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WEIGHT-LENGTH REGRESSIONS IN AQUATIC PREY OF CUBAN WADING BIRDS

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Abstract: Weight-length regressions are a useful tool to estimate biomass from linear measurements of fragments of prey obtained from stomach or regurgitated contents of nestling birds. Here we present 68 equations to estimate wet and dry weight in 16 groups of aquatic prey collected from diet samples of wading birds in Cuban wetlands. In 48 cases the correlation coefficient (*r*) was higher than 0.80 and in only four cases statistical significance was not reached.
Key words: biomass, energy estimation, prey, wading birds, weight-length regression

Resumen: REGRESIONES PESO–LONGITUD EN LAS PRESAS ACUÁTICAS DE AVES VADEADORAS CUBANAS. Las regresiones entre el peso y las longitudes son herramientas útiles para estimar la biomasa a partir de mediciones lineales de estructuras corporales de presas obtenidas en los contenidos estomacales o regúrgitos de pichones. En este trabajo se presentan 68 ecuaciones que pueden ser utilizadas para estimar el peso seco y húmedo en 16 grupos de presas acuáticas encontradas en muestras de alimentación de aves acuáticas en humedales cubanos. En 48 de las regresiones los coeficientes de regresión (*r*) fueron superiores a 0,80 y solo cuatro variables no alcanzaron significación estadística.
Palabras clave: aves acuáticas, biomasa, estimaciones energéticas, presas, regresión de peso-longitud

Résumé : LES RELATIONS POIDS-LONGUEUR CHEZ LES PROIES AQUATIQUES DES OISEAUX D'EAU DE CUBA. Les relations poids-longueur sont utiles pour estimer la biomasse à partir de mesures linéaires de fragments de proies issues de contenus stomacaux ou de régurgitats d'oisillons. Nous présentons ici 68 équations permettant d'estimer le poids humide et sec de 16 groupes de proies aquatiques d'échassiers des zones humides cubaines. Dans 48 cas, le coefficient de corrélation (*r*) est supérieur à 0,80 et dans quatre cas seulement la corrélation n'est pas significative.
Mots clés : biomasse, estimation des ressources energétiques, oiseaux d'eau, relation poids-longueur

Weight-length regression provides a useful tool in estimating biomass and energy of prey consumed by predators. Bioenergetics studies of waterbirds have focused mainly on ecosystem functioning (Kushlan 1977a, Rodgers and Nesbitt 1979, Morales and Pacheco 1986, Morales *et al.* 1981) or nestling growth (Kushlan 1977b, Bennett *et al.* 1995, Kahl 1962), but many involve food analysis using stomach contents or food boluses regurgitated by nestlings. In these cases it is usual to find many triturated or semi-digested pieces of prey from which estimation of total consumed biomass is difficult and often underestimated. Some authors have developed tables and equations to estimate this biomass (Rogers *et al.* 1976, 1977, Schoener 1980), but they have limited uses in different latitudes or ecosystems due to the strong relationship between productivity and taxonomic differences with mean prey mass.

In Cuba, the diets of wading birds have been relatively well studied (e.g., Acosta *et al.* 1990, Torres *et al.* 1985, Denis *et al.* 2000, Mugica *et al.* 2005) and an attempt has been made to study the energetics of aquatic bird guilds in rice agroecosystems (Mugica 2001). Because of the potential value of these tools in future studies, we have assembled in this paper data obtained in Cuban wetlands on the sizes and energy content of prey obtained by wading birds, which can be used in bioenergetics studies. Here we present regression equations to estimate both wet and dry mass of the main prey items of wading birds by using several linear measures from the body or structures more resistant to digestion. These results may be used in Cuba and other Caribbean islands with similar wetland conditions.

METHODS

All prey used in this study were collected from the gut contents of several species of wading birds and from boluses regurgitated by nestlings in the Sur del Jíbaro rice fields and from colonies in Birama Swamp, Cuba, between 1996 and 2001. The birds were collected for diet analysis (Mugica 2001, Mugica *et al.* 2005) and morphometric studies (Acosta *et al.* 2002, 2003). Samples were preserved in 70% alcohol for transportation to the laboratory.

Table 1. Sample sizes and linear measurements in addition to total length and weight of prey consumed by waterbirds, used to obtain regression equations to estimate biomass and energy content.

