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Eco-morphological background of the organization of terrestrial isopod communities

Summary of PhD Thesis

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Introduction

Oniscidean isopods are very successful colonizers of terrestrial habitats. They are cosmopolitan and extremely diverse ecologically and biogeographically, while their dispersion ability is rather limited. Woodlice are key regulators of decomposition ecosystem functions. In forest ecosystems, soil detritivores participate in the comminution of litter and stimulation of microbial activities, thus in fragmentation and mineralization of organic matter.

Terrestrial isopods had to face several ecological and physiological stressors to conquer such a wide range of habitats. Water economy, particularly the amount of water loss, is a crucial factor for terrestrial isopods.

During their evolutionary adaptation, they have developed various morphological, ecological and behavioral solutions to cope with the difficulties of terrestrial respiration, especially protection against desiccation. They may serve as a model taxon for studying the morphological and ecological ways and consequences of terrestrial adaptation. In our study we have investigated the structure and histology of the tergite cuticle, the pleopodal lungs (pseudotracheae), and the brood-pouch (marsupium) as key factors in maintenance of water equilibrium and protection against desiccation.

The main barrier between the body surface of these animals and their environment is the protective sclerotized and mineralized tegumental cover, the cuticle. The Crustacean exoskeleton is composed of four layers: the epicuticle, the exocuticle, the endocuticle, and the membranous layer. In terrestrial isopods, the epicuticle also forms several surface structures such as setae, tricorns, tubercles, plaques and pits. Several studies have shown that the sensory tricorn receptors are common in terrestrial woodlice species, they do not occur in aquatic Crustaceans. Terrestrial crustaceans lose water more rapidly than other arthropods do, primarily because of the terrestrial isopods' dorsal and ventral cuticular transpiration. The amount of water loss is influenced by the temperature and the humidity values.

The main factor in successful colonization of different terrestrial habitats might be the structural and functional adaptation of the respiratory organs. In primitive terrestrial isopod species, oxygen uptake takes place through the pleopod-endopods which function as gills, while the exopods form a kind of covering. In more advanced taxa adapted to drier conditions, respiration occurs in specialized structures (pleopodal lungs or pseudotracheae) situated in the pleopodite-exopodites. These structures occur in one to five pairs of exopodites. Within the Oniscidea, both covered and uncovered lungs are present. Within the Crinocheta pleopodal lungs have evolved several times in different phylogenetic lineages.

The Peracarida crustaceans' brood pouch (marsupium) originally evolved for mechanical protection of eggs and developing embryos in aquatic conditions. In terrestrial environments, the ovigerous females produce a microenvironment in the marsupium, providing fluid and oxygen for the developing young. Five pairs of oostegites cover the marsupium. In some – more developed – species it is divided by segmental cotyledons, which are responsible for nutrition and oxygenation of the offspring. In species belonging to the ‘roller’ eco-morphological type the oostegites bend only slightly, which still allows ovigerous females to conglobate. In such cases sternites arch into the body cavity to provide more space for the developing embryos.

In my thesis, I studied the assemblages of terrestrial woodlice in a deciduous forest area under landscape protection near Budapest, Hungary (Buda Hills). According to a previous study our study area has a relatively species-rich isopod fauna (12 species).

We hypothesised that the species are differentiated on a micro- and mesohabitat scale according to their eco-morphology and habitat preference (tolerance limits), which allow their co-existence.

The aims of our study were

A1)

to characterize the composition of terrestrial isopod fauna

- species richness and abundance;

to obtain data about the spatial distribution of species

- presence–absence and spatial variation in their abundance on different scales;

to look for relationships between the terrestrial isopod species and certain potentially influencing environmental factors;

A2)

to compare

- the seasonal differences in sex ratio;
- temporal differences in the reproductive period

of the abundant species;

A3) to compare

- the efficiency and selectivity of different sampling methods in assessing species richness of terrestrial isopods.

