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New Species of *Petrotilapia* (Teleostei: Cichlidae) from Lake Malaŵi, Africa

JAY R. STAUFFER JR. AND ELLEN S. VAN SNIK

A rock-dwelling cichlid endemic to Chinyamwezi and Chinyankwazi islands, Lake Malaŵi, Malaŵi, Africa is described. The new species is placed in the genus *Petrotilapia* based on the presence of predominantly tricuspid teeth on the major dentigerous areas of the jaws and because the teeth are exposed when the jaws are closed. It is distinguished from congeners by the gold coloration of nonterritorial males and females. Cheek depth, as expressed as percent of head length, is typically much smaller in the new species than in previously described members of the genus.

THE haplochromine cichlid fishes inhabiting lakes Victoria, Tanganyika, and Malaŵi represent an outstanding case of explosive evolution in modern vertebrates. The high diversity, recent speciation, and mophological and genetic similarity of the African haplochromines makes it extremely difficult to delimit both allopatric and sympatric species. Genetic studies of sympatric color morphs of the Lake Malaŵi cichlid fishes *Pseudotropheus zebra* (Boulenger) and *Petrotilapia tridentiger* Trewavas found significant differences in allelic frequencies in several of the polymorphic loci but failed to distinguish any fixed differences (McKaye et al., 1982; 1984). Similarly, the morphological characters of many sympatric and allopatric forms overlap (Marsh, 1983). Despite the lack of fixed genetic and morphological differentiation, specific status of many forms has been confirmed by observation of assortative mating (Marsh, 1983). Lewis (1982) suggested that, in the case of shallow water species, behavioral characters should be used as taxonomic characters. Stauffer et al. (1993) interpreted bower shape as a manifestation of a behavioral character and used it to delimit three *Copadichromis* species from Lake Malaŵi. Among rock-dwelling haplochromine species, coloration has been shown to be important in mate recognition and selection within a species (Fryer, 1959; Schroder, 1980; Stauffer and Boltz, 1989), and in many cases different male color patterns are the primary trait used to delimit species (Marsh, 1983).

Trewavas (1935) diagnosed the genus *Petrotilapia* when she described the type species, *P. tridentiger*, as having all tricuspid jaw teeth. Marsh (1983:2) described *Petrotilapia genalutea* Marsh and *Petrotilapia nigra* Marsh and modified the diagnosis "to include those Lake Malaŵi cichlids with predominantly tricuspid teeth on the major dentigerous area of the jaws excluding the posterior sides of the premaxilla and dentary." The other character deliminating the genus is the visibility of teeth when the jaws are closed.

Certainly, as it is now diagnosed, *Petrotilapia* consists of a complex of sibling species (Marsh et al., 1981). The type material for all of the described *Petrotilapia* species is from Monkey Bay. Marsh (1983) described the three distinct sympatric color forms as separate species based on behavioral observations that demonstrated assortative mating of the three forms. His decision was supported by the study of McKaye et al. (1982), which found frequency differences in seven polymorphic loci among the three sympatric color forms. The purpose of this paper is to describe a new allopatric species of *Petrotilapia* that is endemic to Chinyankwazi (35°00'E, 13°53'S) and Chinyamwezi (35°00'E, 13°56'S) islands. These two islands are known for their high degree of endemism (Stauffer, 1988, 1993; Stauffer et al., 1995).

MATERIALS AND METHODS

Fishes were collected by chasing them into a monofilament gill net while SCUBA diving. External counts and measurements follow Stauffer (1991) and were taken from the left side of the body, except for gillraker meristics, which were taken from the right side. The number of scales in the overlapping portion of the upper and lower lateral lines was not counted; pored scales posterior to the hypural plate were recorded separately. The posterior simple ray of the anal fin was not counted (Stauffer, 1994). Standard length (SL) is used throughout, and morphometric values are expressed as percent SL for measurements which extend past the operculum of the fish and percent head length (HL) for measurements which do not extend past the operculum. Institutional abbreviations follow Leviton et al. (1985), except where noted.

