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Comparative study of leaf litter decomposition of exotic and native species in an ecotop of the hornbeam-oak forest near Báb village, SW Slovakia

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Abstract

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We present here a comparative study of leaf litter decomposition in some exotic and native species in a hornbeam-oak forest ecosystem. We focused on the exotic invasive species *Robinia pseudoacacia, Ailanthus altissima, Impatiens parviflora* and on the expansive native species *Alliaria petiolata*. These species were compared to the native co-occurring species *Acer campestre* and *Mercurialis perennis*. In addition, we studied also cellulose decomposition and site microclimate. We used the litter-bag method on five experimental plots within the managed part of hornbeam-oak forest near Báb, SW Slovakia. The plots were located in closed forest, on forest edge and in a clearing. The course of litter decomposition was fitted with the 1-phase and 2-phase negative exponential decay model for each species. The most conspicuous loss in litter weight was detected in case of the species *Impatiens parviflora* species (26% of mass remaining), followed by *Alliaria petiolata* (29% of mass remaining) and *Mercurialis perennis* (29% of mass remaining). In woody species, the biggest loss of litter was detected in *Ailanthus altissima* (45% of mass remaining), followed by *Acer campestre* (63% of mass remaining) and *Robinia pseudoacacia* (70% of mass remaining). Cellulose decomposition varied significantly in different habitats, with the highest rate in the closed forest. The pattern of herbaceous species was similar. However, this effect of the habitat was not evident in case of woody species.

Key words

Báb village, decomposition, leaf litter, hornbeam-oak forest, invasive species

Introduction

Invasive species influence ecosystem processes in a complex way. According to many examples in literature, an invasive species alters processes and subsequent species composition and biodiversity in the ecosystem (Levine and D'Antonio, 1999; Levine et al., 2003; Vitousek, 1990).

When the species composition has been changed there is a high probability that the subsequent soil-plant interactions and carbon and nutrient cycles will change, too. These consequences may, in turn, have an impact on the invasive susceptibility of ecosystems and the invasivness of species (Ehrenfeld, 2003). Invasive and expansive species have a potential to change many components of the carbon and nitrogen cycles of an ecosystem. Ehrenfeld (2003) has summarized, that invasive plant species frequently increase phytomass production, net primary production, nitrogen availability, alter nitrogen fixation rates and produce litter with higher decomposition rates than the co-occurring native species.

Leaf litter decomposition plays an important role in carbon and nitrogen cycling in ecosystems, being a main source of nutrients and organic matter for plants and soil organisms. Leaf litter decomposition is affected by both biotic and abiotic factors: temperature, moisture, litter chemistry, soil nutrient supply and decomposer community structure. Due to the large number of factors controlling the leaf litter decomposition, comprehensive study of impact of invasive species on leaf litter decomposition rate is difficult to pursue. The impotance of specific factors and their interactions are often studied in order to find the relative effect of each particular factor. Furthermore, specific habitat conditions can affect microbial activity and leaf litter decomposition significantly (Šimonovičová, 1995; Lancuch and Šimonovičová, 2008). Comparative studies of invasive species and co-occurring native species in field conditions can provide valuable information on this topic.

Disturbed ecosystems are examples exhibiting obvious invasions of exotic and expansive plant species. Clear-cut areas and forest openings with high nutrient availability in soil are very sensitive to invaders. The invaders are mostly very effective in nitrogen using. Under conditions of forest opening they can invade extremely (Eliáš, 2000). Even though it is probable that exotic plant invasions may alter soil and ecosystem properties, it is not always the case (Ehrenfeld and Scott, 2001). In addition, environmental conditions much varying on a gradient from clear-cut to closed forest gradient may result in a very variable decomposition rate (Didham, 1998). Therefore, there is still a need for case studies on different invasive plant species in various types of habitats.

In our contribution, we compare the decomposition rates of selected exotic species with relevant native species. We select *Robinia pseudoacacia* and *Ailanthus altissima* from the exotic expansive woody species and Impatiens parviflora and *Alliaria petiolata* from expansive herbaceous species. Although *Alliaria petiolata* is not an exotic species, it is considered as native expansive species. *Acer campestre* and *Mercurialis perennis* were selected as native co-occurring species for comparative analysis. There are many studies on ecology of these invasive species in Slovakia; to our knowledge, however, there has not been performed yet a study of litter decomposition rates in these species in Slovakia.

Material and methods

Study site

The research site is located in the SW Slovakia (48°18´09´´; 17°53´27´´) in the Báb forest situated in a warm and dry region, with the mean annual temperature of 9.3 °C and precipitation total of 580 mm (Tužinský, 2004). The parent material is calcareous loess, the formed soils are Albi-Haplic Luvisols with 2.6–3.3% organic matter content and C/N ratio of 13.9 in the 0–10 cm horizon (Sombathová and Zaujec, 2001; Gonet et al., 2008). The geobiocoenosis belongs to the Fageto-Quercetum group of forest type (Kubíček and Brechtl, 1970), with prevailing oaks – *Quercus robur*, *Q. petraea*, *Q. cerris* with admixture of *Carpinus betulus* and *Acer campestre* in the tree layer of phytocoenosis. The herbaceous layer is dominated by *Mellica uniflora, Dactylis glomerata, Carex pilosa, Asperula odorata, Hedera helix, Pulmonaria officinalis and Geum urbanum*. Since 1966, a part of the Báb forest is protected. In this part has been prohibited forest management. In the adjacent area, 4 clear cuttings were applied at the end of the year 2006. The clear-cut areas were consecutively massively occupied by *Ailanthus altissima, Robinia pseudoacacia* and *Alliaria petiolata* species.

