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Length–weight relationships of four predatory stonefly species in Japan

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Abstract Estimates of biomass are essential for studies modeling the structure, animal growth, production, and energy flow in ecosystems. The relationships between dry weight and head capsule width or body length in summer and winter were examined for four species of predatory stonefly (Perlidae) nymphs in Japan. There were some variations in regression constants between seasons and species. However, the distribution of length–weight plots did not show marked differences between species or season. Our results suggest that length–weight relationship data, regardless of season or including multiple species, are also valid for estimation of dry weight when the target species are classified into the same taxonomic family.

Key words Body length · Dry weight · Head capsule width · Perlidae · Stonefly

Introduction

Estimates of biomass are essential for studies modeling structure, animal growth, production, and energy flow in ecosystems. The relationship between body mass and length is a useful tool in ecological research, because indirect estimation of mass from a length of an organism's body is considerably easier than direct measurement of dry mass. In addition, small invertebrate samples are often fixed with chemical preservatives, which can cause alterations of their dry mass (Johnston and Cunjak 1999). In this article, the relationships between dry mass and body length or head capsule width in summer and winter were examined for four species of predatory stonefly nymphs (Perlidae) in Japan: *Oyamia lugubris* McLachlan, *Paragnetina tinctipennis* McLachlan, *Kamimuria tibialis* Pictet, and *Kamimuria uenoi* Kohno.

Methods

Surveys were conducted in the Kuro-kawa River (35°53′ N, 137°40′ E; 840 m above sea level) in Kiso, Nagano Prefecture, Japan, in summer (July 20–August 4, 2001) and winter (December 17–25, 2001). A detailed description of the study area is presented by Genkai-Kato et al. (2005). Water temperature in the study area ranges from 2°C in winter to 19°C in summer (Miyasaka and Genkai-Kato, unpublished data). Stonefly nymphs were collected using a quadrat net (20 × 20 cm, 1.9-mm mesh) from riffle habitats in the study area.

Live stonefly nymphs were transported in cool water to the laboratory within 3 h after collection. Individual nymphs, which were placed in a transparent plastic bag (Unipack, A-4: 70 × 50 × 0.04 mm; Seinichi, Tokyo, Japan) to reduce movement of the nymph by means of slippery inner surface of the bag, were measured for head capsule width and body length to the nearest 0.1 mm using a digital caliper (Digimatic Caliper, series no. 500; Mitsutoyo, Kawasaki, Japan). All nymphs were then preserved in a freezer until later measurement of dry mass. Individual samples were dried at 60°C for 24 h, cooled in a desiccator, and weighted to the nearest 0.1 mg using an electronic balance (AB135-S; Mettler Toledo, Greifensee, Switzerland). Length–weight relationships (a and b values) were calculated by linear regression using the formula $\ln W = \ln a + b \ln L$, where W was dry weight and L was head capsule width or body length.

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Table 1. Results of length–weight regressions

