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Weight–length relationships for twelve cichlid species from Lake Malawi, Africa

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Abstract
We report weight–length relationships for 12 species of cichlid fishes from Lake Malawi, Africa. In total, we analyzed 255 specimens, collected by SCUBA divers with gill nets and dip nets from the rocky littoral zone of Thumbi West Island at the end of the dry season. The *a* and *b* values in the weight–length relationship ($W = aL^b$) ranged from 0.003 to 0.030 and from 2.81 to 3.56, respectively. These relationships may be useful for rapid biomass estimation of this lacustrine fish community, one of the world's most diverse ichthyofauna, just by experienced divers' observation.

Keywords: Allometry, Ancient lake, Growth, Lake Nyasa/Nyassa/Niassa, Mbuna fish

1. Introduction
The weight–length (W–L) relationship has long been appreciated as an important tool for estimating weight-at-age, standing-crop biomass when only length measurements are available [1]. It has been also used for calculating body condition index and for analyzing between-region morphological and life-history disparities in fish biology and fisheries assessment [2–4]. Despite the remarkable diversity of cichlid fishes in Lake Malawi [5, 6], their W–L relationships have seldom been reported, except for a limited number of species in the pelagic zone [7, 8]. The present study reports W–L relationships of 12 cichlid species from the littoral zone of Lake Malawi, which harbors one of the most diverse lacustrine fish communities in the world.

2. Materials and Methods
Lake Malawi is one of ancient lakes along African Great Rift Valley. Fish sampling was conducted at the end of the dry season (17–20th of November, 2013) in the littoral zone of Thumbi West Island in the Lake Malawi National Park (14°01′32.73″ S, 34°49′27.78″ E). Fish were captured by SCUBA divers using dip nets and gill nets with the mesh size of 1 cm. Immediately after sampling, species identification was done according to Konings [9]; however, species names in this paper are according to Fishbase [10]. Among 32 cichlid species from 19 genera (629 specimen) caught during the four-day sampling event, 12 species were selected for analysis of W–L relationships because of their wide size ranges.
Total length was measured with a slide caliper to the nearest 0.1 cm. Wet weight was determined to the nearest g, by introducing sample fish into an improvised miniature fish aquarium (approximately 300 ml) on a digital balance. Live fish were released after the measurements at the same locations where the samples were collected.
The W–L relationship was calculated using the equation $W = aL^b$, where W is the weight in g and L the total length in cm, while a and b are constants [1]. The a and b values were determined by linear regression of the transformed equation $\log W = \log a + b \times \log L$. The model fit to the data was measured by the coefficient of the Pearson r-squared (r^2). Statistical analyses were performed using R ver. 2.12.0 software [11].

3. Results
In total, 255 specimen of 12 cichlid species belonging to 7 genera were analyzed (Table 1). The W–L relationships were statistically significant ($P < 0.01$) for all analyzed species, with r^2 values > 0.85 (Fig. 1). The a value ranged from 0.0037 to 0.0298, indicating wide interspecific variations in body shape. The b value ranged from 2.81 to 3.56.

