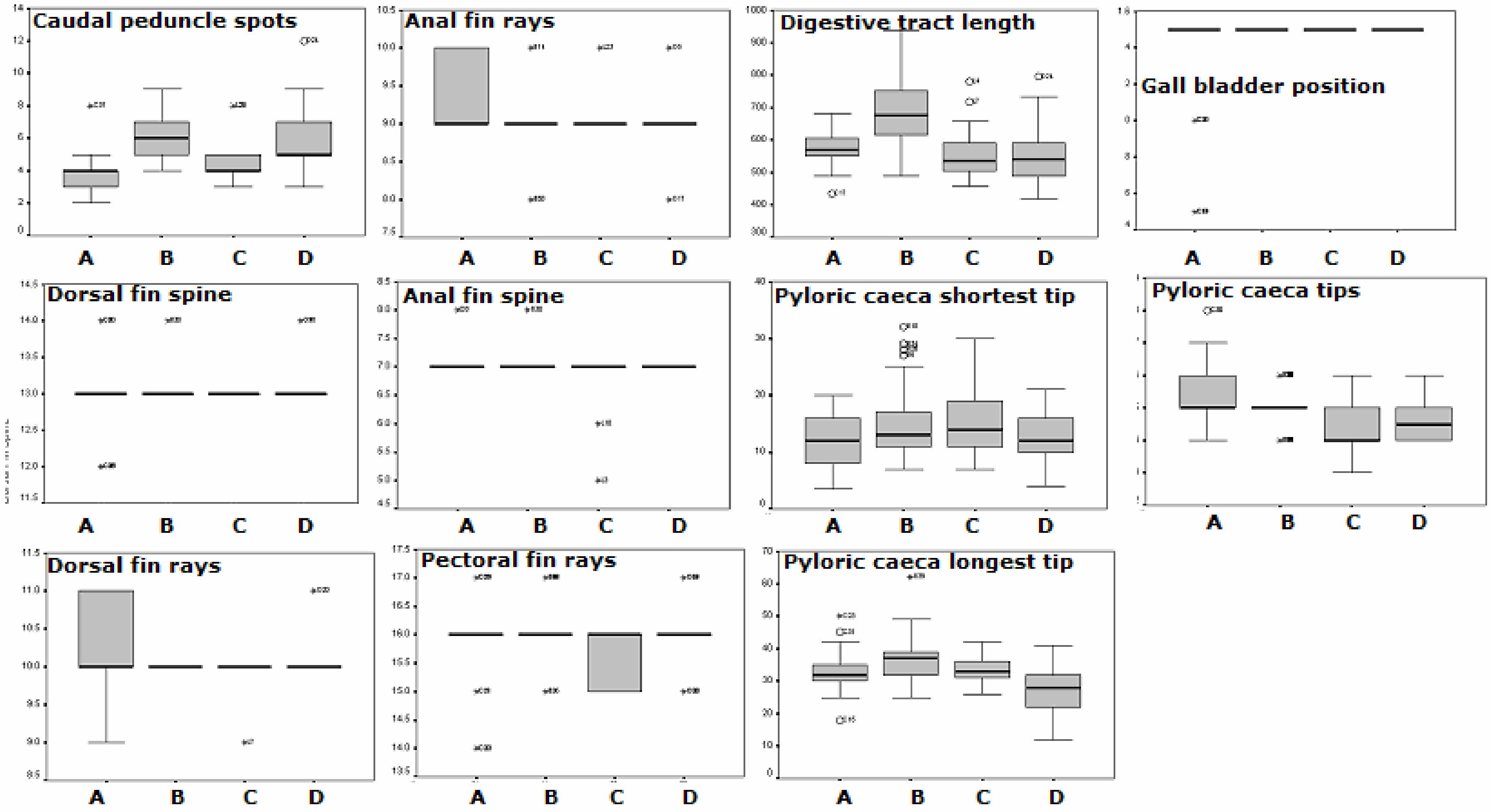

Figure 5. Boxplots for the comparison of meristic characters in *S. guttatus* from four sampling locations (A-MSU-Naawan; B- Bacolod-Kauswagan; C- Lopez Jaena; D-Ozamis City).

