JOURNAL OF FOREST SCIENCE

Volume 51, No. 4 **April 2005**

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Forest decline and pedobiological characteristics of humus forms in the Šumava National Park

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ABSTRACT: Humus forms dynamics and characteristics of different forest sites were studied in the area of Smrčina Mt. in the Šumava National Park territory. The study was performed in vital Norway spruce forest, dead Norway spruce forest (bark beetle *Ips typographus* infestation) and on a clear-cut area (site conditions were comparable for all three plots). The amount of surface organic matter was not affected by forest decline or by clear-cut (95.5 t/ha, 73.1 t/ha and 100.2 t/ha, respectively), pH being comparable (between 2.3 and 3.2 pH KCl). A slight favourable effect of grass litter on pH increase was obvious; higher leaching of bases occurred in lower horizons. Nitrogen losses were detected from the L + F horizons, falling from 1.93–1.83% (living stand) to 1.73–1.83% (clear-cut area). Higher ammonia production was documented in substrates (F and H horizons) from the living stand (from 263 and 103 mg/kg before incubation to 610 and 248 mg/kg after incubation – nitrogen content in ammonia form), and higher nitrification rates (nitrogen content in nitrate form) were recorded on the clear-cut area (103 and 80 mg/kg to 153 and 87 mg/kg) and especially in the dead stand (160 and 93 mg/kg to 216 and 139 mg/kg). Respective values for the living stand increased from 52 and 61 mg/kg to 119 and 84 mg/kg. Respiration activity, both potential and basic, was more balanced, indicating more intensive dynamics in the case of dead stand and clear-cut area.

Keywords: Šumava National Park; mountain spruce forests; forest decline; bark beetle; microbial activity; respiration activity; nitrogen mineralization; soil chemistry; humus forms

Soils including humus forms are among the main ecosystem compartments, supporting the forest stands, supplying them with water and nutrients and representing the environment for different soil biota. Their state and dynamics determine the state of the whole ecosystem (Barnes et al. 1998). On the contrary, the dynamics of forest stand determines and affects the forest soils. Tree species composition, nutrient uptake and litter production as well as transformation belong to the main factors of humus form genesis. The vital role of uppermost, holorganic layers and humus forms was documented in many studies (Binkley 1984, 1986; Sevink 1997; Emmer, Sevink 1994; Podrázský et al. 2001). The character and parameters of humus horizons determine the nutrient cycles, soil moisture conditions and thermic regime of uppermost soil layers, important as the rooting zone for forest trees, playing an important role in the forest site production at the same time. Humus forms represent an eminent indicator of ecosystem processes and/or degradation as well as regradation phase (Green et al. 1993).

Large areas of the Šumava National Park are exposed to heavy infestation by the bark-beetle (*Ips typographus* and other species). At present, up to 5,000 ha of dead forest occur in the highest localities of the National Park, representing continuous large areas without effective tree layer cover. This leads not only to potential shifts in the plant and animal communities, expected on a larger scale in future (Viewegh 1999) but also especially to profound changes in hydric characteristics of mountain

Supported by the Grant Agency of the Czech Republic, Research Project No. 206/03/1583 *Nutrient Cycles in Mountain Forest Ecosystems Saturated by Nitrogen: Past, Present and Future State of Water, Soil and Norway Spruce Stands.*

catchments (Hrádek et al. 2000). On these areas, humus forms are exposed to considerably different conditions, resulting in shifts of organic matter transformation and decomposition. Introskeletal erosion appears at the most exposed sites, posing a threat of long-term, almost permanent, and drastic site degradation (Šach 1990; Šach, Pašek 2000). Natural forest regeneration leads only to slow forest ecosystem restoration, not preventing undesirable ecosystem changes (Podrázský et al. 1999). Preliminary results indicate an increased pedobiological activity after forest stand decline and a threat of organic matter losses, including soil nutrients and space for tree roots (Svoboda, Podrázský 2000).

The objectives of this study were to document pedobiological characteristics of holorganic horizons after forest stand decline (spontaneous development), to compare their dynamics with stand parts where the dead forest was clear-cut for artificial forest regeneration. The results should contribute to a decision process on forest management of mountain spruce forests under heavy bark-beetle attack in the Šumava National Park territory.

