Distribution of Myriapods in Forest Mosaic

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Proclamation

I, Marea Grinvald hereby proclaim that I wrote this thesis by myself, under the supervision of Dr. Ivan H. Tuf and using only cited literature.

May 5th, 2011 in Olomouc ____________________________

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Abstract

This study is focused on distribution of myriapods (centipedes and millipedes) in fragmented forest environment. We studied their distribution in relation to specific environmental factors in different forest growths and ecotones in between them. The research was conducted in Protected Landscape Area Litovelské Pomoraví from March 2004 until February 2006. Samples were taken using pitfall traps, passing through 87 years old growth *Querco-Ulmetum*, 10 years old *Quercus* monoculture, 2 years old clear-cut with seedlings, 127 years old *Querco-Ulmetum* floodplain forest and ecotones between them. Measured environmental factors were: percentual presence of herbs, shrubs and shade by tree canopies; percentual presence of litter coverage and litter thickness; the age of the growth in which traps were placed.

We collected 6061 myriapoda individuals. Both centipedes and millipedes were represented by 10 species, with the most dominant *Lithobius mutabilis* and *Glomeris tetrasticha,* respectively*.* The Shannon-Wiener index of diversity was the highest in 87 years old *Querco-Ulmetum* vegetation and in 10 years old *Quercus* vegetation. Two out of three ecotones have been characterized by noticeably higher abundances of species. All the environmental factors were evaluated as significant, litter coverage being the most important one.

Key words: myriapoda, fragmentation, floodplain forest, ecotone, leaf litter

Abstrakt

Tato studie se zaměřuje na distribuci stonožek a mnohonožek ve fragmentovaném lesním porostu. Studovali jsme jejich distribuce v souvislosti s konkrétními environmentálními faktory v různých typech lesních porostů a v ekotonech mezi nimi. Výzkum byl proveden v Chráněné krajinné oblasti Litovelské Pomoraví v období od března 2004 do února 2006. Vzorky byly odebrány pomocí zemních pastí, umístěních v osmdesátisedmiletém porostu *Querco-Ulmetum*, desetileté dubové monokultuře, dvouleté mýtině se semenáčky, stodvacetisedmiletém porostu *Querco-Ulmetum* a v ekotonech mezi nimi. V daném území jsme testovali význam následujících environmentálních faktorů: procentuální zastínění bylinami, keři a stromovými korunami; procentuální pokrytí listovým opadem a tloušťku listového opadu; stáří porostu, v němž byly umístěny pasti.

Celkem bylo získáno 6061 jedinců, v 10 druzích stonožek a 10 druzích mnohonožek. Nejdominantnějším druhem byl *Lithobius mutabilis*, resp. *Glomeris tetrasticha*. Shannon-Wienerův index diverzity byl nejvyšší v osmdesátisedmiletém porostu *Querco-Ulmetum* a v desetileté dubové monokultuře. Dva ze tří ekotonů byly charakterizovány výrazně vyšší početnosti jedinců jednotlivých druhů. Všechny zkoumané environmentální faktory se ukázaly jako významné, z nichž pokryvnost listovým opadem představovala ten nejdůležitější.

Klíčová slova: stonožky, mnohonožky, fragmentace, lužní les, ekoton, listový opad

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1. Introduction

Forests and forest lands cover 33.6% (approximately 2 652 941 hectares) of the Czech Republic territory (Ministry of Agriculture, 2010). Early forest management practices, like elsewhere in Central Europe, included clear-cut foresting and conversion of ancient forests to agricultural lands and even-aged monocultures (mainly *Picea abies*), creating fragmented forests and isolated forest patches. Those changes are among the most important causes of significant decline of biodiversity in Czech forests (Hédl et al., 2006).

Fragmented forests are defined by number of new ecological characteristics, such as native habitat´ isolation, patch size or ecotone (habitat edge) length. Those often have a crucial effect on local populations, which are exposed to conditions different than ones in the native forest ecosystems (Murcia, 1995). Newly created patches are characterized by increased solar radiation, different water flux, increased exposure to wind and, consequently, increased transfer of seeds, dust and similar particles, especially if placed at the habitat edge (Saunders et al., 1991). It is precisely why ecotones are considered to be one of the most important emerging effects of fragmentation. Ecotones are defined as transitional zones between neighboring habitats, characterized by different ecological qualities (Ries & Siesk, 2004). They represent areas where species from the neighboring habitats often meet and interact (Yang et al., 2009) and where specialist ecotonal species occur (Lloyd et al., 2000). Abundance of species depends on the specific ecotone type and can be increasing, decreasing or show no differences in comparison to the surrounding areas (Ries & Siesk, 2004). Ecotone influence on invertebrates, which act on considerably small spatial scales, has not been entirely explained (Dangerfield et al., 2003).