Litter bag experiment

For determination of leaf litter decomposition, we used the standard litter bag method (see Harmon et al., 1999). Leaf litter was collected in late summer when senescence was evident. In case of tree species, the litter was collected from branches immediately before shading of leaves in October 2008. The collected material was air dried in the laboratory for 14 days and filled in bags in amounts of 3–5 g. The initial leaf moisture content was estimated with subsamples set aside from litter samples and dried at 75 ºC. Our litterbags were 16 cm × 12 cm in size, made of nylon mesh (1 mm mesh size), with three sides double-stitched with nylon thread, and provided with small plastic tags with identification numbers. We established five plots on a gradient from clears-cut area

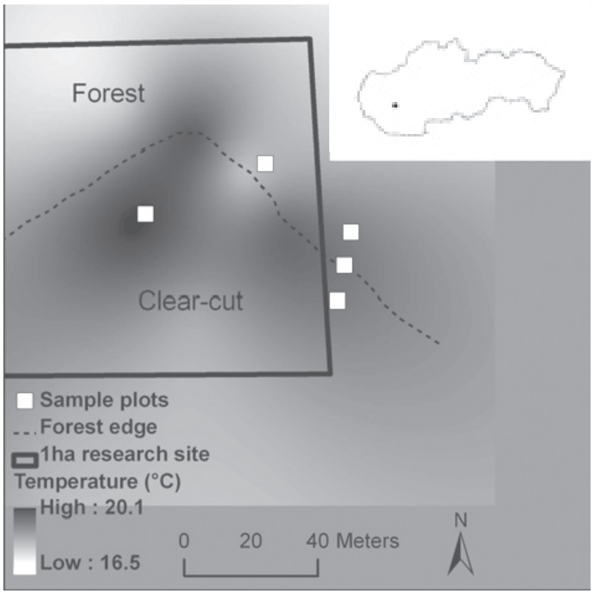

Fig. 1. Location of 5 sampling plots and spatial variation of mean near-ground temperature during the vegetation season 2009.

to closed forest (Fig. 1). The litter bags were placed randomly on particular plots, directly on the ground under the recent litter. The number of litterbags of individual species on particular plot varied from 30 to 50. Altogether we used 500 litterbags in the field. Together 4–6 samples of every species were taken in field in each sampling period. The sampling dates for herbaceous litter were: 4 September 2008, 17 October 2008, 14 November 2008, 19 December 2008, 27 January 2009, 19 March 2009 and 24 July 2009; for woody species: 17 October 2008, 19 December 2008, 27 January 2009, 19 March 2009, 24 July 2009 and 25 September 2009. The species determination was made according to Dostál and Červenka (1991) and the nomenclature follows that of Marhold and Hindák (1998).

The standard cellulose decomposition experiment was made with the aid of cellulose filter paper inserted in the litter bags (Školek, 1980). The litter bags with cellulose filter paper were placed under the leaf litter (ca 1 cm in the topsoil) and exposed for 2 months in the field in spring 2009. Five replicates were used on each plot, together 25 litter bags. Then the litterbags were transported in the laboratory, cleaned of adhering waste (soil, mosses, rock fragments, etc.), oven dried at 75 °C until a stable weight (usually ca. 48 hours), and weighed to determine the dry weight. Two-way ANOVA (StatSoft, INC., 2010) was used in order to reveal significant differences for testing differences in litter decomposition rate among different species across the study site. Herbaceous and tree species were analysed separately. The annual profile of decomposition was analyzed by 1-phase and 2-phase negative exponential decay model (Olson, 1963; Lindsay and French, 2004). The K decomposition constant, half-lives and 90% decay life and R coefficient of determination of the fitted model were obtained by means of GraphPad Prism software (GraphPad Software, 2009).

The near-ground (30 cm) air temperature was monitored in clear cut area and closed forest canopy with HOBO Pro temperature loggers (ONSET Computers, USA) at 30 min intervals. There was analysed the period from 4 September 2008 to 21 September 2009. Volumetric soil moisture was monitored in 30 min interval with Virrib sensors (AMET, ČR) based on phase transmittance method at 10, 30 and 70 cm depth in clear-cut area and closed forest.

