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POST-HARVEST BIOMASS STOCK AND PRODUCTIVITY OF *CALAMAGROSTIS EPIGEJOS* COMMUNITY UNDER BEECH AND SPRUCE FOREST STAND

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We investigated the above- and below-ground standing biomass and production of plant communities dominated by bushgrass (*Calamagrostis epigejos)* colonizing forest clearings created by harvesting beech-spruce forest stands. Above-ground living biomass of these communities was 6.6 $t.ha^{-1}$, while above-ground litter made up 5.6 $t.ha^{-1}$. Below-ground standing biomass was 6.6 $t.ha^{-1}$ and production was 1.6 $t.ha^{-1}$. Inter-annual fluctuations in production were rather high and did not clearly follow weather alternations. We hypothesize about some of the reasons for this. A negative correlation between litter and production of bushgrass rhizomes and root were found. The amount of bushgrass above-ground biomass did not affect species' richness, but a higher amount of its roots inhibited occurrence of other species, especially other dominants in the forest clearings *Epilobium angustifolium* and *Rubus idaeus*. The bushgrass produced rhizomes mainly at micro-sites with higher proportions to other species. The number and average length of the bushgrass blades are related to its above-ground biomass. We conclude that the competition between bushgrass and other species takes place most heavily in the top soil layer. Biomass production of bushgrass communities is not sensitive to weather patterns under the conditions of beech-spruce forest clearings. In terms of the carbon accumulation and nutrient cycling, these communities have an important role in certain periods of forest life.
Keywords: *forest clearings, production, species richness, interspecific competition, grass community*

1. Introduction

Forests in Slovakia cover 44.3% of the country's area (MPSR 2009). Most forest stands are managed by shelterwood cutting resulting in the creation of forest clearings, which represents approximately 5% of forested land. The period immediately after forest stand harvest is an important time; when the whole ecosystem undergoes serious changes. A vast range of tree functions disappear and the main roles of vegetation cover are taken over by plant species with a short life span or above-ground bodies which have a short longevity, mainly one year. This period takes at least 5 years, but in many cases even more, up to 10 years, until the regenerated trees prevail the clearing. The post-harvest vegetation develops very quickly (Ellenberg, 2009). Many forest species persist in species assemblage, but the site is usually occupied by a few ruderal species, which grow on forest clearings in high abundance. Herbaceous plants have up to a threefold higher nutrient concentration than trees, hence the importance of the understorey vegetation for nutrient cycling (Yarie, 1980). Its importance is even higher in disturbed systems such as clearcuts or windthrows, where the understorey vegetation becomes the most important ecosystem component in terms of primary production and nutrient uptake. Increased growth (biomass, shoot length) as well as concentration of nutrients in ground vegetation plants in open cutting areas is observed from boreal (Palviainen *et al*., 2005) to deciduous temperate forests (Pyšek, 1991; Heinrichs *et al.,* 2010).

Communities with a dominance of *Calamagrostis epigejos* (bushgrass) which develop on the forest sites after trees cutting are common and widely distributed within forests in Slovakia (Jarolímek *et al.,* 1997). Bushgrass is a competitively strong species with a high capability for colonization of new habitats (Sedláková, Fiala, 2001). Very dense cover and slow decomposition of litter inhibits growth of other species including trees (Jarolímek *et al*., 1997) and suppresses species diversity (Fiala *et al*., 2004). In general, tall grasses (e.g. *Calamagrostis epigejos, C. villosa, Arrhenatherum elatius*) produce high amounts of biomass (Pyšek, 1991; Fiala *et al*., 2004; Fiala, 2001; Březina *et al*., 2006).

Most studies on bushgrass communities' production are focused on meadows and little is known about the biomass of communities on forest sites. The importance of an investigation in this field is enhanced by the fact that these communities persist on forest sites for rather a long period (cca 5–10 years) and in terms of nutrient cycling they differ considerably from juvenile stands of forest trees.

The aim of this study is to investigate the above- and below-ground biomass standing stock of communities with a dominance of *Calamagrostis epigejos* developed after forest cutting. We focused on the estimation of above- and below-ground biomass production in three consecutive years. Moreover, we analyzed the most important factors which potentially influences inter- annual fluctuations of biomass standing stock and production.

