USE OF QUANTITATIVE MORPHOLOGICAL ANALYSIS COMBINED WITH A LARGE SAMPLE SIZE FOR ESTIMATING MORPHOLOGICAL VARIABILITY IN A CASE STUDY OF ARMoured MITE *Carabodes subarcticus* Trägårdh, 1902 (Acari: Oribatida: Carabodidae)

Uģis Kagainis

Faculty of Biology, University of Latvia, Kronvalda bulv. 4, Riga, LV-1586, LATVIA
oribatida@inbox.lv

Communicated by Viesturs Melecis

*The morphology of Oribatida and similar little-known groups of organisms varies considerably, which complicates morphological analysis (e.g. species descriptions). Qualitative analyses have been carried out mostly on a small number of individuals ($n < 25$). There is lack of studies dealing with mechanisms of how that variation can change in relation to sample size and insufficient discussion on whether qualitative or quantitative analysis is more appropriate for description of morphological variability. A total of 500 adult *Carabodes subarcticus* Trägårdh, 1902 Oribatida were collected from a local population. Six qualitative and six quantitative traits were characterised using light microscopy and scanning electron microscopy. The relationships between the sample size of different subsamples ($n < 500$) and morphological variation were examined using randomised selection (10 000 replicates) and calculation of the percentage of cases in which the size-values were within a certain distance (less than 10%, 25%, or 50%) from the range of the reference population ($n = 500$). Qualitative traits were significantly less variable than quantitative due to binomial distribution of the obtained data; thus they were less comparable and interpretive to describe morphological variability. When sample size was small ($n < 25$), in less than 2 to 15% of cases the observed variability was within 10% distance of the range of the reference population. Larger sample sizes resulted in size-ranges that approached those of the reference population. It is possible that execution of quantitative characterisation and use of relatively larger sample sizes could improve species descriptions by characterising the morphological variability more precisely and objectively.*

Key words: *morphological variability, size range, qualitative and quantitative analysis, sample size, Carabodes subarcticus.*

INTRODUCTION

From the very beginning, our knowledge of the diversity of living organisms mainly has been based on observations and morphological studies (Jonathan, 1984), using both qualitative and quantitative traits to distinguish one from another (Linnaeus, 1758). The development of optics and measuring tools allowed scientists to extend their studies to microscopic-sized animals and improve their species descriptions (Koch, 1835). Oribatida, or so-called armoured mites, are among the most morphologically-diverse and species-rich groups of soil-inhabiting microscopic arthropods (Subias, 2004). The armoured mites represent more than 11 000 species described, yet by mostly comparing qualitative traits (Schatz, 2004).

Description of oribatid species, in general, has been developed by using 1) comparative i.e. qualitative, 2) morpho-

metrical i.e. quantitative and 3) genome analyses (Koch, 1835; Mahunka, 1987; Salomone *et al.*, 2003; Dabert, 2006; Lee *et al.*, 2006; Weigmann, 2006; Murvanidze, 2008; Heethoff *et al.*, 2011). Descriptions of oribatid species have been prepared by using mainly binary traits, i.e. so-called qualitative morphological analysis. The following are the most commonly asked questions during this analysis: Is the shape of the character wide or narrow? Is the character large, medium size or small? Is the character lanceolate or spoon-shaped? Is the character larger in size or smaller than other characters? Also, comparison is made to a single specimen — holotype. Specific characters (e.g. shape, length proportion or colour) of several traits that differ between similar species are used for identification. The most effective morphological elements used for identification in oribatology are setae, body or leg areas or segments, other specific morphological structures like gland openings,

microsculpturation of cuticle, and inner structures. Qualitative traits so far have been used mostly in the study of morphology of armoured mites (Ramsay and Luxton, 1967; Mahunka, 1987; Norton and Kethley, 1989; Caballero *et al.*, 1999; McCullough and Krisper, 2013).

Quantitative morphological analysis of type specimens, when such specimens are available (e.g. paratypes or topotypes), has been carried out on a few traits using a small sample size. The following are very common questions asked during this analysis: How long is the character in micrometers? How far apart is the character from another structure? How thick in micrometers is the character? etc. Yet, quantitative characterisation has only been used rarely as additional data, due to very few individuals available or because this method is more time and effort consuming than qualitative characterisation (Aoki, 1964; Schubart, 1975; Norton and Kethley, 1989; Reeves and Norton, 1990; Behan-Pelletier, 1993; G. Weigmann and A. Taylor pers. comm., 2009; R. Norton pers. comm., 2014). Only a few studies have briefly mentioned that morphological characteristics need to be analysed on many individuals, not only qualitatively, but also quantitatively, to illustrate appropriately the high variability of morphology and to be able to distinguish among different taxa more successfully, thus supplementing the morphological description (Haarlov,

1952; Schubart, 1975; Fujikawa, 1999; Salomone *et al.*, 2003; Fernandez *et al.*, 2013). Genetic data relatively rarely has been used to describe new oribatid species (Salomone *et al.*, 2003; Dabert, 2006; Lee *et al.*, 2006; Heethoff *et al.*, 2011).

Regarding morphometrical studies of Oribatida, from which species descriptions dominate in numbers, 25 or fewer specimens on average have been used to describe or redescribe traits of species quantitatively (Grandjean, 1931; Eglitis, 1943; Zakhvatkin, 1945; Sellnick and Forsslund, 1952; Grandjean, 1956; Reeves and Norton, 1990; Behan-Pelletier, 1993; Salomone *et al.*, 2003; McCullough and Krisper, 2013). Oribatid determination keys and species descriptions may be considered as the most important research elements dealing with morphological observations, yet quantitative morphometrical data mostly in these contributions are presented even without any indication of the number of observed specimens (Michael, 1882; Trägårdh, 1902; Woolley, 1957; Wallwork, 1972; Gilyarov and Krivolutskii, 1975; Reeves, 1987; Weigmann and Miko, 2002; Weigmann, 2006; Murvanidze, 2008; Ermilov, 2011; Fernandez *et al.*, 2013). Characteristics of sample sizes used in published taxonomical studies with incorporated elements from morphometrical analysis are summarised in Table 1.