Results

The decomposition rate leaf litter in herbaceous species varied substantially both among herb species and in time (Fig. 2). The biggest differences in weight of herb species litter are visible before the winter, after exposition in the field one month (1st sampling date) where all mean differences in litter weight were even statistically significant ($p < 0.05$). Later, after 100 days in the field, differences in weight of herb species litter continuously decreased (Fig. 3), mainly in case of *Alliaria petiolata* and *Mercurialis perennis*, where also the inverse pattern occurred on 4th and 5th sampling date. After 324 days of exposure in the field, conspicuous loss of litter weight was detected in case of *Impatiens parviflora* species (74%), followed by *Alliaria petiolata* (71%) and *Mercurialis perennis* species (71%). However, only the mean difference in litter weight loss between *Impatiens parviflora* and Mercurialis perennis species was statistically significant. Mean differences in litter loss of all studied species and their statistical significance for every sampling date are presented in Table 1.

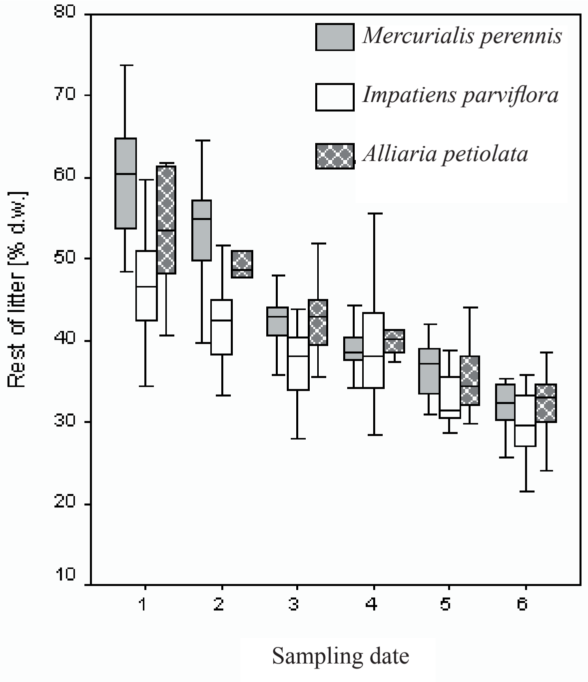

Fig. 2. Leaf litter weight loss from 4. 9. 2008 to 6 sampling dates (1: 17. 10. 2008, 2: 14. 11. 2008, 3: 19. 12. 2008, 4: 27. 1. 2009, 5: 19. 3. 2009, 6: 24. 7. 2009).

In case of woody species, the litter loss differences were statistically significant during the whole monitoring period. The differences slightly increased during the time period in the field. Especiall, the low decomposition of *Robinia pseudoacacia* litter in the later period is noticeable (Fig. 4). After 344 days of exposure in the field, the great loss of litter was detected in case of *Ailanthus altissima* species (55%), followed by Acer campestre (37%) and *Robinia pseudoacacia* species (30%).

The values of regression coefficients show the two-phase exponential decay model as better explaining the litter decomposition in all the plant species than the one-phase exponential model (Table 2). However, the results of the one-phase exponential decay model allow standard comparison with other published results. The first phase of litter decomposition (50% of

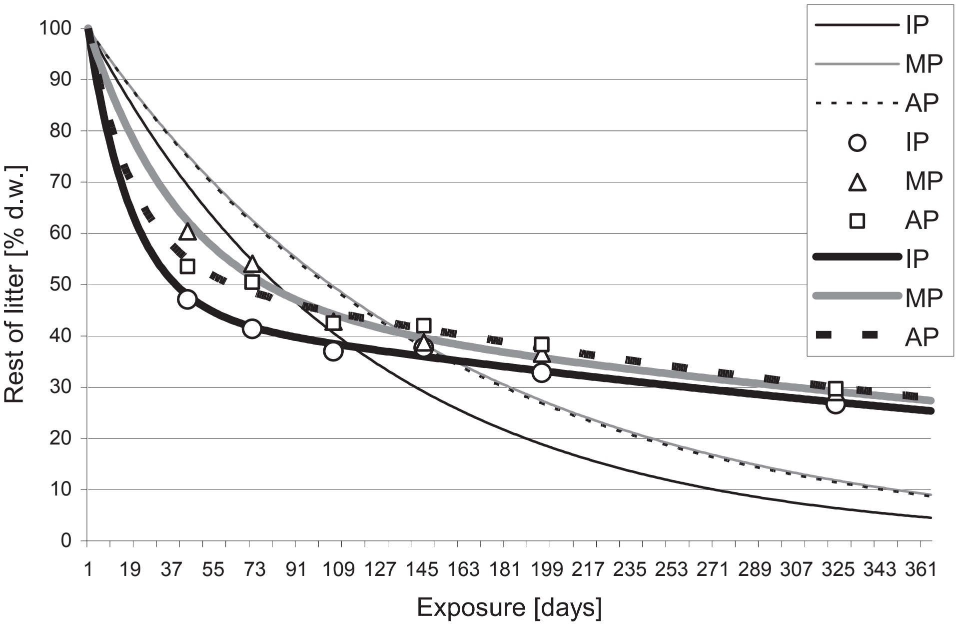

Fig. 3. Course of decomposition of leaf litter fitted by 1-phase (thin line) and 2-phase (bold line) decay models (IP, *Impatiens parviflora*; MP, *Mercurialis perennis*; AP, *Alliaria petiolata*).

