Mountain Norway spruce forests: Needle supply and its nutrient content

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ABSTRACT: Soon after bark-beetle attack as well as after clear cutting, grown-up mountain Norway spruce forest cast the following mass of needles: 50–60 kg of dry matter per tree, or 18–20 tons per hectare, containing 8,800–10,000 kg/ha of carbon, 190 to 250 kg/ha of nitrogen, 13–16 kg/ha of phosphorus, 65–91 kg/ha of calcium, 9–13 kg/ha of magnesium and 56–67 kg/ha of potassium. These values were obtained by application of equations assessing needle mass from measured tree and plot parameters, and from chemical analyses of two types of needle material (from living and dead trees).

Keywords: Šumava Mts. (Bohemian Forest); Mountain Norway spruce forest; needle mass; nutrient content; bark-beetle attack; forest decline

Recent bark-beetle attack causing fast and complete spruce tree defoliation yielded large areas of "nude forests", namely at the borders with Germany in the Šumava Mountains. A number of questions appears due to this situation – e.g., concerning the amount of needles entering the forest floor within a short time of several months, its nutrient contents and rate of its decomposition – nutrient turnover (KOVÁŘOVÁ, FRANTÍK 2001).

Mountain spruce forests represent a unique though labile, largely man-induced ecosystem of high interest. Two hundred years ago, as pollen analyses reveal (SVOBODOVÁ 2002; SVOBODOVÁ et al. 2001, 2002; SOUKUPOVÁ et al. 2001), today single-tree species Norway spruce [*Picea abies* (L.) Karst.] forest was earlier mixed with fir and beech (up to 35%). Forest management then reduced tree species richness and yielded even-aged monocultures with *Picea abies* of various genetic origin. This facilitates not only pest spreading but also balance studies in these habitats.

PROBLEM ANALYSIS

In a natural forest, its particular components adapt to its environment, change with time both in quality and quantity, appear, grow, develop and disappear. Growth, stage, ecological, and cenotic differentiation takes part which seems to be accidental, however, if we look closer and study the component species, it becomes clear that it is a part of integral cyclic development where a number of mutually interconnected cycles might be discerned, such as water and nutrient cycles that are interconnected with flow of energy. This enables existence of natural forests even on very poor mountain soils.

With the onset of bark-beetle attack, the mechanism of autoregulation is deviated. Constancy of plant species in communities, relatively small size of particular developmental stages and phases, relative age diversity and relative evenness in wood mass supply is abruptly disturbed, even in semi-natural spruce forests of the Šumava Mts. A sudden imbalance appears between biomass production and decay. Total defoliation brings about higher amount of cast needles (by one order) and of dead tree biomass (by two to three orders) compared with well-balanced stand conditions.

Dead organic matter is important for pedogenetic processes either as their active component and as an environment enabling activity of soil organisms (cf. BOGATYREV 1996). Nutrients do not re-enter its cycle by merely a fall of dead plant components; their humification and mineralization is necessary. Rate of mineralization is dependent on many environmental factors out of which temperature, moisture, oxygen supply and acidity are the most important.

Quality and quantity of litter and the rate of its decomposition in forest ecosystems were studied by a number of

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authors. Yearly fall of organic matter in grown-up, autochthonous Norway spruce stands in the Krkonoše Mts. represents 1.7–3.1 tons of organic matter per hectare (VACEK, LOKVENC 1992). The lowest values of tree litter were found in stands at the timber line and the highest ones at the lower margin of the spruce forest vegetation zone. Litter fall in young (31 years old) spruce stands in the Orlické hory Mts. as measured by NOVÁK and SLODIČÁK (2000) amounted 4.8 and 3.5 tons per hectare in moderately and heavily managed stands, respectively. CHROUST (1993) brings evidence that the period of the greatest needle biomass increase is between 20 and 25 years of stand age (up to 30 tons of green needle biomass per year).

Amount of litter fall and rate of its decomposition are possible to be regulated by management in commercial forests. E.g., KUKLA (1994) shows that canopy cover decrease in older spruce forests would enhance nutrient turnover, decrease stand stability and increase of weed species biomass.

In commercial forests, cutting of biomass extracts great amounts of nutrients from the ecosystem. BUBLINEC and ILAVSKÝ (1990) conclude that this amount might be adequately replenished only on richer soils by decay of dead organic matter and by rock weathering. From this point of view, soils with natural occurrence of spruce in the Šumava Mts. (podzols to organic soils) are definitely not among the rich ones.