Table 1

MEAN AND MAXIMUM SAMPLE SIZE (N) OF INDIVIDUALS OF ORIBATIDA SPECIES FROM DIFFERENT FAMILIES MORPHOMETRICALLY DESCRIBED IN CHRONOLOGICALLY ORDERED SPECIES DESCRIPTIONS CHARACTERISED BY THE NUMBER OF INVOLVED SPECIES AND THE NUMBER OF MEASURED TRAITS

Reference	Family	Number of species	Number of traits	N	
				Max	Mean
1	2	3	4	5	6
Michael 1882	various	4	3		
Grandjean 1931	various	2 ♀♂	3	15	14
Willmann 1931 ^k	various	233	2		
Eglitis 1943	various	49	2	26	5
Zachvatkin 1945	Palaeacaridae	1	2	3	2
	Aphelacaridae	1 ♀♂	2	1	1
	Aphelacaridae	1 ♀♂	2	1	1
Haarlov 1952	Tectocepheidae*	2	2	85	85
Sellnick and Forsslund 1952 ^k	Carabodidae	1 ♀♂	3	1	1
	Carabodidae	1	2		
	Carabodidae	2 ♀♂	2	1	1
	Carabodidae	2	1		
	Carabodidae	1 ♀♂	2	1	1
	Carabodidae	1 ♀♂	20	1	1
	Carabodidae	1 ♀♂	16	1	1
	Carabodidae	1	15		
	Carabodidae	10	2		
Grandjean 1956	Galumnidae	1 ♀♂	1	6	5
Woolley 1957	Achipteriidae	2	3		
Aoki 1964	Hydrozetidae	1	2	3	3
Ramsay and Luxton 1967	Crotonidae	1 ♀♂	8	1	1
Wallwork 1972 ^k	various	4	2		
Gilyarov and Krivolutskii 1975 ^k	various	778	2		

Table 1 Continued

1	2	3	4	5	6
Schubart 1975	Ameronothridae*	1 ♀♂	6	10	10
	Ameronothridae*	1 ♀♂	7	10	7
	Ameronothridae*	1 ♀♂	7	14	9
	Ameronothridae*	1 ♀♂	7	13	10
	Ameronothridae	9 ♀♂	1	38	17
Mahunka 1987	Carabodidae	10	2		
Reeves 1987	Carabodidae	1 ♀♂	4	26	24
	Carabodidae	1	7		
	Carabodidae	1	10	4	4
Norton and Kethley 1989	various	2	2	5	5
	Oribatidae	1	2		
	various	3	1	7	4
	Oribatellidea	1 ♀♂	1	2	2
	various	2 ♀♂	1	1	1
	Protoribatidae	1	1		
	various	10	1		
Reeves and Norton 1990	Carabodidae	2	2	1	1
	Carabodidae	2 ♀♂	2	10	5
	Carabodidae	2	17	10	10
Behan-Pelletier 1993 ^k	Eueremaeidae*	38 ♀♂	50	14	6
	Eueremaeidae*	2 ♀♂	50	12	9
	Eueremaeidae	44	50		
Weigmann and Miko 2002	Oribatidea	1	6		
	Oribatidea	1	1		
Salomone <i>et al.</i> 2003	Carabodidae	2	2	10	10
Weigman 2006 ^k	various	620	1		
Murvanidze 2008 ^k	Carabodidae*	25	4		
	Carabodidae	2	1		
	Carabodidae	27	1		
Ermilov 2011	Carabodidae	1	2		
Fernandez <i>et al.</i> 2013	Carabodidae	1	2		
	Carabodidae	2 ♀♂	2	3	3
McCullough and Krisper 2013	Scutoverticidae*	1	5	7	4
	Scutoverticidae	1	2	201	201

Families are marked with asterisk in cases where geographically separated populations were compared; literature sources that incorporate elements from species identification keys are marked with “k”; in cases where sex is mentioned, marked with “♀♂”.

As noted by Norton and Kethley (1989), one of many issues that may mislead attempts at identification is unappreciated sexual dimorphism during the morphological research.

Some studies have been focused on morphological mutations and anomalies, which can also be interpreted as extreme values of morphological variation and usually are associated with different genome expression or result of anthropological pollution (Grandjean, 1952; Sellnick and Forsslund, 1952; Kochyńska and Olszanowsky, 2008; Eeva and Penttinen, 2009; Weigmann, 2010). However, some anomalies are the result of natural factors; for example, teneral specimens have extremely light cerotegument due to very recent moulting and because they have not yet finished darkening their cuticle by sclerotisation (Norton, 1994; R.A. Norton pers. comm., 2007). Yet, no articles have discussed whether very extreme morphological abnormality

can be regarded as anomaly or mutation or as natural and normal development with high morphological variability.

Among many published morphometrical studies, for example, species descriptions, redescrptions or determination keys, it has not been considered that use of a small sample size might lead to lower morphological variability compared to natural populations and decrease comparability of morphological data (Michael, 1882; Trägårdh, 1902; Grandjean, 1931; Zakhvatkin, 1945; Grandjean, 1956; Woolley, 1957; Wallwork, 1972; Reeves, 1987; Salomone *et al.*, 2003; Fernandez *et al.*, 2013; McCullough and Krisper, 2013).

The species of *Carabodes subarcticus* Trägårdh, 1902 has been qualitatively described in several publications and is considered to be well studied taxonomically. Adults usually

are coloured almost black to dark brown. Marginal notogastral setae (*h3*, *p1*, *p2*, and *p3*) are significantly smaller than those located on median surface of notogaster (*la*, *h2*, *h1*, *lp*, *lm*, and *c2*). Notogastral setae are lanceolate and scabrous, i.e. lightly bristled. Interlamellar setae (*in*) are very long, slightly curved, as long as the distance between insertions of left and right *in* seta, at least three times as long as notogastral setae. Sensillum (*ss*) is straight, finger-shaped, with a strongly expanded capitulum. Notogastral pits (irregularly shaped microsculpturic granules) are scattered unevenly from one to another (Trägårdh, 1902; Sellnick and Forsslund, 1952; Gilyarov and Krivolutskii, 1975; Weigmann, 2006; Murvanidze, 2008; Ermilov, 2011). The morphological traits described above are illustrated in the Materials and Methods section.

In the original description of *C. subarcticus*, only the total body length was given, estimated as 450 µm for an unstated sample size (Trägårdh, 1902). Further, Sellnick and Forsslund (1952) in their redescription measured the length of notogastral setae *p1* (20 µm) and *h1* (32 µm), and the distance between left and right *h1* seta (95 µm) on a single specimen. Without mentioning sample size, they recorded total body length up to 486 µm and width up to 288 µm, without mentioning the sample size. In Gilyarov and Krivolutskii (1975) the indicated body length was not larger than 490 µm, but again the sample size was not mentioned. In keys of Weigmann (2006) and Murvanidze (2008), body length was noted as 400–490 µm, again without indicating sample size; notes of the latter on numbers of individuals observed are not available anymore (G. Weigmann and A. Taylor pers. comm., 2009). *Carabodes areolatus* Berlese, 1916 is very similar in morphology to *C. subarcticus*, especially when compared by qualitative analysis, which has caused problems in species identification (Sellnick and Forsslund, 1952; Kagainis, 2010; see also Bernini, 1970). *Carabodes* genus is only one of many examples of oribatid mites for which mainly qualitative descriptions have been published, and for which characterisation has been based on sample sizes so small as to hide variation and to make the identification keys unclear (Table 1).

Oribatid mites have a long evolutionary history. Due to complex adaptation processes they have evolved a wide variety of morphological modifications (Norton, 1994). Many oribatid species inhabit a high variety of environments worldwide, such that significant morphological variability could be expected to have evolved (Fujikawa, 1999; Prinzing *et al.*, 2004; Zbikowska-Zdun *et al.*, 2009; Baran *et al.*, 2011). Populations with geographically separate distribution have rarely been compared in species descriptions or determination keys (Haarlov, 1952; Schubart, 1975; Norton, 1978; Behan-Pelletier, 1993; Murvanidze, 2008; McCullough and Krisper, 2013; see also Table 1). Even those oribatid mites that inhabit geographically and biologically closely related habitats can show high morphological variability (Kagainis, 2014). All aspects mentioned above can complicate the development of a species description.