MATERIAL AND METHODS

Research was performed in the mountain seminatural Norway spruce forest in Smrčina Mt. area. The site is of *Calamagrostio-villosae Piceetum* type. Three types of localities were studied: living stand, forest stand with dead tree layer (bark beetle) and clear-cut site. All three localities are in the same site conditions as for altitude (approximately 1,200 m a.s.l.), annual average precipitation (up to 1,200 mm) and temperature (between 4 and 5°C).

Soil sampling took place in September 2000, from particular humus form layers: L + F_1, F_2, H, Ah (Green et al. 1993; Sevink pers. commun.). A steel frame 25 × 25 cm was used for sampling of the holorganic layers, mineral soil horizons were not sampled quantitatively. Bulk samples of particular humus form horizons were formed directly in the field before transport into the laboratory. Four replications of field sampling are on the low limit of the site representativeness (Podrázský 1993). The dry matter amount of holorganic horizons was determined by drying to constant mass at 105°C. Standard procedures were used for soil chemistry analyses (Šarman 1981; Zbíral 1996): pH in 1 N KCl solution, soil adsorption complex characteristics according to Kappen (presented S – base content, T – cation exchange capacity, V – base saturation), total nitrogen content according to Kjeldahl and plant available nutrient content in 1% citric acid solution (presented the CaO content). This part of research was performed in the laboratory of the Forestry and Game Management Research Institute, Forest Research Station Opočno, using standard analytical methods.

Biological respiration activity

Actual biological activity – weighed portion (25 grams of organic matter) was put into the lockable one-litre glass container; this material was outspread around the wall and a glass bucket with 25 ml of 0.1N NaOH was put in the middle. The container was locked and incubated for 24 hours at a temperature of 25°C. This process was repeated with the original sample for five consecutive days, the solution of 0.1N was changed every 24 hours.

Table 1. Basic soil chemistry characteristics in different horizons of particular forest stands

Stand	Horizon	Depth (cm)	Dry matter (t/ha)	pH KCl	S (A)	T (A)	V (%)	N Kj (%)	CaO (mg/kg)
1. Clear-cut area	L + F_1	1.0	11.4	3.1	6.6	52.1	12.7	1.73	2,000
	F_2	2.0	20.7	2.6	6.5	66.8	9.8	1.81	1,173
	H	5.5	68.1	2.3	0.6	94.8	0.6	1.77	573
	Ah	8.5		2.5	1.9	29.0	6.7	0.57	160
2. Dead forest	L + F_1	1.0	7.1	3.2	2.6	49.7	5.3	1.77	1,787
	F_2	1.9	13.4	2.8	6.9	77.0	9.0	1.88	920
	H	4.1	52.6	2.7	0.7	81.1	0.8	1.94	427
	Ah	7.0		3.0	2.4	38.4	6.4	0.82	127
3. Living forest	L + F_1	1.1	9.7	2.7	7.0	48.0	14.7	1.83	2,213
	F_2	2.2	22.8	2.9	4.4	70.2	6.2	1.93	1,427
	H	6.6	63.0	2.8	3.6	84.0	4.3	1.92	413
	Ah	9.9		3.0	2.3	71.8	3.2	0.54	100

(A) – mval/100 g of fine earth, S – base content, T – cation exchange capacity, V – base saturation according to Kappen

Potential biological activity – weighed portion (12.5 grams of organic matter) was put into the lockable glass container, this material was outspread around the wall and a glass bucket with 25 ml of 0.1N NaOH was put in the middle. In this case, the sample was sprayed with 12.5% solution of glucose (2 ml of glucose per 12.5 grams sample). The container was locked and incubated for 24 hours at a temperature of 25°C.

Control determination was made with the same chemicals under the same conditions but without the organic matter sample.

Evaluation – every day when the incubation of sample was determined, the bucket with 0.1N NaOH solution was removed from the container and put into a titration flask. About 2 ml of 25% $BaCl_2$ solution and a few droplets of phenolphthalein were further added into the titration flask. The solution in the flask was titrated with 0.1N HCl solution until absolute discolouring. The consumption of hydrochloric acid was subtracted from its consumption during the control determination and the difference was multiplied by the constant 2.2. The amount of carbon dioxide in milligrams produced by the weighed portion of the sample is the result of the analyses.

