Biomass and element pools of herb layer in the catchments of the Čertovo and Plešné Lakes in Šumava Mts. – preliminary results

Biomasa a zásoba prvků bylinného patra v povodí Čertova a Plešného jezera – předběžné výsledky

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Abstract

This paper presents data on species composition, biomass, and element pools (C, N, P, Ca, Mg, Na, K, Al, Fe, Mn) of the herb layer of spruce forests in the catchments of Čertovo (CT) and Plešné (PL) Lakes in the Bohemian Forest (Šumava, Czech Republic). Calamagrostis villosa was the most abundant species in the CT catchment, while Vaccinium myrtillus was the most abundant species in the PL catchment. The catchments weighted mean (CWM) of above-ground biomass of the herb layer was 288 and 723 g.m^{-2} in the CT and PL catchments, respectively. The significant difference in the biomass between the catchments was caused by much higher abundance of Vaccinium myrtillus in the PL catchment. The catchments weighted mean of below-ground biomass of the fine roots was 491 and 483 g.m^{-2} in the CT and PL catchments, respectively.

Keywords: biomass, forest, herb layer, elements, catchment, Calamagrostis villosa, Vaccinium myrtillus

Abstrakt

Tento příspěvek prezentuje předběžné výsledky studie zabývající se druhovou skladbou, biomasou a obsahem prvků (C, N, P, Ca, Mg, Na, K, Al, Fe, Mn) bylinného patra horského smrkového lesa v povodí Čertova (CT) a Plešného (PL) jezera v NP Šumava. Druh Calamagrostis villosa měl největší abundanci v povodí CT jezera, zatímco druh Vaccinium myrtillus měl největší abundanci v povodí PL jezera. Vážený průměr nadzemní biomasy v povodí CT a PL jezera byl 288 a 723 g.m^{-2}. Významný rozdíl v biomase mezi jezery byl způsoben vyšší abundancí druhu Vaccinium myrtillus v povodí PL jezera. Vážený průměr podzemní biomasy v povodí CT a PL jezera byl 491 a 483 g.m^{-2}.

Klíčová slova: biomasa, bylinné patro, prvky, povodí, Calamagrostis villosa, Vaccinium myrtillus

Introduction

The aim of this paper is to evaluate data on understory vegetation biomass and its element pools in spruce forests of two Bohemian Forest catchments (Plešné and Čertovo Lakes). This investigation is part of an integrated study on the Bohemian Forest catchment-lake ecosystems "Nutrient cycling in the nitrogen-saturated mountain forest ecosystem: History, present, and future of water, soil, and Norway spruce forest status". In this study, primary data are provided on: (1) species composition of the forest herb layer, (2) above-ground biomass of dominant plant species, (3) below-ground biomass of prevailing types of microcoenoses, and (4) concentrations and pools of major nutrients (C, N, P, Ca, Mg, and K) and ecologically important metals (Al, Fe, Mn) in the studied biomass.

Material and methods

The herb layer investigation has been carried out using the following steps: (a) inspection of plant communities (using plant coenological relevés) and determination of boundaries between the community units distinguished; (b) all important types of microcoenoses (sensu Matějka, 1992b), based on the dominant plant species, were determined by terrain reconnaissance; (c) each type of microcoenoses was sampled for determination of both above- and below-ground biomass; (d) representation of each microcoenoses was calculated; (e) total biomass of each dominant species was calculated multiplying the representation of microcoenose by average biomass of that species; (f) contents of set of chemical elements were determined in dried biomass samples (or mixed samples); (g) total content of these elements was calculated using total species biomass and average element content for aboveground biomass or using total below-ground biomass in the type of microcoenose.

Study sites

The research was carried out in the catchments of Plešné Lake (PL; 48° 46' 35" N, 13° 52' 0" E; elevation of 1090 - 1375 m; total forested area of 59.48 ha) and Čertovo Lake (CT; 49° 9' 55" N, 13° 11' 50" E; elevation of 1027 - 1343 m; total forested area of 81.19 ha) in the Bohemian Forest (Šumava). Both lakes differ in terms of biological recovery after long term acidification in the last century caused by air pollution (Kopáček et al. 2002a, Majer et al. 2003). More information describing the lakes, soils in the catchments, and the forest stands are provided by Kopáček et al. (2002b, c).