Hypotheses

We assumed that

A1) within the studied habitat

- the spatial distribution of the species is not even, it differs on meso- and microhabitat scale,
- this difference is correlating with the species' preference / tolerance;

A2) the abundant species'

- individuals from different sexes have divergent surface activity in time. This affects the pitfall trap results.
- reproductive period timing and duration shows partially different pattern, which is also shown in the ratio of the gravid females;

A3) the efficiency of the sampling methods are affected by

- the species' behavior (epigean – endogean), body size, eco-morphology type, surface activity and micro-habitat preference.

<u>Another purpose of the current study was to investigate the morphological properties</u>

B1)

of tergite cuticle

- thickness
- surface structures;

B2)

of pleopodal lungs

- type
- inner structure (extension of respiratory surface);

B3)

of marsupium

- the gross anatomy (in different eco-morphological types)
- ultrastructure of oostegite and cotyledon

as key factors in maintenance of water equilibrium and protection against desiccation.

Hypotheses

We assumed, that

B1) the studied species'

- cuticle has the same structure, but different thickness, which is in relation to their habitat preference / difference,
- cuticle's surface structure and type of their receptors shows similarity according to the phylogenetic relation, influenced by the behavior (epigean - endogean);

B2) according to the morphology of the pleopodal lung,

- the Crinocheta taxon's species' lungs can be categorized into different types (partly covered, covered – mono- and polyspiracular);
- its structure is depending on the environmental tolerance, rather than on the phylogenetic relationship;
- the area of the respiratory surface differs intra-genetically and correlates with the habitat preference / tolerance of the species;

B3) the marsupium

- has the same gross anatomy, its developing is influenced by the specie's eco-morphological type (conglobating – non-conglobating),

- shows inter-specific differences on the level of ultrastructure of the oostegite and the cotyledon.

C) Besides that, we compared some terrestrial isopod species' inter-specific and intra-generic desiccation tolerance

- weight-specific water loss;
- mortality rate.

Hypotheses

C) We supposed, that

- there is a higher similarity in species with similar ecological needs than among closely related species living under quite different environmental conditions.

Materials and methods

Studied species

We studied species belonging to different families and/or genera, but found in the same habitat: *Androniscus roseus*, *Armadillidum nasatum*, *Armadillidium versicolor*, *Armadillidium vulgare*, *Cylisticus convexus*, *Hyloniscus riparius*, *Haplophthalmus danicus*, *Haplophhtalmus mengii*, *Orthometopon planum*, *Platyarthrus hoffmannseggii*, *Porcellionides pruinosus,* *Porcellium collicola*, *Protracheoniscus politus*, *Trachelipus rathkii*.

We also examined four species belonging to the Armadillidium genus, which have different geographical distribution patterns and different tolerance limits oft environmental conditions, which is also reflected in their habitat choice (*A. zenckeri*, *A. nasatum*, *A. versicolor*, *A. vulgare*).

<u>Faunistics and ecology</u>

Study area

The study area lies within the Buda Hills, near the village of Solymár close to Budapest (Hungary). It belongs to the Buda Landscape Protection Area, partly included in the Natura 2000 network. We have chosen two different meso-habitats: the Alsó-Jegenye Valley (Meso-habitat I.) is along a stream (Paprikás Stream) accompanied by a trail. Meso-habitat II. (Felső-patak Hill) can be characterized by quasi-natural deciduous forest. Three sampling sites were selected in each of the two meso-habitats.

Sampling methods

Pitfall traps: five pitfall traps were placed in each sampling site. This design resulted in a total of 30 traps (2 meso-habitats × 3 sites × 5 traps) (from 19th April until 4th October in 2013) *Quadrates:* we gathered 10 litter and soil samples (25 cm x 25 cm) from the six studied sites. Litter and soil samples were extracted in the laboratory using a Berlese-Tullgren apparatus. *Litter sieving:* in each sampling site we collected litter samples (1 m x 1 m, 5 samples). *Time-*

restricted hand sorting: additionally, we collected woodlouse species for 20 minutes in each site.

Habitat characteristics

We measured hourly air temperature and relative humidity above soil surface during the sampling period. Chemical and physical soil properties were analyzed for each sampling site.