Analysis of morphological variation of oribatid mites has rarely progressed beyond simple measurements to the use of coefficients of variation (CV), for both normal as well as for binomial distributions of data. CV can also be compared effectively both within and between species (Sokal and Rohlf, 1995; Zbikowska-Zdun *et al.*, 2009; Coetzee, 2010).

Sample size (i.e. number of measured units of the same trait) significantly affects the accuracy not only of morphological variability assessment, or coefficients of variation, but also values of biological parameters. Indeed, it is impossible to collect and observe 100% of natural variation of any parameter. However, larger sample size can go hand-in-hand with more realistic conclusions (Sokal and Rohlf, 1995; Randal and Myers, 2001; Cao *et al.*, 2003; Seddon *et al.*, 2003; Peres-Neto *et al.*, 2006; Cardini and Elton, 2007; Lindblom, 2009; Schneck and Melo, 2010).

The aim of this work was to describe morphological variation by using qualitative and quantitative traits and to determine the effect of sample size on accuracy of approximation of morphological variation in the oribatid mite *Carabodes subarcticus*.

MATERIALS AND METHODS

Sampling and preparation. The palaearctic oribatid mite *Carabodes subarcticus* was chosen as a model species for this study for three reasons. Firstly, *C. subarcticus* specimens can be collected in high densities from various habitats (Rajski, 1968; Solhøy and Koponen, 1981; Subías, 2004; Wierzbicka and Olszanowski, 2004; Sidorchuk, 2009). Secondly, the external morphology of *Carabodes* species is distinctive – a characteristic body form with strongly pigmented and heavily sclerotised, roughly sculptured cuticle. This makes sorting out individuals from samples with large numbers of soil arthropods relatively easy (Koch, 1835; Sellnick and Forsslund, 1952; Tarba and Semenova, 1976; Alberti *et al.*, 1981). Thirdly, historical morphological studies of this species (as for many other oribatids) have insufficient quantitative morphological analysis and analysis of variation (Trägårdh, 1902; Sellnick and Forsslund, 1952; Gilyarov and Krivolutskii, 1975; Weigmann, 2006).

Mites were collected on 18 October 2008 from a boreal coniferous forest in the Dundaga municipality, within the Slitere National Park (SNP), Latvia (N57°39'16" E22°16'01"). The sampling site was a *Pinus sylvestris* L. stand (Pinetum-Cladonio). Soils were podzols (mean pH – 3.08; mean moisture (ear-dry/ natural) – 0.47) with a raw humus (mor) layer (mean depth – 3.3 cm). *Cladina rangiferina* (L.) Nyl. and *Cladina stellaris* (Opiz) Brodo were the dominant lichen species at the site.

At the sampling site, 25 soil samples were taken two meters apart along a randomly chosen north-south transect. Soil samples were collected using a soil corer (diameter: 100 mm², max. depth: 100 mm). Soil organisms were extracted

using Tullgren funnels (Dunger *et al.*, 1997) over seven days. All adult individuals of *C. subarcticus* were sorted from the extracted material and stored in 70% ethyl alcohol.

The measurement procedure. Specimens prepared for scanning electron microscopy (SEM) including coating cannot be used for transmitted light observations. Therefore measurements under transmitted light microscope (TLM) were made before examination with SEM.

A binocular compound light microscope *Olympus BX41* combined with a digital camera *Olympus DP12* was used to make measurements during TLM and to record images. The microscope was equipped with reticle eyepiece. A micrometer slide was used to calibrate the eyepiece. Each mite was measured in lactic acid using cavity slides (Grandjean, 1949). By rotating the specimen, all necessary morphological structures (traits) were located and measured. Measurements were made by turning the examined morphological structure to the respective side profile and then recording measurement units of the reticle eyepiece. Units from reticle eyepiece were afterwards transformed into micrometers by calibration with the micrometer slide.

The following quantitative morphological traits were measured: notogastral setae *la*, *h3* and *h2* on right side of the body, total body length (*L*) from the rostrum to the posterior tip of the hysterosoma, total body width (*W*) measured at the widest part of the hysterosoma (both *L* and *W* were measured in dorsal view, discounting legs, setal structures, and foreign particles), and distance between right and left *h1* setal insertions (*h1-h1*) also in the dorsal view (Fig. 1a). Damaged or covered structures were not measured.

Species determination. Mites were prepared for SEM to verify the determination of species. Specimens were air dried and placed onto tape on aluminium stubs. Specimen stubs were coated with 20 nm Au-Pd in an Eiko IB3 Ion Coater and imaged using a Hitachi TM-3000, Hitachi High Technologies® scanning electron microscope in accordance

with Griffiths *et al.*, (1971). Adults of *C. subarcticus* were identified from electron micrographs using appropriate taxonomical literature (Sellnick and Forsslund, 1952; Mahunka, 1987; Murvanidze, 2008; Ermilov, 2011). Those individuals that were determined as not *C. subarcticus* were excluded from the study.

Qualitative analysis. Qualitative morphological traits were characterised on 318 individuals for which all six morphological traits were successfully measured under light microscopy and SEM. Qualitative traits were used in strict accordance to species descriptions, redescrptions and keys of *C. subarcticus* (Trägårdh, 1902; Sellnick and Forsslund, 1952; Gilyarov and Krivolutskii, 1975; Weigmann, 2006; Murvanidze, 2008; Ermilov, 2011). Some taxonomical elements were also used in other literature regarding *Carabodes* (Bernini, 1970; Reeves, 1987; 1988; Bernini and Baratti, 1990; Reeves, 1990; Reeves and Norton, 1990; Reeves, 1991a; 1991b, 1993; 1995; Baratti and Bernini, 1994; Salomone *et al.*, 2003; Monson, 2009).

Six qualitative traits were described: 1) colour of the integument black to dark brown (Sellnick and Forsslund, 1952; Ermilov, 2011) or brown to light brown; 2) length of the interlamellar seta *in* smaller (Weigmann, 2006) or larger than the distance of the insertions of *in* setae; 3) notogastral pits located unevenly one from another according to Gilyarov and Krivolutskii (1975) or evenly; 4) the shape of the medial and marginal notogastral setae is lanceolate according to Weigmann (2006) and Murvanidze (2008) and bristled according to Sellnick and Forsslund (1952) or shaped differently; 5) the length of marginal seta *h3* is smaller (after Trägårdh, 1902; Sellnick and Forsslund, 1952; Weigmann, 2006; Murvanidze, 2008) or larger than the length of the seta *h2* on the median surface of the notogaster; 6) sensillum finger-shaped (after Murvanidze, 2008) or shaped differently (Fig. 1b).