The ecological consequence of forest fragmentation and uprising ecotone effect on myriapoda (centipedes and millipedes) has been insufficiently studied. Worldwide distributed, myriapoda count over 14 000 species (Adis & Harvey, 2000), out of which 2233 live in Europe (Enghoff, 2011). In the Czech Republic, they are represented by 80 millipede species and 66 centipede species (Tuf & Tufová, 2008). Myriapoda (re)colonization possibilities are highly limited due to their walk-limited dispersal mode and inability to overcome water boundaries (Lawrence, 1984). As a result, many species are limited to very specific habitats and are highly vulnerable to human induced small scale habitat changes (Hopkin & Read, 1992). Myriapoda often occur near the moist environment, together with the other forest invertebrates (Khanna, 2005). They inhabit the forest floor – the leaf litter, the litter/soil interface, the uppermost soil or deadwood, where humidity is sufficiently high to satisfy their ecological requirements (Golovatch & Kime, 2009). Yet, some of them also appear in deeper layers of litter and humus, as well as in forest soils rich in minerals (Tajovský, 2008). Lack of waterproof, waxy cuticle explains their habitat preferences with high humidity, mostly even temperature and low intensity of light (Eason, 1964). Those specific microclimatic conditions are changed in fragmented forest landscapes, where edge habitats are exposed to higher temperatures (Chen et al., 1995) and increased solar radiation (Matlack, 1993). For the specific habitat preferences and close contact with soil, myriapoda have been used as bioindicators in soil analyses (de Godoy & Fontanetti, 2010; Nogarol & Fontanetti, 2010; Voigtländer, 2005). Millipedes, as phytophages, detritovores or saphrophages (Stoev et al., 2010), upturn the soil, disintegrate humus, decompose leaves and, in the absence of vegetation, consume soil, which is rich in decaying matter (Khanna, 2005). Those processes play the irreplaceable role in aeration and humification of soil and revolvement of mineral and organic materials (Nogarol & Fontanetti, 2010). Centipedes, on the contrary, are mostly predators, praying earthworms, snails, slugs and other soil animals (Stoev et al., 2010). Both groups have relatively long life-span compared to other invertebrates; some species of millipedes can live over ten years (Hopkin & Read, 1992). Due to combination of ecological and biological characteristics, myriapoda present a very important component of soil fauna and as such are often used as a research model.

This paper focuses on distribution of myriapods in a fragmented habitat, generated as a consequence of anthropogenic influence in a floodplain forest. The main objective of our research was to determinate specific ecological factors and their influence on diversity and distribution of myriapoda in the forest mosaic. As a secondary objective, we examined ecological preferences of some species, which were collected during the research. Issues concerning creation of secondary habitats as a result of modern forest management have been also addressed.

2. Material and methods

2.1. Locality

Protected landscape area Litovelské Pomoraví, in which the research was done, lies in the area of 96 km² between towns of Mohelnice and Olomouc (middle Moravia, Czech Republic), following the alluvial plains formed by the meandering river of Morava. The very core of the area is composed of the regularly flooded floodplain forests and wetland meadows, which are among the most important of its kind in Central Europe.

The research was conducted at the precise location 2 km north from the village Horka nad Moravou (49°65´ N, 17°20´ E, altitude 210 m). Locality was composed from four neighboring forest patches. The first one, 87 years old *Querco-Ulmetum* vegetation, was consisting primarily of *Quercus robur* and *Carpinus betulus*, accompanied by *Acer platanoides*, *Acer pseudoplatanus*, *Tilia platyphyllos* and *Fraxinus excelsior.* Shrub layer was represented by *Tilia platyphyllos* and *Acer platanoides,* while the herb layer included spring flora, such as *Anemone nemorosa, Anemone ranunculoides, Glechoma hederacea, Ficaria bulbifera, Corydalis cava, Galanthus nivalis, Pulmonaria officinalis, Lathyrus vernus, Polygonatum verticillatum* and *Maianthemum bifolium*. The second patch, 10 years old *Quercus* vegetation, was represented by *Quercus petraea* at the forest floor, and mainly *Urtica dioica* and *Rumex obtusifolius* at the herb layer. This patch is a transitional type of vegetation between above-mentioned 87 years old *Querco-Ulmetum* vegetation and a clear-cut. The third patch was consisting of 2 years old clear-cut with seedlings belonging to *Quercus petraea* (80%), *Tilia cordata* (10%) and *Ulmus glaber* (10%). Herb floor included primarily *Calamagrostis epigejos* and *Impatiens glandulifer.* In the middle of the clear-cut, there is a period pool lying. The last patch, 127 year old floodplain forest *Querco-Ulmetum*, was primarily represented by *Quercus robur* and *Carpinus betulus,* accompanied by *Tilia platyphyllos* and *Fraxinus excelsior* at the forest floor, and *Anemone nemorosa, Anemone ranunculoides, Glechoma hederacea, Ficaria bulbifera, Corydalis cava, Pulmonaria officinalis, Lathyrus vernus, Isopyrum thalictroides* and *Galanthus nivalis* at the herb floor.

2.2. Sample collection

Animal communities were sampled using pitfall traps, which are widely used for the research of surface-dwelling invertebrate fauna. Pitfall traps were constructed of a glass jar (volume: 0.7 liters), in which a plastic cup (Ø: 65 mm, height: 100 mm) was placed. Approximately one third of a plastic cup was filled with a previously prepared fixative (4% aqueous solution of formaldehyde). At selected locations, holes of a jar-size were excavated and pitfall-traps were placed inside them, having their edges adjusted to the ground level. Upon each pitfall trap there has been a 30 x 30 cm metal roof constructed, in order to prevent litter, rain and snow from getting inside. Pitfall traps were located in two parallel lines, passing through all four above-mentioned transects. Each line counted 17 traps, placed 10 meters from each other. They were coded according to the number of line and number of trap in the line, from 101 to 117, respectively from 201 to 217. Samples were picked up at 14-days intervals (in winter time once a month), from March 2004 until February 2006.

2.3. Sample analysis

Biodiversity of individual traps and abundance of species in forest mosaic were analyzed in Microsoft Office Excel 2007. Alpha diversity of myriapoda, in each of the traps, was measured by Shannon-Wiener Diversity Index. Abundance of individual species was analyzed for each of transects as an average number of individuals per trap for the whole study period in a specific transect.

2.4. Environmental variables analysis

We used *Canoco for Windows 4.5*© (ter Braak & Šmilauer, 1998) to examine impact of tracked environmental factors on myriapods. Those were: percentual presence of shrubs; percentual presence of herbs; shade by tree canopies, counted as percentual presence of canopies, covering the area of 2 meters around each trap; percentual presence of litter coverage and litter thickness; the age of the growth in which traps were placed. All the environmental factors, apart from the age of the growth, have been semi quantified at the scale of 25%, as well as coded for the purposes of analyzing in the program (Table 1).

