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The crustacean fauna of Bayan Onjuul area (Tôv Province, Mongolia) (Crustacea: Branchiopoda, Copepoda, Ostracoda)

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Abstract. Due to the wide extension of the country and to the shortness of the ice-free season, the inland-water crustacean fauna of Mongolia is, to date, incompletely known. However, based on the available literature, Mongolian inland waters appear to be characterised by a high biodiversity, including some taxa still waiting to be described. Novel data on the branchiopod, copepod, and ostracod crustaceans from central Mongolian steppe, from the "Tuul" and "Umard goviin guveet-Khalhiin" hydrographical basins, are presented herein. While large branchiopods, some anomopod families, and copepods are well-represented in the collected samples, ostracods are rare, and the anomopod family Chydoridae is apparently absent in the sampled water bodies. The anomopod *Macrothrix dadayi* and the cyclopoid *Microcyclops afghanicus* are here reported for the first time for the Mongolian fauna. Furthermore, two branchiopods (i.e. *Moina* sp. and *Artemia* sp.), three copepods (i.e. *Diacyclops* sp., *Arctodiaptomus* cf. *alpinus*, and *Arctodiaptomus* cf. *wierzejskii*), and one ostracod taxon (i.e. *Heterocypris* sp.), were not identified to species level and therefore deserve further study. The main ecological determinants of species distribution in the study area were examined using canonical multivariate analysis, which explained around 40% of total variation of the species similarity matrix; the main environmental drivers of crustacean assemblages in the study area were elevation, water turbidity, water temperature and electrical conductivity. The ecological preferences of crustacean species in the area are briefly discussed.

Key words: biodiversity, zoogeography, central Asia, *Macrothrix dadayi*, *Microcyclops afghanicus*, *Arctodiaptomus* spp.

Introduction

The first studies on the non-malacostracan crustaceans of Mongolia date back to the beginning of the XX century (e.g. Sars 1901, Daday 1901, 1913) and led to the description of a rich and diversified fauna. In the last decades, several contributions to the knowledge of Mongolian crustaceans were published (e.g. Brtek et al. 1984, Flössner 1986, Martens 1991, Horn & Paul 2004, Flössner et al. 2005; Van der Meeren et al. 2009, 2010, Krylov 2012) but, with few exceptions (e.g. Naganawa & Zagas 2002, Alonso 2010), these were based on scattered data collected in restricted areas, so that a synopsis of Mongolian crustacean fauna is to date missing. This gap of knowledge is largely due to the great extension of the country and to the shortness of the ice-free season, the only period when sampling activity is possible; furthermore, some areas are just not easily accessible, thus making the realisation of a country-wide sampling coverage even harder. Recently, a research project realised by one of us (MA) in the framework of the project "Biodiversity of Crustacea Entomostraca in the Palaearctic" faced the challenge of describing the diversity and ecology of Mongolian crustaceans, and led to the description of several new branchiopod taxa (e.g. Alonso & Naganawa 2008, Sinev et al. 2009, Alonso & Ventura 2013), thus confirming the exceptional interest of the Mongolian inland-water crustacean fauna.

This paper provides further data on the crustacean fauna of Mongolia, focusing on the Bayan Onjuul area of the Tôv Province (Central Mongolia).

Material and methods

The eighteen sampled sites are located in the Tôv Province, approximately 120 km south of Ulaanbaatar, and lie

Table 1. List of sampled sites. See text for details. (1) Code in the page <http://oslo.geodata.es/mongolian_lakes/map/mongolia-map.php?lang=e> of the "Limnological Catalogue of Mongolian Lakes" <http://www.geodata.es/mongolian_lakes/>. "n.a.": not applicable.