2. Material and Methods

Site description

The study area is situated at approximately 960 m. a. s. l. with an annual air temperature of around 6.3°C and an annual sum of precipitations ca. 1000 mm. On the parent rock, which is granodiriote, the Cambisols were developed. More detailed information about site conditions is mentioned in Konôpka *et al.* (2013). The potential forest vegetation is dominated by *Fagus sylvatica* with an admixture of *Abies alba* and several other broadleaved species, mostly *Fraxinus excelsior* and *Acer pseudoplatanus*. In many stands high proportions of *Picea abies* is present due to its preference by the forest management.

The vegetation cover of the study site is developed after the cutting of mixed beech-spruce stands. Currently it is created mostly by juvenile and dense stands of beech and spruce, accompanied by grass communities with the dominance of *Calamagrostis epigejos* (bushgrass) which are present on sites where the natural regeneration of trees was poor. The proportion of grass communities cover is rather high, by visual estimation it reaches at least one third of investigated area. *Calamagrostis epigejos* is the most abundant species in the grass community.

Sampling design and data analyses

In order to investigate above- and below-ground biomass of the grass community, in 2010 we established five square plots with an area of cca 35 m^2, where subplots for detailed measurements and sampling with a size of 0.5 × 0.5 m were plotted. Plots were placed in those parts of the forest clearing where the abundance of *Calamagrostis epigejos* was high. The reason was to investigate well developed communities of this grass and not the ecotone with other types of forests clearing vegetation or any beginning stages of this community. Above-ground biomass was taken three times a year, in early spring, the middle and the end of the growing season. In each period, one new subplot from each plot was sampled. All living plants growing within the 0.5 × 0.5 m subplot were cut, separated into species and later oven-dried and weighed in the laboratory. For the estimation of below-ground biomass two methods were used. Soil cores for estimation of standing stock and in-growth bags for production. Soil cores (diameter of 7.0 cm) were taken in early spring from a depth of up to 50 cm. In-growth bags (cylinder shaped with a diameter of 7.0 cm, made of nylon net with a mesh sized 2 × 2 mm) were placed into the soil in early spring up to 30 cm depth, filled with sand and taken out at the same time as above-ground biomass was sampled. Roots were separated into two groups – roots of *Calamagrostis epigejos* and roots of other species, oven-dried and weighed with a precision of 10^{-4} g.

The relations between selected variables (e.g. biomass and species richness) were investigated using linear regression with Pearson correlation in Statistica software.

3. Results and Discussion

The studied grass community manifested rather poor species richness (Table 1). The most abundant species in the investigated grass stands was *Calamagrostis epigejos*. Its proportion in above- and below-ground biomass was very similar, around 81.5% on average (Table 2). During the whole investigation, we observed 31 species at sampling subplots, but only nine species could be considered as frequent (percentage frequency at least 25; see Table 1). The average number of species per each subplot was 6.05. Although species richness should be inhibited by the increasing biomass of *Calamagrostis epigejos* (Fiala *et al*., 2004), we found no significant relationship between the number of species and living biomass and the litter of bushgrass. It could be caused by the sampling design used, since we sampled only stands with an evident prevalence of bushgrass. In order to examine this issue, the data from a broader gradient of bushgrass abundance would be more suitable. On

Table 1. Production characteristics of the communities with a dominance of *Calamagrostis epigejos* based on all samplings during vegetation periods of three years