Table 1. Mean differences in rate of litter decomposition and their statistical significance (IP, *Impatiens parviflora*; MP, *Mercurialis perennis*; AP, *Alliaria petiolata*; AC, *Acer campestre*; AA, *Ailanthus altissima*; RP, *Robinia pseudoacacia*)

Sampling date	Species A	Species B	Rest of litter [%]	Sig.	Sampling date	Species C	Species D	Rest of litter [%]	Sig.
17. 10. 2008	IP	MP	13.29(*)	.00					
		AP	6.86(*)	.02					
	MP	IP	–13.29(*)	.00					
		AP	–6.43(*)	.05					
	AP	IP	–6.86(*)	.02					
		MP	6.43(*)	.05					
14. 11. 2008	IP	MP	12.70(*)	.00	19, 12. 2008	AC	AA	12.33(*)	.00
		AP	3.60	.19			RP	.98	.34
	MP	IP	–12.70(*)	.00		AA	AC	–12.33(*)	.00
		AP	9.09(*)	.00			RP	–11.34(*)	.00
	AP	IP	–3.60	.19		RP	AC	–.98	.34
		MP	9.09(*)	.00			AA	11.34(*)	.00
19. 12. 2008	IP	MP	5.80(*)	.00	27. 1. 2009	AC	AA	16.17(*)	.00
		AP	.32	.85			RP	1.54	.22
	MP	IP	–5.80(*)	.00		AA	AC	–16.17(*)	.00
		AP	–5.49(*)	.00			RP	–14.63(*)	.00
	AP	IP	–.32	.85		RP	AC	–1.54	.22
		MP	5.49(*)	.00			AA	14.63(*)	.00
27. 1. 2009	IP	MP	–.47	.83	19. 3. 2009	AC	AA	17.92(*)	.00
		AP	–3.26	.17			RP	3.48	.19
	MP	IP	.47	.83		AA	AC	–17.92(*)	.00
		AP	–2.79	.28			RP	–14.43(*)	.00
	AP	IP	3.26	.17		RP	AC	–3.48	.19
		MP	2.79	.28			AA	14.43(*)	.00

Table 1. Continued

Sampling date	Species A	Species B	Rest of litter [%]	Sig.	Sampling date	Species C	Species D	Rest of litter [%]	Sig.
19. 3. 2009	IP	MP	3.76	.16	24. 7. 2009	AC	AA	14.35(*)	.00
		AP	–1.76	.53			RP	–10.65(*)	.00
	MP	IP	–3.76	.16		AA	AC	–14.35(*)	.00
		AP	–5.53	.06			RP	–25.01(*)	.00
	AP	IP	1.76	.53		RP	AC	10.65(*)	.00
		MP	5.53	.06			AA	25.01(*)	.00
24. 7. 2009	IP	MP	3.54(*)	.05	25. 9. 2009	AC	AA	15.73(*)	.00
		AP	.75	.68			RP	–8.33(*)	.00
	MP	IP	–3.54(*)	.05		AA	AC	–15.73(*)	.00
		AP	–2.79	.08			RP	–24.07(*)	.00
	AP	IP	–.75	.68		RP	AC	8.33(*)	.00
		MP	2.79	.08			AA	24.07(*)	.00

*The mean difference is significant at the .05 level.

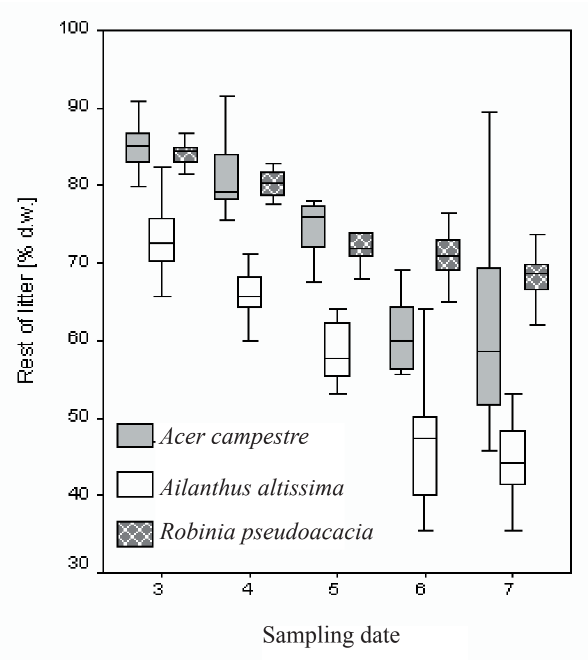

Fig. 4. Leaf litter loss from 17. 10. 2008 to 5 sampling dates (3: 19. 12. 2008, 4: 27. 1. 2009, 5: 19. 3. 2009, 6: 24. 7. 2009, 7: 25. 9. 2009).

weight) was found the fastest in *Impatiens parviflora* species, followed by *Alliaria petiolata* and *Mercurialis perennis*. The substantial decrease of decomposition is evident in winter season; however, in later periods the decay profile is very similar for all species (Fig. 5).