Code	Code (1)	Name	Sampling date (dd/mm/yy)	Latitude (N, WGS84)	Longitude (E, WGS84)	Altitude (m a.s.l.)	Area (ha)	Cond (µS/cm)	Temp (°C)	Turb	Macr
MNG001	136 TU	Khar nuur	12/08/12	46.819167	105.913611	1269	505	1925	27	1.5	2.5
MNG002	540 TU	Khalzangiin goliin toirom 7	13/08/12	47.072500	105.841111	1157	1,6	2270	16	3	1
MNG003	545 TU	Khalzangiin goliin toirom 11	13/08/12	47.073611	105.845833	1157	4,4	16000	21	1.5	1
MNG004	531 TU	Khangai nuur	15/08/12	46.921111	105.888333	1252	8,1	2460	25	2.5	1
MNG005	537 TU	Shiliin nuuriin toirom 6	16/08/12	47.008889	106.131111	1321	0.3	1750	21	2	1
MNG006	537 TU	Shiliin nuuriin toirom 6	16/08/12	47.007500	106.129722	1320	0.3	2850	26	2	2
MNG007	541 TU	Shiliin nuuriin toirom 8	16/08/12	46.994444	106.135556	1331	1.4	1100	25.5	3	1
MNG008	542 TU	Khalzangiin goliin toirom 8	18/08/12	47.080278	105.873333	1165	1.2	1995	18.7	3	1
MNG009	543 TU	Khalzangiin goliin toirom 9	18/08/12	47.093333	105.715278	1128	0.9	3550	19	3	1
MNG010	544 TU	Khalzangiin goliin toirom 10	18/08/12	47.082778	105.758333	1135	0.5	21350	18.2	1	2
MNG011	139 TU	Khar nuuriin toirom 3	19/08/12	46.778611	105.919444	1279	11.0	1800	9.7	3	2
MNG012	538 TU	Khalzangiin goliin toirom 6	21/08/12	47.066389	105.791944	1152	6.4	880	20	3	1
MNG013	539 TU	Khalzangiin gollin toirom 7	21/08/12	47.075833	105.799167	1146	2.6	1750	19.5	2.5	2
MNG014	132 TU	Khalzangiin goliin toirom 3	23/08/12	47.076111	105.853889	1159	13.0	2860	20	3	1.5
MNG015	546 TU	Khalzangiin goliin toirom 12	23/08/12	47.074167	105.854722	1161	1.1	2160	22	3	1
MNG016	547 TU	Khalzangiin goliin toirom 13	24/08/12	47.080833	105.955000	1187	3.5	5490	19	3	1
MNG017	548 TU	Khalzangiin goliin toirom 14	24/08/12	47.071944	105.853056	1161	0.7	n.a.	n.a.	n.a.	n.a.
MNG018	148 TU	Baraatiin toirom 2	25/08/12	46.810724	106.295684	1426	11.9	n.a.	n.a.	n.a.	n.a.

in the central Mongolian steppe, in the "Tuul" and "Umard goviin guveet-Khalhiin" hydrographical basins (Tab. 1). The sampled sites occur at altitudes comprised between 1,150 and 1,430 m a.s.l., and the whole area is characterized by a typical continental climate, with important seasonal annual variation in temperature; the mean annual temperature is comprised between 0 and -2 °C (ranging from 18 °C in July to -22 °C in January), and the average precipitation, mostly concentrated from May to September, is about 270 mm y^{-1} (UNEP 2009).

Sampling was carried out in August 2012, upon the acquisition of a sampling permission by the Department of Environment and Natural Resources Management of the Ministry of Nature, Environment and Tourism of Mongolia (authorization #0000053 dated July 19th, 2012).

A 200 µm mesh-sized hand net was used to sample along shorelines and swept through submerged vegetation, when this was present. Open waters were sampled by means of a 125 µm mesh-sized towing net. In those sites where, due to their shallowness, the use of nets was not possible, water samples were collected with a beaker and filtered with a 200 µm mesh-sized sieve. Finally, a 500 µm mesh-sized hand net was used to collect the so-called "large branchiopods" (Branchiopoda: Anostraca, Notostraca, Spinicaudata), which are known to be able to actively avoid thicker nets. Attention was paid to collecting crustacean samples in all the microhabitats present in each sampled site.

Two water bodies (MNG017 and MNG018, see codes in Tab. 1) were completely dry at the sampling date, so that core samples were collected and later cultured in laboratory.

Collected samples were fixed *in situ* in 90% ethanol, and sorted in laboratory under a dissecting stereomicroscope. Copepods were identified according to Kiefer (1978), Borutzky et al. (1991), Ranga-Reddy (1994), Alekseev (2000), and Ueda & Reid (2003); branchiopods according to Daday (1914), Longhurst (1955), Alonso (1996),

Van Damme et al. (2004), and Alonso & Naganawa (2008); ostracods according to Martens (1991), Meisch (2000), and Zhai & Zhao (2014); some further references were consulted for the most problematic taxa.