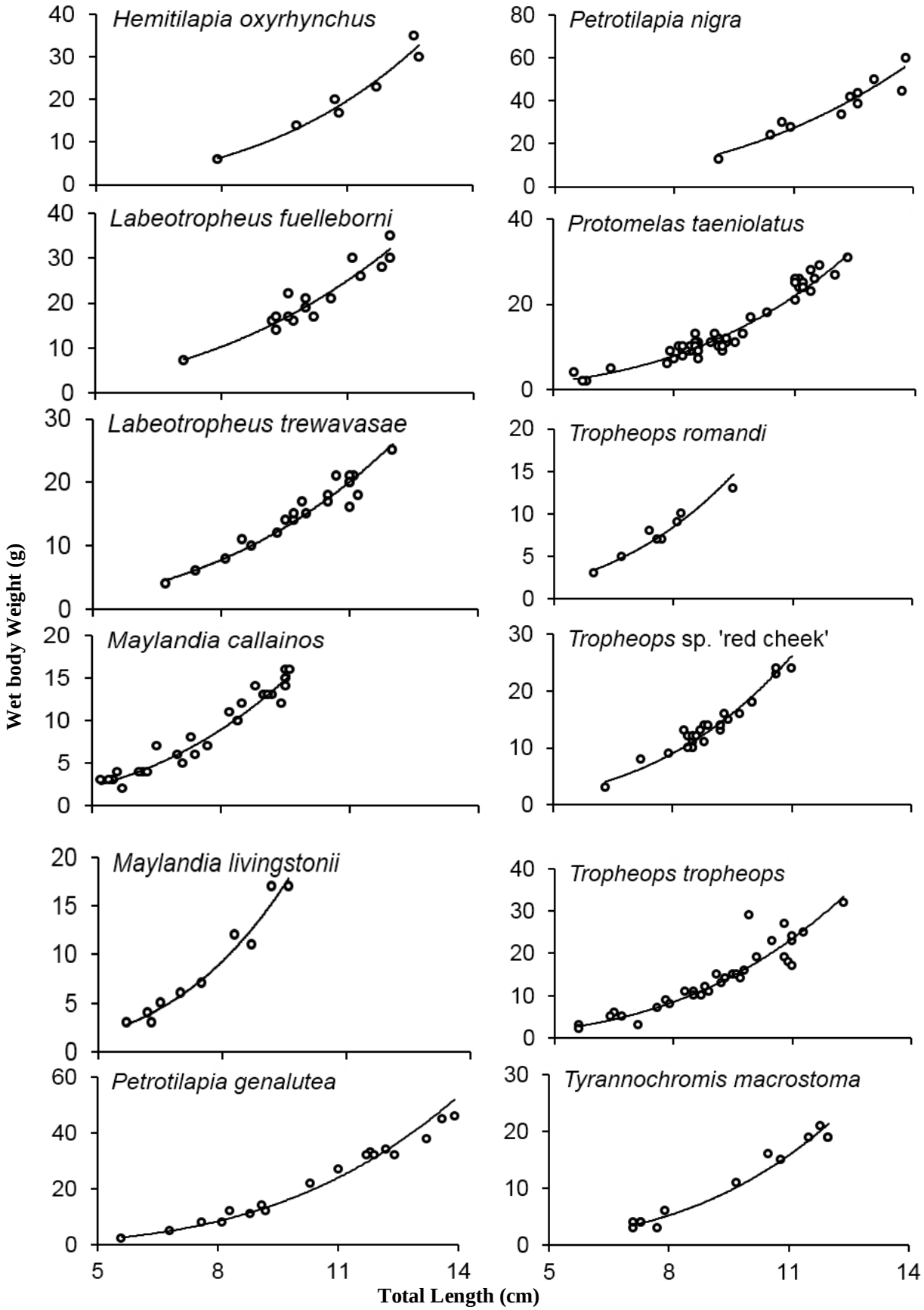

Fig 1: Relationships between wet body weight and total length of 12 cichlid species collected in Lake Malawi. Lines indicate regression curves (Table 1)

Table 1: Parameters in weight–length relationships ($W = aL^b$) of 12 cichlid species from Lake Malawi

Species name	*n*	TL (cm)	Max. TL (cm)*	*a*	*b*	r^2
Hemitilapia oxyrhyncha	7	7.9–12.7	20.0 / 20	0.0045	3.50	0.974
Labeotropheus fuelleborni	17	7.1–12.0	S30.0 / 18	0.0299	2.81	0.911
Labeotropheus trewavasae	22	6.7–12.0	11.7 / 14	0.0161	2.97	0.953
Maylandia callainos	35	5.2–9.6	S8.0 / 11	0.0212	2.89	0.919
Maylandia livingstonii	10	5.7–9.6	15.0 / 14	0.0057	3.56	0.957
Petrotilapia genalutea	18	5.6–13.9	S13.1 / 15	0.0085	3.31	0.978
Petrotilapia nigra	11	9.1–13.8	S12.2 / 14	0.0139	3.14	0.919
Protomelas taeniolatus	54	5.5–12.3	11.3 / 13	0.0106	3.18	0.924
Tropheops romandi	8	6.0–9.5	S6.3 / —	0.0114	3.18	0.934
Tropheops sp. 'red cheek'	26	6.3–11.0	— / 12	0.0157	3.06	0.851
Tropheops tropheops	34	5.6–12.3	14.0 / 14	0.0110	3.20	0.909
Tyrannochromis macrostoma	13	7.1–12.0	30.0 / 35	0.0037	3.48	0.953

n, sample size; TL, total length (min.–max.); *a*, intercept of the regression; *b*, slope of the regression; r^2, coefficient of determination. *Maximum TL is according to Fishbase [10] / Konings [19]. S indicates that standard length is only available. — indicates no length data available. All regressions were significant ($P < 0.01$).

4. Discussion

This is the first reference on W–L relationships for all the analyzed species according to Fishbase [10]. This paucity of data is likely primarily due to difficulties of species identification in these species-rich but closely-related Malawian cichlids. However, because most of these cichlid species are abundant and resident in the rocky littoral zones where they guard their feeding territories [12, 13], total length of these species could be quickly determined by experienced SCUBA divers even without catching them. Thus, biomass estimation could be done non-invasively using the W–L relationships provided by the present study.

All estimated *b* values are within the range 2.5–3.6. The number of specimens examined, the area and season in which fish samples are collected, habitat, degree of stomach fullness, gonadal maturity, sex, general fish condition as well as differences in the observed length ranges of the specimens caught may all bear on the magnitude of disparities observes in the values of *b* [3]. In the literature, *b* values outside of this range are generally considered to be erroneous [14, 15]. Although the *b* value has been sometimes analyzed to test whether the focal species has isometric or allometric growth in previous studies [15, 16], our data were not analyzed for this purpose because of their small sample sizes. Since our samples did not include small individuals primarily due to their rareness in the field, the W–L relationships of small individuals should not be extrapolated from the parameters estimated in this study. Also, since our specimens were captured in the dry season, these parameters should not be used in the rainy season, when the W–L relationships may not be identical due to different feeding rate and spawning activity [17, 18].

5. Conclusion

The weight–length relationships ($W = aL^b$) were investigated for 12 species of cichlid fishes from Lake Malawi, Africa. The *a* and *b* values ranged from 0.003 to 0.030 and from 2.81 to 3.56, respectively. These relationships may be useful for rapid biomass estimation of this lacustrine fish community just by experienced divers' observation.

p6. Acknowledgements

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