The rate of cellulose decomposition varied significantly among the habitats, with the maximum in the closed forest (Fig. 6). This pattern was to extent similar to the decomposition pattern in herbaceous species litter (Fig. 7). However, the results of ANOVA proved the habitat effect to be significant only for the species *Mercurialis perennis* and *Impatiens parviflora*. This habitat effect was not observable in woody species (Fig. 8). However, the evident considerable variability in these values may be caused by many factors of habitat affecting the decomposition rate of litter. Varying site microclimate was detected throughout the forest clear-cut area to closed forest gradient (Fig. 1, Fig. 9). The mean difference in values of near-ground air temperature recorded in clear-cut area and in closed

Table 2. Results of 1-phase and 2-phase exponential decay models (IP, I*mpatiens parviflora;* P, *Mercurialis Perennis;* AP*, Alliaria petiolata*; AC, *Acer campestre*; AA, *Ailanthus altissima*; RP, *Robinia pseudoacacia*)

Model	Parameter	AC	AA	RP	IP	MP	AP
1-phase	K [years]	0.71	1.24	0.61	3.09	2.41	2.44
	R square	0.88	0.73	0.61	0.63	0.79	0.66
	Half-lives [days]	335	188	391	82	105	103
	95% decay time [years]	4.2	2.4	4.9	0.97	1.25	1.23
	90% decay time [years]	3.3	1.8	3.8	0.74	0.96	0.94
2-phase	KFast [years]	47.3	34.47	20.78	19.24	9.17	18.49
	KSlow [years]	0.49	0.6	0.23	0.58	0.56	0.66
	R square	0.984	0.9928	0.966	0.997	0.996	0.995
	Half–lives [days]	544	256	1098	38	77	63
	95% decay time [years]	5.87	4.5	11.97	3.80	4.06	3.61
	90% decay time [years]	4.47	3.35	9.01	2.60	2.81	2.56

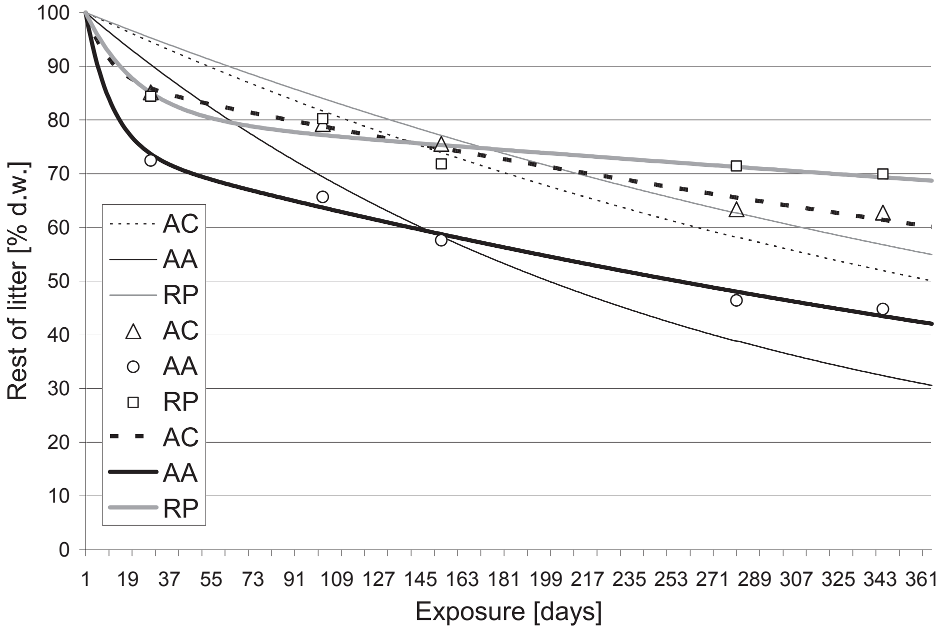

Fig. 5. Course of decomposition of tree leaves litter fitted by 1-phase (thin line) and 2-phase (bold line) decay model (AC, *Acer campestre*; AA, *Ailanthus altissima*; RP, *Robinia pseudoacacia*).

forest during the period from 4 September 2008 to 21 September 2009 made 0.36 °C. However, the mean daily temperature difference (7.00 a.m.–18.00 p.m.) made 2.76 °C. In daily profile, the greatest differences were identified between 13.00 and 14.00 p.m. Similarly, the values of mean difference of relative air humidity recorded during the period from 22 April 2009 to 21 September 2009 in clear-cut area and closed forest made 12% and the mean daily difference 2.3% (Fig. 10). The soil moisture value in the clear-cut area was permanently higher compared to the soil moisture in the closed forest (Halabuk, 2010). The biggest differences in soil moisture values recorded in the clear-cut area and closed forest were detected mainly at a depth of 70 cm. In topsoil, where cellulose decomposition was measured, the moisture differences were not such conspicuous, probably due to the higher input of precipitation water and due to dew formation.