			Thorax or Cephalothorax	
Order or Family (Stage of Life Cycle)	*n*	Head Width	Width	Length
Anura (larvae)	20			
Anura (adults)	15	X		
Arachnidae: Araneae	80		X	X
Blattoptera: Blattidae	30		X	
Coleoptera (larvae)	12	X	X	
Coleoptera (adults)	13	X	X	
Decapoda	79		X	X
Hemiptera	73	X	X	X
Lepidoptera (larvae)	42	X		
Lepidoptera (adults)	36		X	
Odonata (larvae)	24			
Odonata (adults)	31		X	
Orthoptera: Gryllidae	52	X	X	X
Orthoptera: Tettigonidae	40	X	X	X
Orthoptera: Others	4	X	X	X
Osteichthyes: Gambusidae	43	X[a]		
Osteichthyes: Cichlidae	64	X[a]		

[a]Length and height at operculum

Biases due to the dehydration of samples in the preservation liquid are assumed to be less than 10% of fresh weight.

We used 569 items not altered significantly by digestion; however, we assume a small underestimation of wet weights. Prey were identified up to the taxonomic level of family or order. For each prey item, wet and dry weights, total lengths, and some additional variables were measured (Table 1). Additional measurements to those presented in Table 1 were taken for some groups, including quela length in crayfishes, femur length in crickets, elytra length in beetles, and length of the labrum in dragonfly larvae (family Aeshnidae). These are fragments frequently found in diet samples.

All measurements were taken with Mitutoyo electronic calipers and weights with an electronic precision of 0.001 mm and balance of 0.0001 g, respectively.

RESULTS AND DISCUSSION

Insects of the order Hemiptera (various bugs) belonged mainly to the families Belostomatidae (giant water bugs), Gerridae (water striders), and Notonectidae (backswimmers). The sample from order Coleoptera (beetles) included the families Carabidae (ground beetles), Cicindelidae (tiger beetles), Curculionidae (snout beetles), and Dytiscidae (diving beetles). Families Gryllidae (true crickets) and Tettigonidae (katydids) of order Orthoptera (various hopping insects) were treated separately due to their strong differences. The equations obtained are show in Table 2.

The best variable to estimate wet weight in orders Hemiptera, Lepidoptera (butterflies, and moths), and Arachnida (spiders) was total length. Thorax width was the best for orders Blatoptera (cockroaches, mantises, and termites) and all Orthoptera. In Gryllidae, the measurement of thorax is the best weight estimator followed by femur length. In Tettigonidae, thorax length is the best weight estimator. The remaining regressions were weaker. In Osteichthyes (bony fishes), head height at operculum and total length were the best estimators of wet weight.

The water content of invertebrates averaged 74.2% (95% CI = 72.7-75.6%). Vertebrates contained slightly more water, averaging 76.2% (95% CI = 74.6-77.8 %).

These equations may be used in all prey not larger than the maximum length stated in the table.

Table 2. Regression equations to estimate individual biomass of prey of wading birds in wetlands of Cuba. A = adults; Bp = bucal piece; DW = dry weight; EL = elytra length; FL = femur length; HH = head height; HW = head width; L = larvae; QL = quela length; TL = total length; T×L = thorax or cephalothorax length; T×W = thorax or cephalothorax width; WW = wet weight; * = no statistical significance.

