Forest Ecology and Management 255 (2008) 3606–3612

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Decomposition of stumps in a chronosequence after clear-felling vs. clear-felling with prescribed burning in a southern boreal forest in Finland

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ARTICLE INFO

Article history:
Received 17 August 2007
Received in revised form 21 February 2008
Accepted 28 February 2008

Keywords:
Coarse woody debris
Decomposition
Fragmentation
Bark
Fire
Managed forest

ABSTRACT

The wood bulk density, bark mass and decomposition rate constants of cut stumps of the main European boreal tree species were assessed along a 40-year chronosequence of clear-felled sites with and without prescribed burning. Using the single exponential model, the annual decomposition rate constants *k* of above-ground stumps were calculated as 0.048, 0.052 and 0.068 year^{-1} for Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and birch (*Betula* sp.), respectively. Bark decomposed faster than wood and bark fragmentation increased the rate of decomposition. There was a significant negative effect of burning on decomposition rate for pine wood, and for pine and spruce bark but not for spruce and birch wood or for birch bark. The decomposition of bark of all species was slower with larger diameter stumps but only slightly slower in the case of birch wood. Our results suggest (i) using different decomposition rate constants for wood and bark, (ii) taking into account fragmentation as it greatly increases the volume loss, and (iii) adjusting of *k* in carbon dynamics studies on burned sites. Such refinements to estimates of coarse woody debris decomposition constants could aid in identification of ecosystems and management scenarios necessary to maximize carbon storage and conserve biodiversity. Prescribed burning for restoration purposes decreases decomposition rates and consequently ensures longer persistence of stumps for maintaining biodiversity in intensively managed forests.

1. Introduction

In recent decades, the role of coarse woody debris (CWD) in a variety of ecological functions and processes such as biodiversity, energy flows, carbon and nutrient cycling has been acknowledged; it has become important in many scientific and management questions (Harmon, 2001). Abundance of CWD in forest ecosystems is determined by the balance between inputs (tree mortality and residual timber following harvesting) and outputs (decomposition and removal during different cuttings), both of which change during stand development.

Tree mortality is a result of natural tree senescence, competition and disturbances. Historically, in Fennoscandia, fire has been the main large-scale natural disturbance factor (Zackrisson, 1977; Granström, 2001). Creating post-fire habitats and substrates such as dead and charred wood is important for many fire-dependent species (Rowe and Scotter, 1973; Esseen et al., 1997; Wikars, 2002; Hyvärinen et al., 2005). In Finland, owing to effective fire suppression, the role of fire in forests has been generally reduced (Vanha-Majamaa et al., 2004). Before there was any significant human impact in Fennoscandia forest fires were relatively rare, and usually affected larger areas than is currently the case (Niklasson and Granström, 2000). During the period of initial settlement, slash-and-burn cultivation was widely practiced for centuries, thereby increasing the fire frequency and affecting forest ecosystems (Niklasson and Granström, 2000; Pitkänen et al., 2003; Huttunen, 1980; Tasanen, 2004). After slash-and-burn cultivation ceased at the beginning of the 20th century, prescribed burning became increasingly used as a silvicultural tool to assist in forest regeneration, thereby retaining the role of fires in forests. This forest management activity reached its culmination during the 1950s and 1960s, when the annual area treated by prescribed burning in Finland varied between 15,000 and 35,000 ha (Metla, 2003). Since then, mainly due to the development of alternative site preparation methods, there has been a steady decline in the use of prescribed burning. The annually burned area is currently around 500–2000 ha only. At the same time, wild fire prevention and control has become more effective and the area burned in wildfires has decreased (Vanha-Majamaa et al., 2004). This reduction has recently led to suggestions in forest certification criteria and forest conservation programmes to increase the use of prescribed burning (Lindberg and Vanha-Majamaa, 2004).

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doi:10.1016/j.foreco.2008.02.042

Because of intensive commercial use of forests in Finland since the end of World War II, clearcutting is the major factor currently affecting ecosystem dynamics and in particular CWD dynamics. The structure of forests has become relatively even-aged, and the amount of dead wood has been reduced considerably, from 60 to 90 $m^3\,ha^{-1}$ in the natural forests of southern Finland to 7–15 $m^3\,ha^{-1}$ in managed mature *Picea abies* stands (Siitonen et al., 2000; Jalonen and Vanha-Majamaa, 2001). In the forest environment, intensive management has changed the forest structure (e.g. the reduced abundance of deciduous tree species and dead wood), which has led to changes in biodiversity (Rassi et al., 2001; Reinikainen et al., 2000; Siitonen, 2001).

