Russian Entomol. J. 13(3): 107–113

Relationship between head capsule length and body length in some Svalbard species of Collembola

Соотношение между длиной головной капсулы и длиной тела у некоторых видов ногохвосток архипелага Свальбард

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KEY WORDS: Collembola; Svalbard; body length; head capsule length

КЛЮЧЕВЫЕ СЛОВА: ногохвостки; Свальбард; длина тела; длина головной капсулы

ABSTRACT. Body length (*L*) and head capsule length (*h*) in 12 common species of Svalbard Collembola were measured, and *h*/*L* ratios calculated. For all the species studied, *h*/*L* relationships could be approximated by linear regressions, which could be used for calculations of individual body weight and related parameters, and analyses of species population structure.

РЕЗЮМЕ. Проведены измерения длины тела (*L*) и длины головной капсулы (*h*) у 12 обычных видов ногохвосток архипелага Свальбард и рассчитаны отношения *h*/*L*. Для всех изученных видов связь между этими показателями аппроксимируется линейной регрессией, что может быть использовано для расчетов индивидуального веса тела и связанных с ним параметров, и анализа структуры популяции изученных видов.

Introduction

Morphometric information on Collembola and other microarthropods had been intensively collected and widely used in the times of IBP for various structural and functional comparisons of species and populations [e.g. Petersen, 1995; Persson & Lohm, 1977; Petersen & Luxton, 1982]. For studies analysing population structure, demography and productivity of springtail species, knowledge of morphometric parameters (like body or head capsule length) and interrelationships between them, individual biomass and metabolic processes is crucial for necessary calculations and treatment of mass materials obtained [Hale, 1966; Healey, 1967; Persson & Lohm, 1977; Uvarov, 1994]. However, only small number of collembolan species are so far investigated in this respect [Petersen, 1975; Uvarov, 1987]. It was shown [op. cit.] that head capsule length (*h*) and body length (*L*) are linearly related and therefore *h* (being easier to measure than *L*) may be used as the basic morphometric parameter.

Various studies on population strategies, demography, reactions to site conditions and migrations have been recently performed for abundant collembolan species on Svalbard [Hertzberg, 1997; Birkemoe & Sømme, 1998; Hertzberg & Leinaas, 1998; Hertzberg et al., 2000; and others]. In contrast, few investigations were aimed at participance of Collembola in Svalbard ecosystem functioning [Byzova et al., 1995]. Morphometric relationships may be a useful tool for interconnection of these research fields. Extensive morphometric data have been collected for the functionally most important species dominating the main type of Svalbard ecosystems, and the type of *h*/*L* relationship is investigated in the present work.

Materials and Methods

Collembolans were collected at three tundra sites typical for the seashore plain of the southern exposition on the northern coast of Hornsund Bay, southern Spitsbergen, during the snowless season of 1989 [Byzova et al., 1995]. Study area was situated in the vicinity of Polish Polar Station and belonged to the southern watershed of Ariekamen – Fugleberget mountain system. Map and description of the study area were presented in Klekowski & Opaliński [1992]. The sites studied were characterised in detail by Byzova et al. [1995], here the main features are outlined.

Site 1. *Polygonal tundra.* Irregular polygons (1–2 m in diameter) of fine mineral soil covered by a thin layer of cyanobacteria. Soil of gelic gleysol type (FAO classification). Polygons were surrounded by cracks with rocky debris and narrow bands of vegetation dominated by *Salix* spp., *Saxifraga* spp., various mosses and lichens.

Site 2. *Mossy-lichenous tundra.* Compact plant cover dominated by *Salix polaris*, lichens and mosses, on the soil of histic regosol type.

Site 3. *Mossy swamp.* A 20–30 cm deep moss and turf layers on the soil of histic gleysol type. Moss cover dominated by *Calliergon stramineum*. Regular season-

Table 1. Summary of morphometric data: total number (n), h and L ranges (mm) of specimens measured, and equations of h/L relationship.
L_{ad} values represent upper limits of body length in adult animals [after Fjellberg, 1980, 1994, 1998; Babenko et al., 1994; Potapov, 2001).
Таблица 1. Результаты морфометрических измерений: общее количество измеренных особей, диапазон h и L (мм), и уравнения зависимости между h и L.
Значения L_{ad} представляют предельную длину тела у взрослых особей [по: Fjellberg, 1980, 1994, 1998; Бабенко и др., 1994; Potapov, 2001].