Data analysis. Data that were used for qualitative morphological analysis confirmed to the binomial distribution. Coefficient of variation (Sokal and Rohlf, 1995) were determined for qualitative and quantitative traits. All six morphological traits were successfully measured for 318 individuals – this subset formed the main group for analysis. Seta *h2* was successfully measured on a larger number of individuals (*n* = 500), and thus a larger data set (complementary group) was available for analysis of this trait.

All statistical analyses were performed using the programme R 3.1.0. (R Core Team, 2014). Empirical data on measured morphological traits (*la*, *h2*, *h3*, *L*, *W* and *h1-h1*) of *C. subarcticus* (main group: *n* = 318, complementary group: *n* = 500) was considered to represent a population. For each trait, samples with size from 10 to 318 were randomly chosen with repetition 10 000 times (iterations) (Manly, 2007). For each sample size, the proportion of repetitions for each trait that had range (minimal and maximal measurement value) differencing by distance of less than 10%, 25% or 50% compared to the range of the whole population (*n* = 318 or *n* = 500 for *h2*) was tested. In addition,

Fig. 1. Measured quantitative morphological traits (A): *L* – total body length, *W* – total body width, *la*, *h3* and *h2* – notogastral setae; *h1-h1* – distance between insertions of medial notogastral *h1* setae; and observed qualitative morphological traits (B): *ss* – sensillum; *in* – interlamellar seta; *c2*, *lm*, *lp*, *h1*, *la* and *h2* – medial notogastral setae; *h3*, *p3*, *p2* and *p1* – marginal notogastral setae; *not* – microsculpturic pits on the notogaster; of *Carabodes subarcticus* (dorsal aspect, legs absent, after Weigmann 2006, modified).

Fig. 2. Qualitative morphological traits of *Carabodes subarcticus*: a – colour of cerotegument black to dark brown, b – colour of cerotegument brown to light brown, c – colour of cerotegument light yellow (teneral specimen), d – lamellae (indicated by asterisk) commonly shaped, e – lamellae unusual and positioned peculiarly (specimen with mutation/ anomaly, see Fig. 1b for the reference), interlamellar setae longer than the distance between insertions these setae, f – micro- sculpturic pits on the notogaster scattered unevenly from one to another, g – medial notogastral seta *h2* lanceolate and scabrous, h – medial notogastral seta *la* lanceolate and scabrous, i – marginal notogastral seta *h3* lanceolate and scabrous, j – o – variability of finger-shaped sensillum *ss*. Images taken by TLM (a – c) and SEM (d – o). Scale (μm): (a – c) 100; (d – f) 50; (g – o) 10.

for trait *h2*, the difference in range was calculated using increasing sample sizes from 2 to 500 individuals: first, from two individuals then adding a third individual and recalculating the difference, and continuing this process until all individuals were selected. This process was repeated 10 000 times, each after randomly shuffling individuals so far unselected; the mean and 95% confidence interval (calculated as 2.5 and 97.5 percentile) of range difference for each sample size were calculated.

RESULTS

41.8% of *C. subarcticus* specimens were coloured almost black to dark brown. The others were brown to light brown, or lighter (CV = 0.066). Length of interlamellar setae (*in*) compared to the distance between insertions of interlamellar setae *in-in* had extremely low variance (CV = 0.003); only one individual had the size of *in* setae larger than the distance *in-in* (Fig. 2e). Notogastral pits were scattered unevenly in 100% of observed *C. subarcticus* (CV = 0). Also, for all examined individuals, notogastral setae were lanceolate and scabrous (CV = 0). 95.6% of examined individuals had a marginal notogastral setae *h3* smaller than seta *h2* located on median surface of notogaster (CV = 0.014). All examined sensilli (*ss*) were straight in general, finger-shaped with a strongly expanded capitulum (CV = 0), yet minor expression of these particular characteristics slightly varied (Fig. 2j, k, l, m, n, o).

Characteristics of measurements of morphological traits are illustrated by boxplots (Fig. 3) and summarised in Table 2. Total body length (*L*) was the least variable quantitative morphological trait of *C. subarcticus*. The most variable trait was length of notogastral seta *h3*. When the sample size was 318 individuals, size range of length of *h2* seta was 20 µm. When the sample size was increased to 500, the size range was 22.5 µm; thus size range deviated (increased) by 12.5% with an increase of the sample size by 57%.

Three of six qualitative traits showed morphological variability (CV > 0). All quantitative traits showed high morphological variability (CV = 0.086–0.279, see also Fig. 3). Quantitative traits showed 9.6 times higher morphological variability than qualitative traits (Table 2).

One teneral specimen and one specimen with an anomaly (mutation) in lamellae were also recorded (Fig. 2c, e).

When a relatively small sample size was used (n = 25), the observed morphological variability was within 10% of that in the full reference population (n = 318) in less than 2 to 15% of cases (repetitions) (Table 2, see also Fig. 4). A minimal sample size of 153–276 individuals for different traits (Table 2) was necessary to reach the level of 95% of repetitions. For a distance range of 50% of that of the reference population, the minimal sample size needed to reach 95% of

Table 2
CHARACTERISTICS OF MORPHOLOGICAL TRAITS OF CARABODES SUBARCTICUS MITES DESCRIBED BY THE AUTHOR

	Morphological traits						
	<i>la</i>	<i>h2</i>	<i>h3</i>	<i>L</i>	<i>W</i>	<i>h1-h1</i>	<i>h2</i> ⁿ⁼⁵⁰⁰
m-M*				400-490'	< 288''		
m-M	17.5-45.0	15.0-35.0	7.5-30.0	315.0-545.0	185.0-305.0	53.8-115.0	12.5-35.0
mean	30.9	24.7	7.17	429.2	233.8	77.5	24.4
SD	4.6	3.8	3.2	36.8	22.4	10.3	3.8
CV	0.148	0.154	0.179	0.086	0.096	0.133	0.156
minS D50	33	23	52	37	28	31	28
minS D25	144	74	176	184	117	107	116
minS D10	248	153	310	276	192	205	319

The main group, n = 318; m – minimal value; M – maximal value; * values published by Weigmann (2006)' and Sellnick and Forsslund (1952)''; mean – mean value; SD – standard deviation; CV – coefficient of variation; minS – minimal sample size necessary to have sample range difference (less than 10%, 25%, or 50% distance) with reference population value range in 95 % of repetitions. Morphological traits: *la*, *h3* and *h2* – notogastral setae; *h1-h1* – distance between left and right *h1* setae insertions; *L* – body length; *W* – body width. Data on the trait *h2*ⁿ⁼⁵⁰⁰ are calculated from the complementary group (n = 500).

Fig. 3. Size of morphological features (µm) of *Carabodes subarcticus* sampled from the pine forest (Pinetum-Cladonio). Morphological traits: *la*, *h3* and *h2* – notogastral setae; *h1-h1* – distance between left and right *h1* setae insertions; *L* – body length; *W* – body width. Data on the trait *h2*ⁿ⁼⁵⁰⁰ are calculated from the complementary group (n = 500). The boxes indicates the 25% lower and upper quartiles around the median. The whiskers indicate the extreme minimum and maximum values.