Latin name of species	Average production [t.ha^{-1}]	Standard deviations	Frequency in subplots [%]
Calamagrostis epigejos	5.146	± 1.97	100
Rubus idaeus	0.138	± 0.15	82.5
Epilobium angustifolium	0.273	± 0.27	77.5
Galeobdolon luteum agg.	0.073	± 0.07	52.5
Milium effusum	0.270	± 0.12	32.5
Stellaria nemorosa	0.091	± 0.13	30
Hypericum perforatum	0.474	± 0.36	25
Poa nemoralis	0.346	± 0.45	25
Rubus fruticossus agg.	0.248	± 0.19	25
Galeopsis sp.	0.056	± 0.08	22.5
Athyrium fylix-femina	1.403	± 1.40	15
Hypericum maculatum	0.392	± 0.24	12.5
Veronica chamaedrys	0.068	± 0.07	12.5
Agrostis stolonifera	0.819	± 0.77	12.5
Senecio nemorensis agg.	0.487	± 0.21	10
Veronica officinalis	0.051	± 0.07	10
Gymnocarpium dryopteris	0.036	± 0.03	10
Ajuga reptans	0.031	± 0.02	5
Anemone nemorosa	0.007	± 0.00	5
Fragaria vesca	0.018	± 0.01	5
Mercurialis perennis	0.025	± 0.02	5
Viola reichenbachiana	0.005	± 0.00	5
Populus tremula	0.533	± 0.69	5
Oxalis acetosela	0.019	—	2.5
Rumex acetosa	0.002	—	2.5
Polygonatum verticillatum	0.016	—	2.5
Urtica dioica	0.062	—	2.5
Veronica montana	0.014	—	2.5
Luzula luzuloides	0.108	—	2.5
Fraxinus excelsior	0.328	—	2.5
Sorbus aucuparia	0.078	—	2.5

Table 2. Contribution of *Calamagrostis epigejos* to standing biomass and production of a grass community (standing below-ground biomass based on soil cores in spring; production of below-ground biomass based on in-growth bags taken out in autumn; standing above-ground biomass based on sampling in the middle of vegetation period; production of above-ground biomass based on sampling in autumn)

Contribution of *Calamagrostis epigejos* to	Average ± Standard deviations [%]
Standing above-ground biomass	81.4 ± 13.0
Standing below-ground biomass	81.2 ± 11.6
Total standing biomass	81.3 ± 12.3
Production of above-ground biomass	85.0 ± 10,6
Production of below-ground biomass	82.0 ± 12.8
Total production of biomass	81.6 ± 14.6

the other hand, we found a significant negative correlation between species richness and annual production of below-ground biomass at a depth up to 10 cm ($r^2 = 0.178$; $p = 0.007$). This suggests that interspecific competition occurs mainly in the soil, which is also a conclusion of Fiala (2001). Furthermore, the denser roots of bushgrass inhibit mostly species with a similar life strategy, which are able to spread and colonize forest clearings rapidly – *Epilobium angustifolium* and *Rubus idaeus*. Their above-ground biomass is negatively correlated with the annual production of *Calamagrostis epigejos* below-ground biomass at a depth up to 10 cm ($r^2 = 0.161$; $p = 0.011$ and $r^2 = 0.098$; $p = 0.049$). Moreover, *Epilobium angustifolium* above-ground biomass is positively correlated with species richness ($r^2 = 0.388$; $p = 0.001$). An important tool of the competition pressure of *Calamagrostis epigejos* are its rhizomes, which spread up to several meters (Dolečková, Osbornová, 1990). We found that the production of rhizomes (measured in ingrowth bags) does not depend on bushgrass above- or below-ground biomass, but it is related to above-ground biomass of other species ($r^2 = 0.166$; $p = 0.043$). *Calamagrostis epigejos* creates more rhizomes at sites with a higher proportion of other species and spreads its rhizomes ingeniously, giving priority to sites occupied by other species.

The above-ground living biomass of the *Calamagrostis epigejos* community (all present species) was 6.6 t.ha^{-1} expressed as an average over three years. In comparison to bushgrass stands on nutrient-poor shallow soils covered by dry grassland, where 3.4 t.ha^{-1} (Fiala *et al*., 2011) and on alluvial meadows, where 5.3 t.ha^{-1} (Fiala *et al*., 2004) was found, it is higher in comparison. Communities of another tall grass, *Calamagrostis villosa*, growing on forest clearings in similar site conditions reach a markedly lower biomass (3.2 t.ha^{-1}, Pyšek, 1991). In our case, litter was 5.6 t.ha^{-1}, which is similar to dry grasslands (4.9 t.ha^{-1}) and alluvial meadows (7.0 t.ha^{-1}), but less than on forest clearings (8.7 t.ha^{-1}). Living biomass to litter ratio in our case was much higher (1.16) than in grasslands and meadows (0.69 and 0.75) or forest clearings with a dominance of *Calamagrostis villosa* (0.37). This suggests, that the decomposition of litter in *Calamagrostis epigejos* communities at forest sites is much faster than on grasslands and meadows, or *Calamagrostis villosa* communities. This could be caused by differences in site conditions, as decomposition of organic matter is dependent on many environmental properties, mainly climate or differences in the chemical composition of litter (Kirschbaum, 1995; Berg, 2000).