Species	n	h range	L range	L_{ad}	$L = bh + a$	R^2
Hypogastrura tullbergi (Schäffer, 1900)	651	0.06–0.29	0.29–1.54	1.5–2.0	$L = 4.964\ h - 0.029$	0.92^{***}
juveniles (L<0.85 mm)		0.06–0.22	0.29–0.85	—	$L = 4.776\ h - 0.027$	
adults (L>0.85 mm)		0.16–0.29	0.86–1.54	—	$L = 6.814\ h - 0.396$	
H. viatica (Tullberg, 1871)	713	0.08–0.36	0.34–1.85	1.9–2.0	$L = 5.135\ h - 0.049$	0.98^{***}
H. (Ceratophysella) longispina (Tullberg, 1876)	140	0.09–0.39	0.45–2.02	1.5–2.0	$L = 5.501\ h - 0.132$	0.94^{***}
Xenylla humicola (Fabricius, 1780)	371	0.07–0.34	0.36–1.72	1.3–2.0	$L = 5.114\ h - 0.099$	0.93^{***}
Anurida polaris (Hammer, 1954)	423	0.07–0.29	0.32–1.44	1.5–2.0	$L = 5.335\ h - 0.035$	0.92^{***}
Micranurida pygmaea Börner, 1901	24	0.06–0.09	0.27–0.44	0.5	$L = 4.897\ h - 0.030$	0.46^{***}
Oligaphorura groenlandica (Tullberg, 1876)	402	0.09–0.35	0.45–1.78	1.6–1.7	$L = 5.393\ h - 0.096$	0.93^{***}
Folsomia alpha Grow & Christiansen, 1976	65	0.08–0.18	0.36–0.84	1.2	$L = 3.976\ h + 0.143$	0.76^{***}
F. quadrioculata (Tullberg, 1871)	826	0.07–0.28	0.34–1.52	1.0–1.5	$L = 5.392\ h - 0.026$	0.92^{***}
juveniles (L<0.92 mm)		0.07–0.19	0.34–0.92	—	$L = 4.462\ h + 0.075$	
adults (L>0.92 mm)		0.16–0.28	0.93–1.52	—	$L = 6.276\ h - 0.177$	
Agrenia bidenticulata (Tullberg, 1876)	20	0.14–0.34	0.52–1.83	1.9	$L = 6.171\ h - 0.275$	0.89^{***}
Isotoma anglicana Lubbock, 1862	23	0.27–0.70	1.36–3.74	3.0–4.0	$L = 5.716\ h - 0.362$	0.93^{***}
Desoria tshernovi (Martynova, 1974)	91	0.09–0.28	0.42–1.36	1.1–1.5	$L = 4.861\ h - 0.024$	0.93^{***}

al pasture of barnacle geese.

The sites were contrast by microclimatic conditions. Depth of snow cover was maximum at site 3 (up to 1 m), and sequence of complete snow melting was site 1 (mid-May) — site 2 (beginning of June) — site 3 (mid-June). Soil moisture levels (measured throughout the vegetative season, % of wet weight) significantly increased in the above row, from 18–25% and 33–49% (site 1, soil on polygons and under vegetation belts, respectively), to 52–74% (site 2) and 79–88% (site 3). In contrast, soil of open polygons was markedly warmer than under vegetation of any site. In general, site 1 had the most harsh conditions, being the driest in summer and the least snow-covered during the cold seasons. Site 3 was presumably the most favourable being the best frost protected in winter and having stable moisture condition in summer, whereas other sites were increasingly dried towards the end of summer season. Consequently, densities and biomass of soil microarthropods (in particular springtails) generally increased from site 1 to site 3 [Byzova et al., 1995].