Fig. 4. Effect of sample size on percentage of corresponding samples of *C. subarcticus* with range difference for quantitative morphological trait “length of *h2* seta (μm)” ($n = 500$) in randomisation study within 10%, 25%, and 50% distance of population true range.

Fig. 5. Mean (black line) range difference with 95% confidence interval (grey area) of *C. subarcticus* measurements of setae *h2* (μm) in relation to sample size.

repetitions with that range was 23–37 specimens. For the trait *h2*, with a population of 500 individuals, the minimal sample size required to be within 10% distance of the population range in 95% of cases was even higher (Fig. 4).

In 95% of repetitions, a sample with size smaller than 33 individuals did not contain the whole population range of measurement values of trait *h2*. By increasing sample size

the number of repetitions within the true range rapidly increased (Fig. 5).

DISCUSSION

Information on the morphological variability might provide higher precision to the description of species (Haarlov, 1952; Schubart, 1975; Fujikawa, 1999; Salomone *et al.*,

2003; Fernandez *et al.*, 2013). Qualitative traits in most cases are based on binomial data, which may be interpreted more subjectively and hide information on high morphological variability (Sokal and Rohlf, 1995; Zbikowska-Zdun *et al.*, 2009; Coetzee, 2010).

Morphological traits that are used in qualitative analysis have less or no variation compared to traits used in quantitative analysis (Table 2, see also Figs. 2c, d, e, f, g, h, 3, see also the “Results” section). There was a high proportion of light brown individuals and also one teneral specimen (Fig. 2a). However, the available literature indicates that the colour of cerotegument of *C. subarcticus* is black to dark brown (Sellnick and Forsslund, 1952; Ermilov, 2011). Similarly, morphological variability in other qualitative traits that does not correspond to keys and species descriptions was observed. In the present study, *C. subarcticus* showed a relatively high morphometrical variability (Fig. 3), which might explain the historical problems faced when comparing this species with *C. areolatus* (Sellnick and Forsslund, 1952; Kagainis, 2010; see also Bernini, 1970).

In total, 57 cases (Table 2, see 2nd column) of morphological observations of oribatid mites presented in 26 published studies were qualitatively analysed (Table 1). In 52 cases, samples with 25 individuals or less were observed. Traits examined in this study showed that, on average, 25 individuals could illustrate 50% deviation of size range compared to the reference population ($n = 500$) with true size range. In five previously published studies (Table 2), a larger sample ($n > 25$) was used to describe the morphology of the particular species. The present study showed that 26 to 319 individuals can represent the size range that is less than 10% deviation from the size range of the reference population ($n = 500$) (Table 2, Fig. 4).

The common questions asked during the qualitative morphological analysis usually are as follows: Is the character wide or narrow? Is the character large, medium size or small? Is the character lanceolate or spoon-shaped? Is the character larger in size or smaller than the other character? Such traits had low coefficients of variation (0–0.066), while quantitative traits were relatively variable (0.086–0.156, see also Fig. 3), compared with data on different species observed in similar studies (Zbikowska-Zdun *et al.*, 2009; Coetzee, 2010). The quantitative morphological analysis provided information on the morphological variability of *C. subarcticus* species (Fig. 3) and can be used to supplement descriptions of this particular species (Trägårdh, 1902; Sellnick and Forsslund, 1952; Gilyarov and Krivolutsii, 1975; Weigmann, 2006; Murvanidze, 2008; Ermilov, 2011).

The study showed that quantitative morphological traits have to be measured on larger sample sizes to represent the true morphological variability (Figs. 4, 5). It is very important to include ranges of morphometrical values in morphological studies, including species descriptions and identification keys (Table 1; see also Cardini and Elton, 2007). When based on a small sample size, ranges of morphometri-

cal size values may not even be close to those of a large sample (i.e. sample more similar to the true natural population, see Figs. 4, 5). The results of the analysis of *C. subarcticus* morphometrical data of six traits might be extrapolated also to other oribatid taxa or even other similar little-known groups of organisms.

A larger sample size will lead to a wider range of morphological variability (including extreme specimens with very large or small sizes) (Sokal and Rohlf, 1995; Cardini and Elton, 2007, see also Fig. 5).

A larger sample size can more adequately represent morphological variability, which can be useful in description. Haarlov (1952) and Caballero *et al.* (1999) considered that a large initial population sample may expose more of the morphological variability. The very first description of a species is often limited by few specimens available at that time, and hence a low range of values for traits due to relatively small sample sizes ($n < 25$) examined (Michael, 1882; Trägårdh, 1902; Grandjean, 1931; Zakhvatkin, 1945; Grandjean, 1956; Woolley, 1957; Wallwork, 1972; Reeves, 1987; Salomone *et al.*, 2003; Fernandez *et al.*, 2013; McCullough and Krisper, 2013; see also Table 1 and Fig. 5). Frequently, relatively small sample sizes are still examined in species redescrptions (Sellnick and Forsslund, 1952; Reeves and Norton, 1990; Behan-Pelletier, 1993; Weigmann and Miko, 2002), compared to the sample size in the present study (Table 2).

The results of this study show that quantitative traits are more informative than qualitative traits, as they have a higher coefficient of variation, which were more commonly used in previous studies (Aoki, 1964; Mahunka, 1987; Ramsay and Luxton, 1967; Schubart, 1975; Norton and Kethley, 1989; Reeves and Norton, 1990; Behan-Pelletier, 1993; Caballero *et al.*, 1999; McCullough and Krisper, 2013).

In the present study *C. subarcticus* was collected from a relatively small territory and cannot represent the full habitat- and geographic-wide morphological variability. Still, the results indicated a wider size range of the total body length (L : 315–545 μm) than in morphometrical study of the same species in Central Europe (Weigmann, 2006, body length is indicated: 400–490 μm , see also Fig. 3). Identification keys contain no data on the sample size from which measurements were obtained, or these numbers are no longer available (G. Weigmann and A. Taylor, pers. comm., 2009). Total body length is the only trait that can be compared, because there are no size ranges given for other morphological traits described in the available literature (Trägårdh, 1902; Sellnick and Forsslund, 1952; Gilyarov and Krivolutsii, 1975; Weigmann, 2006; Murvanidze, 2008; Ermilov, 2011).

C. subarcticus was used in this study only as an example of how the size range is related to the sample size (Fig. 5); even with large sample size of this study, the absolute largest and smallest specimens from the natural population

(n = 500) were probably not captured. In the future, information on the coefficient of variation alongside with the size range would be useful to ensure intra-specific comparisons.

In conclusion, it is suggested that future studies dealing with quantitative morphological data, including species descriptions, redescrptions or identifications, comparability and usefulness of results can be improved by: (1) including the number (and sex, if possible) of individuals observed (Table 1); (2) using (if possible) a large sample size (n > 200) in cases when morphometrical data is added so that morphological variability is more realistically portrayed (Figs. 4, 5); (3) taking into consideration whether the description relates to a local or wide territory; and (4) when morphometry is involved, employing coefficients of variation to make results more easily comparable among different species (Table 2).