Table 1: Environmental factors codes

	code	0.1	0.2	0.3	0.4
presence of shrubs	%	0-25	25-50	50-75	75-100
presence of herbs	%	0-25	25-50	50-75	75-100
presence of trees	%	0-25	25-50	50-75	75-100
litter coverage	%	0-25	25-50	50-75	75-100
litter thickness	mm	0-1	1-3	3-5	5≥

According to the length of gradient for species-data, environmental factors were analyzed by canonical correspondence analysis (CCA). Generalized additive models were used to express species distribution dependence on the strongest environmental factors, which were graphically illustrated in CanoDraw for Windows 4.0© (part of CANOCO software).

3. Results

3.1. Diversity

During the research, there were 6061 myriapoda individuals collected and identified in total. Centipedes counted 3744 individuals (10 spp., Table 2) with the most dominant *L. mutabilis* (76% of centipedes); millipedes were represented by 2317 individuals (10 spp.) with *G. tetrasticha* (63% of millipedes) as the most dominant species.

Biodiversity of individual traps (Figure 1) was analyzed for each of the lines. It was the highest in 87 years old *Querco-Ulmetum* vegetation (traps 102, 201) and in 10 years old *Quercus* vegetation (trap 107). The lowest biodiversity was identified in the ecotone, between 2 years old clear-cut with seedlings and 127 years old floodplain forest *Quercus-Ulmetum* (trap 113). In the remaining ecotones, biodiversity was similar to the one in the surrounding habitats. Millipedes alone reached the highest diversity in the 87 years old forest and the ecotone alongside. Centipede species were relatively evenly distributed along all sites; slight decline in its diversity was spotted in 127 years old forest and the bordering ecotone.

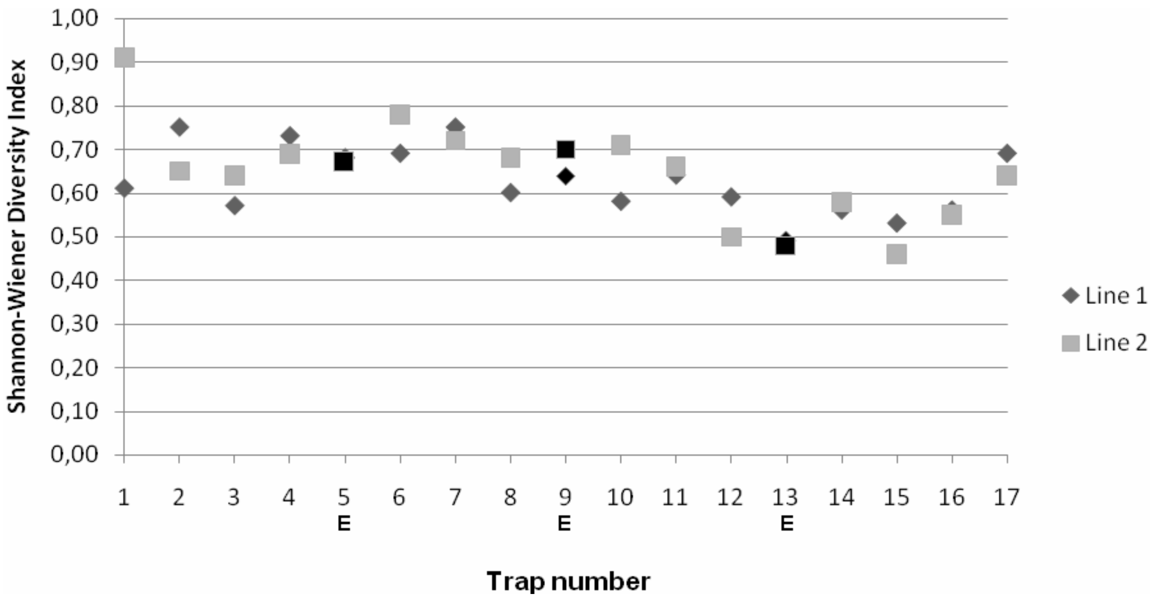

Figure 1: Biodiversity of individual traps

Species abundances in the forest mosaic point at their preferences towards certain habitats (Table 2). Concerning centipedes, both *L. mutabilis* and *L. forficatus* were the most frequent in the ecotone between 10 years old *Quercus* vegetation and 2 years old clear-cut with seedlings. Majority of millipedes also had positive relation towards ecotones: *P. germanicum* and *H. oculodistincta* were the most abundant in the ecotone between 87 years old *Querco-Ulmetum* vegetation and 10 years old *Quercus* vegetation; *L. proximus* and *G. tetrasticha* reached the highest abundances in the ecotone between 10 years old *Quercus* vegetation and 2 years old clear-cut with seedlings, while *U. foetidus* was represented by the most individuals in the ecotone between 2 years old clear-cut with seedlings and 127 years old floodplain forest *Querco-Ulmetum*. Hence, two out of three ecotones examined during the research, resulted in having higher abundances than the other studied fragments.

Table 2: Average number of individuals per trap for the whole study period in a forest mosaic