Nitrogen transformation

Weighed portion (25 grams of organic matter) was moistened with distilled water and put into a glass container. The glass container was then put into the incubator and processed for 14 days at a temperature of 25°C. During the incubation period, the same weighed portion of the sample was cryopreserved for the purposes of further evaluation. The amount and forms of soil nitrogen determined in the control and incubated samples were then compared.

Preparation of extract – incubated and control samples were embedded with 200 ml of 1% K_2SO_4 solution and then they were macerated over night. The next day, they were processed and filtered. The contents of N-NH_4 and N-NO_3 (ammonia and nitrate nitrogen) were then determined in the filter liquor.

N-NH_4 – ammonia nitrogen was determined using a photoelectric colorimeter with Nessler's reagent.

N-NO_3 – nitrate nitrogen was determined using an ion-selective nitrate electrode.

Statistical evaluation

Statistical evaluation of microbiological characteristics (set of sixteen samples for each analyzed

Table 2. Microbial activity characteristics of holorganic horizons – nitrogen dynamics

Plot – forest	Horizon	Moisture (%)	NH_4 – N (mg/kg of dry matter)		NO_3 – N (mg/kg of dry matter)	
			before inc.	after inc.	before inc.	after inc.
Clear-cut area	F	72.5	164	436a	103	153a
	H	77.2	87	208a	80	87a
Dead forest	F	72.9	165	446a	160	216b
	H	78.1	47	228ab	93	139b
Living forest	F	67.0	263	610b	52	119c
	H	68.3	103	248b	61	84a

Different indexes indicate significant differences between variants

Table 3. Microbial activity characteristics of holorganic horizons – respiration activity

Plot – forest	Horizon	Biological respiration activity – basal (mg CO_2/100 g of dry matter per 24 hours)					Biological respiration – potential	Moisture (%)
		day 1	day 2	day 3	day 4	day 5		
Clear-cut area	F	84a	5a	67a	90	71	312a	72.5
	H	63a	59	73	88	72	170	77.2
Dead forest	F	117b	82b	97b	87	81	380b	72.9
	H	74a	59	72	65	65	164	78.1
Living forest	F	125b	91b	101b	97	87	399b	67.0
	H	92b	47	40	71	55	135	68.3

Different indexes indicate significant difference biological and chemical characteristic) was performed by one-factor analysis of variance with the significance level 0.05 to evaluate the final values of nitrogen dynamics and biological respiration activity (living versus dead forest was used as a factor of the statistical analysis). The different indexes a, b, c, and d (Tables 2 and 3) indicate significant differences in individual chemical and biological characteristics. Values with different indexes significantly differ between each other.

RESULTS AND DISCUSSION

Results of similar research conducted in comparable conditions are missing in the literature. The threat of forest decline in this area is still underestimated and neglected. The forest decline and/or forest cut lead to the lowering of the thickness of humus form layers, amount of organic matter being comparable, even assuming high variation. The mass of organic matter reached 100.2 t/ha (clear-cut), 73.1 t/ha (dead forest) and 95.5 t/ha (living forest).

Soil reaction (pH) did not differ between the site types; a tendency to higher values in the litter layer was detectable, caused by the vital grass layer growth and litter production. In localities with dead or cut forest stand, the base content (S-value), cation exchange capacity (T-value) and base saturation (V-value) decreased considerably in the H layer (Table 1), indicating increased leaching without nutrient (base) uptake (Binkley 1986; Tietema 1992; Wesemael 1992).

Despite high variation in all pedo-chemical characteristics, the total nitrogen content showed a tendency to decrease in the uppermost holorganic horizons (L + F layers). This can be due to increased nitrogen mineralization and leaching, caused by the changed environment in the soil compartment (temperature, moisture conditions and dynamics), promoting microbiological activities (Binkley 1986). Similar trends were observed on clear-cut areas after liming, also promoting the soil biota activities (Podrázský, Ulbrichová 2004). Higher probability of nutrient leaching is to be supposed also in the case of plant available calcium.