Species identification

For identification, we used the keys by Gruner (1966) and Farkas & Vilisics (2013). Species were sorted according to sex and reproductive status (males, gravid females, non-gravid females).

Data analysis

Diversity was quantified by species richness, Shannon's diversity (H') and equitability (E_H) indices (MS Excel 2016 software). Isopod species were also qualified by naturality index (TINI – Terrestrial Isopod Naturalness Index).

The differences among sampling sites were evaluated by hierarchical agglomerative clustering based on (1) the microclimatic values and (2) the presence/absence of terrestrial isopod species, using Gower distance and UPGMA linkages (Past3 software).

Relationships between the studied environmental factors and the abundance of individual species were evaluated by canonical correspondence analysis (CCA) (R

3.2.3 software). We used generalized linear models (GLM) incorporating key environmental variables that were significantly ($p<0.05$) correlated with isopod species abundance (R 3.2.3 software).

We observed the seasonal sex ratios of populations of abundant species (*A. vulgare*, *P. collicola*, *P. politus*). Alterations from a hypothetic 1:1 ratio were tested with χ^2 test (R 3.2.3 software).

Morphology

Light microscopy (LM)

To reveal the characteristics of 1) the exoskeleton, 2) the pleopodal lungs, and 3) the marsupium, light microscopic investigations (LM) were applied. The studied specimens were fixed in 4% paraformaldehyde. Following fixation, tissues were decalcified in 8% ethylenediamine-tetraacetic acid disodium salt (EDTA). After that the samples were dehydrated through an ascending series of ethanol. After dehydration, the tissues were kept in xylene. Thereafter the samples were infiltrated and embedded in paraffin wax. The histological sections (7 µm) were cut with a Reichert 2040 sliding microtome and stained with Weighert's hematoxylin-eosin (HE) and Periodic Acid-Schiff (PAS) reagent. With PAS reagent, we could detect polysaccharides in tissues.

Transmission electron microscopy (TEM)

We studied 1) the pleopodal lungs and 2) the marsupium on semi- and ultra-thin sections. The specimens were fixed in 4 % paraformaldehyde, 2 % glutaraldehyde and 10 % picric acid (in 0.1 M phosphate buffer). The samples were postfixed in 2 % osmium tetroxide. Besides that, two ovigerous females (same size, identical stage) from *C. convexus* and *T. rathkii* were injected under the tergite with 12.5% glutaraldehyde (in 0.1 M phosphate buffer). Dissected oostegites and cotyledons with some eggs were fixed (the solution containing 2.5% glutaraldehyde, 2% paraform-aldehyde in 0.1 M cacodylate buffer (2 h)) and postfixed in 1 % osmium tetroxide and 0.8% potassium ferricyanide.

The samples were dehydrated in a graded series of ethanol. Finally, the pieces were embedded in Durcupan. Sections (0,5 µm, 60 nm) were cut with a Reichert Ultracut ultramicrotome, studied and photographed with an electron microscope (JEOL 100 C).

Scanning electron microscopy (SEM)

We studied 1) the surface tergal ornaments and 2) the pleopodal lungs with scanning electron microscope. The samples were dehydrated through an ascending series of ethanol. Specimens were attached to aluminium holders, coated with gold palladium and then examined with a scanning electron microscope (Hitachi S-2600N).

Statistical methods

To compare and quantify cuticle thickness 100 measurements (2 specimens, 5 slides, 10 measurements/slide) were taken for each investigated species (Image J and R 3.2.3 software) using the LM cross-sections of the 2nd tergite. In order to assess the relevancy of the differences in tergite thickness we performed a one-way ANOVA test followed by a post-hoc Tukey-test on the cross section specific cuticle thickness (R 3.2.3 software).

We quantified two morphological properties of the respiratory organs: total surface area [Ar], which is the extent of the interfacial endothelium between the respiratory space and the hemolymph; and surface area density [Dr], using digitalized images of the histological cross-sections (GIMP 2.6 software).