The decomposition rate of CWD can be influenced by several factors, such as the substrate itself, the community of the decomposing organisms and the external environment (Boddy, 2001; Laiho and Prescott, 2004). Estimates of decomposition rate constants of CWD formed after disturbances such as windthrows if biased by even a few percent can influence the estimates of carbon release to the atmosphere by several Mg C $ha^{-1}\,year^{-1}$. A lack of CWD dynamic studies after clearcutting hinders the accurate modeling of woody decomposition throughout succession in general. Despite the fact that stumps are the most common CWD in commercial forests, only a few studies on their rates of decomposition have been undertaken (but see e.g. Janish et al., 2004).

Because charcoal is highly resistant to decomposition, it is generally assumed that the decomposition of logs is reduced by fire. However, according to observations by Mackensen and Bauhus (1999), the surface of logs is seldom entirely charred by fire, and the cracks in the charcoal allow entry of fungal spores (if they were not already present before the logs were charred). Charring can also influence the decomposition processes by modifying pH, moisture and temperature regimes of both wood and bark. It also modifies the albedo, which could then influence radiation balance and temperature. Information on the effects of prescribed burning on spatial and temporal availability of CWD and, in particular, on the decomposition rate of stumps in relation to harvesting and prescribed burning is still very limited.

We studied the decomposition of stumps of the three most common tree species in southern Finland: Norway spruce (*Picea abies* Karst.), Scots pine (*Pinus sylvestris* L.) and birches (*Betula pubescens* Ehrh. and *B. pendula* Roth.). The wood bulk density, bark mass and decomposition rate constants of cut stumps in a chronosequence of clear-felled sites with and without prescribed burning were compared. Our first hypothesis was that the decomposition rate and mass loss of stumps are negatively influenced by (i) presence of bark as assumed to be a more decay-resistant substrate than wood, (ii) burning and (iii) increasing size of stumps. Our second hypothesis was that the decomposition rate and mass loss of stumps are positively influenced by mechanical and biological fragmentation of bark.

2. Materials and methods

2.1. Study sites

All the studies were performed in the Evo-Vesijako area of southern Finland, a large, mostly publicly owned, relatively uninhabited forested area (61°N, 25°E). It is located in the southern boreal zone (Ahti et al., 1968). The mean annual temperature is +3.1 °C and the duration of the growing period is 160 days. The annual average precipitation is ca. 670 mm. The bedrock consists of orogenic granitoids and is covered with a thick layer of till (Anon., 1995).

The study plots before logging were mainly representative of the mesic (*Vaccinium myrtillus*) mature spruce forest type. The dominant tree species were Norway spruce (*Picea abies* Karst.), with Scots pine (*Pinus sylvestris* L.) and birches (*Betula pubescens* Ehrh. and *B. pendula* Roth.) as co-dominants.

Burnings were carried out using the traditional Finnish prescribed burning technique as utilized for silvicultural site preparation (Lemberg and Puttonen, 2003). With this method, the ignition lines form a circle around the stand and the burning front advances partly against the wind, thus decreasing the risk of fire escape.

2.2. Sampling and calculations

The field sampling for this study was conducted in June 2006. A chronosequence of plots 5, 10, 20, 30 and 40 years after being clear-cut with and without prescribed burning was established. On each plot a number of randomly chosen and evenly distributed stumps were sampled: in total 100 uncharred and 60 charred stumps of pine; 202 uncharred and 109 charred stumps of spruce; and 73 uncharred and 38 charred stumps of birch.

The height, base and top diameters of all stumps were measured. Assuming a conical shape for each stump, its volume (V_S) in m^3 was calculated as follows:

$$V_S = \frac{\pi h(R^2 + Rr + r^2)}{3} \quad (1)$$

where h is the height of the stump in m; R and r are respectively the maximum and minimum radii in m.

Samples from stumps were taken using a chain saw and axe, knife, or soil borer as follows: the top 5 cm was removed, the area proportion (%) of parts at different stages of decomposition was visually estimated for each cross-section. Holes due to fragmentation or complete decomposition were evaluated as well. Area percentage was assumed to correspond to the volume proportion of each sample. Samples of regular shape were taken from each part and measured in three dimensions. A soil borer was used for severely decomposed parts of stumps. Stumps from burned areas were chosen with as much char as possible.