Nitrogen dynamics is documented in Table 2. Soil moisture was comparable at all sites, lower horizons (H) showed higher water content in the dead/cut forest. Ammonia (NH_4 – N) ion content was highest in the living stand (F + H horizons), being lower in the declined forest parts. After incubation, ammonia ion contents increased considerably, this trend was significantly lower in the disturbed forest ecosystems.

On the contrary, nitrate ion content was lowest in the holorganic layers of the living stand, being especially low in the surface layer. Increased nitrification activity was detectable before incubation of substrates following forest disturbance. After incubation in laboratory conditions a significant increase in nitrification occurred, lowest in the soil from the living forest stand, higher from the clear-cut area and highest in substrates from the dead forest.

Much better conditions for nitrogen mineralization result in increased nitrogen dynamics and losses, which is also documented in Table 1 (Binkley 1986; Tietema 1992; Wesemael 1992).

Table 3 documents the potential and basal respiration activity of holorganic substrates from all three site variants. On the first day of incubation, the substrates from the living stand showed the significantly highest respiration activity. Respiration intensity fluctuated among the variants during incubation. This probably means the depletion of rapidly mineralizable substances also in the substrates from the living stand, being less transformed there. Potential respiration activity is also highest in the living stand, but only in the F horizon. In lower horizons, the mineralization potential appears to be greater in the dead/cut stands.

CONCLUSIONS

In the studied locality, the effects of forest decline and clear-cutting on different ecosystem processes can be studied. This locality is representative of large areas affected by the bark-beetle gradation and consequent salvage activities. These general conclusions can be drawn from the humus layer dynamics:

– after several years (2–3) that elapsed since Norway spruce stand decline/cut, no significant changes in surface humus amount can be observed,
– soil reaction (pH) of the uppermost layers is affected by the grass and herbal (minor effect) litter; in lower horizons, the absence of protective forest function is reflected by higher base leaching,
– nitrogen losses are observable very rapidly, especially from the holorganic layers,
– this assumption is supported by higher N-mineralization rates (nitrification) in the dead/cut site type, ammonification being higher in the living stand,
– respiration activity does not differ very much between the variants, depletion of rapidly mineralizable substances in the humus forms in dead/cut stands is remarkable,
– the dead forest site type is closer by its character to the clear-cut area than to the living stand, forest

decline will probably change the forest ecosystem functions profoundly,
– more extended and long-term research is needed for more detailed description and quantification of these processes.

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Received for publication November 1, 2004
Accepted after corrections January 31, 2005

Pedobiologické charakteristiky humusových forem v závislosti na odumírání lesa v NP Šumava

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ABSTRAKT: Dynamika a vlastnosti humusových forem na různých stanovištích byly studovány v oblasti Smrčiny na území NP Šumava. Srovnávány byly: vitální horský smrkový les, les odumřelý v důsledku působení kůrovce (*Ips typographus*) a holina vzniklá vytěžením dřevní hmoty; stanovištně byly plochy srovnatelné. Hynutím a vytěžením nebylo významně ovlivněno množství nadložního humusu (95,5 t/ha – živý les, 73,1 t/ha – mrtvý les a 100,2 t/ha – holina), také půdní reakce byla srovnatelná (mezi 2,3–3,2 v KCl), pouze slabý vliv opadu travin a bylin byl patrný v nejsvrchnějších vrstvách. V hlubších holorganických horizontech bylo patrné vyplavování bází. Byly prokázány ztráty dusíku v celkové formě z povrchových L + F vrstev nadložního humusu, pokles dosáhl hodnot z 1,93–1,83 % (živý les) na 1,73–1,83 % (holina). Vyšší úroveň produkce amonného dusíku byla prokázána v substrátech ze živého lesa (vždy F a H horizont), nárůst byl z hodnot 263 a 103 mg/kg před inkubací na 610 a 248 mg/kg N-NH_4^+ po inkubaci. Vyšší intenzita nitrifikace (obsah N-NO_3) byla doložena na holině (nárůst ze 103 a 80 mg/kg před inkubací na 153 a 87 mg/kg po inkubaci) a zejména v nadložním humusu mrtvého porostu (nárůst ze 160 a 93 mg/kg na 216 a 139 mg/kg), odpovídající hodnoty pro substráty původem z živého lesa byly: nárůst z 52 a 61 mg/kg na 119 a 84 mg/kg po inkubaci. Hodnoty respirační aktivity bazální i potenciální byly více vyrovnané, indikovaly intenzivnější rozkladné procesy na holině a v odumřelém lesním porostu.