Desiccation tolerance

Studied species and experimental design

For interspecific comparison six isopod species were tested: *A. vulgare*, *C. convexus*, *O. planum*, *P. politus*, *P. pruinosus* and *T. rathkii*. We also examined four species belonging to the Armadillidium genus: *A. zenckeri*, *A. nasatum*, *A. versicolor* and *A. vulgare*.

The water loss rate and mortality were studied on three different rH values: extremely dry (~30%), relatively dry (~60%) and nearly 100%. The humidity level was acquired using silica gel (rH 30%), sodium-chloride (rH 60%) and water (rH 100%) in glass exsiccators. We measured 20 specimens per species individually.

Data analysis

To assess the relevancy of the difference in the water loss rate we performed a one-way ANOVA test followed by a post-hoc Tukey-test (R 3.2.3 software). We used linear models (LM), which were developed by testing the initial weight and the tergal cuticle thickness individually and incorporating those that were significantly ($p<0.05$) correlated with the weight-specific water loss rate (R 3.2.3 software).

Results

Faunistics and ecology

Species richness and diversity

The yearly summarized data from pitfall trapping resulted in a total of 4136 individuals of 5 terrestrial isopod species. The most abundant species was *P. politus,* followed by *A. vulgare* and *P. collicola*. The rest of the collected specimens belonged to *O. planum* and *H. riparius*.

The highest species richness, diversity and equitability values were experienced at site I/3, along the stream valley, in the moist flood area. Terrestrial isopod diversity values were the lowest at site II/3. The Shannon's diversity values were higher in Meso-habitat I.

Correlation between environmental factors and terrestrial isopod species

CCA revealed a positive correlation between relative humidity, soil $CaCO_3$ content and the abundance of *P. collicola* and *H. riparius* isopod species. In case of *A. vulgare* CCA showed positive interaction with $CaCO_3$ content. The abundance of *O. planum* was affected by high temperature values. GLM analysis revealed significant relationships between soil $CaCO_3$ content and the assemblages of *A. vulgare*, *P. collicola* and *H. riparius* ($p<0.05$) while minimum values of relative humidity marginally significantly correlated with the abundance of *P. collicola* and *H. riparius* species ($0,076<p<0,067$).

Seasonal differences in sex ratio

Before the reproductive period the population of *P. politus* was dominated by males (96%). That was followed by an activity peak of females (80%). After the reproductive period we found no great difference in the male – female ratio. In case of *A. vulgare* the seasonal sex ratio did not differ significantly from the expected 1:1 ratio. Before the reproductive period the male – female ratio was 1:1 in *P. collicola*. During and after the reproductive period the populations were dominated by females (78%; 76%).

Temporal differences in the reproductive period

The reproductive period of *P. politus* was long, a so-called univoltin type with a high ratio of gravid females. The *A. vulgare* reproductive period was shorter than the other two abundant species'. The reproductive period of *P. collicola* began earliest and the fecundity rate was high.

The efficiency of different field sampling methods

Using quadrates and litter sieving were similar in their efficiency: we caught three species: *P. collicola*, *P. politus* and *A. vulgare*. Hand sorting resulted in altogether 12 isopod species. In addition to the 5 previously listed species we collected *P. pruinosus*, *T. rathkii*, *C. convexus*, *P. hoffmannseggii*, *A. roseus*, *H. danicus* and *H. mengii*, too.

Morphology

Cuticle

Based on the average cuticle thickness the species can be sorted in decreasing order: *A. vulgare >C. convexus >P. politus >T. rathkii >P. collicola >H. riparius >P. pruinosus >P. hoffmannseggii >O. planum >H. danicus >H. mengii >A. roseus*. In *Armadillidium* species also *A. vulgare* has the thickest tergal cuticle, while *A. zenckeri* has the thinnest one, the others were between the two extreme values (*A. nasatum*, *A. versicolor*). In the case of terrestrial isopods which belong to the group of Crinocheta there are tricorn exteroreceptors on the cuticular surface. In *O. planum* and *P. pruinosus* PAS positive spheres cover the tergite. In the small (usually endogean) species the tergal surface is characterized by tubercles and plaques.