The decomposition of bark was analyzed as follows. The lateral surface area of stumps was calculated by the formula:

$$S = \pi L(R + r) \quad (2)$$

where R and r are respectively the maximum and minimum radii, m, and L is the slant height of a cone, m. To account for the loss of bark fragments from by machinery and insects, the percent cover of bark remaining on a stump (f) was visually estimated. Two to three regularly shaped bark samples were taken from the southern and northern sides of each stump and measured in two dimensions.

The samples were oven-dried at 103 °C for 48 h then weighed. The bulk density (ρ, in Mg m^{-3}) of each wood sample was calculated by the formula:

$$\rho = \frac{m}{V} \quad (3)$$

where m is the dry mass in Mg, and V is the volume in m^3.

The weighted average (in terms of proportion of wood samples at different degrees of decomposition) for bulk density was calculated for each stump. The initial (pre-decomposition) bulk density (ρ_0) for each tree species was estimated as an average of 10 stumps per tree species sampled similarly on an area that had been felled that same year (2006). To model the decomposition process and determine the annual decomposition rate constants we used the single exponential model (Olson, 1963) for bulk density:

$$\rho = \rho_0\, e^{-k_W t} \quad (4)$$

where t is the time of decomposition, years; ρ_0 the initial bulk density, Mg m^{-3}; and k_W is the annual decomposition rate constant, year^{-1}. To assess temporal variation, k values for individual stumps were also calculated as (Olson, 1963):

$$k_W = \frac{\ln(\rho_0) - \ln(\rho)}{t} \quad (5)$$

The mass loss (δ_W, %) was calculated as:

$$\delta_W = (\rho_0 - \rho)\rho_0^{-1} \times 100 \quad (6)$$

The specific mass of bark (mass per unit of surface area) was calculated as:

$$M_b = \frac{m}{s} \quad (7)$$

where M_b is the specific mass of bark, Mg m^2; m is the dry mass of a bark sample, Mg, and s is the area of sample, m^2.

To determine the total area of remaining bark (S_f), the lateral surface area of stump (S) was multiplied by the percent of remaining bark (f). The total mass of stump bark (M_{sb}) was calculated by multiplying the total area of remaining bark (S_f) by the specific mass of bark (M_b). The initial specific mass (M_{0b}) was calculated as an average of 10 stumps for each tree species, sampled similarly in the area that had been felled in 2006. The annual decomposition rate constants (k_{M_b}, year^{-1}) were calculated on the basis of the single exponential model (formulae (4) and (5)) using the specific mass of bark (M_b) and initial specific mass (M_{0b}). The annual decomposition rate constants of decomposition including fragmentation ($k_{M_{sb}}$) were calculated by the formulae (4) and (5) using the total mass of stump bark (M_{sb}) and initial total mass of bark (M_{0Sb}). The mass loss due to decomposition of bark (δ_{M_b}, %) was calculated by formula (6) using the specific mass of bark (M_b) and initial specific mass (M_{0b}). The mass loss due to decomposition and of bark ($\delta_{M_{Sb}}$, %) was calculated using the total mass of stump bark (M_{sb}) and initial specific mass of bark (M_{0Sb}).

To determine the decomposition parameters for all above-ground parts of stumps, the mass of stumps (M_S) was estimated as the sum of wood mass calculated by multiplying the volume of wood (V_S, formula (1)) by bulk density (ρ, formula (3)) and bark mass (M_{sb}, formula (1)). Then the annual decomposition rate constants (k_S) and mass loss were calculated by analogy with calculations of these parameters for wood and bark (formulae (4)–(6)).

2.3. Statistical analysis

All distributions were checked for normality and log-transformed if necessary. An analysis of covariance (ANCOVA) and analysis of variance (ANOVA) (Statistica, 6.0) were implemented to estimate the effects of tree species, prescribed burning and diameter of stumps on variability of bulk density of wood and mass of bark. Time was treated as a continuous predictor variable. The diameter of stumps was analyzed as a continuous predictor as well as a categorical predictor with two diameter groups: less than 20 cm and equal to or greater than 20 cm. ANOVA was implemented test for differences in initial bulk densities of wood and masses of bark as well as differences of decomposition parameters by periods.