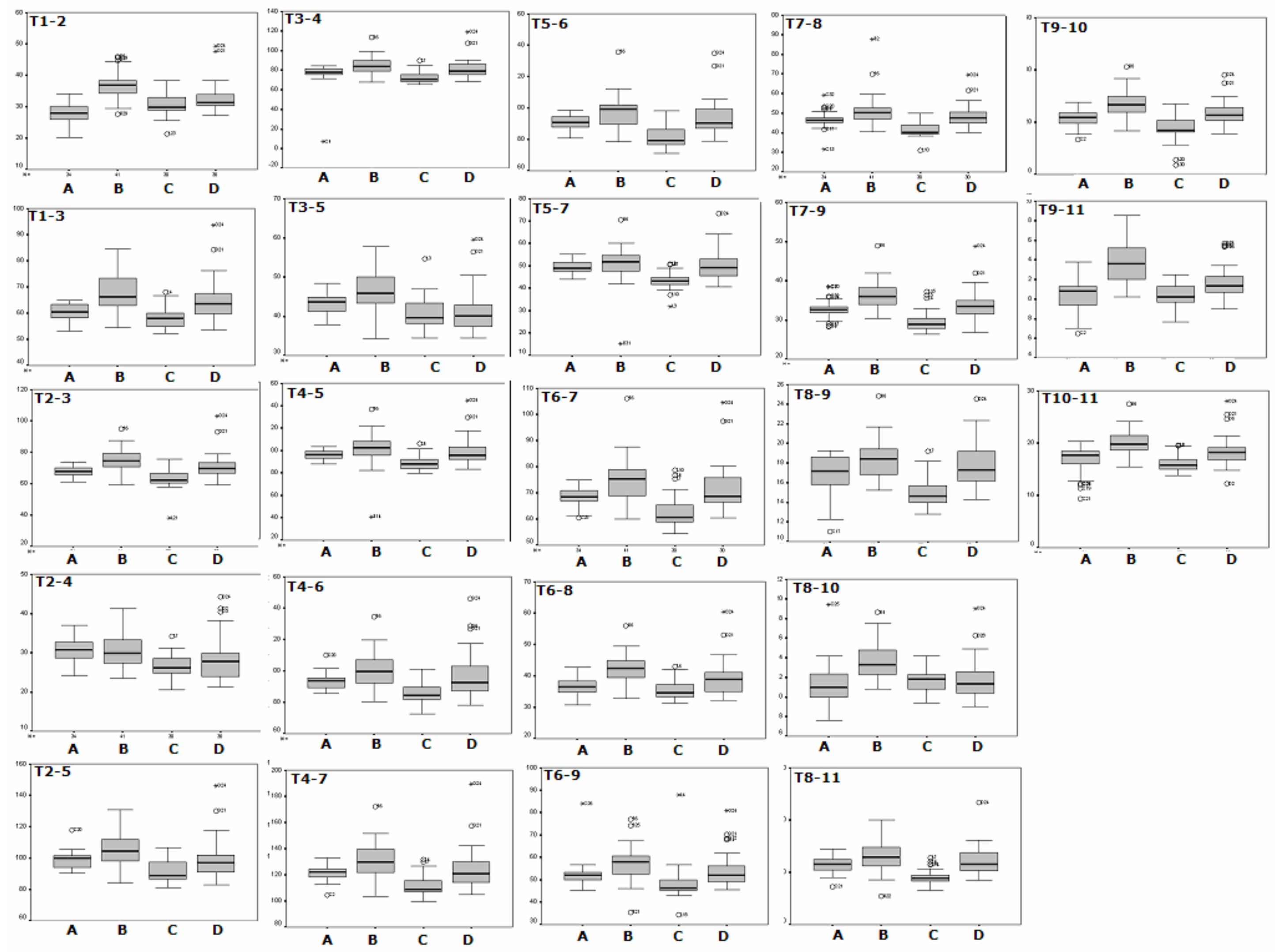

Figure 6. Boxplots for the comparison of landmark distance characters in *S. guttatus* from four sampling locations (A-MSU-Naawan; B-Bacolod-Kauswagan; C- Lopez Jaena ; D-Ozamis City).

In consideration that the mensural traits change continuously with size and age because of continuous growth in fishes (Lagler et al 1977; Strauss & Bond 1990), all logical morphometric measurements were divided out by the standard length. A conventional technique for assessing shape differences is to use ratios as measurements of characters. Ratios are generally assumed to remove the effects of body size by dividing out with standard length (Strauss & Bond 1990; Cailliet et al 1986). The arcsine transformed morphometric data and square root transformed meristic data were subjected to homogeneity test and one way analysis of variance (ANOVA). A comparison of morphometric and meristic characters and landmark distances and gut morphomeristic characters among the four geographical locations in Northern Mindanao are presented in Table 2.