In spruce forests, only part of the nutrients (60% N, 40–50% P and 30–40% Ca) re-enter the cycle with litter, the remaining part being fixed in organs of higher age (GRIŠINA 1984). NOVÁK and SLODIČÁK (see above) conclude that the amount of N, P and Ca gradually increases with increasing yearly amount of litter (to 40–60 kg N, 7–9 kg P and 8–10 kg Ca per hectare). The yearly input of nutrients with litter in adult autochthonous spruce stands of the Krkonoše Mts. represent 14–32 kg N, 2–6 kg P, 3–7 kg Ca, 3–8 kg K and 0.3–1.2 kg Mg per hectare (VACEK, LOKVENC 1992). Up to 1,000 kg N per hectare might be contained in the fallen dead organic matter (HÝSEK et al. 1993). Under the spruce stand, cumulation of raw humus is due to slowly decomposing needles with high amounts of resins, waxes, lignin and phenolic compounds. Lignin is reported to be important with respect to the rate of organic matter decay. BERG (1986) suggests that high concentration of lignin in the litter is responsible for nitrogen fixation in organic matter. FLANAGAN and VAN CLEVE (1983) found that higher nitrogen content increased but higher lignin content decreased the turnover rate of organic matter. According to KLIMO (1990) and PODRÁZSKÝ (1996), the C/N ratio of organic soil horizons is important. It is high (above 30 C/N) in spruce stands where the decay rate is slow. Decomposition rate of fallen organic matter is enhanced by increased calcium content causing lower soil acidity and increased activity of the soil flora and fauna.

The above knowledge was derived from a variety of environmental conditions of spruce stands. However, the needle mass and nutrient supply in mountain Norway spruce stands during a bark-beetle attack, when an instant fall of all age classes (6–11) of needles occurs, have not been evaluated up-to-now.

The aim of this work is to quantify needle mass and nutrient supply in grown-up spruce forests attacked by bark-beetle in the Šumava Mts., as a basis for the study of decomposition.

Site

There is practically no bare ground due to 30–40% gaps in the canopy coverage through which the light penetrates to forest floor which is thus covered by mosaic of patches dominated by mosses and any of the three or four understorey species – *Calamagrostis villosa*, *Deschampsia flexuosa*, *Luzula sylvatica* and, optionally, *Vaccinium myrtillus*. Trees are richly covered by lichens, namely *Pseudoevernia furfuracea*, *Hypogymnia physodes* and *Platismatia glauca.*

The spruce stands affected by bark beetle cast all their needles within a short time during one season, followed by a slow breakdown and fall of finer (mostly within the two following seasons) to thicker twigs and branches till trunks. There is also a lot of lichen material falling from the trees. The trunk disintegration is enhanced by the dominant fungi *Phomitopsis pinicola* massively infecting the dead spruce trunks which break from ca 3 m height up so that only the topless columns remain upright. These standing branched trunks, together with the fallen logs, serve a shelter to spruce offspring. Deciduous trees spontaneously appearing on the site, like birch or mountain ash, cannot survive under heavy game grazing so that the planted mountain ash, maple or beech must be protected either by wooden fences for numerous tree groups, or by plastic tubes followed by wooden cages for individual trees.

The management of the Protected Landscape Area changed: at first, the hit stands were left to their natural development, namely in the zone of total protection. However, as the bark beetle spread to the zones with lower degree of protection, the hit stands were extensively cleared or the trees were selectively cut. This resulted in a waste area with standing dead trees neighbouring large waste extended clearings and the rare remains of spruce stands untouched by any type of disturbance.

Large amounts of spruce needles get to the ground and the needles and other material then end up in the tufts of some of the above mentioned patchy understorey dominants. It is of interest to follow the response of the ground layer system to this huge import of energy and nutrients. This will be a subject of another study. We need to know the cast amounts – this report tries to answer the question of needle mass influx.