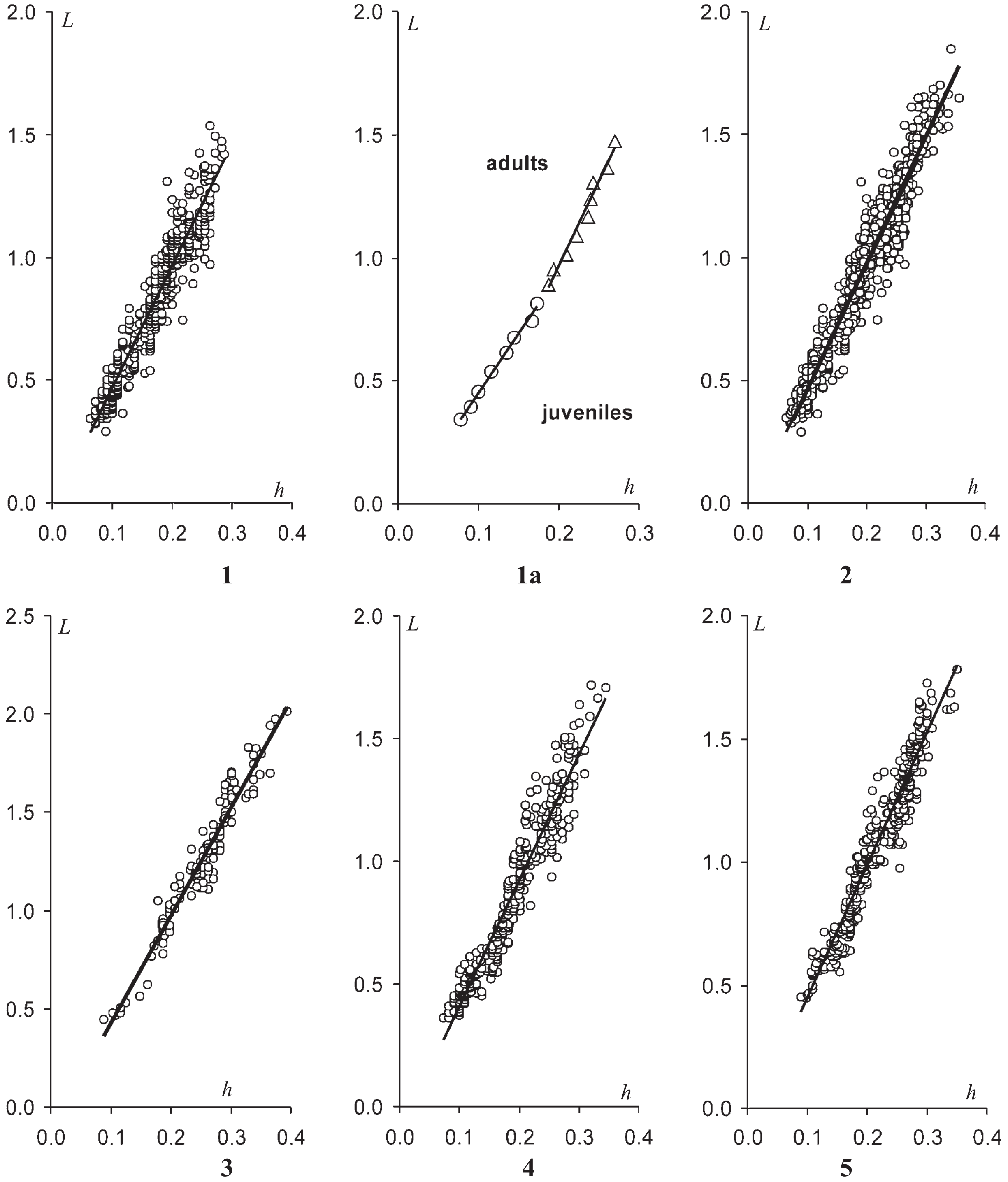
Sampling was performed in three-week intervals, during May – August (site 1) or June – August (sites 2 and 3). Samples were taken with a 5 x 5 cm metal corer to the inhabited soil depth (usually 5–15 cm). Collembolans were extracted into 70° ethanol by means of Tullgren funnels and mounted on constant slides in Faure medium. To avoid pressure of covering glass and distortion of the preserved animals, props under the covering glass (small pieces of the same glass or sand granules) were used.

Head and body lengths of springtails were measured following the method described by Tamura [1974]. By means of microscope with a drawing apparatus, body length of a specimen was drawn at a 100^x magnification as a curved line on a sheet of paper, by tracing through the central line of the body from the tip of the mouthparts to the abdominal end [op. cit.]. Head dimensions were indicated on the body length line. Then head capsule length (straight line) and body length were measured to the nearest 0.5 and 1 mm by a ruler and a curvimeter, respectively. The values obtained were divided by 100, which gave actual dimensions studied with the precision of 0.005 and 0.01 mm, respectively. Since the length of alcohol preserved and slide-mounted springtails increases by 4–15% (various species, after Petersen [1975]) or ca. 10% (*Hypogastrura tullbergi*, after Birkemoe & Leinaas [1999]) as compared with living specimens, a correction of (-10%) to the measured L and h was introduced. At any site, numbers of measured specimens of the species studied were distributed more or less evenly across the sampling season.