Taxon Season	*a*	*b*	r^2	*P*	*n*	Length range (mm)	Weight range (mg)
Length: head capsule width (mm)							
Oyamia lugubris							
Summer	0.327	2.960	0.90	<0.001	60	1.99–6.23	2.4–67.9
Winter	0.184	3.387	0.96	<0.001	44	2.56–7.49	2.8–199.4
Year average	0.225	3.242	0.94	<0.001	104	1.99–7.49	2.4–199.4
Paragnetina tinctipennis							
Summer	0.313	3.297	0.93	<0.001	36	2.26–7.17	5.3–244.4
Winter	0.425	3.099	0.46	0.015	12	3.60–5.61	15.5–79.2
Year average	0.326	3.274	0.89	<0.001	48	2.26–7.17	5.3–244.4
Kamimuria tibialis							
Summer	0.0918	4.153	0.69	<0.001	20	3.17–4.34	6.3–41.7
Winter	0.4520	2.875	0.72	<0.001	29	3.25–5.51	14.0–73.0
Year average	0.4098	2.975	0.69	<0.001	49	3.17–5.51	6.3–73.0
Kamimuria uenoi							
Summer	0.0289	4.701	0.61	0.038	7	3.83–4.79	13.6–53.6
Winter	0.2000	3.472	0.80	<0.001	36	3.14–5.10	8.1–64.5
Year average	0.2017	3.449	0.76	<0.001	43	3.14–5.10	8.1–64.5
Kamimuria (two species)							
Summer	0.1738	3.616	0.60	<0.001	27	3.17–4.79	6.3–53.6
Winter	0.3106	3.140	0.78	<0.001	65	3.14–5.51	8.1–73.0
Year average	0.2945	3.194	0.73	<0.001	92	3.14–5.51	6.3–73.0
Perlidae (four species)							
Summer	0.236	3.318	0.86	<0.001	123	1.99–7.17	2.4–244.4
Winter	0.332	3.089	0.89	<0.001	121	2.56–7.49	3.8–199.4
Year average	0.202	3.449	0.76	<0.001	244	1.99–7.49	2.4–244.4
Length: body length (mm)							
Oyamia lugubris							
Summer	0.0196	2.453	0.84	<0.001	60	7.45–29.71	2.4–67.9
Winter	0.0031	3.228	0.98	<0.001	44	8.95–30.64	3.8–199.4
Year average	0.0048	3.008	0.86	<0.001	104	7.45–30.64	2.4–199.4
Paragnetina tinctipennis							
Summer	0.0142	2.712	0.93	<0.001	36	9.62–37.32	5.3–244.4
Winter	0.0045	3.133	0.89	<0.001	12	12.82–21.32	15.5–79.2
Year average	0.0144	2.714	0.92	<0.001	48	9.62–37.32	5.3–244.4
Kamimuria tibialis							
Summer	0.0269	2.361	0.68	<0.001	20	12.26–24.61	6.3–41.7
Winter	0.0023	3.313	0.71	<0.001	29	13.72–22.38	14.0–73.0
Year average	0.0093	2.785	0.65	<0.001	49	12.26–24.61	6.3–73.0
Kamimuria uenoi							
Summer	0.0027	3.232	0.74	0.014	7	13.88–19.59	13.6–53.6
Winter	0.0574	2.149	0.78	<0.001	36	11.49–23.21	8.1–64.5
Year average	0.0467	2.223	0.76	<0.001	43	11.49–23.21	8.1–64.5
Kamimuria (two species)							
Summer	0.0209	2.466	0.67	<0.001	27	12.26–24.61	6.3–53.6
Winter	0.0249	2.463	0.74	<0.001	65	11.49–23.21	8.1–73.0
Year average	0.0257	2.434	0.70	<0.001	92	11.49–24.61	6.3–73.0
Perlidae (four species)							
Summer	0.009	2.770	0.85	<0.001	123	7.45–37.32	2.4–244.4
Winter	0.005	3.055	0.90	<0.001	121	8.95–30.64	3.8–199.4
Year average	0.0077	2.865	0.85	<0.001	244	7.45–37.32	2.4–244.4

a, b = constants in $W = a\,L^b$, where W and L correspond to weight and length, respectively

Results and discussion

We obtained head capsule width–dry weight and body length–dry weight relationships for four Perlidae stonefly species (Table 1). The relationships were expressed as summer data, winter data, and data averaged over the year.

There was considerable variation in the regression constant a, compared with variation in b. The b values of *K. tibialis* and *K. uenoi* showed greater seasonal variations than those of *Oyamia* and *Paragnetina*. In practice, b values represent the rate of increase (i.e., slope) of dry weight against length in log-transformed relationship (i.e., $\ln W = \ln a + b \ln L$), whereas the constant a only represents the dry mass of an organism at a unit length (i.e., 1 mm). Thus, a is