METHODS

The question on needle biomass may be answered using several approaches: (1) by finding out the actual needle amounts for several trees and calculation the average val-

Table 1. Data for assessement of needle biomass on the plots studied

Parameter/Plot	1	2	3	4	Sum/Mean
Number of trees/ha	337.5	284.0	286.7	450.0	333.3
Area measured (ha)	0.16	0.25	0.15	0.16	0.72
No. of trees in a measured area	54	71	43	72	240
Diameter at 1.3 m (cm)	41.6	45.9	46.2	36.6	42.2
Tree height (m)	27.4	26.6	30.3	25.5	26.9
Crown length (m)	17.8	20.5	26.6	15.1	19.0
Basal area (m^2/ha)	48.6	51.0	52.7	55.1	51.7

ue, or (2) by calculation the needle biomass from suitable tree parameters measured, using prediction equations for tree biomass components derived by several authors (see ČERNÝ 1988, 1990; VINŠ, ŠIKA 1981; VYSKOT 1985). Another possibility is (3) to set up containers collecting the cast material and measure its amounts from the very beginning to the end of defoliation of a hit forest stand.

For the sake of this study, approaches (2) and (3) were chosen. In 2000, sets of 10 collectors were placed in four grown up forests neighbouring the defoliated ones. However, until 2003, no one of the tree groups followed was hit by bark beetle and this approach thus yielded no relevant results so far. The only viable method thus appeared to be the method (2), e.g., measuring of suitable tree parameters and calculation of needle amounts using equations published in the literature.

Study plots

Measured stands belong to those intensely studied within botanical and zoological research in the Šumava National Park at Březník, in 1,150–1,200 m a.s.l. (KOVÁŘOVÁ, FRANTÍK 2001; NEUHÄUSLOVÁ, WILD 2000, 2001; NEUHÄUSLOVÁ 2002; WILD 2001).

Parameters

The following parameters were measured: tree height, diameter at breast height (1.3 m), crown length, tree number per hectare. The following equations by Burger, Malkonen and Del Favero quoted by ČERNÝ (1990) were applied to the data measured:

$DMF = 1.1057E^{-1} \times (DBH^2 \times dH/H)^{8.8344E^{-1}}$ Burger 1953
$DMF = -4.6E^{-1} + 4.5E^{-2} \times (DBH^2 \times dH/H)$ Malkonen 1973
$DMF = 1.2333E^{-2} \times (DBH^2 \times dH/H)^{1.2340}$ Del Favero 1983

where: DMF – dry matter of foliage per tree (kg),
DBH – diameter at breast height (cm),
dH – crown length (m),
H – tree height (m).

Needle analysis

For chemical analyses, needle material was collected from one plot in Březník in summer 1999 (1) by random sampling of branches from freshly cut spruce trees after the first signs of bark beetle presence. The branches were air dried at room temperature and the falling needles then collected quantitatively; (2) by collecting the needles falling from shaken defoliating trees. The collected material was finely pulverized, dried at 60°C and analysed in the Analytical laboratory of the Botanical Institute AS CR, for total contents of the main nutrients: carbon and nitrogen using CHN analyzer (Heraeus), phosphorus after mineralization by colorimetry as blue phosphomolybdate complex, and calcium, magnesium and potassium by flame AAS spectrophotometry.

RESULTS AND DISCUSSION

Table 1 shows data measured for calculation of needle amounts.

If all the three equations are taken into account, average amounts of dry needles are 66.4 kg per tree and 22.1 tons per hectare. However, the mountain conditions would presumably better correspond with lower values from Scandinavia, i.e., 56–60 kg per tree and 18–20 tons per hectare.

Table 3 shows nutrient contents in two types of needle material, sampled from freshly cut and shaken from defoliating trees.

Based on these data, it is possible to calculate the nutrient content as follows (Table 4):

Data on needle nutrient content reveal that needles cast by bark-beetle hit trees is lower in nitrogen and magnesium and higher in calcium, compared with the needles from freshly cut trees. It is known that calcium content in the plant material is rising in the process of decomposition (e.g., KOVÁŘOVÁ 1984; HADINCOVÁ et al. 1990) as Ca is an immobile cation firmly fixed in plant tissues. Its content relatively increases as the mobile and degradable elements contained in plant cells are leached out. Lower

Table 2. Equations applied to the data measured in Table 1 and the values obtained. Values are for dry needle mass

Equation by	Needle biomass (kg/tree)	Needle biomass (t/ha)
Burger 1953	60.53	20.19
Malkonen 1973	56.19	18.73
Del Favero 1983	82.40	27.47
Average	66.37	22.13

Table 3. Nutrient contents in two types of needle material: C – green needles from freshly cut trees, D – greyish needles cast from defoliating bark-beetle hit trees

Needle type	C	N	P	Ca	Mg	K	C/N
	(%)	(%)	(mg/g)	(mg/g)	(mg/g)	(mg/g)	
C	49.13	1.23	0.793	3.610	0.665	3.118	39.85
D	49.70	1.05	0.737	4.537	0.483	3.325	47.33