Table 2

Comparison of morphometric, meristic, landmark distances and gut morpho-meristic characters of *S. guttatus* samples among the four geographic locations

Morphological characters	*Homogenity test*		*ANOVA*		*Homogeneous locations*
	Levene Statistic	*Sig.*	*F*	*Sig.*	
			Morphometric characters		
Body depth	3.8575	0.011*	1.754	0.159^{ns}	ALL
Caudal fin length	15.0873	0.000**	1.780	0.154^{ns}	ALL
Caudal peduncle depth	5.1926	0.002**	5.794	0.001**	MSU, OZ, BK
Caudal peduncle length	1.7000	0.170^{ns}	23.751	0.000**	LJ, OZ
Eye diameter	0.7348	0.533^{ns}	21.994	0.000**	BK, OZ
Head length	1.3397	0.264^{ns}	18.048	0.000**	BK, OZ
Head width	457.7895	0.000**	34.641	0.000**	MSU, OZ, BK
Pectoral fin length	1.8134	0.148^{ns}	28.152	0.000**	LJ, OZ, BK
Pre dorsal length	3.8425	0.011*	1.952	0.124^{ns}	ALL
Snout length	0.4833	0.694^{ns}	10.800	0.000**	LJ, OZ, BK
Sub orbital width	1.1133	0.346^{ns}	0.755	0.521^{ns}	ALL
Upper jaw length	1.0831	0.359^{ns}	19.595	0.000**	BK, OZ
Ventral fin length	3.9697	0.010**	11.734	0.000**	MSU, LJ, BK
			Meristic characters		
Anal rays	19.5961	0.000**	7.489	0.000**	LJ, OZ, BK
Anal spines	4.4120	0.005**	2.557	0.059^{ns}	ALL
Caudal peduncle spots	4.3310	0.006**	21.757	0.000**	MSU, LJ, OZ, BK
Dorsal rays	75.5071	0.000**	11.778	0.000**	LJ, OZ, BK
Dorsal spines	2.8707	0.039*	0.522	0.668^{ns}	ALL
Pectoral rays	1.7764	0.155^{ns}	3.651	0.014*	MSU, OZ, LJ
			Landmark distances		
T1-2	0.3177	0.813^{ns}	27.304	0.000**	LJ, OZ, BK
T1-3	7.8969	0.000**	2.734	0.046*	ALL
T2-3	3.5934	0.015*	0.643	0.588^{ns}	ALL
T2-4	0.0318	0.992^{ns}	8.698	0.000**	LJ, OZ, BK
T2-5	4.2166	0.007**	2.252	0.085^{ns}	ALL
T3-4	0.6376	0.592^{ns}	0.630	0.597^{ns}	ALL
T3-5	1.9994	0.117^{ns}	8.027	0.000**	MSU, LJ, BK
T4-5	3.7599	0.013*	1.848	0.142^{ns}	ALL
T4-6	3.2643	0.024*	2.896	0.038*	ALL
T4-7	5.7758	0.001**	1.797	0.151^{ns}	ALL
T5-6	7.1630	0.000**	5.442	0.001**	MSU, OZ, BK
T5-7	2.4366	0.068ns	4.968	0.003**	LJ, OZ, BK
T6-7	1.6325	0.185ns	1.839	0.143^{ns}	ALL

Morphological characters	Homogenity test		ANOVA		Homogeneous locations
	Levene Statistic	Sig.	F	Sig.	
Landmark distances					
T6-8	3.2667	0.023*	3.005	0.033*	ALL
T6-9	1.9866	0.119ns	0.396	0.756 ns	ALL
T7-8	3.3653	0.021*	4.156	0.008**	MSU, OZ, BK
T7-9	4.9335	0.003**	4.032	0.009**	MSU, OZ, BK
T8-9	5.5265	0.001**	3.826	0.011*	MSU, LJ, BK
T8-10	1.5912	0.195ns	4.698	0.004**	MSU, OZ, BK
T8-11	1.9669	0.122ns	2.925	0.036*	ALL
T9-10	0.3804	0.767ns	7.731	0.000**	MSU, OZ, BK
T9-11	3.0903	0.029*	14.919	0.000**	MSU, OZ, LJ
T10-11	3.0252	0.032ns	4.591	0.004**	MSU, OZ, LJ
Gut morphomeristic characters					
Digestive tract L/SL	0.8867	0.450ns	9.347	0.000**	MSU, OZ
Gall bladder position	59.3240	0.000**	9.007	0.000**	LJ, OZ, BK
Pyloric caeca tip maximum length	1.3182	0.271 ns	15.320	0.000**	MSU, BK, LJ
Pyloric caeca tip minimum length	2.2173	0.089 ns	3.722	0.001**	MSU, OZ, BK
Pyloric caeca tips	5.7290	0.001**	12.240	0.000**	LJ, OZ

* significant at α = 0.05, ** highly significant at α = 0.05, ns not significant at α = 0.05, BK = Bacolod – Kauswagan, OZ = Ozamis City, LJ = Lopez Jaena – Plaridel, MSU = MSU Naawan.