	87 y.o.	ecotone	10 y.o.	ecotone	2 y.o.	ecotone	127 y.o.
Lithobius agilis (Koch, 1847)	0.9	0.0	**1.4**	0.5	0.5	0.5	0.5
Lithobius erythrocephalus (Koch, 1847)	0.1	0.0	0.2	**1.0**	0.2	0.0	0.4
Lithobius forficatus (Linnaeus, 1758)	27.9	32.5	28.2	**33.0**	18.0	6.5	15.6
Lithobius mutabilis (Koch, 1862)	54.8	64.0	71.5	**112.0**	96.4	96.0	105.6
Geophilus flavus (de Geer, 1778)	0.0	0.0	**0.2**	0.0	0.0	0.0	0.0
Geophilus insculptus (Attems, 1895)	0.1	0.0	0.0	**0.5**	0.0	**0.5**	0.0
Schendyla nemorensis (Koch, 1837)	0.1	0.0	0.0	0.0	0.5	0.0	**0.8**
Strigamia acuminata (Koch, 1835)	0.5	**2.0**	1.4	0.0	0.7	0.0	1.0
Strigamia crassipes (Koch, 1835)	0.1	0.0	0.0	**0.5**	0.4	**0.5**	0.3
Strigamia transsilvanica (Verhoeff, 1928)	0.0	0.0	0.0	0.0	0.0	**1.0**	0.0
Polyzonium germanicum (Brandt, 1837)	5.4	**14.0**	2.0	1.5	0.0	1.0	0.8
Haplogona oculodistincta (Verhoeff, 1893)	21.5	**22.0**	16.5	5.0	6.4	6.5	4.6
Melogona voigtii (Verhoeff, 1899)	0.8	0.0	0.0	0.0	**1.0**	0.0	0.6
Leptoiulus proximus (Nemec, 1896)	2.9	0.5	0.7	**4.5**	1.0	1.0	1.3
Unciger foetidus (Koch, 1838)	4.4	5.0	2.5	2.5	4.4	**8.5**	5.3
Unciger transsilvanicus (Verhoeff, 1899),	**6.9**	4.5	1.7	1.5	2.0	1.5	2.3
Brachydesmus superus (Latzel, 1884)	0.0	0.0	0.0	0.0	**0.2**	0.0	0.0
Polydesmus complanatus (Linnaeus, 1761)	**0.5**	**0.5**	0.2	0.0	0.2	**0.5**	0.1
Polydesmus denticulatus (Koch, 1847)	0.0	0.5	0.0	0.0	**0.8**	0.0	0.0
Glomeris tetrasticha (Brandt, 1833)	48.5	80.0	67.5	**111.5**	30.0	14.0	9.8
Sum	175.3	**225.5**	193.7	**274.0**	162.4	138.0	148.7

3.2. Environmental factors analysis

According to the length of gradient for species-data, we selected canonical correspondence analysis (CCA). The whole model is significant (F=4.945; p=0.0002) and explains 16.8% of species variability. First canonical axe explains 11.1% of variability and the second one 3.5%. All the environmental factors were evaluated as significant (Table 3).

Table 3: Significance of individual environmental factors

	lambda	P	F
litter coverage	0.08	0.000	13.85
herbs	0.03	0.000	4.38
shrubs	0.02	0.000	4.19
litter thickness	0.01	0.001	2.51
age of growth	0.02	0.003	2.42
tree-crowns shade	0.01	0.012	2.13

The importance and impact of each of the studied environmental factors on distribution of myriapoda was then demonstrated by using generalized additive models (GAM) (Table 4).

Litter coverage was evaluated as the most significant factor, having impact on abundance of 11 species. The majority of them have shown positive correlation towards it, reaching higher abundances in the environment where litter coverage was higher. It had the strongest effect on *G. tetrasticha* (F=44.92). Only *L. mutabilis* (F=8.43) had different preferences than the other species, being more abundant in the areas with no or little litter coverage (Figure 2).

Presence of herbs was evaluated as the second most significant factor. It had impact on abundance of 10 species. *B. superus* (F=7.85) and *L. mutabilis* (F=5.19) were found in habitats where herbs were present in high amounts. On the contrary, *G. tetrasticha* (F=17.35), *L. forficatus* (F=8.8) and *G. flavus* (F=4.6) have shown preferences towards habitats with no or little herbs (up to 25%). Some species, e.g. *P. germanicum* (F=12.47) or *U. transsilvanicus* (5.04) had the highest abundances in habitats where presence of herbs counted between 25% and 75% (Figure 3).

Presence of shrubs in the environment was significant for 10 species. *B. superus* (F=28.46), *L. mutabilis* (F=11.42), *G. tetrasticha* (F=4.02) and *M. voigtii* (F=3.81) had higher abundances in habitats where more shrubs were present. *H. oculodistincta* (F=6.25) had the highest abundances in the area with 25% to 50% presence of shrubs (Figure 4).

The litter thickness had significant impact on abundance of 6 species. It had the strongest influence on distribution of *G. tetrasticha* (F=42.47), which has shown strong preferences towards habitats where litter thickness was at least 3 mm. *L. forficatus* (F=5.03) and *H. oculodistincta* (F=3.24) were also present in the environment with higher amount of litter. *L. mutabilis* (F=6.09) has shown strong preferences towards habitats in which amount of litter was between 1 and 3 mm; in habitats where litter-thickness was over 3 mm abundances of *L. mutabilis* were significantly lower (Figure 5).

The age of growth was significant environmental factor for abundance of 11 species. It had the highest influence on abundance of *G. tetrasticha* (F= 53.42); although it was found in the whole range of habitats, this species strongly prefers young habitats, up to 40 years of age, where it reaches its highest abundances; in habitats with older growth, it rapidly declines along with the increasing age of growth. *L. mutabilis* (F=29.6) is a mirror image of the previous species. It shows strong positive correlation towards very old (over 80 years of age) or very young growth, while it appears in small numbers in the growth between 20 and 80 years old. *L. forficatus* (F=13.13), *H. oculodistincta* (F=8.8) and *P. germanicum* (F=8.5) had slight preferences towards the growth between 20 and 80 years of age, although they also inhabit the remaining areas composed of growth of different age. *G. flavus* (F=4.19) shows strong preferences towards habitats from 20 to 60 years of age, reaching its maximum abundance in the 35 years old growth. *U. foetidus* (F=3.5) was highly abundant in the habitats composed of very old growth (Figure 6).