Chemical analysis of the biomass

The dry biomass samples were analyzed for total content of the following elements. Total P was determined from a HNO_3 and $HClO_4$ acid digest using the phosphomolybdate blue method (Kopáček et al. 2001). Carbon (C) and nitrogen (N) were determined by a CN analyser (NC 2100, ThermoQuest, Italy). The total concentration of metals (Ca, Mg, Na, K, Al, Fe, and Mn) was analyzed using a H_2SO_4, HNO_3, and HF mixed acid digest (200 °C, 2 h) by flame atomic absorption spectrometry.

Statistical analyses

The phytosociological relevés were classified using TWINSPAN (Hill 1979). The distribution of the phytosociological relevés within the vegetation groups, the distribution of the vegetation groups in the watersheds, and the map notes made during the surveys were used in GIS to analyze and distinguish borders and areas of individual vegetation groups. The final area of the vegetation groups was later used to calculate the total biomass of the ground vegetation in each catchment.

Dry weight values of individual plant species samples, except *A. distentifolium*, were used to calculate the mean AG biomass. The following competition model of coexistence of the selected plant species was used (Matějka 1992a):

$Af.a^{-1} + Cv.c^{-1} + Ls.l^{-1} + Vm.v^{-1} = 1$,

where *a, c, l, v* are the values of the carrying capacity representing the maximum weight of the biomass (g m^{-2}) of the species growing in a monocoenose of the sample plot size, and *Af* (*A. flexuosa*), *Cv* (*Calamagrostis villosa), Ls* (*L. sylvatica*), *Vm* (*V. myrtillus*) are the mean dry weights of biomass (g.m^{-2}) of the species in the given sample. The least square method was used to calculate this regression model.

AG biomass values of *A. distentifolium* were calculated using a regression model, where the weight of AG biomass (*m*; g) is expressed as a function of tussock diameter (*D*; cm):

$m = a \times D^b$.

The carrying capacity values for individual plant species (or average biomass of *A. distentifolium*), plant species cover in the vegetation groups, and the area of the vegetation groups were used to calculate the catchment weighted mean of AG biomass (CWM AG) of the herb layer in both catchments. The mean BG biomass was calculated for all types of microcoenoses. The final BG biomass means therefore have limited significance. The catchments weighted mean (CWM) of BG biomass was calculated as a function of mean BG biomass, representation of the types of microcoenoses, and the area of the vegetation groups. The element pools were calculated as a function of the CWM biomass and element concentrations in biomass of different species. Relationships among the content of chemical elements in different plant material were studied using principal component analysis (PCA).

Results

Plant coenological surveys

Clear differences were found between the plant communities in the catchments of both lakes. *C. villosa* was the most abundant species in the CT catchment, while *V. myrtillus* was the most abundant species in the PL catchment. There were 5 main groups of understory vegetation in each catchment based on the results of the TWINSPAN classification.

Biomass of the herb layer

A total of 40 and 50 biomass samples were analyzed in the CT and PL catchments, respectively. The biomass of individual samples was highly variable. The mean AG biomass carrying capacity values of dominant plant species, except *A. distentifolium*, are given in tab. 1. The mean biomass of *A. flexuosa* was 88.1 and 160.5 g.m^{-2} in the CT and PL catchments, respectively, while it was 153.8 and 198.2 g.m^{-2} for *C. villosa*. The mean biomass of *L. sylvatica* was 278.3 and 225.6 g.m^{-2} in the CT and PL catchments, respectively, while it was 560.9 and 712.6 g.m^{-2} for *V. myrtillus*. The mean biomass of *C. villosa* and *L. sylvatica* was comparable between the catchments, while those of *A. distentifolium* and *V. myrtillus* were relatively different. Biomass allocation to the aboveground plant parts of *V. myrtillus* was as follows: leaves – 15.0 and 11.0, annual shoots – 37.7 and 47.2, and woody stems – 47.3 and 41.7% in the CT and PL catchments, respectively (tab. 1). The estimated biomass of an average-sized *A. distentifolium* tussock (1.4 m diameter) ranged from 187 to 205 g in CT and PL catchments, respectively. Estimated AG biomass of A. *distentifolium* ranged from 191 to 234 g.m^{-2}. Mean AG biomass was estimated as 213 g.m^{-2} in both catchments.