Pleopodal lung

The studied species which belong to the *Armadillidium* genus have polispiracular covered lungs (*A. zenckeri*, *A. nasatum*, *A. versicolor*, *A. vulgare*). *O. planum*, *P. pruinosus* and *P. politus* have monospiracular covered pleopodal lungs. In the case of *C. convexus*, *P. collicola* and *T. rathkii* the lungs are partly covered.

The LM cross sections show several differences among the pleopodal lung structure of the four *Armadillidium* species. Both total surface area (Ar) and the surface area density (Dr) was found to be the lowest in the specialist *A. zenckeri* and the highest in the generalist *A. vulgare*, respectively. The other two species had intermediate values.

Marsupium

The LM cross sections show several similarities but also some differences between the compared marsupial structures of the two eco-morphological types. In the 'non-roller' isopod species the oostegites bend outwards. In the

’roller’ species the sternites arch into the body cavity. Both species have five pairs of oostegites, which have the same structure. In both species, the space between the inner and outer cuticle consists of cellular elements and hemolymph space. Cotyledons appear in the marsupium among developing offspring in both species. The maternal fat body and the cells of the hepatopancreas contain densely stained lipid inclusions, similarly to the proximal part of the cotyledon, whereas along its longitudinal axis these line up in a bead-like array. TEM studies revealed some differences in the oostegite and cotyledon ultrastructure of the studied species.

<u>Desiccation tolerance</u>

Under extreme dry conditions (rH 30%) we found high weight-specific water loss rate at each investigated species. *Protracheoniscus politus* had the highest and *A. vulgare* had the lowest water loss (*P. politus >O. planum >C. convexus >T. rathkii >P. pruinosus >A. vulgare*). Mortality appeared in each species group except *A. vulgare* (0%) whith the highest rates in *P. politus* (100%). Within the Armadillidium genus the single species also had high weight-specific water loss rate at 30% relative humidity. We found that *Armadillidium vulgare* had the lowest and *A. zenckeri* had the highest weight-specific loss values. At 60% relative humidity, the weight-specific water loss rate ranked by species were: *C. convexus >P. pruinosus >O. planum >P. politus >T. rathkii >A. vulgare.* Only *P. pruinosus* specimens died during the study (10%). Under higher humidity (60%) the order of weight-specific water loss was the same (*A. zenckeri >A. nasatum >A.versicolor >A. vulgare*). We detected the lowest water loss without significant interspecific differences at the highest humidity level.

According to the linear models the initial weight and tergal cuticle thickness significantly correlate with the weight-specific water loss.

Discussion

<u>Faunistics and ecology</u>

Species richness and diversity

In total, 12 woodlouse species were identified, which represent 21% of the Hungarian terrestrial isopod fauna. Our study area has a relatively species rich and diverse isopod and diplopod fauna due to the proximity of the village, which supports the settlement of disturbance-tolerant and synanthropic species. A high number of species can be misleading and does not always show the conservational value of a habitat but rather the appearance of homogenizing species with broad tolerance, which in some cases – in addition to the maintenance of native species – results in a significant increase in species richness.

Correlation between environmental factors and terrestrial isopod species

We assumed that the high number of woodlouse species in site I/3 resulted from the high $CaCO_3$ content of the soil and high relative humidity due to the vicinity of the Paprikás Stream. Our results showed that the terrestrial isopod species prefer different microhabitats within the same habitat because of the micro-climatically patchy environment.

Seasonal differences in sex ratio

In the population of *P. politus* seasonal changes of sex ratio had an interesting pattern. Before the reproductive period there was an activity peak of males, because they were searching for receptive females. In the reproductive period this was followed by an activity peak of gravid females, which were looking for shelter sites that are optimal for incubation.

We conclude that the temporal differences in reproductive period of the abundant species help to avoid any competition between them.

The efficiency of different field sampling methods

Microhabitat preference and eco-morphological type may determine the efficiency of pitfall trapping. We found that hand sorting was the most efficient in terms of species richness for isopod species, but not in terms of abundance.