Klíčová slova: NP Šumava; horské smrčiny; odlesnění; kůrovec; mikrobiální aktivity; respirační aktivity; mineralizace dusíku; půdní chemismus; humusové formy

Půda, jejíž součástí jsou humusové formy, je jednou z nejdůležitějších součástí lesních ekosystémů (Barnes et al. 1998). Význam humusových forem v lesních ekosystémech byl dokumentován v mnoha studiích (Binkley 1984, 1986; Sevink 1997; Emmer, Sevink 1994; Podrázský et al. 2001). Charakter a parametry humusových forem významně ovlivňují cyklus živin a vlhkostní a teplotní režim vrchní části půdy. V humusových horizontech se nachází velké množství kořenů lesních dřevin a mají vliv na produktivitu stanoviště (Green et al. 1993).

Cílem práce je studium dynamiky a vlastností humusových forem na různých stanovištích v oblasti Smrčiny na území NP Šumava. Srovnával se: vitální horský smrkový les, les odumřelý v důsledku působení kůrovce (*Ips typographus*) a holina vzniklá vytěžením dřevní hmoty; stanovištně byly plochy srovnatelné.

Vzorky humusových horizontů F a H byly odebrány ve čtyřech opakováních na náhodně zvolených místech v odumřelém i živém lesním porostu na každé ploše. Analýzy byly provedeny standardními metodami (Šarman 1981; Zbíral 1996) v laboratoři Výzkumného ústavu lesního hospodářství a myslivosti Jíloviště-Strnady, Výzkumná stanice Opočno. Analýzy zahrnovaly stanovení $pH_{(H2O)}$ a $pH_{(KCl)}$, charakteristiky sorpčního komplexu (S, H, T, V), výměnnou aciditu a její složky, obsah humusu a obsah celkového dusíku podle Kjeldahla. Pro holorganické horizonty byla dále stanovena biologická respirační aktivita a dynamika dusíku.

V dostupné literatuře chybějí studie zabývající se touto problematikou v podobných stanovištních podmínkách. Nebezpečí plynoucí z odumírání lesa v této oblasti je výrazně podceněno. Hynutím a vytěžením nebylo významně ovlivněno množství nadložního humusu (95,5 t/ha – živý les, 73,1 t/ha – mrtvý les a 100,2 t/ha – holina), také půdní reakce byla srovnatelná (mezi 2,3–3,2 v KCl), pouze v nejsvrchnějších vrstvách byl patrný slabý vliv opadu travin a bylin. V hlubších holorganických horizontech bylo patrné vyplavování bází. Byly prokázány ztráty dusíku v celkové formě z povrchových L + F vrstev nadložního humusu, pokles dosáhl hodnot z 1,93 až 1,83 % (živý les) na 1,73–1,83 % (holina). Tento proces může být způsoben zvýšenou mineralizací, na kterou mají přímý vliv změny stanovištních podmínek (teplotní a vlhkostní režim) (Binkley 1986). Vyšší úroveň produkce amonného dusíku byla prokázána v substrátech z živého lesa (vždy F a H horizont), nárůst byl z hodnot 263 a 103 mg/kg před inkubací na 610 a 248 mg/kg N-NH_4^+ po inkubaci. Vyšší intenzita nitrifikace (obsah N-NO_3) byla doložena na holině (nárůst z 103 a 80 mg/kg před inkubací na 153 a 87 mg/kg po inkubaci) a zejména v nadložním humusu mrtvého porostu (nárůst ze 160 a 93 mg/kg na 216 a 139 mg/kg), odpovídající hodnoty pro substráty původem z živého lesa byly nárůst z 52 a 61 mg/kg na 119 a 84 mg/kg po inkubaci. Hodnoty respirační aktivity bazální i potenciální byly více vyrovnané, indikovaly intenzivnější rozkladné procesy na holině a v odumřelém lesním porostu.

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