Kolmogorov–Smirnov's λ [Lakin, 1973] was used to test intersite differences in population structure (size classes distribution) of species studied. Range of size classes was arbitrarily taken 0.07 mm (by body length) for all species. Regression slopes were compared after Sokal & Rolph [1995].

Results and discussion

Body length (L) and head capsule length (h) were measured for 12 common Svalbard species representing 4 families (after Babenko et al. [1988]): Hypogastruridae



1 1a 2

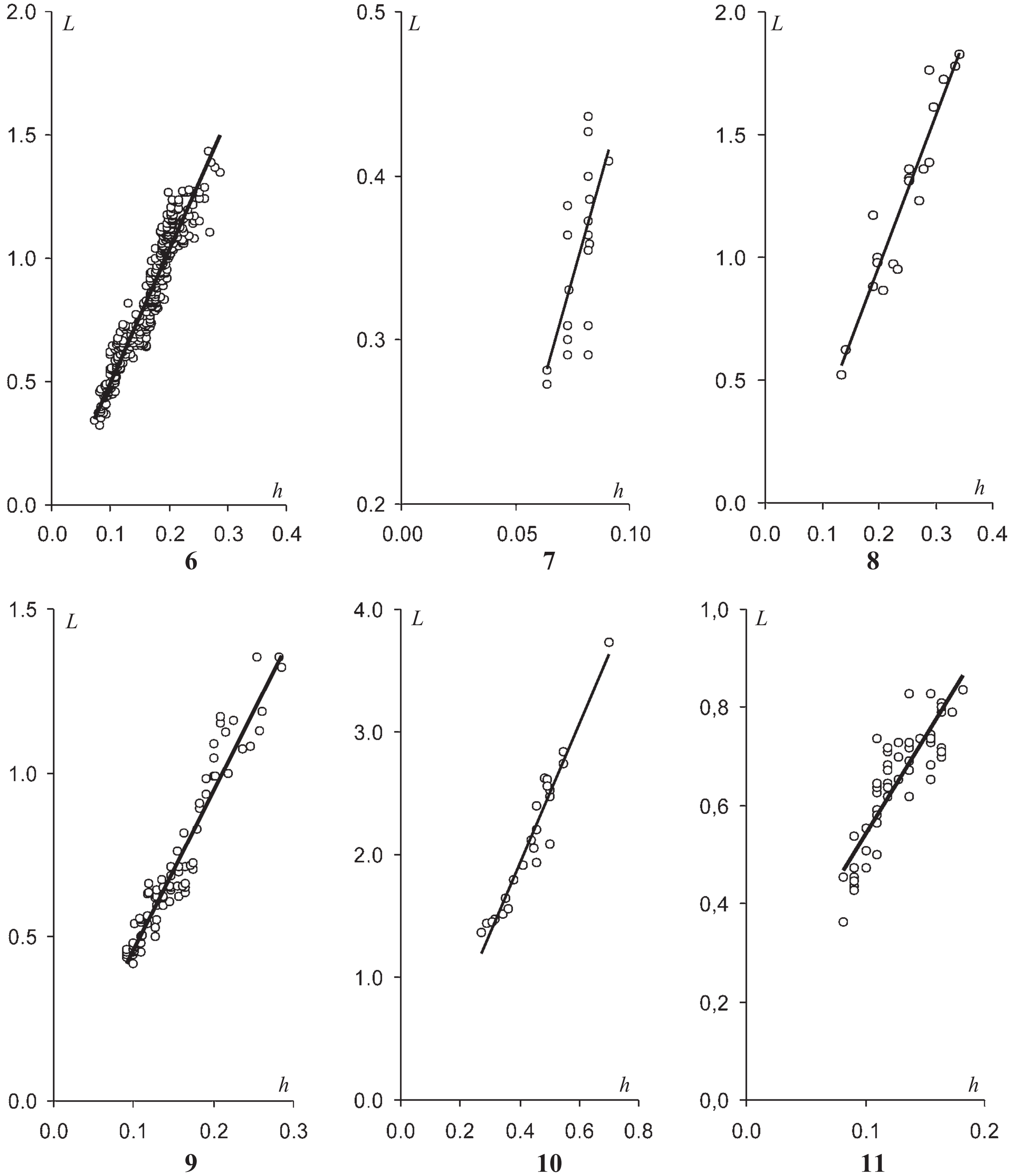
3 4 5

Figs 1–5. Relationship between head capsule length (*h*, mm) and body length (*L*, mm) in Collembola of Svalbard: 1–1a — *Hypogastrura tullbergi*, 2 — *H. viatica*, 3 — *H.* (*Ceratophysella*) *longispina*, 4 — *Xenylla humicola*, 5 — *Oligaphorura groenlandica*.