The BG biomass of woody roots and rhizomes varied greatly among individual species and between the catchments. Mean fine root biomass also differed among species and between catchments, but was not as variable as for woody roots and rhizomes.

Tab. 1: Aboveground biomass according to the main types of microcoenoses (N – number of samples, CT – Čertovo Lake, PL – Plešné Lake).
Nadzemní biomasa podle jednotlivých typů mikrocenóz. (N – počet vzorků, CT – Čertovo jezero, PL – Plešné jezero).

Locality[1]	Type of microcoenose[2]	N	Average biomass[3] (g.m^{-2})	Carrying capacity for dominant pecies[4] (g.m^{-2})	Leaves[5] (%)	Annual shoots[6] (%)	Woody stems[7] (%)
CT	Avenella flexuosa	5	88	95			
CT	Calamagrostis villosa	23	154	219			
CT	Luzula sylvatica	4	278	282			
CT	Vaccinium myrtillus	12	561	924	15.0	37.7	47.3
PL	Avenella flexuosa	4	160	178			
PL	Calamagrostis villosa	6	198	222			
PL	Luzula sylvatica	5	226	231			
PL	Vaccinium myrtillus	20	713	1178	11.0	47.2	41.7

[1]Lokalita, [2]Typ mikrocenózy, [3]Průměrná biomasa, [4]Nosná kapacita dominantního druhu, [5]Listy, [6]Výhony, [7]Stonky

The CWM AG biomass of the herb layer recorded in this study was 288 and 730 g.m^{-2} in the CT and PL catchments, respectively. The difference in the CWM AG biomass between the catchments was caused by the much higher abundance of *V. myrtillus* in the PL catchment. The woody stems of this dwarf shrub accounted for 41 – 47% of its AG biomass (tab. 1). About 680 g.m^{-2} of the CWM AG biomass in this catchment (730 g.m^{-2}), was represented by *V. myrtillus*. However, the seasonal AG biomass was comparable for both catchments (142 and 124 g.m^{-2} in the CT and PL catchments, respectively). The CWM BG fine root biomass recorded in this study was 491 and 483 g.m^{-2} in the CT and PL catchments, respectively. The CWM biomasses of woody roots and rhizomes were not determined, because of high variability in the original data.

Chemical elements in the biomass

Mean element concentrations differed between the AG and BG biomass of the herb layer in both catchments. There were differences also within and between the individual plant species in both catchments. However, the original data were highly variable, with only a relatively low number of samples.

It was possible to distinguish three groups of species based on the PCA analysis of the content of specific elements in the AG biomass: (1) *V. myrtillus* with high Ca (from 175.6 to 126.9 mol.kg^{-1}) concentrations in leaves and annual shoots and Mn (from 9.8 to 14.0 mmol.kg^{-1}) concentrations in leaves, annual shoots, and woody stems, (2) *A. distentifolium* with high N (from 2.0 to 2.1 mol.kg^{-1}) and P (from 89.6 to 135.5 mmol.kg^{-1}) content; and (3) other species (*A. flexuosa*, *C. villosa* and *L. sylvatica*) with similar concentrations of K, P, Mg and N. Al content was generally higher in the BG biomass of all plant species (from 18.9 to 166.1 mmol.kg^{-1}) compared to that in the AG biomass (from 1.1 to 7.1 mmol.kg^{-1}) in both catchments.