The new species was compared with the type series of *P. tridentiger* (BMNH 1935.6.14.244–246), *P. genalutea* (BMNH 1981.2.2.222-224), and *P. nigra* (BMNH 1981.2.2.207–209), all from Monkey Bay. In addition, specimens of *P. tridentiger* were collected from Songwe Hill (34°56'E, 14°00'S; n = 11, PSU 3021), Mazinzi Reef (34°58'E, 14°07'S; n = 2, PSU 3019, 3020), and Crocodile Rocks (35°10'E, 14°17'S; n = 9, PSU 3018).

Meristic differences were analyzed by principal component analysis (PCA) in which the correlation matrix was factored (SAS 6.07). Body shape was assessed by analyzing the morphometric data with a sheared PCA (Humphries et al., 1981; Bookstein et al., 1985), in which the covariance matrix was factored (SAS 6.07). This procedure restricts size variation to the first principal component; thus, subsequent components are strictly shape related. Comparisons among species were made by plotting the sheared second principal component of the morphometric data with the first principal component of the meristic data. A multivariate analysis of variance (MANOVA) was used to test differences among the minimum polygon clusters formed by each species in the above plot.

Petrotilapia chrysos n. sp.

Petrotilapia "gold" Ribbink et al., 1983:211
Figures 1–2; Table 1

Holotype.—PSU 2726, adult male, 116.9 mm SL, Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 13 March 1991.

Paratypes.—PSU 2727, 16 (84.9–131.3 mm), data as for holotype, PSU 2728, 3 (106.5–117.4 mm), Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 28 Feb. 1988; PSU 2729, 4 (94.2–112.2 mm), Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 4 May 1991; PSU 2730, 8 (83.7–116.3 mm), Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 18 June 1991; PSU 2731, 5 (88.4–

TABLE 1. MORPHOMETRIC AND MERISTIC VALUES OF THE TYPE SERIES OF *Petrotilapia chrysos* (n = 78). Mean, standard deviation (SD), and range include the holotype.

	Holotype	Mean	SD	Range
Standard length, mm	116.9	105.9	10.8	79.0–131.3
Head length, mm	36.5	33.6	4.3	22.7–42.1
Percent of standard length				
Head length	31.2	31.7	1.6	28–35
Snout to dorsal-fin origin	36.6	36.9	1.9	31–41
Snout to pelvic-fin origin	36.3	35.7	2.1	31–40
Pectoral-fin length	32.7	29.0	4.3	18–39
Pelvic-fin length	23.8	26.0	2.3	20–32
Dorsal-fin base length	62.7	60.6	2.2	55–68
Anterior dorsal to anterior anal	53.4	55.4	2.3	47–60
Posterior dorsal to posterior anal	16.6	16.8	1.3	14–20
Anterior dorsal to posterior anal	66.2	65.6	2.2	60–71
Posterior dorsal to anterior anal	32.0	31.0	2.2	25–37
Posterior dorsal to ventral caudal	17.1	18.1	1.2	15–22
Posterior anal to dorsal caudal	18.6	18.8	1.7	14–22
Anterior dorsal to pelvic-fin origin	29.7	28.2	1.9	24–33
Posterior dorsal to pelvic-fin origin	57.7	57.8	2.3	52–63
Pecent of head length				
Horizontal eye diameter	24.4	26.8	2.6	19–34
Vertical eye diameter	24.7	25.0	3.1	17–35
Snout length	34.4	37.7	3.1	29–46
Postorbital head length	51.7	47.7	3.2	36–54
Preorbital depth	30.6	34.3	3.6	27–45
Lower-jaw length	27.2	30.2	3.2	25–37
Cheek depth	30.7	30.9	3.8	21–39
Head depth	121.3	119.9	8.0	97–139
Counts	Holotype	Mode	% Freq.	Range
Lateral-line scales	32	31	44.9	26–33
Pored scales posterior to lateral line	2	2	57.7	0–3
Scale rows on cheek	4	4	94.9	3–5
Dorsal-fin spines	18	18	76.9	16–19
Dorsal-fin rays	9	9	47.4	7–10
Anal-fin spines	3	3	100.0	3–3
Anal-fin rays	7	7	91.0	6–8
Pectoral-fin rays	14	13	73.0	12–14
Pelvic-fin rays	5	5	100.0	5–5
Gillrakers on first ceratobranchial	10	10	52.6	8–11
Gillrakers on first epibranchial	2	2	87.2	2–3
Teeth in outer row of left lower jaw	21	21	20.5	17–25
Teeth rows on upper jaw	10	7	25.6	5–12
Teeth rows on lower jaw	12	10	25.6	6–14