Table 4. Nutrient content in needles entering the process of decomposition (assessed)

Needle type	Green, from freshly cut trees		From defoliating trees	
Element	(kg/tree)	(kg/ha)	(kg/tree)	(kg/ha)
Carbon	27.5–29.5	8,840–9,830	27.8–29.8	8,940–9,940
Nitrogen	0.69–0.74	220–250	0.59–0.63	190–210
Phosphorus	0.044–0.048	14–16	0.041–0.044	13–15
Calcium	0.202–0.227	65–72	0.254–0.272	82–91
Magnesium	0.037–0.04	12–13	0.027–0.029	9–10
Potassium	0.175–0.187	56–62	0.186–0.200	60–67

magnesium contents probably reflect the chlorophyll decay (needles loose its colour already on the hit trees) and the lower content of highly mobile nitrogen may be due to leaching with rain water and/or loss of volatile substances into the air. Trees hit by bark-beetle breath out an intense smell especially during sunny days – gas chromatography would reveal that exactly.

Comparison of these data obtained from mountain Norway spruce stands in the Šumava Mts. with those from alike habitat and stand conditions in other parts of the Czech Republic, especially in the Krkonoše Mts. and Orlické hory Mts., showed similar values of both needle mass and its nutrient content. Some variation is due to difference in forest types, environmental conditions, air pollution impact, growth and development stage of stands, and their structure and health status.

CONCLUSIONS

Recent massive bark-beetle attack in the Šumava National Park, namely at the border with Germany, caused large areas of defoliated, standing dead spruce monocultural "forests" surrounded by extended clearings and rare remains of functional forests. It is thus of interest to assess the amounts of needle litter and its nutrient contents cast within a short time of several months, even weeks. Several tree parameters were thus measured, such as: tree height, crown length, diameter at b.h., number of trees per hectare and nutrient content in needles. Three different equations published were applied to these data to calculate the supply of needles for average tree. The following budgets were assessed: 56–60 kg of dry matter per tree, or 18–20 tons per hectare, containing 8,800–10,000 kg/ha of carbon, 190–250 kg/ha of nitrogen, 13–16 kg/ha of phosphorus, 65–91 kg/ha of calcium, 9–13 kg/ha of magnesium and 56–67 kg/ha of potassium. This represents a huge amount of matter, energy and nutrients entering the processes of decomposition – these were and will be the subject of other papers.

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Množství jehličí a zásoba živin v šumavských horských smrčinách

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ABSTRAKT: V porostech brzy po kůrovcové kalamitě (stejně jako po holoseči) shodí dospělý smrkový porost 50–60 kg sušiny jehličí na strom neboli 18–20 t sušiny na hektar. Tato sušina obsahuje 8 800–10 000 kg/ha uhlíku, 190–250 kg/ha dusíku, 13 až 16 kg/ha fosforu, 65–91 kg/ha vápníku, 9–13 kg/ha hořčíku a 56–67 kg/ha draslíku. Tyto hodnoty byly zjištěny přepočtem hodnot masy jehličí měřených stromů na parametry plochy a chemickými analýzami dvou typů jehličí (z živých čerstvě pokácených a mrtvých opadávajících stromů).

Klíčová slova: Šumava; horská smrčina; množství jehličí; zásoba živin; kůrovcová kalamita; odumírání porostů

V souvislosti s kůrovcovou kalamitou, která v minulých letech postihla velkou část smrčin NP Šumava, je aktuální otázka, jak reaguje ekosystém horského smrkového lesa na náhlý přísun velkého množství odumřelé rostlinné hmoty se značným obsahem živin, neboť zde na velkých plochách došlo k úplné defoliaci během několika málo měsíců. Protože pro šumavské horské smrčiny nebyly příslušné údaje k dispozici, bylo nutné jako podklad pro studium procesu dekompozice nejprve kvantifikovat množství jehličí a zásobu živin v těchto porostech.

V horských smrčinách je v důsledku lesnických zásahů v posledních 200 letech monokulturně vysazovaný a tedy i stejnověký smrkový porost tvořen jediným druhem *Picea abies* (L.) Karst. různého genetického původu, což usnadňuje nejen šíření kůrovce, ale i bilanční studie v těchto porostech.