Among the morphometric characters, the body depth, pre-dorsal length, sub orbital width and caudal fin length are not significantly different (P > 0.05) among the four sampling locations. However, nine other morphometric characters have highly significantly difference (P < 0.01) among the four sampling locations (Table 2). Post Hoc Test using Scheffe indicate homogeneous locations.

Among the meristic characters, dorsal fin spines and anal fin spines are not significantly different (P > 0.05) among the four sampling locations. However, the anal fin rays, dorsal fin rays and caudal peduncle spots have highly significant difference (P < 0.01) among the four sampling locations. The pectoral fin rays have significant difference (P < 0.05) among the four sampling locations.

Among the landmark distances, T2-3, T2-5, T3-4, T4-5, T4-7, T6-7 and T6-9 are not significantly different (P > 0.05) among the four sampling locations. Eleven (11) landmark distances have highly significant difference (P < 0.01) among the four sampling locations and five (5) landmark distances have significant difference (P < 0.05) among the four sampling locations.

Discriminant function analysis (DFA) was also done to compare the different populations of *S. guttatus* based on the different characters (Figure 7). The primary purpose of discriminant function analysis (DFA) is classification and it is an ideal tool for classifying individual fish such as *S. guttatus* to populations from geographical locations. DFA is a multivariate procedure whereby *a posteriori* character weighting is done in such a way as to maximize, through linear combination, the probability of correctly identifying individuals to one of two or more groups.

For morphological characters, DFA was conducted based on the arcsine transformed values of the morphometric characters in *S. guttatus* from different sampling locations. A scatter plot of the DFA for all the characters evaluated is presented in Figure 7a. Classification results indicate >70% original grouped cases correctly classified and cross-validated grouped cases correctly classified.