115.0 mm), Chinyankwazi Island, Lake Malaŵi, Africa, 1–3 m, 6 May 1988; PSU 2732, 12 (84.8–113.4 mm), Chinyankwazi Island, Lake Malaŵi, Africa, 1–3 m, 13 March 1991; PSU 2733, 9 (103.0–121.0 mm), Chinyankwazi Island, Lake Malaŵi, Africa, 1–3 m, 4 May 1991; PSU 2734, 10 (84.8–116.9 mm), Chinyankwazi Island, Lake Malaŵi, Africa, 18 June 1991; USNM 336590, 6 (95.7–117.6 mm), Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 13 March 1991; USNM 336591, 6 (85.0–117.8 mm), Chinyankwazi Island, Lake Malaŵi, Africa, 1–3 m, 6 May 1988; Malaŵi Fisheries Unit (MFU) 9, 3 (109.8–120.2 mm), Chinyamwezi Island, Lake Malaŵi, Africa, 1–3 m, 4 May 1991.

Diagnosis.—The presence of predominately tricuspid teeth on the major dentigerous areas of the jaw, with the exception of the posterior regions of the premaxilla and dentary, and the fact that the teeth are exposed when the jaws

TABLE 2. MEAN, STANDARD DEVIATION (SD), AND RANGE OF MORPHOMETRIC AND MERISTIC CHARACTERS OF TYPE SPECIMENS OF *Petrotilapia genalutea* (n = 3), *P. nigra* (n = 3), AND *P. tridentiger* (n = 3 TYPES PLUS AN ADDITIONAL 22 SPECIMENS).

	P. genalutea			*P. nigra*	
	Mean	SD	Range	Mean	SD
Standard length, mm	118.2	5.6	111.7–121.8	109.5	10.0
Head length, mm	37.5	2.3	35.3–40.0	35.6	4.0
Percent of standard length					
Head length	32.0	1.0	31.0–33.0	32.3	1.1
Snout to dorsal-fin origin	35.6	0.5	35.4–36.5	36.0	1.0
Snout to pelvic-fin origin	35.6	0.5	35.3–36.7	36.6	0.5
Pectoral-fin legnth	27.3	1.5	26.0–29.1	30.6	4.7
Pelvic-fin length	25.3	0.5	25.0–26.4	28.3	1.5
Dorsal-fin base length	60.6	2.3	58.7–62.7	61.0	2.0
Anterior dorsal to anterior anal	54.0	1.7	52.5–55.6	54.0	2.0
Posterior dorsal to posterior anal	17.0	1.7	15.7–18.3	16.6	2.0
Anterior dorsal to posterior anal	63.6	1.5	62.6–65.5	63.6	1.5
Posterior dorsal to anterior anal	32.3	2.0	30.4–34.7	31.0	1.0
Posterior dorsal to ventral caudal	17.3	0.5	17.9–18.3	16.3	1.1
Posterior anal to dorsal caudal	20.6	0.5	20.0–21.1	19.3	1.5
Anterior dorsal to pelvic-fin origin	28.6	1.1	28.1–30.2	28.6	1.1
Posterior dorsal to pelvic-fin origin	58.3	0.5	58.0–59.3	59.0	1.0
Percent of head length					
Horizontal eye diameter	28.6	1.1	28.1–30.5	28.3	1.5
Vertical eye diameter	25.3	2.0	23.4–27.0	27.6	3.0
Snout length	34.6	1.1	34.1–36.4	36.6	1.1
Postorbital head length	42.0	1.0	41.5–43.6	41.6	2.0
Preorbital depth	32.6	3.0	30.7–36.2	34.0	0.0
Lower-jaw length	32.0	2.6	29.6–34.9	33.3	1.5
Cheek depth	39.3	1.5	38.5–41.4	41.3	4.1
Head depth	114.6	4.0	111.1–119.1	113.6	11.0
Counts	Mode	% Freq.	Range	Mode	% Freq.
Lateral-line scales	32	66.7	31–32	29	33.3
Pored scales posterior to lateral line	2	66.7	1–2	1	66.7
Scale rows on cheek	4	0.0	4–4	4	100.0
Dorsal-fin spines	17	66.7	17–18	18	100.0
Dorsal-fin rays	8	0.0	8–8	8	66.7
Anal-fin spines	3	0.0	3–3	3	100.0
Anal-fin rays	6	66.7	6–7	6	66.7
Pectoral-fin rays	13	66.7	12–13	12	66.7
Pelvic-fin rays	5	0.0	5–5	5	100.0
Gillrakers on first ceratobranchial	9	33.3	8–10	9	66.7
Gillrakers on first epibranchial	3	0.0	3–3	3	100.0
Teeth in outer row of left lower jaw	16	33.3	15–23	21	66.7
Teeth rows on upper jaw	6	66.7	6–8	8	66.7
Teeth rows on lower jaw	7	66.7	7–8	9	33.3