Discussion

It is obvious that decomposition rate of herbaceous litter is faster than that of tree leaf litter (Mayer, 2008). Decomposition of plant litter is strongly affected by plant litter quality. The rate of microbial decomposition of

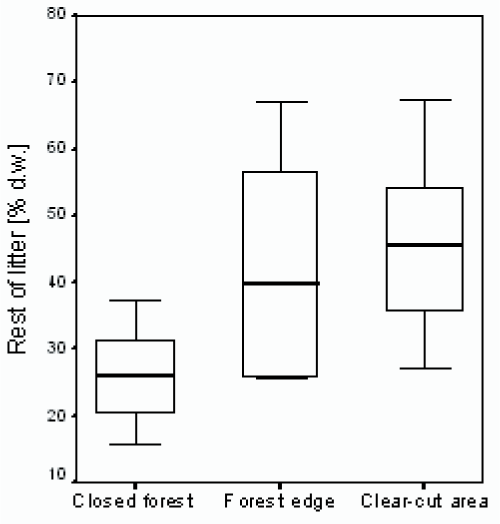

Fig. 6. Habitat effect on rate of cellulose decomposition.

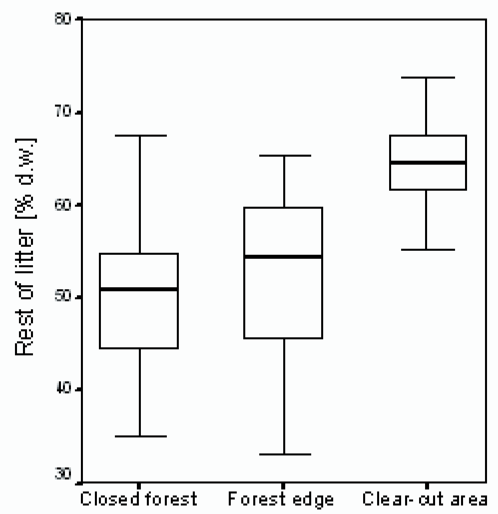

Fig. 7. Habitat effect on rate of litter decomposition of herbaceous species in the 1st stage of decomposition.

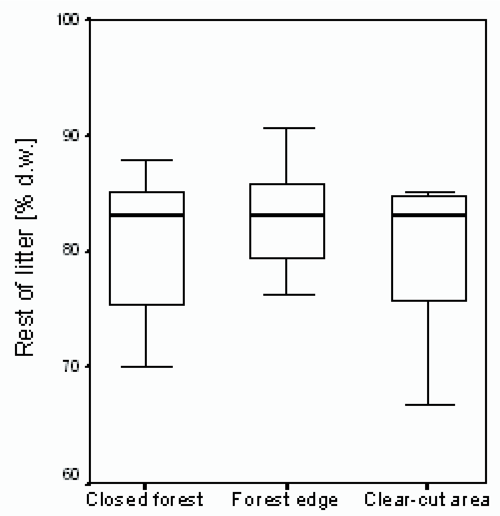

Fig. 8. Habitat effect on rate of litter decomposition of woody species in the 1st stage of decomposition.

plant litter is usually highly positively correlated with increasing N concentration and negatively correlated with increasing C/N ratios in this litter, probably reflecting differences in its structural and secondary compounds, such as lignin and phenols (Tůma. 2002). This variable chemistry of litter during decomposition results in a two stage decay profile exhibiting evidently faster decomposition of labile compounds at the beginning of exposure in the field. That is why the two-phase decomposition model usually better explains decomposition within a shorter period (Lindsay, 2004); and allows, in such a way, better comparison of results of decomposition of different species litter (Didham, 1998). However, better long-term prediction of litter decomposition pattern requires longer exposition of samples in the field (e.g. during the next winter), which in turn would need more litter of herbaceous species in the bags. On the other hand, regarding the studied effect of invasive plant species on mineral cycling during decomposition, the short term decomposition, with the major part of biomass decomposed is important. Invasive species considered having higher leaf N content and lower C/N ratios, usually decompose faster (Ehrenfeld, 2003; Ashton, 2005; Lindsay, 2004). The fast decomposition rate of rich-in-nutrients leaves of *Ailanthus altissima* (Castro-Diez, 2009), *Robinia pseudoacacia* (Tateno et al., 2007), *Alliaria petiolata* (Rodgers, 2008) and *Impatiens parviflora* species (Vanderhoeven et al., 2007) has been documented; although their decomposition differences have never been compared in the same environmental conditions. Our results showed that the litter decomposition of invasive