ACKNOWLEDGEMENTS

The author is thankful to Didzis Elferts (LUBF, Latvia) for provided help on statistical data analysis. The author is thankful to Raimonds Poplauskis (LU, KFI, Latvia) for advising on coating mites for SEM. The author also wishes to thank Tūrs Selga and Valters Gobiņš (both from LUBF, Latvia) for assistance during the SEM procedures. Finally, the author sincerely thanks Roy Norton (New York, USA) for his valuable comments on an earlier version of the manuscript.

This study has been supported by the European Social Fund within the project “Support for Doctoral Studies at University of Latvia”.

REFERENCES

- Alberti, G., Storch, V., Renner, H. (1981). Über den feinstrukturellen Aufbau der Milbencuticula (Acari, Arachnida). *Zool. J. Anat.*, **105**, 183–236.
- Aoki, J. (1964). A new aquatic Oribatid mite from Kauai Island. *Pac. Insects*, **6**, 483–488.
- Baran, S., Altun, A., Ayyildiz, N., Kence, A. (2011). Morphometric analysis of oppiid mites (Acari, Oribatida) collected from Turkey. *Exp. Appl. Acarol.*, **54**, 411–420.
- Baratti, M., Bernini, F. (1994). Taxonomic revision of *Carabodes coriaceus* C.L. Koch, 1836 and *C. arduinii* Valle, 1955 (Acari: Oribatida). *Acarologia*, **35**, 247–265.
- Behan-Pelletier, V. M. (1993). Eremaeidae (Acari: Oribatida) of North America. *Mem. Entomol. Soc. Can.*, **168**, 1–193.
- Berlese, A. (1916). Centuria terza di Acari nuovi. *Redia*, **19**, 289–338 (in Italian).
- Bernini, F. (1970). Nollulae Oribatologicae II. Gli Oribatei (Acarida) delle Alpi Apuane (1a serie). *Lav. Soc. Ital. Biogeog.*, **1**, 390–432 (in Italian).
- Bernini, F., Baratti, M. (1991). Notulae Oribatologicae LIII. *Carabodes intermedius* Willman, 1951 (Acarida, Oribatida) new findings in Italy. *Redia*, **74** (1), 211–223.
- Caballero, A. I., Iturrondobetia, J. C., Saloña, M. I. (1999) A biometrical study of *Berniniella serratirostris* (Acari: Oribatei) and some related species. In: Bruin, J., van der Geest, L. P., Sabelis, M. W. (eds.). *Ecology and Evolution of the Acari*. Kluwer Academic Publishers, Dordrecht, pp. 569–579.
- Cao, Y., Hawkins, C. P., Vinson, M. R. (2003). Measuring and controlling data quality in biological assemblage surveys with special reference to stream benthic macroinvertebrates. *Freshwater Biol.*, **48**, 1898–1911.
- Cardini, A., Elton, S. (2007). Sample size and sampling error in geometric morphometric studies of size and shape. *Zoomorphology*, **126**, 121–134.
- Coetzee, L. (2010) Species or morphological variation? A multivariate morphometric analysis of *Afrozeius simplex* (Acari: Oribatida: Haplozetidae). In: Sabelis, M. W., Bruin, J. (eds.). *Trends in Acarology. Proceedings of the 12th International Congress*. Dordrecht, Springer, pp. 267–269.
- Dabert, M. (2006). DNA markers in the phylogenetics of the Acari. *Biological Lett.*, **43** (2), 97–107.
- Dunger, W., Fiedler, G., Fiedler, H. J. (1997). *Methoden der Bodenbiologie*. Gustav Fischer Verlag, Jena. 539 pp.
- Eeva, T., Penttinen, R. (2009). Leg deformities of oribatid mites as an indicator of environmental pollution. *Sci. Total Environ.*, **407**, 4771–4776.
- Eglitis, V. (1943). Material zur Oribatidenfauna Lettlands. *Folia Zoologica et Hydrobiologica*, **12** (1), 122–128.
- Ermilov, S. G. (2011). The biology of the development of the oribatid mite *Carabodes subarcticus* (Oribatida: Carabodidae). *Zool. Zhurnal*, **90** (6), 665–673.
- FAO WRB (2006). *World Reference Base for Soil Resources 2006: A Framework for International Classification, Correlation and Communication*. Rome: Food Agriculture Organization of the United Nations. 128 pp.
- Fernandez, N., Theron, P., Rollard, C. (2013). The family Carabodidae (Acari: Oribatida) I. Description of a new genus, *Bovicarabodes* with three new species, and the redescription of *Hardybodes mirabilis* Balogh. *Int. J. Acarol.*, **39** (1), 26–57.
- Fujikawa, T. (1999). Individual variations of two reared oribatid species, *Tectocepheus velatus* (Michael, 1880) and *Oppiella nova* (Oudemans, 1902). *Edaphologia*, **62**, 11–46.
- Gilyarov, M. C., Krivolutsii, D. A. (1975). *Sarcoptiformes. Identification Guide to Soil Inhabiting Mites* [Гиляров М. С., Криволюцкий Д. А. Определитель обитающих в почве клещей (Sarcoptiformes)]. Nauka, Moscow, 491 pp.
- Grandjean, F. (1931). Observations sur les Oribates (1^{re} ser.). *Bull. Mus. Nat. His. Nat.* (2), 3, 131–144.
- Grandjean, F. (1952). Sur les variations individuelles. Vertitions (ecarts) et anomalies. *C. R. Acad. Sci. Paris*, III ser., **235**, 640–643.
- Grandjean, F. (1956). Observations sur les Galumnidae. I sér. (Acariens, Oribates). *Rev. Fr. Entomol.*, **23**, 137–146.
- Griffiths, D. A., Macfarlane, D., Sheals, J. G. (1971). The scanning electron microscope in Acarology. *Ann. Zool. Ecol. Anim.*, **3** (1), 49–55.
- Haarlov, N. (1952). Systematics and ecology of the genus *Tectocepheus* Berlese, 1896 (Acarina). *Entomol. Meddr.*, **26** (5), 424–427.
- Heethoff, M., Laumann, M., Weigmann, G., Rasputnig, G. (2011). Integrative taxonomy: Combining morphological, molecular and chemical data for species delineation in the parthenogenetic *Trhypochthonius tectorum* complex (Acari, Oribatida, Trhypochthoniidae). *Front. Zool.*, **8**, 2.
- Jonathan, B. (1984). *The Complete Works of Aristotle: The revised Oxford Translation*. Princeton University Press, Princeton. 1256 pp.
- Kagainis, U. (2010). *Carabodes rugosior* Berlese, 1916 and *C. subarcticus* Trägårdh, 1902 – new species of oribatid mites (Acari: Oribatida: Carabodidae) for fauna of Latvia, with brief discussion of their microscoping. *Latvijas Entomologs*, **48**, 115–117.
- Kagainis, U. (2014). A morphometrical study of oribatid mites (Acari: Oribatida) of the genus *Carabodes* CL Koch, 1835 (Carabodidae) using a Confocal Laser Scanning Microscope — an alternative approach to quantitative analysis of various features. *Zoomorphology*, **133** (2), 227–236.

