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Length–weight Relationships in Six Amphibian Species of Japan

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Abstract: Relationships between weight (W: wet or dry weights) and length (L: snout-vent length, head width, tibia length, or total length) were examined for six amphibian species of Japan. The formulae $W = a\ L^b$, expressing the relationships between those parameters, varied both among taxa and between larval and adult stages. The results suggest that researchers should make their own regressions for a target species at a given life stage in a given local environment.

Key words: Adult; Frog; Larva; Salamander; Snout-vent length

Estimates of biomass are essential for studies modeling the structure, biomass growth, and energy production and flow in ecosystems. The relationships between the whole body mass and lengths of body parts offer a useful tool to infer biomass of a given taxon from measurement data (e.g., Culver et al., 1985). In Japan, the relationships have been obtained for some freshwater animals, such as zooplankton (Kawabata and Urabe, 1998), benthic invertebrates (Genkai-Kato and Miyasaka, 2007), crabs (Miyasaka et al., 2007), and fishes (Miyasaka et al., in preparation). However, there have been no reports describing the relationships of body length to body mass in the Japanese amphibian species. In this study, we examined the relationships for six amphibian species of Japan.

Adults or larvae or both were sampled for three anuran species (*Hyla japonica*, *Rana catesbeiana*, and *R. nigromaculata*) from two rivers, Oota-gawa River and Bansawa-gawa River, in Toyota, Aichi, central Japan, in May and July 1997. Also, larvae of *R. pirica* were collected from Horonai-gawa River, Tomakomai, Hokkaido, northern Japan, in December 1992 and June 1995. Besides these, we also collected samples of two urodelan species: adults and larvae of *Hynobius retardatus* from ponds in Obihiro, Hokkaido, northern Japan, in May 1995, and larvae of *Onychodactylus japonicus* from Akashio-zawa Brook in Kiso, Nagano, central Japan, in July 2001. All samplings were made by hand with or without the aid of a hand net.

All specimens were preserved in 10% buffered formalin solution in the field. They were then identified to the species level following Uchiyama et al. (2002). Each specimen was measured for snout-vent length or head width. In addition, larvae of *R. catesbeiana* and *R. nigromaculata* were measured for total length, and adults of *H. japonica* and *R. nigromaculata* were measured for tibia length. All measurements were taken to the nearest 0.1 mm using digital calipers (Digimatic Caliper, Series No. 500, Mitsutoyo, Kawasaki, Japan). All specimens were also weighed to the nearest 0.01 g using an electronic balance (HL-100, A&D, Tokyo, Japan). Except for the larvae of *R. pirica*, *H. retardatus*, and *O. japonicus*, specimens were then dried at 60°C for 72 h, cooled in a desiccator for 24 h, and weighed again to the nearest 0.001 g using a different electronic balance (AB135-S, Mettler Toledo, Greifensee, Switzerland).

Length–weight relationships were calculated by linear regression using the formula: ln

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TABLE 1. Results of length–weight regressions ($P<0.05$ for all statistics). a, b=constants in $W=a\ L^b$. n=sample size.