The CWM element pools in the AG biomass of the PL catchment were higher than for the CT catchment. This is probably related to higher AG biomass of the herb layer. The evergreen tissues of the dominant *V. myrtillus* in the PL catchment contain higher amounts of elements compared to the annual plant species that are dominant in the CT catchment. However, the recorded values were similar in both catchments when only element pools stored in annually produced AG biomass were compared. The CWM element pools stored in the BG biomass of the CT and PL catchments were similar for most of the elements except Al and Fe. The higher CWM Al and Fe pools in the CT catchment are probably related to the greater abundance of *C. villosa* and its higher concentrations of Al and Fe.

Discussion

Plant communities

There are several possible explanations for difference in the abundance of the dominant herb species in the two catchments. The catchments differ in terms of species composition of the natural forest vegetation and soil types. The soils of the CT catchment were mostly cambisols, while the PL catchment was dominated by undeveloped organic rich soils (Kopáček 2002b, c). This second soil type is often dominated by *V. myrtillus.*

The catchments also have different disturbance histories. Based on the phytosociological classification, the forest stands of the CT catchment would be dominated by beech in the absence of human impact. However, the forest stands in this catchment were logged in the past and the species composition of the tree layer was probably changed, being now dominated by spruce (Veselý 1994, Kopáček 2002c). The forest stands of the PL catchment are more or less naturally dominated by spruce. There is evidence that the coverage of grasses could increase, while that of dwarf shrubs would decrease following man-made disturbance (Uotila, Kouki 2005). The dense canopy of the beech stands results in an often sparse herb layer, while the canopy of the spruce stands lets through more light, which enables the development of light demanding grass species such as *C. villosa*.

Acid deposition, resulting in soil acidification in the catchments of both lakes, is another important factor that could possibly affect species composition (Kopáček 2002a). There is some evidence that long-term soil acidification may cause changes in forest understory vegetation (Tonje et al. 2004). Nitrogen deposition was shown to be main factor affecting the vitality of dwarf shrubs in boreal forests of Fennoscandia (Nordin et al. 1998, Strengbom et al. 2002, Strengbom et al. 2003, Strengbom et al. 2004). Their decline was followed by an increase in grass coverage induced by increased light availability. The fate of N differs between the PL and CT catchments, With the CT catchment being more saturated by N than the PL catchment. But because increased light availability, and not nitrogen deposition, is probably the main factor affecting the herb layer species composition (Strengbom et al. 2004), it seems that past changes in forest structure and composition would have a greater effect on the herb layer than N deposition.

Biomass

The CWM AG biomass for the herb species recorded in this study was 288 and 730 $g.m^{-2}$ in the CT and PL catchments, respectively. There are only a few studies that measured the biomass of the herb layer on the stand or catchments scales in similar site conditions. The recorded means for AG and BG biomass were 1290 and 516 $g.m^{-2}$, respectively in a spruce forest in Germany (Scarascia - Mugnozza et al. 2000). Even though the herb layer at this site was composed of similar species as in our sites (*C. villosa*, *A. flexuosa*, and *V. myrtillus*), the total biomass of the herb layer was higher. Much lower biomass values were reported from another spruce forest in Germany, where the recorded mean AG and BG values were 107 and 77 - 188 $g.m^{-2}$, respectively (Gerstberger et al. 2004). The herb layer at this German site was composed mostly of *C. villosa.* Similar AG and BG biomass values were reported from an old-growth spruce boreal forest in Finland. The herb layer at this site was composed mostly of *V. myrtillus*, which accounted for 150 and 300 $g.m^{-2}$ of AG and BG biomass, respectively (Palviainen et al. 2005a). The characteristics of the tree stand, soil fertility, soil properties and climate have to be always considered when comparing the biomass of herb layer between sites. Herb layer vegetation is heterogeneous and can exhibit wide variability due to numerous factors (Jalonen et al. 1998). The biomass values recorded in this study correspond to the specific site and climate conditions of our study sites. The biomass was higher in the more productive German site, but lower in the less productive Finland site.