Order or Family	Regression Equation	*r*	*n*	Water Content (%)	Max. Prey Size (TL)
Odonata (L)	DW = 0.0014 + 0.1764 * WW	0.926	27	80.1 ± 2.3	23.8
	WW = -0.3033 + 0.0938 * HW	0.901	35		
	WW = -0.2671 + 0.0268 * TL	0.771	41		
	WW = -0.2334 + 0.0611 * BP	0.797	14		
Hemiptera	DW = 0.0118 + 0.1657 * WW	0.639	60	73.0 ± 4.6	21.2
	WW = -0.2022 + 0.0215 * TL	0.864	39		
	WW = -0.4021 + 0.1443 * HW	0.660	55		
	WW = -0.4262 + 0.2096 * T×L	0.998	3		
	WW = -0.5433 + 0.1178 * T×W	0.711	49		
Blattoptera	DW = 0.0127 + 0.1147 * WW	0.617	19	73.8 ± 4.6	23.0
	WW = -0.3442 + 0.0956 * T×W	0.852	30		
Coleoptera	DW = 0.0042 + 0.2949 * WW	0.998	5	72.1 ± 2.6	50.6
	DW_L= -0.0019 + 0.2190 * WW_L	0.993	6		
	WW = -0.1655 + 0.0117 * TL	0.855	15		
	WW = -0.1375 + 0.0991 * HW	0.849	11		
	WW = -0.3442 + 0.0633 * EL	0.951	8		
	WW = -0.1721 + 0.0692 * T×W	0.887	5		
Lepidoptera	DW_L= -0.0010 + 0.2234 * WW_L	0.994	23	82.4 ± 1.1	81.4 (L)
	WW_L= -2.1670 + 0.0787 * TL_L	0.952	38		45.1 (A)
	WW_L= -2.7830 + 1.2393 * HW_L	0.955	37		
	DW_A= 0.0081 + 0.1107 * WW_A	0.749	31		
	WW = -0.1018 + 0.0116 * TL_A	0.871	33		
Orthoptera	DW = -0.0034 + 0.2472 * WW	0.886	73	75.5 ± 1.2	38.2
	WW = -0.0905 + 0.0175 * TL	0.714	46		
	WW = -0.2873 + 0.1535 * HW	0.877	72		
	WW = -0.2304 + 0.1333 * T×L	0.582*	36		
	WW = -0.1268 + 0.0422 * FL	0.458*	69		
	WW = -0.4084 + 0.1641 * T×W	0.960	42		
Family Gryllidae	DW = -0.0065 + 0.2505 * WW	0.846	41	76.4 ± 1.4	24.7
	WW = -0.1503 + 0.0283 * TL	0.851	15		
	WW = -0.4885 + 0.1883 * HW	0.910	40		
	WW = -2.0050 + 0.6328 * T×L	0.990	19		
	WW = -0.7170 + 0.1071 * FL	0.937	41		
	WW = -0.5348 + 0.1844 * T×W	0.946	33		
Family Tettigonidae	DW = 0.0146 + 0.1440 * WW	0.777	27	74.4 ± 2.2	38.2
	WW = -0.2417 + 0.0220 * TL	0.888	31		
	WW = -0.2482 + 0.1433 * HW	0.666	28		
	WW = -0.1995 + 0.0952 * T×L	0.858	19		
	WW = -0.2665 + 0.0343 * FL	0.742	21		
	WW = -0.1106 + 0.0736 * T×W	0.288*	7		

Table 2 continued.

Order or Family	Regression Equation	*r*	*n*	Water Content (%)	Max. Prey Size (TL)
Arachnida	DW = 0.0074 + 0.2280 * WW	0.924	66	62.6 ± 2.6	17.2
	WW = -0.4138 + 0.0510 * TL	0.808	40		
	WW = -0.2330 + 0.0723 * TL	0.665*	47		
	WW = -0.0032 + 0.0182 * T×W	0.699	54		
Decapoda	DW = 0.0191 + 0.2014 * WW	0.975	77	78.0 ± 0.6	52.0
	WW = -1.3750 + 0.0774 * TL	0.871	47		
	WW = -0.9395 + 0.1148 * T×L	0.679*	37		
	WW = -0.8360 + 0.2241 * T×W	0.872	36		
	WW = -0.2196 + 0.1044 * QL	0.781	41		
Osteichthyes	DW = -0.0054 + 0.2711 * WW	0.952	61	75.6 ± 0.9	42.8
	WW = -1.0820 + 0.0670 * TL	0.890	100		
	WW = -2.3170 + 0.6137 * HH	0.922	36		
	WW = -0.9060 + 0.1743 * LCab	0.908	88		
Family Cichlidae	DW = -0.0053 + 0.2687 * WW	0.949	38	76.5 ± 1.3	42.8
	WW = -1.1020 + 0.0735 * TL	0.940	60		
	WW = -1.9330 + 0.5592 * HH	0.922	25		
	WW = -0.8456 + 0.1645 * LCab	0.926	49		
Family Gambusidae	DW = -0.0063 + 0.2768 * WW	0.958	23	74.2 ± 1.4	42.4
	WW = -0.9233 + 0.0528 * TL	0.922	40		
	WW = -3.5760 + 0.7959 * HH	0.980	11		
	WW = -1.5030 + 0.2510 * LCab	0.910	39		
Amphibia, Anura	$DW_L = -0.0046 + 0.2922 * WW_L$	0.945	8	78.0 ± 1.5	15.3 (L)
	$DW_L = -0.0297 + 0.0055 * TL_L$	0.801	8		60.2 (A)
	DW = -0.1069 + 0.3734 * WW	0.982	13		
	WW = -0.6503 + 0.0735 * TL	0.701	8		
	WW = -1.5920 + 0.2842 * HW	0.948	8		

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