Although there are significant differences between these studies, it is necessary to take into consideration the annual variation of biomass production, which strongly depends on the weather conditions of each year. The biomass of living matter in a dry year reaches only a half of that reached in a wet year (Fiala *et al*., 2011).

In our case, the weather in 2010 was extraordinarily wet (annual sum of precipitations /ASP/ 1527 mm), in 2011 it was rather dry (ASP 683 mm) while in 2012 it was about average (ASP 966 mm). Furthermore an average annual temperature of the air was more than 1°C lower in 2010 than the next two years (see also climate-diagrams in Konôpka *et al*., 2013). In contrast to the findings of Fiala *et al*. (2011), Figures 1 and 2 show that the highest above- and below-ground biomass were not produced in the most moist year (2010). This contradiction could be the result of different climatic conditions of the investigated sites. The study area of Fiala *et al*. (2011) is situated in lowland at an elevation of 320 m, while our site is located at a much higher altitude, where the moisture does not have to play a key role.

The production of living matter markedly differs between years. It seems, that production could oscillate from year to year. A year with a high production is relayed by a year with low production. The litter in 2010 (in fact it is a production of living mass in 2009) was the highest one and the production in 2010 was rather low. The high production of living mass in 2009 (deduced on the basis of the amount of litter in 2010), is confirmed by the standing biomass of below-ground parts (Figure 3 – the amount shown in 2010 was actually more or less produced in the previous year 2009). Furthermore, high production in 2011 again resulted in low production in 2012. This presumption is a bit uncertain, because the high production in 2011 was not followed by a high amount of litter in 2012. In general, on the basis of results shown in Figures 1, 2 and 3 it is possible to state, that above- and below-ground biomass follow similar annual fluctuations. Especially in the year 2010, when the lowest above- and also below-ground production was found. As these fluctuations are not clearly related to weather alternations, they still remain unexplained.

In order to investigate whether the production could be inhibited by litter, we looked more closely at this issue. We investigated the influence of litter on the production of various species and production characteristics. No significant correlations were found between above-ground production and litter, but there is a significant negative relationship between litter and below-ground production of bushgrass rhizomes ($r^2 = 0.211$; $p = 0.003$) and roots (mainly up to the depth of 10 cm; $r^2 = 0.291$; $p = 0.001$).

Below-ground production of *Calamagrostis epigejos* communities is 1.6 t.ha^{-1} in an average of three years (Figure 2) and below-ground standing biomass is 6.6 t.ha^{-1} (Figure 3). In comparison to forest clearing with a dominance of *Calamagrostis villosa* (21.5 t.ha^{-1}; Pyšek, 1991) and *Calamagrostis epigejos* stands on alluvial meadows (20.6 t.ha^{-1}, Fiala *et al*., 2004), it is much lower. Consequently, the ratio between above- and below-ground parts is very different. In our case, the above- to below-ground biomass ratio is 1.06, while in the compared studies it is 0.55 (Pyšek, 1991) and 0.60 (Fiala *et al*., 2004). Al-

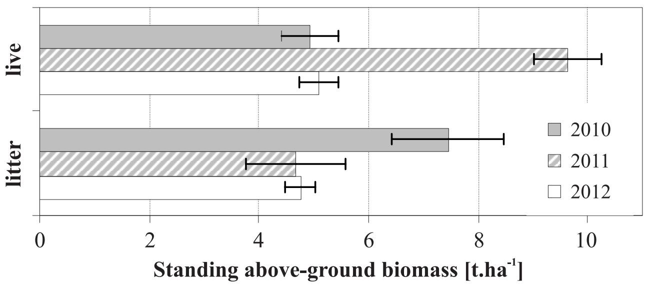

Fig. 1. Living above-ground biomass and litter in three years (average values with standard errors are shown; sampling in the middle of vegetation period)