- Koch, C. L. (1835). *Deutschlands Crustaceen, Myriapoden und Arachniden*. Regensburg, Heft 3.
- Kochyńska, M., Olszanowsky, Z. (2008). The abnormal morphology of the oribatid mite from the genus *Platynothrus* (Acari: Oribatida: Camisiidae). *Acarologia*, **48** (1–2), 111–114.
- Lee, K. H., Yu, H. S., Park, S. K., Lee, S. J., Lee, K. A., Kim, S. M., Ock, M. S., Jeong, H. J. (2006). Phylogeny of mite taxa (Acari: Sarcoptiformes) based on small subunit ribosomal RNA sequences. *J. Life Sci.*, **16** (1), 71–75.
- Lindblom, L. (2009). Sample size and haplotype richness in population samples of the lichen-forming ascomycete *Xanthoria parietina*. *Lichenologist*, **41** (5), 529–535.
- Linnaeus, C. (1758). *Systema naturæ per regna tria naturæ, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis* (10th ed.). Laurentius Salvius, Stockholm. 824 pp.
- Mahunka, S. (1987). A survey of the family Carabodidae CL Koch, 1836 (Acari: Oribatida), II. *Acta Zool. Hung.*, **33**, 399–434.
- Manly, B. F. J. (2007). *Randomization, Bootstrap and Monte Carlo Methods in Biology*. Chapman & Hall/CRC, Boca Raton. 326 pp.
- McCullough, E., Krisper, G. (2013). Morphological analysis of the oribatid mite species *Scutovertex pannonicus* Schuster and description of its juvenile stages (Acari: Oribatida: Scutoverticidae). *Zootaxa*, **3619** (3), 201–245.
- Michael, A. D. (1882). Further notes on British Oribatidae. *J. Roy. Microsc. Soc.*, **2** (2), 1–18.
- Monson, F. D. (2009). A new species of the genus *Carabodes* C. L. Koch, 1835 (Acari: Oribatida: Carabodidae) from the British Isles. *Naturalist*, **134**, 99–107.
- Murvanidze, M. (2008). Checklist and key to species of *Carabodes* (Acari, Oribatida, Carabodidae) of Caucasian region, with description of a new species. *Acarina*, **16** (2), 177–186.
- Norton, R. A. (1978). Notes on Nathan Banks' species of the mite genus *Carabodes* (Acari: Oribatei). *Proc. Entomol. Soc. Wash.*, **80** (4), 611–615.
- Norton, R. A. (1994). Evolutionary aspects from oribatid mite life histories and consequences for the origin of the Astigmata. In: Houck, M. (Ed.). *Mites. Ecological and Evolutionary Analyses of Life-History Patterns*. Chapman & Hall, New York, pp. 99–135.
- Norton, R. A., Kethley, J. B. (1989). Berlese's North American oribatid mites: Historical notes, recombinations, synonymies and type designations. *Redia*, **67**, 421–499.
- Peres-Neto, P., Legendre, P., Dray, S., Borcard, D. (2006). Variation partitioning of species data matrices: Estimation and comparison of fractions. *Ecology*, **87** (10), 2614–2625.
- Prinzling, A., Lentzsch, P., Voigt, F., Woas, S. (2004). Habitat stratification stratifies a local population: Ecomorphological evidence from a bisexual, mobile invertebrate (*Carabodes labyrinthicus*: Acari). *Ann. Zool. Fennici*, **41**, 399–412.
- R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. Retrieved 15 October 2014, from R-project <http://www.R-project.org/>.
- Rajski, A. (1968). Autecological-zoogeographical analysis of moss mites (Acari, Oribatei) on the basis of fauna in the Poznań environs. Part II. *Fragm. Faun.*, **14** (12), 277–405.
- Ramsay, G. W., Luxton, M. (1967). A redescription of the type specimen of *Crotonia* (=Acronothrus) *obtecta* (O. Pickard-Cambridge, 1875), (Acari, Cryptostigmata) and a discussion of its taxonomic relationships. *J. Nat. Hist.*, **4**, 473–480.
- Randal, P. J., Myers, A. A. (2001). Effects of resource matrix, gut region analysed and sample size on diet statistics in co-existing species of flatfish. *J. Mar. Biol. Ass. U. K.*, **81**, 1041–1048.
- Reeves, R. M. (1987). A new arboreal *Carabodes* from eastern North America (Acari: Oribatida: Carabodidae). *Proc. Entomol. Soc. Wash.*, **89** (3), 468–477.
- Reeves, R. M., Norton, R. A. (1990). Berlese's North American species of *Carabodes* (Oribatida: Carabodidae). *Int. J. Acarol.*, **16** (4), 191–199.
- Reeves, R. M. (1988). Distribution and habitat comparisons for *Carabodes* collected from conifer branches with descriptions of *brevis* Banks and *higginsii* n. sp. (Acari: Oribatida: Carabodidae). *Proc. Entomol. Soc. Wash.*, **90** (3), 373–392.
- Reeves, R. M. (1990). Two new species of *Carabodes* (Acari: Oribatida: Carabodidae) from North America. *Can. J. Zool.*, **68**, 2158–2168.
- Reeves, R. M. (1991a). *Carabodes niger* Banks, *C. polyporetetes* n. sp. and unverified records of *C. areolatus* Berlese (Acari, Oribatida, Carabodidae) in North America. *Can. J. Zool.*, **69**, 2925–2934.
- Reeves, R. M. (1991b). Jacot's *Carabodes falcatus* and *Carabodes clavatus* redescribed (Acari: Oribatida: Carabodidae). *Int. J. Acarol.*, **17**, 233–240.
- Reeves, R. M. (1993). New *Carabodes* (Acari: Oribatida: Carabodidae) from the southern Appalachian Mountains, USA. *Acarologia*, **34** (4), 363–376.
- Reeves, R. M. (1995). New *Carabodes* from the Eastern United States (Acari: Oribatida: Carabodidae). *Acarologia*, **36** (1), 83–92.
- Salomone, N., Avanzati, A. M., Baratti, M., Bernini, F. (2003). Genetic and morphological analysis of some European species of the "coriaceus group" of *Carabodes* Acari, Oribatida, Carabodidae) and description of *C. tyrrhenicus* sp. nov. *Zool. Anz.*, **242**, 121–136.
- Schatz, H. (2004). Diversity and global distribution of oribatid mites (Acari, Oribatida) — evaluation of the present state of knowledge. *Phytophaga*, **14**, 485–500.
- Schneck, F., Melo, A. S. (2010). Reliable sample size for estimating similarity among macroinvertebrate assemblages in tropical streams. *Int. J. Limn.*, **46**, 93–100.
- Schubart, H. (1975). Morphologische Grundlagen für die klärung der Verwandtschaftsbeziehungen innerhalb der Milberfamilie Ameronothridae (Acari, Oribatei). *Zoologica*, **123**, 23–91.
- Seddon, P. J., Ismail K., Shobrak, M., Ostrowski, S., Magin, C. (2003). A comparison of derived population estimate, mark-resighting and distance sampling methods to determine the population size of a desert ungulate, the Arabian oryx. *Oryx*, **37**, 286–294.
- Sellnick, M., Forsslund, K. H. (1952). Die Gattung *Carabodes* CL Koch, 1836 in der schwedischen Bodenfauna (Acar. Oribat.). *Arkiv Zoologie*, **4**, 367–390.
- Sidorchuk, E. A. (2009). New data on the fauna of oribatid mites (Acari, Oribatida) from the Polar Urals. *Zool. Zhurnal*, **88** (7), 800–808.
- Sokal, R. R., Rohlf, F. J. (1995). *Biometry*. W. H. Freeman and Co, New York. 887 pp.
- Solhøy, T., Koponen, S. (1981). Oribatei fauna (Acari) on alpine heath at Kevo, Finland. *Rep. Kevo Subarct. Res. Stn.*, **17**, 41–43.
- Subías, L. S. (2004). Listado sistemático, sinónimo y biogeográfico de los ácaros oribátidos (Acariformes, Oribatida) del mundo (1758–2002). *Graellsia*, **60**, 3–305.
- Tarba, Z. M., Semenova, L. M (1976). Cuticle structure of the Oribatei in relation to their ecology. *Pedobiologia*, **16**, 127–135.
- Trägårdh, I. (1902). Beiträge zur Kenntniss der schwedischen Acaridenfauna. I. Lappländische Trombidiiden und Oribatiden. *Bihang till Kongliga Svenska Vetenskaps-akademiens handlingar*, **28**, 1–26.
- Wallwork, J. A. (1912). Mites and other microarthropods from the Joshua Tree National monument, California. *J. Zool.*, **168**, 91–105.
- Weigmann, G. (2006). *Hornmilben (Oribatida)*. Die tierwelt Deutschlands. Goecke & Evers, Keltern. 520 pp.
- Weigmann, G. (2010). Anomalies of notogastral structures in poronotic oribatid mites (Oribatida: Poronota) interpreted as cryptic ancestral