Shade by tree-canopies was the least significant factor examined in the research. It had impact on distribution of 7 species. The majority of species, namely *P. germanicum* (F=14.53), *L. forficatus* (F=5.05), *G. tetrasticha* (F=3.86) and *H. oculodistincta* (F=3.36) were evenly distributed in habitats with high and low amounts of shade, although they all have shown slight preferences towards the shaded areas. *L. mutabilis* (F=9.27) has shown the negative correlation towards the shadow, i.e. it was most abundant in the areas with little or no shade (Figure 7).

Table 4: Influence of environmental factors on abundance of myriapoda in forest mosaic

	LITTER C		HERBS		SHRUBS		LITTER-T		AGE		TREES	
	F	p	F	p	F	p	F	p	F	p	F	p
L. agilis	1.82	0.1637	1.74	0.1761	1.85	0.1597	0.528	0.4105	0.617	0.4607	1.74	0.1772
L. erythrocephalus	0.082	0.0826	0.285	0.2541	0.776	0.4555	0.386	0.3264	0.507	0.4034	0.393	0.3322
L. forficatus	10.63	**3E-05**	8.8	**0.0002**	4.17	**0.0165**	5.03	**0.0072**	13.13	**3E-06**	5.05	**0.0069**
L. mutabilis	8.43	**0.0003**	5.19	**0.006**	11.42	**1E-05**	6.09	**0.0025**	29.6	**< 1.0e-6**	9.27	**0.0001**
G. flavus	7.61	**0.0005**	4.6	**0.0138**	7.6	**0.0005**	2.33	0.1037	4.19	**0.018**	1.61	0.2048
G. insculptus	4.57	**0.0105**	0.318	0.275	1.26	0.2838	2.03	0.1347	1.03	0.3557	1.03	0.3573
S. nemorensis	6.23	**0.0026**	0.208	0.1913	0.537	0.4226	4.01	**0.0202**	3.03	0.051	0.307	0.2689
S. acuminata	1.91	0.1486	0.423	0.3457	0.034	**0.0332**	1.9	0.151	0.802	0.4483	0.67	0.4881
S. crassipes	0.859	0.4189	3.33	**0.0369**	1.51	0.2223	1.29	0.2756	0.73	0.4772	1.13	0.3218
S. transsilvanica	2.47	0.0883	1.02	0.3605	0.448	0.3649	2.12	0.1219	2.98	0.0513	1.95	0.1445
P. germanicum	11.44	**1E-05**	12.47	**6E-06**	6.4	**0.0019**	3.47	**0.0318**	8.5	**0.0002**	14.53	**1E-06**
H. oculodistincta	2.12	0.1208	1.87	0.1552	6.25	**0.002**	3.24	**0.0398**	8.8	**0.0002**	3.36	**0.0353**
M. voigtii	4.86	**0.0086**	3.75	**0.025**	3.81	**0.0236**	1.33	0.2658	0.55	0.4237	0.578	0.4409
L. proximus	1.38	0.2518	1.28	0.2792	0.353	0.3092	0.891	0.4104	3.61	**0.0289**	2.63	0.0745
U. foetidus	3.11	**0.045**	1.65	0.1924	1.01	0.3637	2.06	0.128	3.5	**0.0306**	1.1	0.3343
U. transsilvanicus	2.32	0.1013	5.04	**0.0067**	2.86	**0.0603**	1.44	0.2372	13.5	**2E-06**	2.61	0.074
B. superus	7.61	**0.0005**	7.85	**0.0004**	28.46	**< 1.0e-6**	2.33	0.1037	0.015	**< 1.0e-6**	9.82	**0.0002**
P. complanatus	2.11	0.1219	0.255	0.2297	1.89	0.1515	1.47	0.2316	1.01	0.3635	0215	0.2017
P. denticulatus	4.3	**0.0148**	4.47	**0.0127**	2.3	0.1031	0.565	0.4333	24.58	**< 1.0e-6**	8.83	**0.0002**
G. tetrasticha	44.92	**< 1.0e-6**	17.35	**< 1.0e-6**	4.02	**0.0182**	42.47	**< 1.0e-6**	53.42	**< 1.0e-6**	3.86	**0.0214**