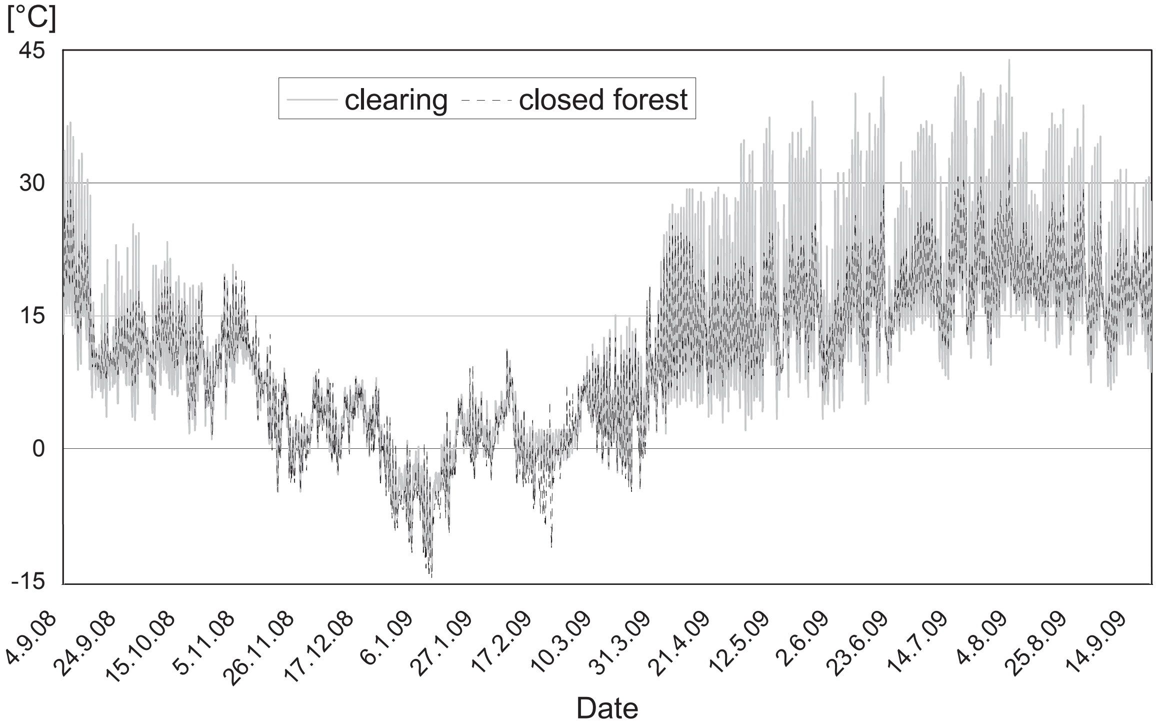

Fig. 9. Course of near-ground (30 cm) temperature in closed forest and clearing during the research period.

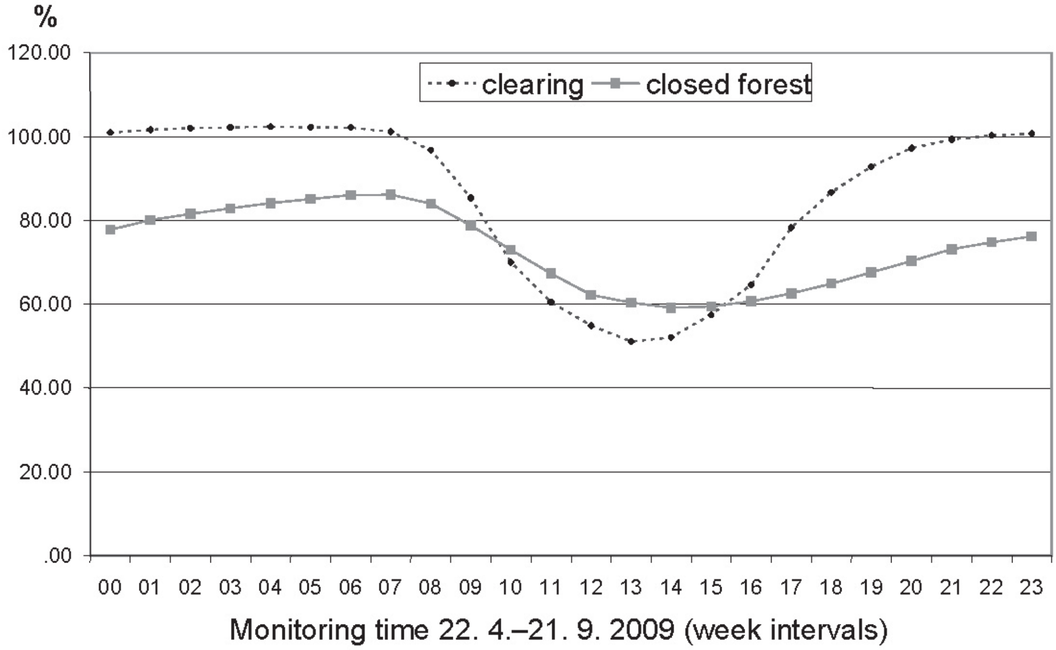

Fig. 10. Course of mean daily relative air humidity in closed forest and clearing.

species was faster compared to the indigenous species, with exception of *Robinia pseudoacaci*a leaf litter. This was a surprise as *Robinia pseudoacacia* is a nitrogen fixing species with high N content and low C/N ratio in leaves. This possible explanation is high lignin content in locust leaves increasing their resistance against most decomposing organisms – as it has been also documented by CastroDies (2009).

Despite the well documented fact that the leaf litter quality of plant species is a main driver of differences in rate of its decomposition (Funk, 2005; Standish et al., 2004), the habitat (site) effect should also be considered in order to identify additional factors possibly affecting the decomposition. Furthermore, canopy of invasive tree species may create a specific environment facilitating decomposition of plant litter irrespective of its quality (Ashton, 2005), providing, in such a way, positive feedback for expansion of this species.