Undissected crustacean specimens were stored in 95% ethanol, dissected soft parts in sealed microscope slides, and ostracod valves were stored dry in micropaleontological slides in the authors' crustacean collections; all samples are available for loan on request.

In each site, electrical conductivity and water temperature were recorded. Three arbitrary qualitative classes were used to estimate water turbidity (from 1: crystal-clear water, to 3: extremely turbid water), and the abundance of macrophytes (from 1: no macrophytes, to 3: macrophytes extremely developed, absence of open waters). Geographical coordinates and elevation were recorded using a GPS.

Relationships between crustacean assemblages and environmental variables (data were previously normalized) were assessed by a distance-based redundancy analysis (dbRDA) applied to a Sorensen's similarity species matrix. dbRDA was performed using PRIMER-E software (Clarke & Gorley 2006) with the add-on package PERMANOVA+ (Anderson et al. 2008).

Our database of sampled sites was compared with that of the "Limnological Catalogue of Mongolian Lakes" (http://www.geodata.es/mongolian_lakes/), and the correspondence among the codes used in the frame of our survey and those used in the Catalogue is reported in Table 1. A novel code was attributed to those sites which were to date not included in the "Limnological Catalogue of Mongolian Lakes" (http://oslo.geodata.es/mongolian_lakes/map/mongolia-map.php?lang=e).

Results and discussion

Out of the 16 sites sampled during their wet phase, 14 were characterised by low to medium electric conductivity values (i.e. those ranging from 880 to 5,490 µS cm^{-1}); conversely, the sites MNG003 and MNG010 were more saline (16,000 and 21,350 µS cm^{-1}, respectively) (Tab. 1). Based on the branchiopod species hatched in laboratory cultures (see below, and Tab. 2), it is possible to infer that MNG017 and MNG018, which were dry at the sampling dates, are to be ascribed to the group of less mineralised ponds (see below).

The results of the distance-based redundancy analysis (dbRDA), limited to the first two axes (explained variance in the fitted relationship between environmental/spatial variables and species distribution: 74.7%; explained total variance: 39.8%) are reported in Fig. 1. The main spatial and environmental drivers of species assemblages and distribution can be identified (Fig. 1b). The first axis (explained variation 23%, and over 43% of the fitted variation) arranges the site along a latitudinal and altitudinal gradient, from the lower (including saline) lakes to southern sites located at higher elevations. The second axis (explained variation 16.8%, explained fitted variation 31.5%) is a gradient from larger and warmer water bodies, rich in macrophytes, and smaller sites with higher turbidity. Electrical conductivity clearly separates lower elevation, mineralised water bodies from the other sites.

On the basis of the results of the canonical multivariate analysis, the taxa collected can be divided into different groups: a first one including species exclusively found in the more mineralised water bodies (i.e. *Artemia* sp., *Phallocryptus tserensodnomi*, *Branchinectella media*, and *Moina salina*); a second group including a few euryhaline taxa (i.e. *Ilyocypris mongolica*, *Thermocyclops kawamurai*, and *Metadiaptomus asiaticus*); a third one including taxa found in the frame of this survey only in larger and warmer sites (like *Moina brachiata*, *Daphnia magna*, and *Microcyclops afghanicus*); a fourth group including species found in smaller, turbid water bodies (*Branchipodopsis affinis, Eocyzicus davidi,* and *Moina* sp.), and finally one species (*Arctodiaptomus* cf. *wierzejskii*) found mainly in higher elevation, poorly mineralized sites.

During the survey, the large branchiopod assemblage observed in the less mineralised ponds is characterised by the presence of the anostracan *Branchipodopsis affinis*, the notostracan *Triops granarius* (but see: Korn et al. 2013), and the spinicaudatan *Eocyzicus davidi*, sometimes associated with the less common anostracans *Galaziella mongoliana* and *Branchinecta orientalis*. Conversely, the more mineralised ponds host a rather typical halophilous branchiopod assemblage, which includes anostracan species belonging to the genera *Phallocryptus*, *Artemia*, and *Branchinectella*, in good agreement with the halophilous assemblages occurring in the west-Palaearctic area, where the Mongolian species are usually replaced by west-Palaearctic vicariants (e.g. Alonso 1990, Alonso 2010, Thiéry & Puente 2002, Samraoui et al. 2006, Belmonte et al. 2012).