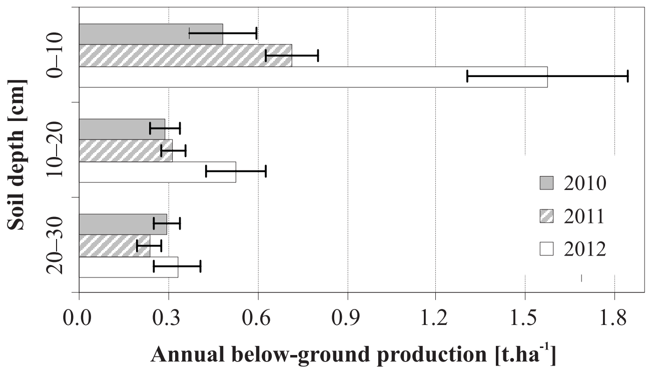

Fig. 2. Fine root production sampled by in-growth bags (average values with standard errors are shown; bags taken out of soil in the middle of vegetation period)

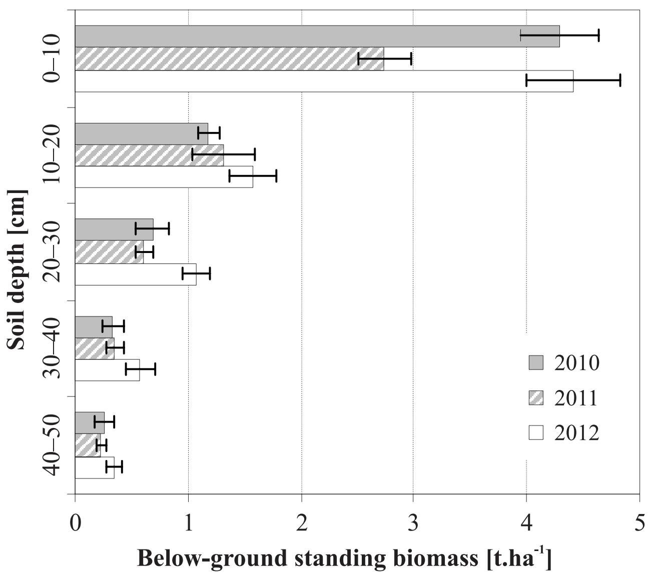

Fig. 3. Fine root standing biomass sampled by soil cores (average values with standard errors are shown; cores taken in the spring, which means, that biomass was produced in the previous year)

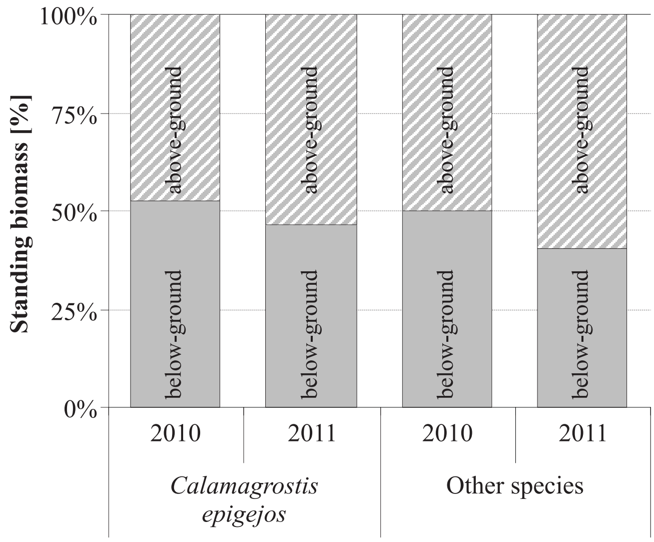

Fig. 4. Proportion of above- and below-ground biomass on total standing biomass in stands dominated by *Calamagrostis epigejos* (below-ground biomass estimated from soil cores taken in spring drawn to correspond to previous year's above-ground biomass)

though, these two studies attained similar results, our case is not extraordinary. The above- to below-ground ratio of grasslands markedly varies and it depends on climate conditions, particularly on aridity (Fan *et al.*, 2008). As Figure 4 shows, the ratio differs between years (0.92 in 2010 and 1.19 in 2011). The annual pattern between *Calamagrostis epigejos* and other species is very similar, but the above-ground parts of other species take the higher proportion of total biomass (55% in average; *Calamagrostis epigejos* 50% in average).