Variable soil moisture and temperature across a disturbed forest could affect plant decomposition (Tesařová, 1993). Logging of forest stands is accompanied by extensive organic matter decomposition and humus mineralization, since conspicuous changes in microclimate on clear-cut areas create more favourable conditions for the activity of soil micro-organisms (Záhora, 1996; Tůma, 1998). However, Tůma (2002) ascertained only positive effect of temperature on decomposition rate. Negative correlation between soil moisture and microbial decomposition rate may reflect possible slower heating of waterlogged soils on clear-cut areas (Tůma, 1999). In our study, there was a consistent effect of plant species leaf litter across the site, since in the two-way Anova, there was no significant interaction between the site effect and the effect of plant species leaf litter. However, we did not register a higher decomposition rates in clear-cut area. Furthermore, herbaceous species litter and cellulose tests proved higher decomposition in the closed forest compared to clear-cut area. We documented that clear-cut area was wetter and warmer than the closed forest, however these differences vary in dependence of the season. Bublinec (1975) stated that the greatest decomposition rates were evident at the beginning of vegetation season and they substantially decreased in August. The author also pointed to the soil moisture as possible cause of temporal dynamics of decomposition. The greatest differences in microclimate between closed forest and clear-cut area, however, where ascertained in summer, being low in autumn and early spring.

In a well designed multifactor experiment by Mayer (2008), the author documented that decomposition rate is more affected by litter moisture than soil temperature, which can explain the higher decomposition loss of plant litter under forest canopies. In fact, higher near-ground air humidity in a closed forest during day time (Fig. 10) may contribute to surface wetness in the litter horizon. Furthermore, litter decomposition in old forest stands is also influenced by communities of decomposers adapted to consuming the large stocks of leaf litter (Mayer, 2008). The specific differences in composition of soil micro-organisms and lower microbial activity in Báb clear-cut area compared to the adjacent closed forest may refer to this fact (Ďugová, 2008). We also need to note that by using mesh litter bags in our study we excluded a well known effect of macrodetrivores on decomposition rate (Mayer, 2008), which may underestimate the faster decomposition of plant litter in well structured forest. However, in the near future, massive expansion of invasive species across the clear-cut area may change this pattern, as these species are able to change the microclimate (Standish, 2004) and community of decomposers at the site (Holly, 2009. The issue requires several years of additional experiments.

We can summarise that, except Robinia pseudoacacia, leaves of exotic and native invasive and expansive species were decomposing faster, mainly in the first stage – decomposition of the most valuable litter parts with high nitrogen content. This pattern was the same across the closed forest, forest edge and clearing. Although the clearing was wetter and warmer on average, decomposition rates of cellulose and of herbaceous litter were higher in the closed forest.

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Porovnanie dekompozície listovej fytomasy vybraných introdukovaných a pôvodných druhov v dubovohrabovom lese pri obci Báb, juhozápadné Slovensko

Súhrn

V predkladanom článku prezentujeme údaje o rýchlosti dekompozície vybraných introdukovaných a pôvodných druhov zistených v rôznych mikrostanovištných podmienkach: na rúbanisku, lesnom okraji a v zapojenom lese. Pomocou metódy vreciek sme po dobu 324 (byliny), resp. 344 (dreviny) dní exponovali listy týchto druhov: *Ailanthus altissima, Robinia pseudoacacia, Acer campestre, Impatiens parviflora, Alliaria petiolata a Mercurialis perennis*. Rýchlosť dekompozície v období 1 roka bola charakterizovaná prostredníctvom 2-fázového negatívne exponenciálneho modelu. Najrýchlejšie sa rozkladá nadzemná fytomasa druhu *Impatiens parviflora* (ostalo 26 % fytomasy), pomalšie sa rozkladali druhy *Alliaria petiolata* a *Mercurialis perenis* (obidva druhy so zostatkom 29 % fytomasy). V prípade drevín bol zdokumentovaný najväčší úbytok listov *Ailanthus altissima* (ostalo 45 % fytomasy), pomalšie sa rozkladali listy druhov *Acer campestre* (63 % zvyšok) a *Robinia pseudoacacia* (70 % zvyšok fytomasy). Dekompozícia celulózy významne závisela od vlastností mikrostanovišťa, pričom najväčšia bola v zapojenom lesnom poraste. Podobne prebiehala aj dekompozícia bylín, zatiaľ čo v prípade drevín nebol zaznamenaný vplyv mikrostanovištných rozdielov na priebeh dekompozície. Listy inváznych rastlín (okrem druhu *Robinia pseudoacacia*) podliehajú rýchlejšiemu rozkladu (najmä v prvej fáze, kedy je spotrebovaný materiál s vysokým obsahom dusíka), čo môže v prípade ich expanzie podstatne zlepšiť najmä dusíkový režim stanovišťa a následne zvýšiť zastúpenie nitrofilných druhov rastlín.

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