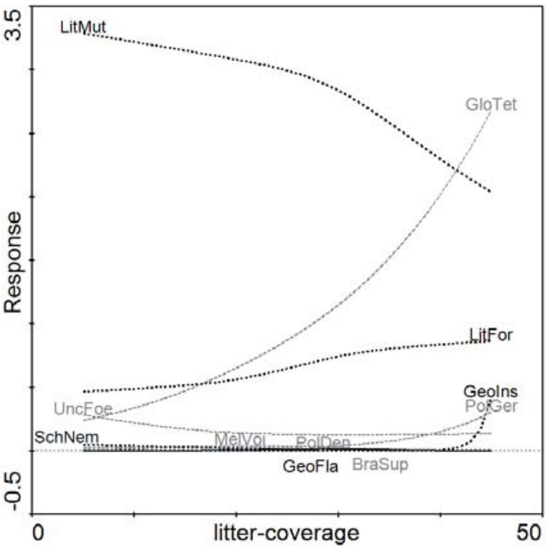

Figure 2: Influence of litter coverage on species abundance

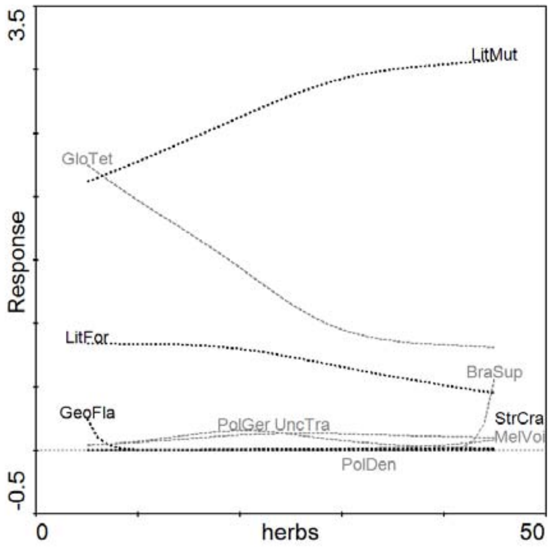

Figure 3: Influence of presence of herbs on species abundance

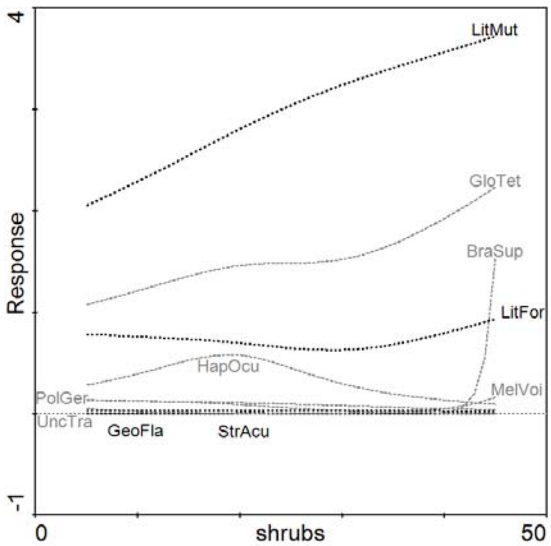

Figure 4: Influence of presence of shrubs on species abundance

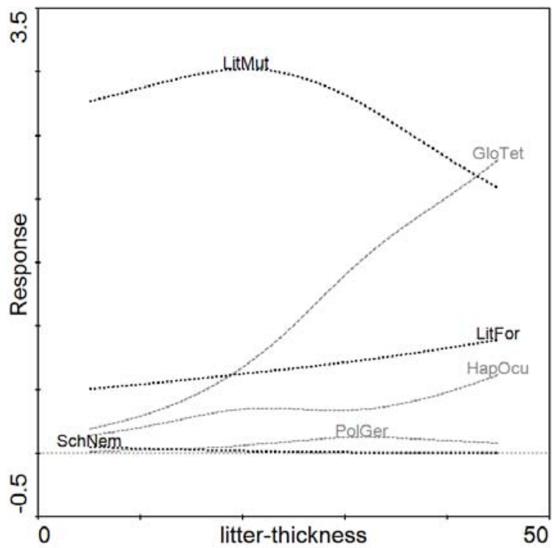

Figure 5: Influence of litter thickness on species abundance

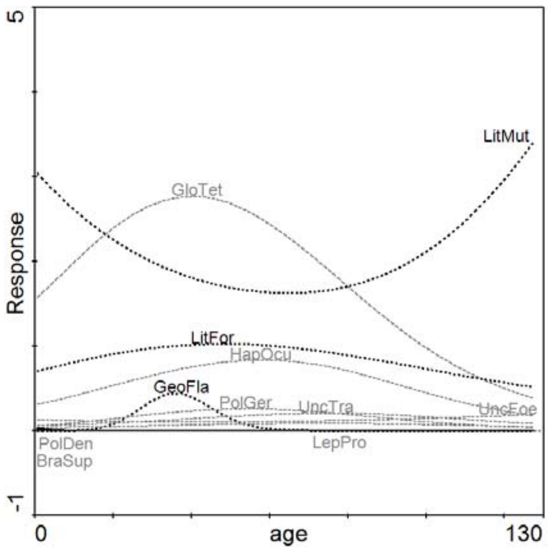

Figure 6: Influence of the age of growth on species abundance

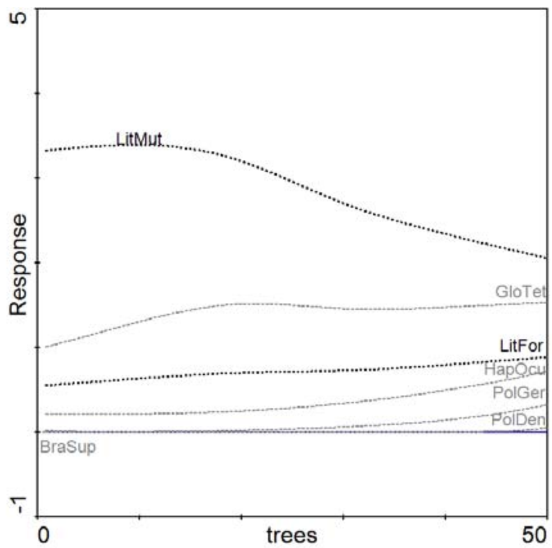

Figure 7: Influence of shade by tree-canopies on species abundance

L. mutabilis and *L. forficatus* have shown opposite ecological preferences, towards all the examined factors. Their distribution within the examined sites points at the contrary trends of those two species (Figure 8). *L. mutabilis* was much more abundant at sites where traps 108-117, respectively 208-217 were placed, while decline in number of individuals of *L. forficatus* at those sites was observed.