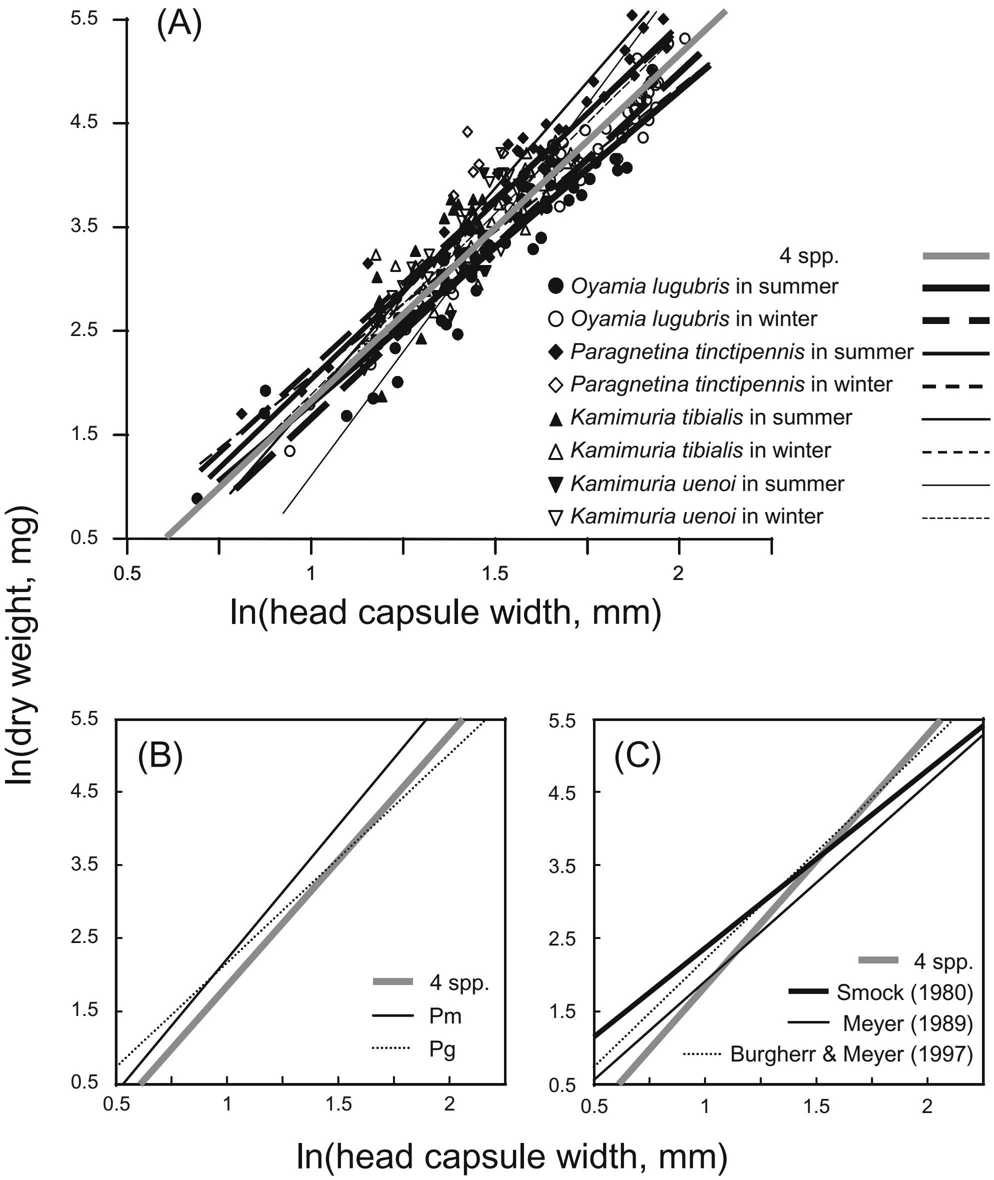

Fig. 1. Relationships between dry weight and head capsule width. **A** Plots and regression lines of all individuals including four Perlidae species collected both in summer and in winter in the present study. **B** Comparison of regression lines between the present study and other Perlidae species. *Pm* and *Pg* represent *Perla marginata* from Meyer (1989) and *Perla grandis* from Burgherr and Meyer (1997), respectively. **C** Comparison between the line for four Perlidae species in this study and lines for the order Plecoptera reported in other literature. The *thick line in gray* (indicated as "4 spp." on each panel) was obtained from all individual data, including four species in summer and winter

less important as a measure of the length–weight relationships. Although we found some variations in *a* and *b* (Table 1), regressions of four species took similar lines in both relationships between head capsule width and dry weight (Fig. 1A) and between body length and dry weight (Fig. 2A), except for head capsule width of *Kamimuria* species in summer (Fig. 1A). However, the distributions of *K. tibialis* and *K. uenoi* in summer scattered within intermediate ranges of head capsule width (i.e., 1.15–1.47 and 1.34–1.57, respectively, on the log-transformed *x*-axis in Fig. 1A). Overall, plots of our Perlidae species fit well on the regression line obtained for all four species (lines "4 spp." in Figs. 1A and 2A).

In both relationships of dry weight with head capsule width (Fig. 1B) and with body length (Fig. 2B), our regression lines of all four species had similar slopes to other Perlidae species in North America (Smock 1980) and Europe (Meyer 1989; Burgherr and Meyer 1997). Furthermore, they were not so different even from the lines of the order Plecoptera in the literature (Figs. 1C, 2C).

For estimating dry weight of a species in a season, application of the length–weight relationship of the species in the season is certainly the best way. However, the distributions of most length–weight plots in Figs. 1 and 2 did not show marked differences between species or seasons, in spite of some variations in regression constants between species and seasons (Table 1). Our results suggest that length–weight relationships including multiple species can be used for estimation of stonefly dry weight regardless of season.