Množství jehličí lze odhadnout pomocí následujících postupů: (1) přímo, tj. tak, že zjistíme skutečnou zásobu jehličí na několika stromech a pak vypočítáme průměrnou hodnotu, nebo (2) nepřímo, dosazením naměřených parametrů stromů do rovnice, kterou po aplikaci uvedeného postupu již někteří autoři sestavili (ČERNÝ 1988, 1990; VINŠ, ŠIKA 1981; VYSKOT 1985). Dále je (3) možné rozmístit do porostů dosud nezasažených spadové kontejnery na zachycování spadu a ten ve vhodných intervalech odebírat a vážit tak dlouho, dokud nedojde k úplné defoliaci okolních stromů napadených v průběhu sledování.

S ohledem na dané možnosti byl pro zjišťování zásoby jehličí zvolen postup druhý a třetí. Protože v průběhu sledování v letech 2000–2002 nedošlo k napadení ani jedné skupiny stromů u spadových kontejnerů, které byly rozmístěny ve čtyřech stejnověkých dospělých porostech horské smrčiny, je předmětem sdělení zjišťování zásoby jehličí druhým postupem – změřením parametrů, po jejichž dosazení do rovnice se vypočítá množství jehličí.

Porosty vybrané k měření jsou dospělé porosty na plochách, na nichž současně probíhá další botanický a ekologický výzkum i v rámci mezinárodní spolupráce (např. NEUHÄUSLOVÁ, WILD 2000, 2001; NEUHÄUSLOVÁ 2002; WILD 2001). Nacházejí se v NP Šumava v oblasti Březníku, v nadmořské výšce 1 150–1 200 m n. m.

Byly měřeny následující parametry: výška stromu v metrech, bazální plocha, průměr kmene z hodnot obvodu stromu ve výšce 130 cm, počet stromů na hektar. Tyto údaje byly postupně dosazeny do rovnice Burgera, Malkonena a Del Favera, které uvádí ČERNÝ (1990):

$$DMF = 1{,}1057E^{-1} \times (DBH^2 \times dH/H)^{8{,}8344E^{-1}} \quad \text{Burger 1953}$$
$$DMF = -4{,}6E^{-1} + 4{,}5E^{-2} \times (DBH^2 \times dH/H) \quad \text{Malkonen 1973}$$
$$DMF = 1{,}2333E^{-2} \times (DBH^2 \times dH/H)^{1{,}2340} \quad \text{Del Favero 1983}$$

kde: DMF – sušina jehličí na 1 strom (kg),
DBH – průměr kmene ve výšce 130 cm (cm),
dH – délka koruny (m),
H – výška stromu (m).

Jehličí pro chemické analýzy bylo v létě 1999 získáno (1) ze smrků čerstvě pokácených po zjištění prvních závrtů – větve byly ponechány volně na vzduchu uschnout a jehličí poté kvantitativně setřeseno, (2) z opadávajících, stojících napadených stromů oklepáváním a otřásáním větví – materiál byl pod stromem zachycován do plachet. Získaný materiál byl po vysušení při 60°C a rozemletí analyzován v Analytické laboratoři Botanického ústavu AV ČR na celkové obsahy hlavních živin: uhlík a dusík na CHN analyzátoru, ostatní prvky po mineralizaci – fosfor stanoven kolorimetricky jako fosfomolybdenanový komplex a vápník, hořčík a draslík plamennou fotometrií na atomovém absorpčním spektrofotometru.

Z výsledků uvedených v tabulkách vyplývá, že na povrch půdy a vegetace o ploše 1 ha se dostává během krátké doby po masivním napadení vzrostlé šumavské horské smrčiny kůrovcem (ale i po pokácení zelených, čerstvě napadených stromů) 18–20 tun jehličí (v suché váze) obsahujícího asi 8 800–10 000 kg uhlíku, 190 až 250 kg dusíku, 13–16 kg fosforu, 65–91 kg vápníku, 9–13 kg hořčíku a 56–67 kg draslíku.

Získané výsledky ze smrčin Šumavy, vezmeme-li v úvahu konkrétní stanovištní a porostní poměry, jsou co do kvantity jehličí (v přepočtu na ročníky jehličí) a zásoby živin srovnatelné s údaji ze smrkových porostů z ostatních oblastí ČR, zejména pak z Krkonoš a Orlických hor. Určité odchylky jsou dány především odlišnými lesními typy, imisně ekologickými poměry, růstovými a vývojovými stadii porostů, jejich strukturou a zdravotním stavem.

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