are closed, clearly place this new species in the genus *Petrotilapia. Petrotilapia chrysos* is distinguished from *P. nigra*, *P. genalutea*, and *P. tridentiger* on the basis of coloration. In addition, *P. chrysos* is the only *Petrotilapia* species in which the some of the males are gold in color. In general, *P. chrysos* has a greater number of anal rays (mode 7; range 6–8) than *P. genalutea* (mode 6; range 6-7), *P. nigra* (mode 6; range 5–6), and *P. tridentiger* (mode 7; range 6–7) (Tables 1–2). The presence of a submarginal stripe in the dorsal fin further distinguishes *P. chrysos* from *P. tridentiger*. Cheek depth, as expressed as percent of head length, is typically much smaller in *P. chrysos* (mean 30.9; range 21–39) than in *P. genalutea* (mean 39.3; range 38–41), *P. nigra* (mean 41.3; range 38–46), and *P. tridentiger* (mean 42.6; range 35.9–49.3).

TABLE 2. EXTENDED.

P. nigra	*P. tridentiger*		
Range	Mean	SD	Range
98.1–116.7	101.3	12.5	83.1–128.2
30.9–38.0	33.7	4.0	27.5–41.6
31.2–33.8	33.3	14.7	29.9–36.5
35.1–37.0	37.2	19.0	33.2–41.3
36.2–37.3	36.5	17.0	33.3–40.9
27.0–36.6	30.1	37.9	24.0–39.7
27.4–30.9	26.8	26.8	18.8–32.3
59.0–63.4	60.3	23.7	55.9–64.6
52.0–56.2	55.6	21.6	52.8–60.6
15.2–19.6	16.4	11.8	14.2–19.2
62.8–65.4	65.9	24.3	59.8–70.4
30.1–32.7	30.4	24.3	25.8–35.2
15.0–17.1	18.2	9.8	16.4–19.9
18.3–21.7	184.4	18.1	15.4–23.8
28.2–30.6	28.9	15.7	26.0–32.1
58.4–60.6	57.0	23.0	51.1–60.8
27.4–30.9	25.5	25.5	19.9–30.3
25.5–31.6	24.7	26.8	20.2–31.2
36.3–38.6	38.0	36.3	31.1–45.2
40.7–44.8	45.4	32.4	39.4–55.9
34.5–34.3	35.2	25.2	31.1–41.4
32.7–35.4	32.0	32.0	26.3–39.2
38.3–46.7	42.6	30.8	35.9–49.3
101.2–121.4	115.5	71.2	98.3–131.9
Range	Mode	% Freq.	Range
28–33	29	48.0	27–31
1–2	1	44.0	0–2
4–4	4	92.0	3–5
18–18	17	52.0	16–20
7–8	8	84.0	7–9
3–3	3	100.0	3–3
5–6	7	84.0	6–7
12–13	13	52.0	11–13
5–5	5	100.0	5–5
8–9	10	36.0	7–11
3–3	3	64.0	2–3
18–21	19	36.0	16–2-2
8–9	8	28.0	5–10
8–10	8	36.0	7–11