Category		n		Weight (g)		Length (mm)*			Constants			
				range	x̄±SE		range	x̄±SE	a	b	r^2	P
Hylidae												
Hyla japonica	Adult	4	Wet	0.12–3.69	1.92±0.89	SVL	11.6–31.6	23.0±4.8	0.077	3.372	0.99	0.001
						HW	4.6–13.3	9.4±2.0	1.585	3.279	0.99	<0.001
						TiL	4.0–16.0	11.2±2.8	1.050	2.464	0.98	0.008
		4	Dry	0.014–0.868	0.420±0.210	SVL			0.008	4.042	0.99	0.002
						HW			0.309	3.935	0.99	<0.001
						TiL			0.189	2.962	0.99	0.007
Ranidae												
Rana catesbeiana	Larva	4	Wet	0.43–3.73	2.11±0.91	SVL	14.3–28.5	21.5±3.7	0.142	3.176	0.99	0.002
						HW	8.1–18.0	13.2±2.5	0.751	2.808	0.99	0.001
						TL	30.9–65.7	48.9±9.4	0.018	2.834	0.99	0.001
		4	Dry	0.028–0.238	0.140±0.054	SVL			0.013	2.822	0.95	0.026
						HW			0.058	2.518	0.97	0.016
						TL			0.002	2.504	0.94	0.03
Rana nigromaculata	Larva	6	Wet	0.04–1.58	0.55±0.28	SVL	6.3–19.6	12.2±2.3	0.179	3.136	0.99	<0.001
						HW	4.0–12.6	7.7±1.5	0.762	3.009	0.99	<0.001
						TL	17.4–51.4	30.6±5.3	0.007	3.414	0.98	<0.001
		6	Dry	0.004–0.148	0.050±0.024	SVL			0.018	2.503	0.70	0.038
						HW			0.061	2.515	0.77	0.022
						TL			0.001	2.882	0.77	0.022
	Adult	9	Wet	2.67–64.00	24.10±6.64	SVL	28.7–80.2	55.3±5.3	0.080	3.196	0.99	<0.001
						HW	9.7–25.7	18.9±1.7	2.439	3.207	0.97	<0.001
						TiL	13.3–39.7	27.6±2.9	1.004	2.897	0.98	<0.001
		9	Dry	0.312–15.800	4.490±1.579	SVL			0.007	3.580	0.98	<0.001
						HW			0.332	3.542	0.93	<0.001
						TiL			0.120	3.238	0.97	<0.001
Rana pirica	Larva	38	Wet	0.02–0.04	0.03±0.00	SVL	5.0–6.0	5.4±0.0	0.050	0.833	0.16	0.012
						HW	3.1–3.8	3.5±0.0	0.110	1.227	0.34	<0.001
Hynobiidae												
Hynobius retardatus	Larva	153	Wet	0.10–1.70	0.56±0.02	SVL	12.8–31.5	20.3±0.3	0.123	2.085	0.77	<0.001
						HW	4.5–10.5	7.2±0.1	1.005	1.893	0.61	<0.001
	Adult	121	Wet	0.26–12.00	1.07±0.19	SVL	21.7–80.0	29.1±1.0	0.033	2.860	0.98	<0.001
						HW	5.2–15.0	6.9±0.2	2.587	3.726	0.95	<0.001
		8	Dry	1.120–2.444	1.700±0.168	SVL	64.7–80.0	70.4±1.7	0.001	3.756	0.74	0.006
Onychodactylus japonicus	Larva	22	Wet	0.10–1.10	0.40±0.06	SVL	18.4–31.3	22.0±0.8	0.025	3.360	0.79	<0.001

* Abbreviations are: SVL, snout-vent length; HW, head width; TiL, tibia length; TL, total length.

$W=\ln a+b \ln L$, where W was the wet or dry weight and L was the snout-vent length, head width, tibia length or total length. All correlation coefficients were significant at the $P<0.05$ level. The b value in the above formula represents the rate of increase (i.e., slope) of the weight against the length, whereas the a value represents the weight of an organism at a unit length (i.e., 1 mm). Thus, a is less important as a measure of length–weight relationships (Genkai-Kato and Miyasaka, 2007).

The relationships of the wet weight with a length measure (snout-vent length, head width, tibia length, or total length) in the six species of amphibians and of the dry weight with a length measure in four species are shown in Table 1.

Relationships in adults were obtained for three species and in larvae for five species, respectively.

Coefficients of determination (r^2) in the relationships between weight and length for frogs were high (0.70–0.99), except for *R. pirica*. Kishida and Nishimura (2004) showed that tadpoles of *R. pirica* exhibited a bulgy bodied morphology when threatened by the gape-limited salamander predators. The low values of r^2 for *R. pirica* larvae (SVL: 0.16; HW: 0.34) may therefore be attributable to the predator-induced variation. Otherwise, frogs had almost cubic length–weight relationships (b≈3).

Coefficients of determination for salamanders tended to be higher for adults (0.74–0.98) than for larvae (0.61–0.79). In general, the r^2 values for larval salamanders were also lower than those for larval frogs. This is probably due to cannibalism-related head shape variation commonly observed in many salamanders (e.g., Pfennig et al., 1991; Kohmatsu et al., 2001). Variation in b values for salamanders was high, and this also seems to be attributable to the variation in head shape.

We also obtained ratios of dry weight to wet weight for *H. japonica* adults (median (range); 19.4% (11.5–23.5)), *R. nigromaculata* adults (15.4% (11.7–24.7)), *H. retardatus* adults (19.6% (17.9–21.3)), *R. catesbeiana* larvae (6.6% (6.1–10.5)), and *R. nigromaculata* larvae (9.6%(3.4–31.8)). Larval stages of these organisms tended to contain more water in the body (i.e., lower dry/wet weight) than adults. This difference in water content in the body may be related to their contrasting habitat and related physiological traits (i.e., aquatic habitats with gills in the larval stage vs. terrestrial habitats with lungs in the adult stage). Our results indicate that for amphibians, researchers should devise their own regressions for a target species at a given life stage (adult or larva) in a given environment (e.g., predator present/absent), because of the peculiar biological characteristics of this group of organisms, such as the presence of metamorphosis in growth and phenotypic polyphenisms (Kohmatsu et al., 2001; Kishida and Nishimura, 2004; Takahara et al., 2006).

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