The below-ground production of *Calamagrostis epigejos* is not related to its above-ground biomass. We found that above-ground biomass of *Calamagrostis epigejos* positively correlates with the number ($r^2 = 0.342$; $p = 0.001$) and the average length ($r^2 = 0.234$; $p = 0.002$) of its blades. No significant correlation with below-ground production was found. However, observed correlations are too weak to build any prediction models for estimation of biomass using blade measures.

5. Conclusions

Herbaceous communities remain at forest clearings for a considerable time period, in many cases for a few decades. The above-ground parts of most non-woody species are annual in their nature, thus almost all herbs' production rapidly decomposes. On the other hand, trees with a long life-span accumulate a considerable amount of biomass production in their bodies. Consequently, in terms of the forest function of carbon accumulation and nutrient cycling, the existence of herbaceous communities at forest clearings represents specific time periods in the life of a forest. This has to be considered in evaluation of forests from a productivity and carbon accumulation point of view.

In the conditions of beech forests, the annual fluctuations of weather do not influence the productivity of communities dominated by *Calamagrostis epigejos*. However, the biomass produced each year varies to a large degree. In order to elucidate this task, further investigation, especially in terms of covering more consecutive years, is needed. Further, our findings showed that *Calamagrostis epigejos* has a high competitive ability due to its root system and rhizomes. Moreover, we found that the most intensive competition between *Calamagrostis epigejos* and other species takes place in upper soil layers. This fact should play a key role in reforestation strategy (i.e. soil preparation) of forest clearings.

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Resumé

Predmetom výskumu bola nadzemná a podzemná biomasa a produkcia rastlinných spoločenstiev s dominanciou smlzu kroviskového (*Calamagrostis epigejos*), ktoré sa vyvinuli na lesných rúbaniskách po ťažbe smrekovo-bukového porastu. Tieto spoločenstvá sú na rúbaniskách veľmi časté a z hľadiska produkcie a kolobehu živín predstavujú na relatívne dlhé obdobie niekoľkých rokov hlavnú zložku ekosystému. Vo výskumnom objekte pri osade Vrchslatina bola počas obdobia troch rokov odoberaná nadzemná a podzemná biomasa. Produkcia podzemnej biomasy bola stanovená s využitím podzemných vrastavých valcov. Živá nadzemná biomasa spoločenstiev smlzu bola 6,6 $t.ha^{-1}$, nadzemná nekromasa bola v množstve 5,6 $t.ha^{-1}$. Podzemná biomasa dosahovala takmer rovnaké množstvo ako nadzemná, 6,6 $t.ha^{-1}$, a ročná produkcia podzemnej biomasy bola 1,6 $t.ha^{-1}$. Medziročné fluktuácie v produkcii boli dosť výrazné, avšak nemožno ich jednoznačne pripísať medziročným zmenám v počasí. V článku diskutujeme o iných možných príčinách. Preukázal sa napríklad negatívny vzťah medzi množstvom opadu a produkciou koreňov aj výbežkov. Množstvo nadzemnej biomasy smlzu nevplýva na druhovú bohatosť spoločenstva, avšak vyššie množstvo koreňov inhibovalo výskyt iných druhov, a to najmä iných dominánt rúbanísk ako *Epilobium angustifolium* a *Rubus idaeus*. Smlz dosahoval vyššiu produkciu výbežkov tam, kde bola vyššia biomasa iných druhov. Množstvo nadzemnej biomasy smlzu pozitívne korelovalo s počtom a dĺžkou jeho stebiel. Na základe výsledkov usudzujeme, že konkurencia medzi smlzom a ostatnými druhmi prebieha najmä v oblasti povrchových vrstiev pôd. Produkcia rúbaniskových spoločenstiev s dominanciou smlzu sa nejaví ako senzitívna na medziročné zmeny počasia v prírodných podmienkach jedľovo-bukových lesov.