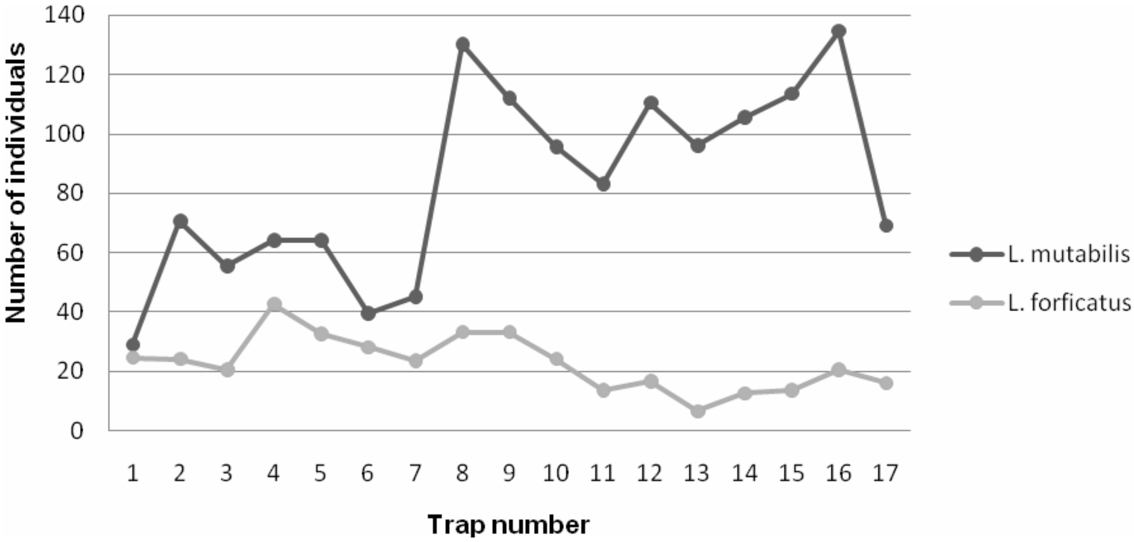

Figure 8: Distribution of *Lithobius mutabilis* and *Lithobius forficatus*

4. Discussion

4.1. Environmental factors

Protected landscape area Litovelské Pomoraví is home to 22 millipede and 19 centipede species (Tajovský, 2000). During the research, we collected 10 species of each group, which coincides with the previous findings in floodplain forests at this location (Tuf & Ožanová, 1998). The highest biodiversity was found in 87 years old *Querco-Ulmetum* vegetation. Centipede species were evenly distributed, while millipedes reached the highest diversity in the 87 years old *Querco-Ulmetum* vegetation and the neighboring ecotone. In general, their communities in the old growth forests count more species, which might be a consequence of more diverse leaf litter offer (David, 2009). Somewhat higher diversity in the bordering ecotone is presumably caused by dispersal from the forest site. There were no indications which would suggest that diversity of myriapoda in young growths (clear-cut with seedlings and 10 years old vegetation) created as a consequence of forest management, was negatively affected. Ewers & Didham (2006) affirm that arthropods, depending on individual species, have various (often opposite) responses to habitat fragmentation. In case of centipedes, maintaining certain level of heterogeneity, which secures habitats of different size and different development phases for both forest and open area species, leads to increase in diversity (Grgič & Kos, 2005).

At all examined sites, *G. tetrasticha* was the most dominant millipede and *L. mutabilis* the most dominant centipede species. High abundances at ecotones suggest the ability of species to migrate between habitats. Forest ecotones are of a special importance for centipedes, because they allow them to hunt in the open area and to reproduce at well protected forest habitats (Voigtländer, 2005). Ecotone theory suggests that predator species will be more common in ecotones, because predator activity often occurs at forest-edges (Kareiva, 1987). High abundances of *L. forficatus* and *L. mutabilis* in ecotones correspond with the theory. Spatial distribution of *G. tetrasticha, P. germanicum* and *U. foetidus* also indicates existing migration between habitats. *S. transsilvanica* was the single species found in the ecotone only, but number of individuals collected during the research is too low to lead to any conclusions. Tuf & Ožanová (1998), who carried a research on myriapoda diversity in Litovelské Pomoraví, collected the only individual of this species also in the forest-field ecotone. On the contrary, *G. flavus*, *S. nemorensis*, *M. voigtii* and *B. superus*. were present at forest sites only. In case of species with poor dispersal ability, such as myriapoda, risk of extinction increases with habitat fragmentation (Hanski, 2005). Yet, their migration between sites is possible, but depends on distance between patches, its spatial arrangement, species and specimens characteristic and instraspecific interactions (Grgič & Kos, 2003).

For diversity of myriapoda the most important environmental factor is litter coverage. All the species, apart from *L. mutabilis*, have shown positive correlation towards it. Leaf litter and litter interface present the basic myriapoda habitat, which secures them environment with optimal microclimate; it also contributes to diversity of other soil invertebrates (Niemelä, 1997). It leads to creation of new niches, which enable higher number of species to coexist (Koivula et al., 1999). Further, microhabitats composed of leaf litter provide invertebrates with shelter against evaporation and predators (Koivula et al., 1999). Apart from creation of suitable habitats, for millipedes leaf litter is the main source of food. That makes them more vulnerable to changes in habitat structure, than centipedes (Wytwer & Zalevski, 2005). In temperate forests, millipedes consume between 10 and 15% of annual leaf litter production (Golovatch & Kime, 2009; Stoev et al. 2010).

Forest management leads to changes in vegetation, which affects quality and quantity of leaf litter, and consequently, invertebrate communities. Replacement of the old-growth forests by low-diversity growth or even monocultures generally has negative impact on diversity of myriapoda (David, 2009; Leśniewska et al., 2005). Yet, until certain degree, forest fragmentation increases the heterogeneity of environment and leads to creation of new habitats. Management practices that lead to creation of microhabitats within the existing ones generally have positive influence on arthropod communities (Topp et al. 2006). David et al., (1999) state that habitat mosaic has irreplaceable role on diversity of millipede, as their communities tend to change according to the land cover over very short distances.

The importance of ecotones, which emerge as a result of forest fragmentation, has already been highlighted in number of papers. Especially in heavily fragmented areas, ecotone effect plays a dominant role on invertebrate assemblages (Kotze & Samways, 1999). Magura et al. (2001) forewarn on combination of herbs and shrubs in the ecotone, which significantly contributes to landscape heterogeneity. The combination of environmental factors in the ecotone often leads to creation of microhabitats which do not exist in either of the bordering habitats. A usual response of invertebrates to those conditions is an increase in abundance and diversity (Didham, 1997). Because of weak relation between area and species richness in case of invertebrates, ecotones often play crucial role for survival of some species (Webb & Thomas, 1993). Concrete information of the ecotone effect on myriapoda is pretty limited. It is known that diversity of open-habitat millipede specialists has been affected by significant decrease of coppicing and extensive grazing in Europe and the extension of closed-canopy forests (David, 2009). Therefore, habitat fragmentation and subsequently emerging ecotones will rather have a positive effect on those species. One of the most important characteristics, concerning centipede and other invertebrates, is distance between habitats (i.e. edge length) and environmental conditions in between (Grgič & Kos, 2005). That is why human-induced changes in plant composition and landscape mosaic can be of a critical importance for their distribution (David, 2009).