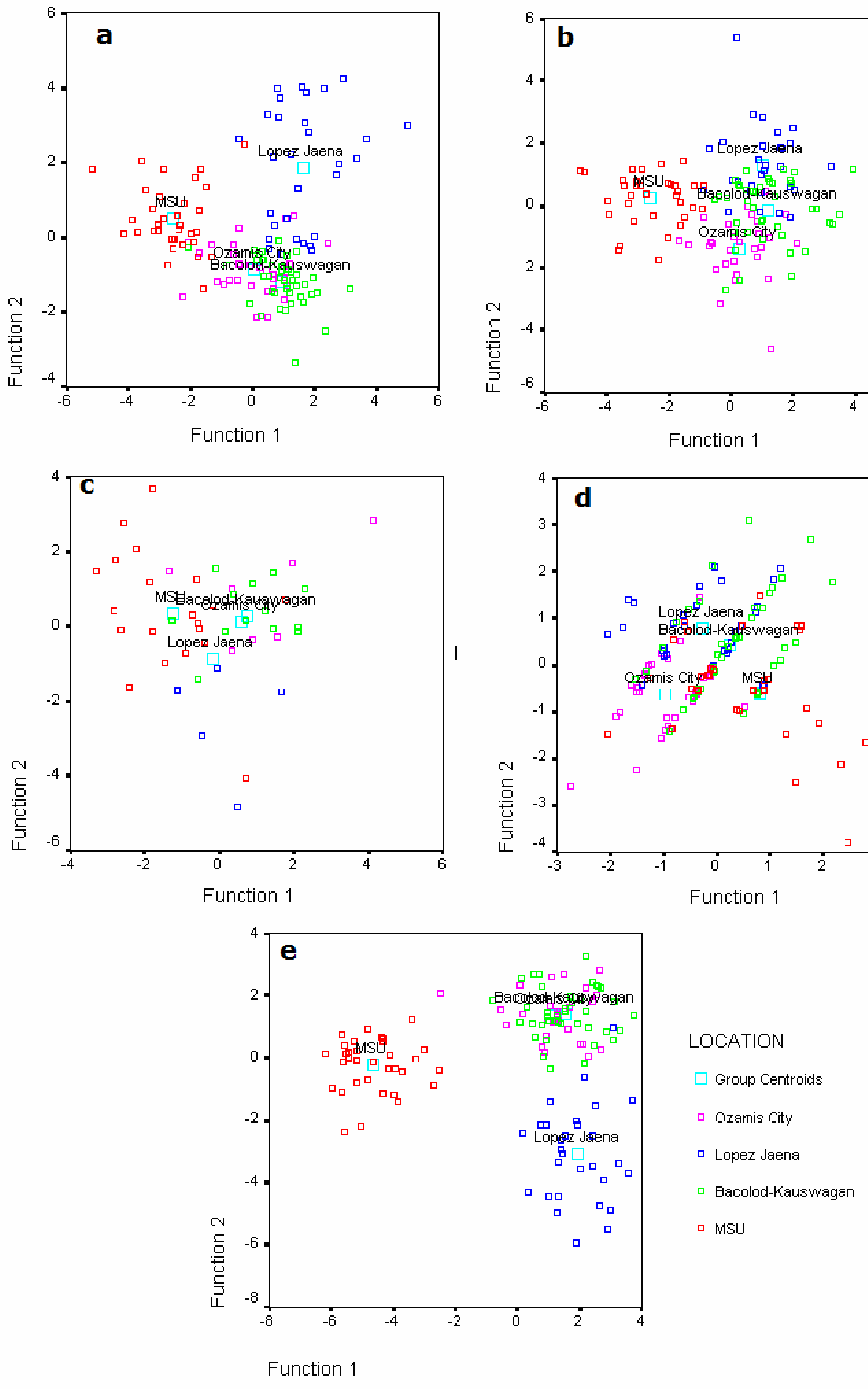

Figure 7. All-groups scatter plot of the Discriminant Functions Analysis based on morphometric characters. (a-morphometric characters b- Landmark distances; c-meristic characters; d-gut morphometric characters; e-combined morphometric characters). Classification results indicate >80% original grouped cases correctly classified and >75% cross-validated grouped cases correctly classified.

For landmark distances, DFA was also conducted based on the arcsine transformed values. A scatter plot of the DFA for landmark distance characters is presented in Figure 7b. Classification results indicate 82.2% original grouped cases correctly classified and 66.7% cross-validated grouped cases correctly classified.

For meristic characters, discriminant function analysis was conducted based on the square root transformed values. A scatter plot of the DFA for meristic characters is presented in Figure 7c. Classification results indicate 49.6% original grouped cases correctly classified and 45.2% cross-validated grouped cases correctly classified. The classification results show poor utility of the meristic characters for grouping and discriminating *S. guttatus* in different locations.

For gut characters, discriminant function analysis was conducted based on the arcsine transformed values and square root transformed values. Results are shown in a scatter plot in Figure 7d. Classification results indicate 58.5% original grouped cases correctly classified and 52.6% cross-validated grouped cases correctly classified. Utility of the gut morphomeristic characters show a poor classification results.

When all morphological characters investigated were used in the DFA, a scatter plot of the DFA for all morphological characters presented in Figure 7e show a better classification of individual *S. guttatus*. Classification results indicate 96.3% original grouped cases correctly classified and 83% cross-validated grouped cases correctly classified.

It can be seen from the results presented that while variability within populations is observable, between sampling locations were also clearly evident (Tables 1, 2 and Figures 4-7). Variations in morphological characters in populations of the fish could be attributed to food quality and quantity and other environmental factors in the feeding areas. Studies have shown that the quality and quantity of food are among the most important factors affecting phenotypic responses in fishes (Wootton 1990; Jennings & Beverton 1991; Roff 1992; Wainwright 1988). The structure of the digestive apparatus has been shown to have a direct correlation with the feeding habit of fishes (Suyehiro 1942; Al-Hussaini 1949; Angelescu & Gneri 1949; Junger et al 1989; Veregina 1990). Work on the ecomorphology of locomotion has shown patterns of association between habitat use and functional design of the swimming apparatus (Westneat 1996; Walker & Westneat 2000, 2002; Vogel 1994; Wainwright et al 2002; Bellwood & Wainwright 2001; Fulton et al 2005) thus its can also be argued that the morphological variations in *S. guttatus* can be associated with differences in habitats.

Conclusions. Results of the study have shown the existence of variability within and between populations of *S. guttatus* based on morphometric, meristic, landmark distances and gut morphomeristic characters. It is hyspothesized that the variations observed can be attributed to possible association of habitat use and functional design of morphological characters.

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