Chemical elements in the biomass

The CWM element pools differed between the CT and PL catchments. The total amount of elements stored in the PL catchment herb layer was considerably higher, because of the higher CWM biomass of its herb layer. But the element pools were similar when only annual AG biomass was compared. Surprisingly, there are few studies reporting total element pools in herb layer biomass in spruce forests across Europe. One of the few exceptions is the study published by Palviainen et al. (2005b). The reported element pools are within the range found in the boreal forest, given that our study site was more productive.

Conclusion

There were found clear differences between the plant communities in the catchments of both lakes. *C. villosa* was the most abundant species in the CT catchment, while *V. myrtillus* was the most abundant species in the PL catchment. The CWM element pools in the AG biomass of the PL catchment were higher than for the CT catchment. This is probably related to higher AG biomass of the herb layer. The catchments weighted mean (CWM) of above-ground biomass of the herb layer was 288 and 723 $g.m^{-2}$ in the CT and PL catchments, respectively. The significant difference in the biomass between the catchments was caused by much higher abundance of *Vaccinium myrtillus* in the PL catchment. The catchments weighted mean of below-ground biomass of the fine roots was 491 and 483 $g.m^{-2}$ in the CT and PL catchments, respectively. Mean element concentrations differed between the AG and BG biomass of the herb layer in both catchments. There were differences also within and between the individual plant species in both catchments. The evergreen tissues of the dominant *V. myrtillus* in the PL catchment contain higher amounts of elements compared to the annual plant species that are dominant in the CT catchment. The higher CWM Al and Fe pools in the CT catchment are probably related to the greater abundance of *C. villosa* and its higher concentrations of Al and Fe.

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Souhrn

Cílem této prezentované studie byl odhad biomasy a zásoby prvků v bylinném patře v povodí Čertova a Plešného jezera na Šumavě (NP Šumava). Tato studie je součástí integrovaného výzkumu v povodí ledovcových jezer na Šumavě. V této práci předkládáme základní data: (1) druhová skladba bylinné vegetace, (2) nad-

zemní biomasa bylinného patra (3) podzemní biomasa bylinného patra (4) koncentrace a zásoba prvků v biomase bylinného patra.

Postup prací se skládal z následujících kroků: (a) fytocenologický průzkum v povodí obou jezer s vyznačením hranic mezi jednotlivými typy vegetace, (b) odběr vzorků nejvýznamnějších druhů bylinného patra, (c) výpočet zastoupení jednotlivých druhů (d) výpočet biomasy jednotlivých druhů, (e) stanovení koncentrace prvků u jednotlivých prvků, (f) stanovení celkové zásoby biomasy a prvků v biomase bylinného patra.

Byly nalezeny významné rozdíly v druhovém složení bylinné vegetace v povodí obou jezer. Druh *Calamagrostis villosa* měl největší abundanci v povodí CT jezera, zatímco druh *Vaccinium myrtillus* měl největší abundanci v povodí PL jezera. Celkem bylo odebráno 40 vzorků biomasy v povodí PL jezera a 50 vzorků v povodí CT jezera. Průměrná nadzemní biomasa pro jednotlivé druhy je uvedena v tab. 1. Vážený průměr nadzemní biomasy v povodí CT a PL jezera byl 288 a 723 $g.m^{-2}$. Významný rozdíl v biomase mezi jezery byl způsoben vyšší abundancí druhu *Vaccinium myrtillus* v povodí PL jezera. Druh *Vaccinium myrtillus* má výrazně vyšší biomasu v porovnání s ostatními druhy bylinné vegetace. Pokud ale porovnáme nadzemní biomasu pouze každoročně vytvořených vegetačních orgánů, zjistíme, že biomasa bylinného patra je v povodí obou jezer srovnatelná (142 $g.m^{-2}$ pro CT jezera a 124 $g.m^{-2}$ pro PL jezero). Vážený průměr podzemní biomasy v povodí CT a PL jezera byl 491 a 483 $g.m^{-2}$. Průměrná koncentrace prků se lišila mezi podzemní a nadzemní biomasou bylinné vegetace. Byly nalezeny rozdíly také mezi jednotlivými druhy.

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