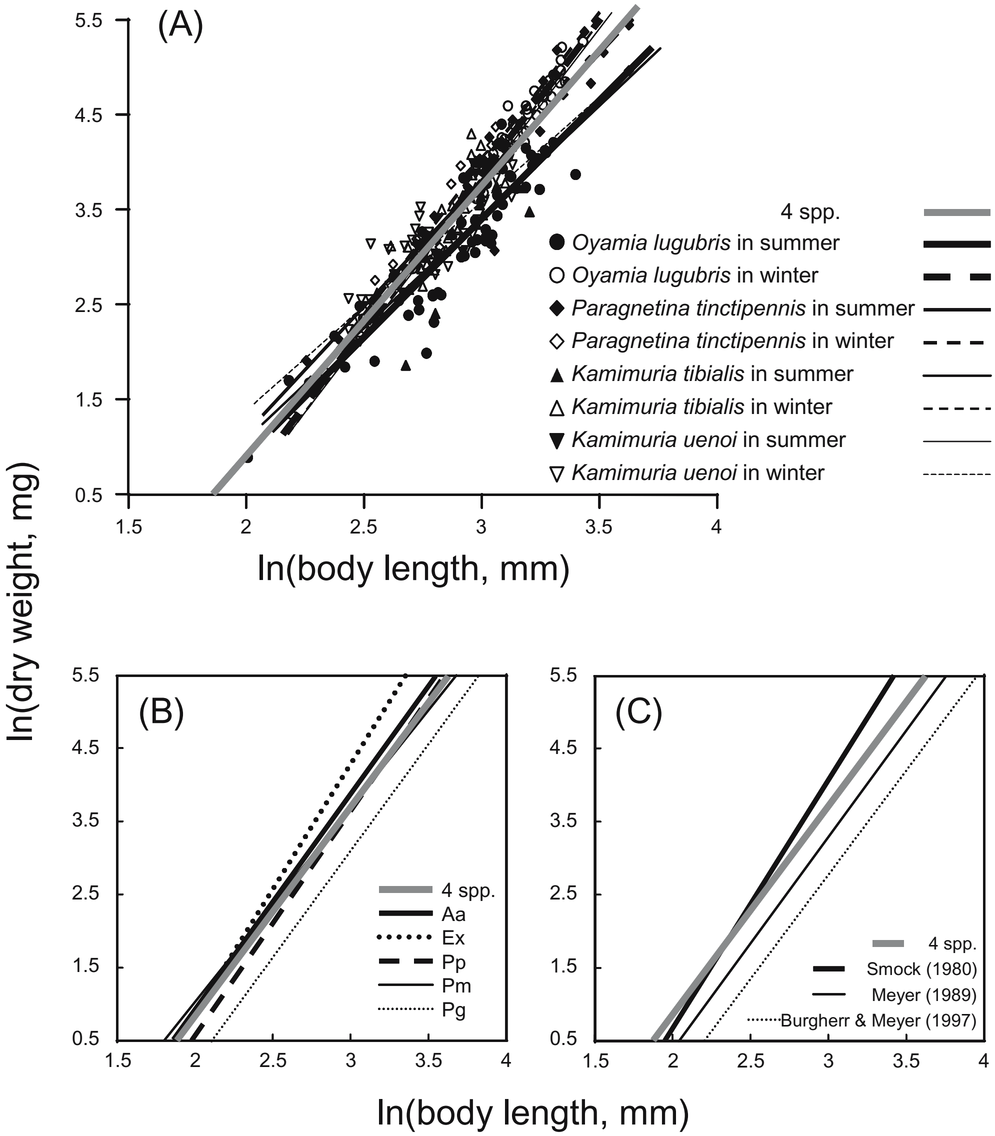

Fig. 2. Relationships between dry weight and body length. **A** Plots and regression lines of all individuals including four Perlidae species collected in both summer and winter in the present study. **B** Comparison of regression lines between the present study and other Perlidae species. *Aa*, *Acroneuria abnormis*; *Ex*, *Eccoptura xanthenes*; *Pp*, *Perlesta placida* (Smock 1980); *Pm*, *Perla marginata* (Meyer 1989); *Pg*, *Perla grandis* (Burgherr and Meyer 1997). **C** Comparison between our Perlidae regression and lines for the order Plecoptera reported in the literature. The *thick line in gray* (indicated as "4 spp." on each panel) was obtained from all individual data including four species in summer and winter

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