Description.—Jaws isognathous (Fig. 1) and protrusible; tricuspid teeth in jaws 5–12 rows (10 rows in holotype) on the upper jaw and 6–14 rows (12 rows in holotype) on the lower jaw. Lateral scales ctenoid; holotype with 32 pored lateral-line scales, paratypes with 26–33; pored scales posterior to hypural plate 0–3 (Table 1). Holotype with four scale rows on cheek; paratypes with 3–5. Lower pharyngeal bone triangular in outline with villiform teeth (Fig. 2). Gillrakers simple, outer arch with 8–11 on ceratobranchial, 2–3 on epibranchial, and one between ceratobranchial and epibranchial. Holotype with 15 abdominal and 15 caudal vertebrae, 10 paratypes with 14–15 abdominal and 14–16 caudal vertebrae.

Lateral body coloration of territorial males blue with 7–9 black bars; belly black. Caudal fin with black rays and blue membranes; anal fin dark blue/black with 4–5 orange ocelli; pectoral fin with black rays and clear membranes; pelvic fin black with light blue leading edge; dorsal fin dark blue/black with light blue lappets. Lateral body coloration of nonterritorial males gold with blue highlights, 7–10 black bars, and a lateral and supralateral stripe. Caudal fin gold; anal fin gold with black leading edge and five orange ocelli; pectoral fin with black rays and clear membranes; pelvic fin gold with black leading edge; dorsal fin gold with submarginal black band and gold lappets. Head gold with black markings and yellow/gold gular. Females overall beige coloration with pale ocelli on anal fin.

Etymology.—The specific epithet is derived from the Greek *chrysos* meaning gold, to depict the gold coloration of the numerous nonterritorial males that can be seen in the shallows. A noun in apposition.

Life history.—*Petrotilapia chrysos* is similar to the other *Petrotilapia* species (Marsh, 1983) in that it scrapes algae from the rocks over which it lives (Fig. 3). However, it also has been observed foraging in the water column presumably on both phytoplankton and zooplankton. *Petrotilapia chrysos* is endemic to Chinyankwazi and Chinyamwezi islands in the southeast arm of Lake Malaŵi and is the only *Petrotilapia* species which inhabits these islands. Territorial males are mainly found below 3 m, whereas nonterritorial males usually are found above 3 m.

DISCUSSION

As noted by Marsh (1983), there are few morphometric or meristic characters that can be used to distinguish *Petrotilapia* species (Table 2). When the sheared second principal component of the morphometric data is plotted against the first principal component of the meristic data, *P. chrysos* is clearly distinct from the other *Petrotilapia* species (Fig 4). Size accounts for 67.6% and the second principal component accounts for 9.4% of the total variance of the sheared PCA. Variables with the highest loadings on the