The main message of our present results can be that the applied method must be chosen depending on the specific research question. Thus, to assess the most complete local diversity, a combination of different methods may be necessary. For the estimation of species composition and species richness, a combined use of the different methods is the most effective. Pitfall trapping should be complemented at least with time-restricted hand sorting in the case of both terrestrial isopods and millipedes to provide an expected full faunistic data set.

Morphology

Cuticle

Our results show that the very thick cuticle offers effective protection to the globally wide-spread, habitat generalist *A. vulgare*.

The tergal surface of the exoskeleton is adapted to the microhabitat type (epigean – endogean). The tuberculate cuticular surface provides anti-adhesive qualities for small species. The tricorn receptors function as mechano- and chemoreceptors. In the case of *O. planum* and *P. pruinosus* we found very thin exoskeletons, however the polysaccharide spheres on the dorsal surface might also reduce water loss.

Pleopodal lung

We did not find any evidence that the type of pleopodal lung is related to the phylogenetic relationships. The evolution of lungs is probably forced towards the development of very similar structures by functional constraints.

Our quantitative analysis revealed that the moisture tolerance of the four investigated *Armadillidium* species is in accordance with their total surface area [Ar], surface area density [Dr] and cuticle thickness, suggesting that these morphological traits are important determinants of their distribution on a habitat scale. The habitat generalist A. vulgare has the highest total surface area and surface area density while having the thickest cuticle. An enlarged and fine grained surface presumably ensures a more efficient respiration and a broader environmental tolerance, permitting the colonization of drier habitats.

Marsupium

Our findings show that the gross anatomy of the brood pouch in the examined species is highly similar to that of the species studied earlier. We found only small histological differences in the oostegite and cotyledon structures of the two species with different eco-morphological backgrounds. Since both species belong to the same lineage of Oniscidea, these differences probably reflect the physiological state of the animal, rather than the eco-morphological type.

Desiccation tolerance

Based on our results these morphological traits – body size, thickness of cuticle and cuticular surface structure – are important determinants of terrestrial isopods' distribution on habitat and microhabitat scales and through the existence of suitable habitats – together with many other morphological, physiological and behavioral factors – resulting in the geographical pattern of species occurrence.

The very thick cuticle offers an effective protection to the globally wide-spread, habitat generalist *A. vulgare*. In the case of the *O. planum* and *P. pruinosus* we found very thin exoskeleton, the polysaccharide spheres on the dorsal surface might also reduce water loss. The resistance against exsiccation could not be explained by phylogenetic relationship only. That is confirmed by the *Armadillidium* species' different water loss rate under dry conditions.

New scientific results

1) The spatial distributions (on meso- and microhabitat scale) of the terrestrial isopod species differ from each other within the studied habitat (in a deciduous forest habitat in a Landscape Protection Area near Solymár, Hungary). This is related to the habitat preference and tolerance of the species, as well as the abiotic and biotic heterogeneity of the habitat.
2) The heterogenous habitat resulted in higher species richness (12 species) than what was expected from literature (5-6 species). This is in connection with the heteogenity of the habitat and its ecotone and gradient nature (urban – natural, humid – arid microclimate).
3) The size, surface activity, eco-morphological type and microhabitat preference of the species influences the effectiveness of different sampling methods, therefore it is important to choose adequate field sampling methods for the aim of the study.
4) We have verified the results of previous studies, according to which it is recommended to use beside the pitfall trapping additional sampling methods (e.g. time-restricted hand sorting) for the total surveying of the isopod fauna.
5) There are morphological differences behind the terrestrial isopod species' meso- and microhabitat

preference, distribution and habitat choice. The thick cuticle and the significantly large surface of the pleopodal lung of *Armadillidium vulgare* might contribute to its global range.

6) We have shown that the spherical structures on the tergal surface of *Orthometopon planum* and *Porcellionides pruinosus* are polysaccharides, contrary to previous hypotheses (waxy coating).
7) Our light-microscopic results confirmed that there is a strong connection between the species' eco-morphological type and the development of the brood-pouch.
8) Phylogenetic relation does not have a significant role in the desiccation tolerance, but some properties of the cuticle, like thickness and surface structure, are highly important.