Рис. 1–5. Соотношение между длиной головной капсулы (*h*, мм) и длиной тела (*L*, мм) у коллембол архипелага Свальбард: 1–1a — *Hypogastrura tullbergi*, 2 — *H. viatica*, 3 — *H.* (*Ceratophysella*) *longispina*, 4 — *Xenylla humicola*, 5 — *Oligaphorura groenlandica*; adults — взрослые, juveniles — неполовзрелые.

(4 species), Neanuridae (2), Onychiuridae (1), Isotomidae (5). For all species, size of measured animals covered the range from relatively small juveniles to adults (as compared with body size of adults from literature, Table 1).

Relationships between *h* and *L* were significantly approximated by linear regressions (Figs 1–12) with high values of R^2 (from 0.76 to 0.98), except for the regression for *Micranurida pygmaea* where a small number of measurements resulted in a much lower though also a



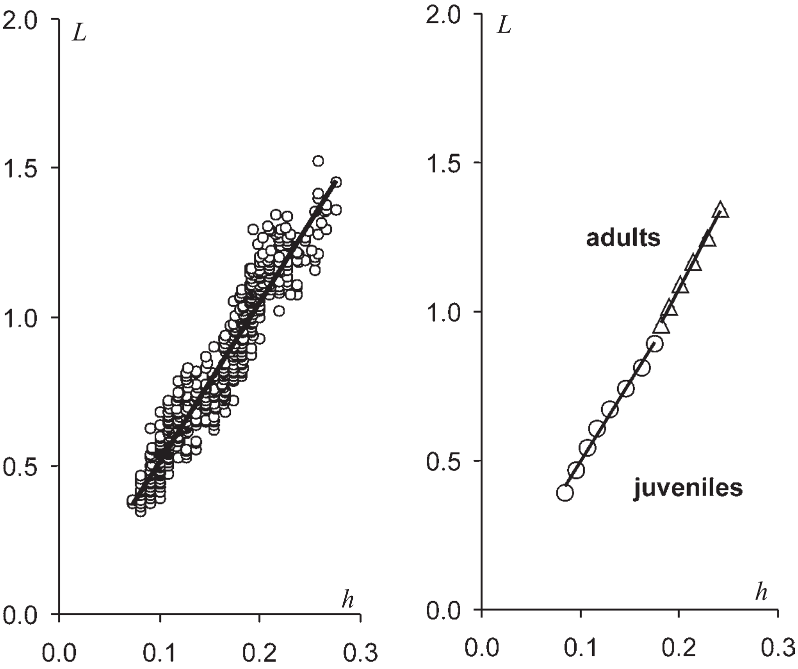
6 7 8

9 10 11

Figs 6–11. Relationship between head capsule length (*h*, mm) and body length (*L*, mm) in Collembola of Svalbard: 6 — *Anurida polaris*, 7 — *Micranurida pygmaea*, 8 — *Agrenia bidenticulata*, 9 — *Desoria tshernovi*, 10 — *Isotoma anglicana*, 11 — *Folsomia alpha*.

Рис. 6–11. Соотношение между длиной головной капсулы (*h*, мм) и длиной тела (*L*, мм) у коллембол архипелага Свальбард: 6 — *Anurida polaris*, 7 — *Micranurida pygmaea*, 8 — *Agrenia bidenticulata*, 9 — *Desoria tshernovi*, 10 — *Isotoma anglicana*, 11 — *Folsomia alpha*.

significant R^2 value (Table 1). Ratio between *h* and *L* has been previously studied for 9 isotomid, onychiurid and neanurid species common in the Moscow region [Uvarov, 1987]. Despite the different method of measurements used in the latter work (by means of an ocular micrometer; *h* was measured from occiput to mandibulae bases), both studies showed highly significant linear relationships between the parameters studied. Thus, proportional increase of *h* and *L* with age may be considered a reliable approximation for various species belonging to primitive