Four *Moina* species were recorded (Tab. 2). One of them could not be identified at species level and might belong to a yet undescribed species. Pending further studies, it is reported in Tab. 2 as *Moina* sp. All the other anomopod species were already known to occur in Mongolia (cf. Brtek et al. 1984, Flössner 1986, Flössner et al. 2005, Alonso 2010), with the exception of the macrothri-

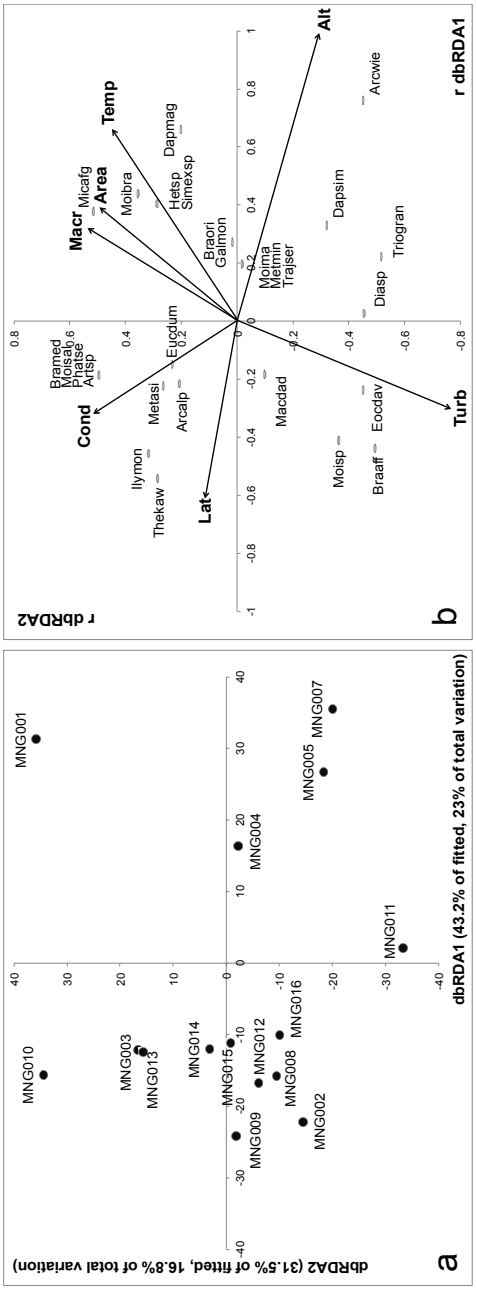

Figure 1. Results of the distance-based Redundancy Analysis (dbRDA); ordination diagrams use the first two axes (explained fitted variance: 74.7%; explained total variance: 39.8%). (a) Ordination of sampling sites (codes as in Table 1); (b) ordination of crustacean species and environmental factors, based on Pearson's correlation coefficients with dbRDA axes. Species acronyms formed combining the first three letters of genus and the first three letter of species names (sp. if unidentified; species list reported in Table 2). Environmental factors codes: Alt = altitude; Temp = water temperature; Cond = electrical conductivity; Turb = turbidity; Macr = aquatic macrophytes coverage; Area = lake area; Lat = latitude (see Table 1 for details)..

cid *Macrothrix dadayi*. However, it has to be stressed that, as already suggested by Behning (1941) and Kotov (2008), it is possible that the taxon reported for China and Mongolia as *Macrothrix spinosa* by Daday (1901) might, in fact, be *Macrothrix dadayi*.

Five cyclopoid species were recorded. Among them, *Eucyclops dumonti* and *Thermocyclops kawamurai* are rather widespread in Mongolia and China (Alekseev 2000, Dussart & Defaye 2006, Alonso 2010); *Microcyclops afghanicus* is widely distributed in Central Asia, from Afghanistan to China (Mirabdullayev et al. 1997, Dussart & Defaye 2006), and *Metacyclops minutus* is a widely-distributed, sub-cosmopolitan species (Dussart & Defaye 2006, Alonso 2010), although it is quite likely that it is actually a "*Rassenkreis*", i.e. that under this name are actually concealed a number of closely related and morphologically similar species. Unfortunately, due to the scarcity of the available material, it was not possible to identify to species level the *Diacyclops* species collected in MNG011. The cyclopoid taxa identified to species level are typical elements of the copepod fauna of Central Asia. *Microcyclops afghanicus* is a new record for Mongolia, although its presence in the country was expected as the species is known to occur in the neighbouring China and Kazakhstan, as well as Tuva and other parts of southern Siberia (Dussart & Defaye 2006).