Own scientific publications related to the topic of the present thesis

a) Full text papers in peer-reviewed journals

Csonka D., Halasy K., Hornung E. 2015: Histological studies on the marsupium of two terrestrial isopods (Crustacea, Isopoda, Oniscidea). ZooKeys 515: 81-92. IF2015: 0,938

Csonka D., Halasy K., Szabó P., Mrak, P., Štrus, J., Hornung E. 2013: Eco-morphological studies on pleopodal lungs and cuticle in *Armadillidium* species (Crustacea, Isopoda, Oniscidea). Arthropod Structure & Development 42(3): 229-235. IF2013: 2,488

Csonka D., Halasy K., Szabó P., Mrak, P., Štrus, J., Hornung E. 2012: *Armadillidium*-fajok (Isopoda: Oniscidea) élőhelyi adaptációjának morfológiai háttere. / The morphological background of the habitat adaptation of *Armadillidium* (Isopoda: Oniscidea) species Természetvédelmi Közlemények 18: 115-126.

b) Conference abstracts

<u>Oral presentations:</u>

Csonka D., Hornung E.: **Morfológia és habitat választás, avagy az ászkarákok és a kiszáradás.** – Hungarian Biological Society, Budapest, 2016. April 6.

Csonka D., Halasy K., Hornung E.: **Eco-morphological comparison on the marsupium of terrestrial**

isopods (Crustacea, Isopoda, Oniscidea) – 9th International Symposium on Terrestrial Isopod Biology, Poitiers (Franciaország), 2014. June 26-30.

Csonka D., Halasy K., Mrak P., Štrus J., Hornung E.: **Eco-morphological comparison of three Armadillidium species (Crustacea: Oniscidea)** – 8th International Symposium on Terrestrial Isopod Biology, Bled (Szlovénia), 2011. June 19-23.

Szabó P., **Csonka D.**, Hornung E.: **Niche elkülönülés vizsgálata talajlakó állatok mozgásmintázatának elemzésével** – MTA Hungarian Academy of Sciences Committee of Veterinary Science, Academic Report, Budapest, 2014. January 27-30.

Csonka D., Halasy K., Hornung E.: **Szárazföldi ászkarákok (Isopoda: Oniscidea) költőtáskájának morfológiai összehasonlítása** – MTA Hungarian Academy of Sciences Committee of Veterinary Science, Academic Report, Budapest, 2013. January 28-31.

Csonka D., Halasy K., Szabó P., Hornung E.: **Armadillidium (Isopoda) fajok élőhelyi adaptációjának morfológiai háttere** – MTA Hungarian Academy of Sciences Committee of Veterinary Science, Academic Report, Budapest, 2012. January 16-19.

<u>Poster presentations:</u>

Csonka D., Hornung E.: **Szárazföldi ászkarák fajok kiszáradással szembeni toleranciájának kísérletes**

vizsgálata – 6th Universal Zoology Symposium, Budapest, 2016. March 18.

Csonka D., Kovács A., Hornung E.: **Szimpatrikus ászkarák populációk (Isopoda, Oniscidea) tér-idő mintázata** – IX. Hungarian Conservation Biology Conference, Szeged, 2014. November 20-23.

Csonka D., Huber J., Ziegler A., Halasy K., Hornung E.: **The morphology of tergal cuticle in two terrestrial isopod species (Crustacea, Isopoda, Oniscidea)** – 9th International Symposium on Terrestrial Isopod Biology, Poitiers (Franciaország), 2014. June 26-30.

Csonka D., Halasy K., Hornung E.: **Terrestrial adaptation: the morphology of terrestrial isopods' broodpouch (Crustacea, Isopoda, Oniscidea)** – VIII. Carpathian basin – I. Sustainable Development in the Carpathian Basin International Conference, Budapest, 2013. November 21-23.

Csonka D., Halasy K., Hornung E.: **Szaporodás és stratégia: szárazföldi ászkarákok (Isopoda: Oniscidea) költőtáskájának ökomorfológiai összehasonlítása** – 5th Universal Zoology Symposium, Vácrátót, 2013. March 22.

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