- characters modulated by regulatory genes. In: Sabelis, M. W., Bruin, J. (eds.). *Trends in Acarology. Proceedings of the 12th International Congress*. Dordrecht, Springer Science, pp. 17–22.
- Weigmann, G., Miko, L. (2002). Redescription of *Oribates lagenula* Berlese, 1904, the type of *Lagenobates* n.gen. (Acarina Oribatida). *Redia*, **85**, 29–35.
- Wierzbicka, A., Olszanowski, Z. (2004). Preliminary studies on mites from families Nothridae, Camisiidae and Carabodidae (Acari, Oribatida) in experimental plots of the Siemianice experimental forest station. *Scientific Papers of Agricultural University of Poznań*, **7**, 75–80.
- Willmann, C. (1931). Moosmilben oder Oribatiden (Cryptostigmata). In: Hahl, F. (Ed.). *Die Tierwelt Deutschlands. Bd. 22*. Fisher, Jena, pp. 79–200.
- Woolley, T. A. (1957). Redescriptions of Ewing's oribatid mites, IV – Family Achipteridae (=Notaspidae) (Acarina: Oribatei). *Entomol. News*, **68**, 177–182.
- Zakhvatkin, A. A. (1945). *On the discovery of Palaeacariformes (Acvarina) in the USSR* [Захваткин, А. А. О нахождении Palaeacariformes (Acarina) в СССР]. Dokl. Acad. Sci. USSR [Докл. АН СССР. Н. С. Т.], **47** (9), 702–705 (in Russian).
- Zbikowska-Zdun, K., Piksa, K., Smaczynska, A. (2009). Variation of selected morphological characters of the cave mite *Oribella cavatica* Kunst, 1962 (Acari, Oribatida). *Biol. Lett.*, **46** (2), 123–127.

Received 6 January 2015

Carabodes subarcticus Trägårdh, 1902 (Acari: Oribatida: Carabodidae) BRUŅĒRČU TAKSONOMIJĀ PLAŠĀK PIELIETOTO PAZĪMJU MORFOLOĢIJAS MAINĪBAS KVANTITATĪVA UN KVALITATĪVA ANALĪZE RELATĪVI LIELĀ PARAUGKOPĀ

Oribatidērcu un līdzīgu mazispētītu organismu grupu augsta morfoloģijas mainība būtiski apgrūtina salīdzinošu morfoloģiska rakstura pētījumu, kā piemēram, sugu aprakstu, izstrādi. Kvalitatīvu pazīmju analīze līdz šim tikusi veikta, izmantojot pārsvarā relatīvi mazas paraugkopas ($n < 25$). Līdz šim nepilnīgi izpētīti jautājumi par paraugkopas lieluma ietekmi uz morfoloģijas mainības aprēķināšanas objektivitāti, kā arī kvalitatīvās un kvantitatīvās analīzes lietošanu morfoloģiska rakstura pētījumos salīdzinošā kontekstā. Tika ievākta relatīvi liela paraugkopa ($n = 500$) ar *Carabodes subarcticus* Trägårdh, 1902 bruņērcu pieaugušiem īpatņiem lokālā populācijā Slīteres nacionālajā parkā, Latvijā. Izmantojot gaismas mikroskopiju un elektronu skenējošo mikroskopiju, morfoloģiski tika raksturotas un salīdzinātas sešas kvalitatīvas un sešas kvantitatīvas pazīmes. Tika raksturota radniecība starp ievāktās pamata populācijas un randomizētu (10 000 atkārtojumu) subpopulāciju bruņērcu morfoloģijas mainību. Tika aprēķināta procentuālā iespējamība gadījumiem, kuros pazīmju izmēra amplitūda atšķīrās (par 10%; 25% vai 50%) no pamata populācijas reālās izmēra amplitūdas. Kvalitatīvās pazīmes tika raksturotas ar relatīvi zemu mainību, kas būtiski atšķīrās no relatīvi augstas kvantitatīvo pazīmju mainības, un tādējādi ir uzskatāmas par vājāk salīdzināmām un interpretatīvām morfoloģijas mainības pētījumos. Izmantojot relatīvi mazas paraugkopas ($n < 25$), 2–15% gadījumu morfoloģiskā mainība, šajā gadījumā – pazīmju izmēru amplitūdas, atšķīrās tikai par 10% no pamata populācijas reālās pazīmju izmēru amplitūdas. Veicot mērījumus graduāli arvien lielākām paraugkopām, izmēru amplitūdas procentuālā atbilstība pamata populācijai graduāli palielinājās. Rezultāti liecina, ka *C. subarcticus* morfoloģijas mainības pētījumos lielāka nozīme ir kvantitatīvai, nevis kvalitatīvai analīzei, kas līdz šim izmantota kā pamata metode un kas morfoloģijas mainību ilustrē vājāk, kā arī ir subjektīvāk interpretējama.