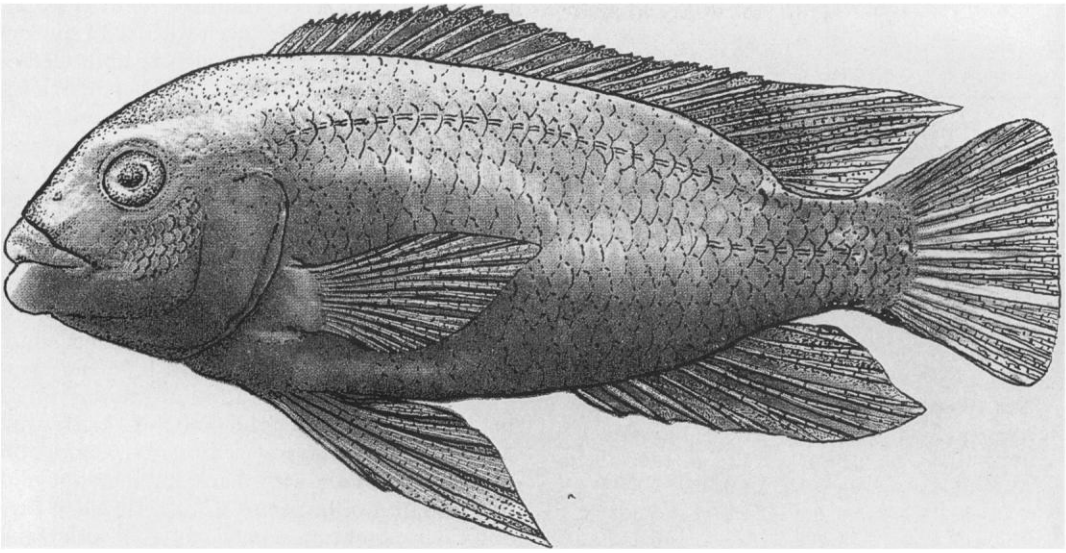

Fig. 1. Holotype of *Petrotilapia chrysos* (PSU 2726, 116.9 mm SL).

sheared second principal component in decreasing order of importance are cheek depth (0.802), preorbital depth (0.279), and snout length (0.201) (Table 3). Cheek depth, as expressed as percent of head length, is typically much smaller in *P. chrysos* (mean 30.9; range 21–39) than in *P. genalutea* (mean 39.3; range 38–41), *P. nigra* (mean 41.3; range 38–46), and *P. tridentiger* (mean 42.6; range 35.9–49.3) (Tables 1–2).

The first principal component of the meristic data explains 21.8% of the variance. Variables with the highest standardized scoring coefficients on the first principal component in decreasing order of rank are lateral-line scales (0.240), teeth rows on the lower jaw (0.229), dorsal-fin rays (0.226), number of teeth in the outer row of the left lower jaw (0.208), and gillrakers on the first epibranchial (−0.200) (Table 4). In general, *P. chrysos* has a greater number of anal rays (mode 7; range 6–8) than *P. genalutea* (mode 6; range 6–7), *P. nigra* (mode 6; range 5–6), and *P. tridentiger* (mode 7; range 6–7) (Tables 1–2).

There is more overlap among the three previously described *Petrotilapia* species than with *P. chrysos*. A MANOVA in conjunction with a Hotelling-Lawley trace demonstrated that the minimum polygon cluster formed by *P. chrysos*

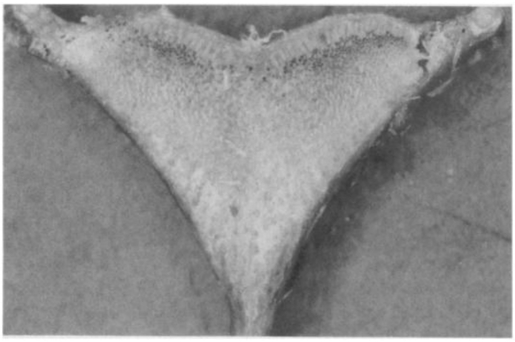

Fig. 2. Pharyngeal bone of the holotype (PSU 2726, 116.9 mm SL).

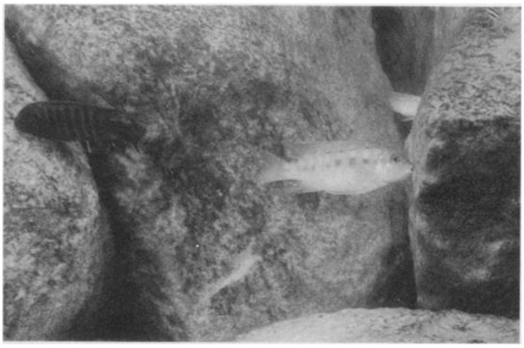

Fig. 3. *Petrotilapia chrysos* scraping algae from the rocks in Lake Malaaai, Africa.