Three calanoid copepods were collected. *Metadiaptomus asiaticus* is one of the few diaptomid species belonging to the subfamily Paradiaptominae which are known to occur outside of Africa (e.g. Marrone & Naselli-Flores 2005, Alfonso & Belmonte 2013, and references therein). Its distribution range includes Eurasian steppes from Mongolia to Ukraine (Dussart & Defaye 2002, Alonso 2010, Samchyshyna 2011) where, thanks to its euryhalinity, it inhabits water bodies ranging from hyposaline to hypersaline. A species close to *Arctodiaptomus* (*Rhabdodiaptomus*) *alpinus* was collected in two eutrophic ponds in the Tuul basin (MNG013 and MNG014). Although this last species was already reported for Mongolia (Flössner 2001, Flössner et al. 2005), the occurrence in the country of this European taxon typical of high-

Table. 2. Checklist of collected taxa. * "*Chirocephalus mongolianus*" according to Rogers (2013). § first record for the Mongolian fauna.

Taxa	Occurrence sites
Branchiopoda	
Order Anostraca	
Family Artemiidae	
Artemia sp.	MNG010
Family Branchipodidae	
Branchipodopsis affinis Sars, 1901	MNG002, MNG008, MNG009, MNG011, MNG016, MNG017
Family Chirocephalidae	
Galaziella mongoliana (Uéno, 1940)*	MNG006, MNG016
Branchinectella media (Schmankevitsch, 1873)	MNG010
Family Branchinectidae	
Branchinecta orientalis G.O. Sars, 1901	MNG006, MNG016, MNG018
Family Thamnocephalidae	
Phallocryptus tserensodnomi Alonso & Ventura, 2013	MNG003, MNG010
Order Spinicaudata	
Family Cyzicidae	
Eocyzicus davidi (Simon, 1886)	MNG002, MNG004, MNG006, MNG008, MNG009, MNG011, MNG012, MNG015, MNG016, MNG017
Order Notostraca	
Family Triopidae	
Triops granarius (Lucas, 1864)	MNG002, MNG004, MNG005, MNG006, MNG008, MNG011, MNG016,MNG018
Order Anomopoda	
Family Daphniidae	
Daphnia (*Ctenodaphnia*) *magna* Strauss, 1820	MNG001, MNG005, MNG006, MNG007, MNG013, MNG014
Daphnia (*Ctenodaphnia*) *similis* Claus, 1876	MNG004,MNG006, MNG007, MNG008, MNG011, MNG013MNG016, MNG018
Simocephalus exspinosus (DeGeer, 1778)	MNG001, MNG007, MNG013
Family Moinidae	
Moina brachiata (Jurine, 1820)	MNG001, MNG003, MNG006, MNG007, MNG013, MNG017
Moina macrocopa (Strauss, 1819)	MNG004
Moina salina Daday, 1888	MNG010
Moina sp.	MNG008, MNG009, MNG011, MNG012, MNG015, MNG017, MNG018
Family Macrothrichidae	
Macrothrix dadayi Behning, 1941§	MNG015, MNG016, MNG017,
Copepoda	
Order Calanoida	
Family Diaptomidae	
Subfamily Paradiaptominae	
Metadiaptomus asiaticus (Uljanin, 1875)	MNG010, MNG016, MNG018
Subfamily Diaptominae	
Arctodiaptomus (*Arctodiaptomus*) cf. *wierzejskii* (Richard, 1888)	MNG004, MNG005, MNG006, MNG007, MNG011,
Arctodiaptomus (*Rhabdodiaptomus*) cf. *alpinus* (Imhof, 1885)	MNG013, MNG014
Order Cyclopoida	
Family Cyclopidae	
Microcyclops afghanicus Lindberg, 1948§	MNG001
Thermocyclops kawamurai Kikuchi, 1940	MNG002, MNG009, MNG010, MNG013, MNG014
Metacyclops minutus (Claus, 1863)	MNG004
Diacyclops sp.	MNG011
Eucyclops dumonti Alekseev, 2000	MNG013

Continued on the next page

Table. 2. (continued).