Forest management practices need to create conditions which will allow migration between habitats and which will secure favorable level of heterogeneity for invertebrates with limited dispersal abilities (Grgič & Kos, 2005). One of the basic issues and main focuses of forest management should be the relation between ecosystem function and the community structure, resulting in preservation of suitable habitats (Perry, 1998).

4.2. Species

Distribution of myriapoda collected during the research points at their strong dependence on habitat type and emerging environmental factors. Yet, individual species responded differently to specific conditions. Below, we discuss preferences of species that were represented by more than 100 individuals collected during the research.

Lithobius mutabilis belongs to typical woodland centipedes (Leśniewska et al., 2005), although in some countries (e.g. Slovenia) it is found primarily in deforested areas (Grgič & Kos, 2005). According to the results of our research, in habitats with the increasing amount of trees (over 25%) and litter, its populations start to decline. It has been primarily collected in either very young or very old growths, preferably with high amount of herbs and shrubs. The highest abundances were spotted in the ecotone zone between 2 years old clear-cut with seedlings and 10 years old *Quercus* vegetation. Its appearance in the ecotone zone, where solar radiation and temperature are higher than in the forest interior, corresponds with Grgič & Kos (2001) findings on *L. mutabilis* preferences towards habitats with higher temperatures. Murcia (1995) suggests that edge-habitats can foster occurrence of species, which are adapted to its specific environmental conditions.

Lithobius forficatus has shown entirely different preferences towards environmental factors, than the previous species. Its populations were increasing with presence of trees, litter (both coverage and thickness) and middle-aged growth. It was also significantly associated with ecotones, reaching the highest abundances in two ecotones examined in the research. This matches previous findings (Fründ et al., 1997; Lee, 1980; Hickerson et al., 2005) in which its distribution was correlated with human-made edge-habitats. Ecological preferences of *L. mutabilis* and *L. forficatus* suggest that, even though those species coexisted at all examined sites, they were differently distributed within them. Their abundances rates point at the existing mutual competition.

Glomeris tetrasticha is a Central European species, that typically occurs in different forest types (Jastrzębski et al., 2006) with sufficient moist and shade

(Haupt, 1990). Our results also suggest its strong preferences towards habitats with lots of trees, shrubs and litter, but limited presence of herbs. Its noticeable increase in younger growths has been previously documented by Tufová (2002) and has now been confirmed. As a millipede adaptable to different environmental factors (Tuf & Tufová, 2008) its appearance in human-disturbed biotopes is typical.

Haplogona oculodistincta was the most numerous in middle-aged growths with lots of trees and thick layer of litter. It responds to ordinary millipede habitat, characterized by enough food, shelter, shade and sufficient humidity (Golovatch et al., 2009). The highest abundances were reached in the ecotone between 87 years old *Querco-Ulmetum* vegetation and 10 years old *Quercus* vegetation. Yet, based on its overall distribution, we conclude it rather is a consequence of migration between those two sites, than a specific preference towards the ecotone habitat.

Unciger foetidus is a European species of wide ecological amplitude (Tufová & Tuf, 2005). In the Czech Republic it mostly inhabits human settlements, gardens and parks. It is also found in forests, at sites with sufficient humidity (Haupt, 1990). In our research, it showed positive relation towards habitats with old growth and limited litter coverage. The highest abundances have been reached in one of the ecotones. In previous researches (Hora et al., 2009) *U. foetidus* has been characterized as a species which appears in ecotone on its way between two habitats.

Unciger transsilvanicus belongs to middle-southeast European species. It prefers drier floodplain forests (Tufová & Tuf, 2005), but can also be found in open habitats (e.g. meadows) (Vagalinski & Stoev, 2007). Our research points at its preferences towards habitat with a low amount of shrubs and limited presence of herbs (25-50%). The highest abundances have been reached in 87 years old *Querco-Ulmetum* vegetation.

5. Conclusion

This paper focuses on distribution of myriapoda in fragmented landscape. We examined their diversity and distribution in relation to individual environmental factors in different habitats of floodplain forest of Protected landscape area Litovelské Pomoraví, the Czech Republic. Samples were collected using pitfall traps, placed in two parallel lines across four forest sites of different age, and ecotones between them. During two-year research, we collected 10 species (3744 individuals) of centipedes and 10 species (2317 individuals) of millipedes. The most dominant species were *L. mutabilis* and *G. tetrasticha*.

The highest diversity of myriapoda was found in 87 years old *Querco-Ulmetum* vegetation. We did not detect the ecotone effect on myriapoda diversity. Yet, species were the most abundant at ecotones, which suggests their ability to migrate between habitats. It means the matrix of fragmented landscape at examined site is suitable for migration of invertebrates with poor dispersal abilities, such as myriapoda. All examined environmental factors had significant impact on distribution of myriapoda. Litter coverage was identified as the most important one. All the species, for which the factor was significant, apart from *L. mutabilis,* have shown positive correlation towards it.

In terms of impact of fragmentation on myriapoda, it is important to maintain effective environmental heterogeneity. We have not identified any negative consequences of habitat fragmentation at site, but biology of species and our findings in relation to environmental factors clearly indicate the need for management practices with regard to species needs, not economic profits only. Myriapoda require a mosaic environment, which secures them different microhabitats, close enough from each other to enable their migration. Therefore, if human interventions are necessary, it is important to find the balance between heterogeneity and fragmentation.

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