12 12a

Fig. 12. Relationship between head capsule length (*h*, mm) and body length (*L*, mm) in Collembola of Svalbard: 12–12a — *F. quadrioculata.*

Fig. 12. Соотношение между длиной головной капсулы (*h*, мм) и длиной тела (*L*, мм) у коллембол архипелага Свальбард: 12–12a — *F. quadrioculata*; adults — взрослые, juveniles — неполовзрелые.

collembolan groups (podurids and isotomids) and occupying contrast geographic zones. Furthermore, for a widely distributed species *Folsomia quadrioculata* occurring both in the Moscow region [op. cit.] and on Svalbard (this study), linear type of *h*/*L* relationship was not affected by geographic distribution.

There is evidence, however, that relative growth of *h* against *L* slows down in larger animals. E.g., regression lines calculated separately for juveniles and adults of *F. quadrioculata* and *H. tullbergi* (divided into size classes of 0.07 mm and separated at 0.92 and 0.85 mm, respectively, after Birkemoe & Sømme [1998]) showed steeper regression slopes for adults in both species (Figs 1a and 12a; Table 1). Thus, *h*/*L* relationships could be further defined more accurately regarding age and possibly sex of the animals studied.

Head capsule length and *h*/*L* relationships were considered useful for estimations of individual dry (W_d) and fresh (W_f) body weights, and other related parameters of the species studied [Uvarov, 1987]. For body weight calculations on the basis of head capsule length, the following algorithm is suggested:

(1) $L = bh + a$;

(2) $W_d = a' L^{b'}$;

(3) $\log W_d = b' \log L + \log a' = b' \log (bh + a) + \log a'$;

(4) $W_f = r W_d$;

(5) $\log W_f = \log W_d + \log r = b' \log (bh + a) + (\log a' + \log r)$,

where

a and b are coefficients of the *h*/*L* relationship; a' and b' are coefficients of the power relationship between L and W_d; r is ratio between dry and fresh body weight. For the species studied, plausible values of a', b' and r compiled from literature, are outlined in Table 2.

Parameters of *h*/*L* relationships may be indicative for intra- and interspecies comparisons of populations inhabiting different sites. Thus, polygonal and mossy-lichenous tundra sites at Hornsund (sites 1 and 2, respectively) studied by Byzova et al. [1995], were dominated by *F. quadrioculata* (70–80% of abundance), *H. tullbergi* and *Xenylla humicola*. Patterns of size classes distribution in populations of all three species, according to Kolmogorov-Smirnov's test, did not differ significantly in the ranges covering 86–100% of their abundance in both sites that made it possible to compare corresponding *h*/*L* regressions (Table 3). In *F. quadrioculata* slopes of *h*/*L* equations were similar, whereas in *H. tullbergi* and *X. humicola* values of F_s showed significant differences between the slopes at sites 1 and 2. For the latter two species different *h*/*L* slopes may reflect variations in population response to contrast site conditions. Indeed, both in *H. tullbergi* and *X. humicola* populations average density and proportion of young animals (<0.85 mm body length) were definitely higher at site 2 than at site 1 [Byzova et al., 1995, and unpubl. data]. *H. tullbergi* on Svalbard is known to be influenced by winter mortality [Birkemoe & Sømme, 1998] which is presumably higher at site 1 with the harshest winter conditions. Besides, density and population structure could be also affected by drier summer conditions at site 1. It is not known whether a similar

Table 2. Parameters of the equations for calculations of dry and fresh body weight on the basis of head capsule length, as compilated from literature. Reference 1 refer to b' and $\log a'$ values, reference 2 — to r values. For explanations see text.

Таблица 2. Параметры уравнений для расчётов сухого и живого веса тела на основе длины головной капсулы, по литературным данным. Reference 1 относится к значениям b' и $\log a'$, Reference 2 — к значениям r. Объяснения в тексте.