Taxa	Occurrence sites
Ostracoda	
Order Podocopa	
Family Ilyocyprididae	
Ilyocypris mongolica Martens, 1991	MNG008, MNG009, MNG010, MNG013
Family Cyprididae	
Trajancypris serrata (G.W. Müller, 1900)	MNG004
Heterocypris sp.	MNG001, MNG007, MNG013

altitude oligotrophic ponds is rather odd. In the light of the morphological conservatism of diaptomid copepods (e.g. Marrone et al. 2010, 2013 but see also Marrone & Naselli-Flores 2004; Alfonso & Belmonte 2014), and of a pronounced intra-population variability of some key characters observed in the sampled populations, the possibility that the Mongolian populations currently assigned to *Arctodiaptomus alpinus* might actually represent a different, undescribed species deserves to be investigated with a combined morphological and molecular approach. Accordingly, in the frame of this paper we report the species as *Arctodiaptomus* cf. *alpinus* (Tab. 2).

Several specimens belonging to an *Arctodiaptomus* species closely resembling *Arctodiaptomus* (*Arctodiaptomus*) *wierzejskii* (Richard, 1888) were collected in five water bodies. All the sampled populations of this taxon consistently differ from typical *A. wierzejskii* in the chaetotaxy of the first antennae in both sexes, which is a taxonomically-important character in diaptomids (e.g. Kiefer 1978, Borutzky et al. 1991, Marrone et al., 2014). Further morphological and molecular investigations including Asian, European, and Maghrebian populations of *A. wierzejskii* s.l. are currently underway with the aim of characterising this putatively new species. *Arctodiaptomus wierzejskii* is reported to occur in Mongolia and neighbouring countries by several authors (e.g. Borutzky et al. 1991, Wen & Zhi-Hui 1999, Dussart & Defaye 2002, Zuikova & Bochkarev 2009, Alonso 2010).

The recorded ostracod fauna is species-poor, being represented by three taxa only. *Ilyocypris mongolica* and *Trajancypris serrata* were already known from Mongolia and adjacent areas (Martens 1991, Van der Meeren et al. 2009, 2010; Zhai & Zhao, 2014). The third taxon is *Heterocypris* sp., occurring in three sites (Tab. 2), but its species-level identity is uncertain: three *Heterocypris* species are to date known to occur in Mongolia (Martens 1991, Van der Meeren et al. 2010), and a fourth one in Inner Mongolia (Zhai & Zhao 2014), but the collected specimens cannot be soundly ascribed to any of them.

Overall, the sampling of 18 water bodies in the central Mongolian soum of Bayan-Onjuul led to the detection of 28 crustacean species (Tab. 2). Crustaceans belonging to the class Branchiopoda were the most diverse and abundant in the samples, having being collected in all the surveyed sites. In particular, the diversity of the so-called large branchiopods is noteworthy, with six anostracan, one spinicaudatan and one notostracan species. Conversely, the absence in the collected samples of anomopods belonging to the family Chydoridae is rather unexpected, and this is even odder when considering that collected samples are rich of other primarily benthic taxa (e.g. spinicaudatan and radopod branchiopods, ostracods, and cyclopoid copepods), thus suggesting that the absence of chydorids in the samples is likely not to be ascribed to a sampling bias. Furthermore, while other branchiopod taxa were successfully raised in laboratory through the culturing of collected core samples, no chydorids hatched in the laboratory cultures.

The crustacean list compiled in this paper provides an account on the crustacean fauna of lentic water bodies of the central Mongolian steppe, including two first records for the country (i.e. *Macrothrix dadayi* and *Microcyclops afghanicus*), and six currently unidentified taxa (i.e. the branchiopods *Artemia* sp. and *Moina* sp., the ostracod *Heterocypris* sp., and the copepods *Diacyclops* sp., *Arctodiaptomus* cf. *alpinus* and *Arctodiaptomus* cf. *wierzejskii*). Considering the scattered nature of the samplings and the limited extension of the sampled area, the present results further highlight the richness and diversity of Mongolian crustacean fauna (e.g. Naganawa & Zagas 2002, Alonso & Naganawa 2008, Alonso 2010; this paper), and the presence in the country of taxa of outstanding evolutionary and phylogenetic importance (e.g. Vekhov 1992, Rogers 2005, 2006); it is thus desirable that further works are realised in order to provide

a more exhaustive picture of Mongolian diverse crustacean fauna.

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