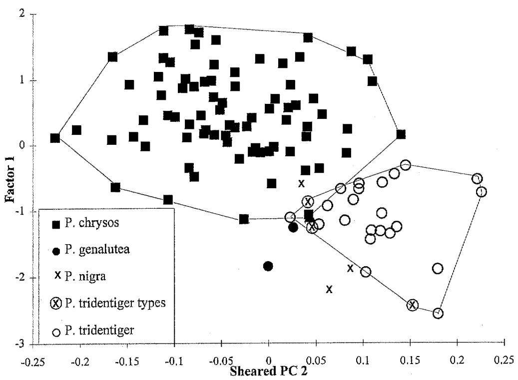

Fig. 4. Plot of the sheared second principal component of the morphometric data and first factor scores of meristic data for *Petrotilapia chrysos* (n = 78), *P. genalutea* (n = 3), *P. nigra* (n= 3), and *P. tridentiger* (n = 3 types, plus n = 22 additional fishes).

was significantly ($P < 0.05$) different from the other described *Petrotilapia* species.

The types of *P. tridentiger* from Monkey Bay grouped on the outside of the cluster formed by *P. tridentiger* specimens from Songwe Hill, Mazinzi Reef, and Crocodile Rocks (Fig. 4). Monkey Bay is the northernmost locality of the four, and it is predicted that as more specimens are collected from different localities, *P. tridentiger* will be comprised of a series of populations that show a clinal variation similar to that demonstrated for *Melanochromis heterochromis* Bowers and Stauffer (Bowers and Stauffer, 1993).

TABLE 4. STANDARDIZED SCORING COEFFICIENTS FOR PCA ON MERISTIC DATA FOR *Petrotilapia chrysos, P. genalutea, P. nigra,* AND *P. tridentiger.*

Characters	Factor 1	Factor 2
Dorsal-fin spines	0.115	−0.165
Dorsal-fin rays	0.226	0.198
Anal-fin spines	0.000	0.000
Anal-fin rays	0.184	−0.194
Pectoral-fin rays	0.168	0.076
Pelvic-fin rays	0.000	0.000
Lateral-line scales	0.240	−0.078
Pored scales posterior to lateral line	0.021	−0.149
Scale rows on cheek	0.084	0.394
Gillrakers on first ceratobranchial	0.174	0.400
Gillrakers on first epibranchial	−0.200	−0.141
Teeth in outer row of left lower jaw	0.208	−0.077
Teeth rows on upper jaw	0.156	0.266
Teeth rows on lower jaw	0.229	0.284

TABLE 3. VARIABLE LOADINGS ON SIZE AND THE SECOND SHEARED PRINICIPAL COMPONENT (SHAPE FACTOR) FOR *Petrotilapia chrysos, P. genalutea, P. nigra,* AND *P. tridentiger.*

Characters	Size	Sheared PC2
Standard length	0.184	−0.046
Head length	0.207	0.081
Lower jaw length	0.264	0.083
Snouth length	0.188	0.201
Postorbital head length	0.210	0.085
Horizontal eye diameter	0.179	−0.118
Vertical eye diameter	0.197	−0.161
Preorbital depth	0.232	0.279
Cheek depth	0.226	0.802
Head depth	0.203	−0.064
Snout to dorsal-fin origin	0.170	−0.043
Snout to pelvic-fin origin	0.196	0.065
Dorsal fin base length	0.192	−0.097
Anterior dorsal to anterior anal	0.190	−0.080
Anterior dorsal to posterior anal	0.186	−0.083
Posterior dorsal to anterior anal	0.219	−0.137
Posterior dorsal to posterior anal	0.201	−0.197
Posterior dorsal to ventral caudal	0.166	−0.067
Posterior anal to dorsal caudal	0.228	−0.171
Posterior dorsal to pelvic-fin origin	0.193	−0.124
Anterior dorsal to pelvic-fin origin	0.222	−0.084
Pectoral-fin length	0.28	−0.156
Pelvic-fin length	0.222	−0.074

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