Species	b'	$\log a'$	Reference 1	r	Reference 2	$\log a' + \log r$
Hypogastrura tullbergi [(1)]	2.55	0.99	*H.* cf. *manubrialis* [Tanaka, 1970]	2.732	Hypogastruridae [Edwards, 1967]	1.426
Oligaphorura groenlandica [(2)]			*Onyciurus armatus* s.l. [Petersen, 1975]		*O. armatus* s.l. [Petersen, 1975]	
small (L<1 mm; h<0.20 mm)	2.532	0.746	Juveniles	4.56		1.405
large (L>1 mm; h>0.20 mm)	2.769	0.748	Adults	4.56		1.407
Folsomia quadrioculata [(3)]:			*F. quadrioculata* s.l. [Petersen, 1975]		*F. quadrioculata* s.l. [Petersen, 1975]	
small (L<0.92 mm; h<0.18 mm)	2.439	0.662	Juveniles	2.81		1.111
large (L>0.92 mm; h>0.18 mm)	2.799	0.750	Adults	2.81		1.199
Isotoma anglicana [(4)]	3.223	0.928	*Parisotoma (Isotoma) notabilis* [Petersen, 1975]	2.56	*P. notabilis* [Petersen, 1975]	1.336
Desoria tshernovi	3.28	0.75	*D. trispinata* [Tanaka, 1970]	2.56	*P. notabilis* [Petersen, 1975]	1.158

[(1)] also for *H. viatica*, *H. (C.) longispina* and *X. humicola*;
[(2)] also for *A. polaris* and *M. pygmaea*;
[(3)] also for *F. alpha;*
[(4)] also for *A. bidenticulata*.

[(1)] также для *H. viatica*, *H. (C.) longispina* и *X. humicola*;
[(2)] также для *A. polaris* и *M. pygmaea*;
[(3)] также для *F. alpha;*
[(4)] также для *A. bidenticulata*.

Table 3. Intersite differences in h/L regression equations. λ — values of Kolmogorov-Smirnov's test; F_s — significance test of differences between the regression slopes [Sokal & Rolph, 1995]; n — number of measured individuals.

Таблица 3. Межбиотопические различия уравнений h/L регрессии. λ — значения индекса Колмогорова-Смирнова; F_s — достоверность различий между коэффициентами регрессии (b) [Sokal & Rolph, 1995]; n — число измеренных особей.

Species	n	h range	L range	λ	$L = bh + a$	F_s
F. quadrioculata						
Site 1	208	0.09…0.24	0.48…1.19	1.16 (NS)	$L = 5.165\,h + 0.031$; $R^2=0.88^{***}$	F_s=0.38; df=706 (NS)
Site 2	502	0.09…0.26	0.47…1.20		$L = 5.186\,h - 0.004$; $R^2=0.91^{***}$	
H. tullbergi						
Site 1	171	0.07…0.26	0.32…1.26	1.11 (NS)	$L = 4.840\,h + 0.006$; $R^2=0.91^{***}$	F_s=4.03; df=612 P<0.05
Site 2	445	0.06…0.26	0.29…1.26		$L = 4.761\,h - 0.011$; $R^2=0.92^{***}$	
X. humicola						
Site 1	90	0.09…0.33	0.42…1.72	0.92 (NS)	$L = 5.397\,h - 0.126$; $R^2=0.93^{***}$	F_s=36.60; df=349 P<0.001
Site 2	263	0.09…0.34	0.42…1.71		$L = 5.045\,h - 0.097$; $R^2=0.93^{***}$	
O. groenlandica						
Site 2	123	0.10…0.34	0.46…1.73	1.02 (NS)	$L = 5.193\,h - 0.049$; $R^2=0.93^{***}$	F_s=59.16; df=394 P<0.001
Site 3	275	0.09…0.35	0.45…1.78		$L = 5.515\,h - 0.126$; $R^2=0.94^{***}$	

explanation can be suggested for the similar response in *X. humicola*. In contrast, *F. quadrioculata* is a habitat-generalist with high densities in various vegetation types [op. cit.], in particular in Hornsund area [Uvarov & Byzova, 1995; Byzova et al., 1995]. Between the sites 1 and 2, its density variations were smaller [op. cit.] and proportions of youngsters (body length <0.92 mm) similar. In highly drought sensitive *O. groenlandica* [Hertzberg et al., 2000], significantly different h/L slopes (Table 3) might indicate population response to more (site 3) or less (site 2) favourable soil moisture conditions. Thus, h/L relationship may be a sensitive test indicating community changes earlier than size classes distribution (λ index).

In general, usage of h instead of L in population analyses may be preferable when mass material is involved, due to faster process of h estimation.

ACKNOWLEDGEMENTS. I wish to thank Dr. A.B. Babenko and Dr. S.K. Stebayeva for the critical comments on the MS. The work was supported by Russian Foundation for Basic Research.

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