3. Results

3.1. Wood

Calculated ρ_0 values were 0.436, 0.525, and 0.547 Mg m^{-3} for spruce, pine and birch, respectively. The rate of loss in wood density varied significantly among species with birch > spruce > pine ($F = 11.874$, $p < 0.001$). There were no significant differences in initial wood bulk density of charred and uncharred stumps ($F = 0.0278$, $p = 0.869$; $F = 0.6690$, $p = 0.418$; $F = 0.0100$, $p = 0.922$ for pine, spruce and birch, respectively). The decomposition of pine wood was slowed down by burning, whereas the decomposition of spruce and birch stump wood did not depend on burning (Figs. 1–3). The decomposition of spruce and pine stumps did not depend on diameter, but birch stumps of larger diameter decomposed slightly more slowly (Table 1, Figs. 1–3).

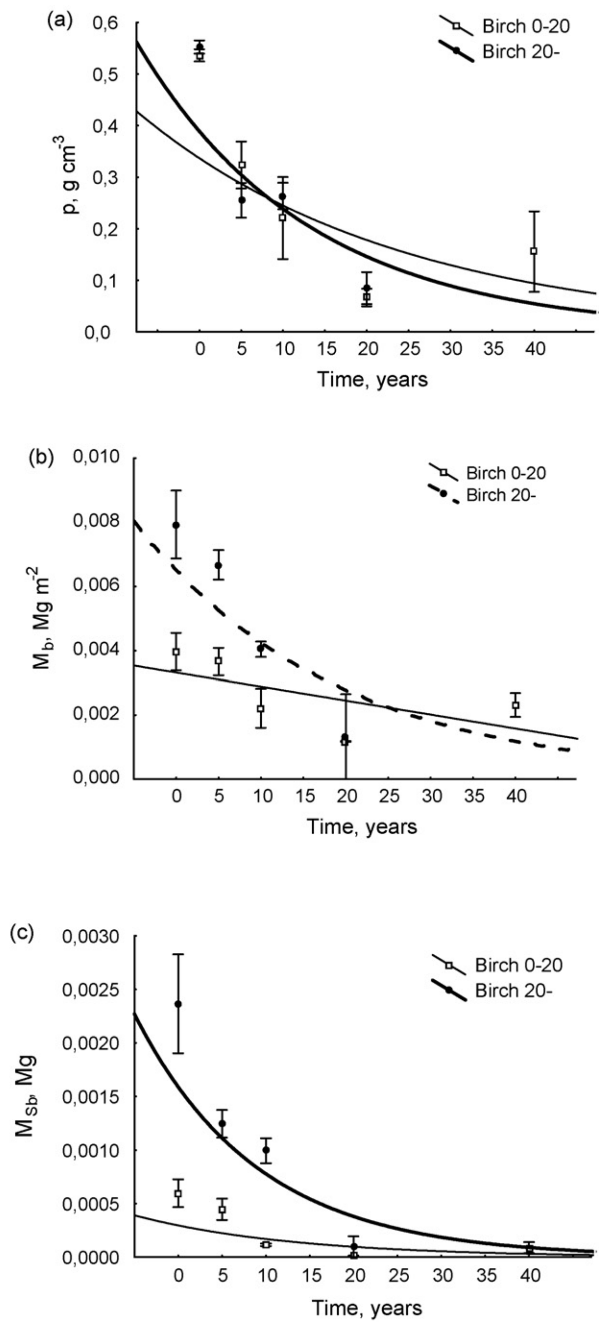

Fig. 1. Decomposition of birch (***Betula pendula*** and ***B. pubescens***) stumps. Means and S.E. are shown. 0–20, 20- are diameter groups. (a) Density loss of wood. Effect of prescribed burning was non-significant (**F** = 1.769, **p** = 0.184). Stumps of larger diameter were decomposed slightly slower (**F** = 4.170, d.f. = 1, **p** = 0.044). (b) Dynamics of specific mass of bark. Effect of prescribed burning was non-significant (**F** = 0.010, **p** = 0.922). ANCOVA effect of diameter was non-significant: **F** = 0.830, d.f. = 1, **p** = 0.365. ANOVA effect of larger diameter for fresh clear-cut and 5 years since clear-cut, respectively: **F** = 7.357, **p** = 0.013; **F** = 12.104, **p** = 0.002. (c) Mass loss of all bark. Effect of prescribed burning was non-significant (**F** = 2.273, **p** = 0.135). Stumps of larger diameter were decomposed slower, **F** = 26.037, d.f. = 1, **p** < 0.0001.

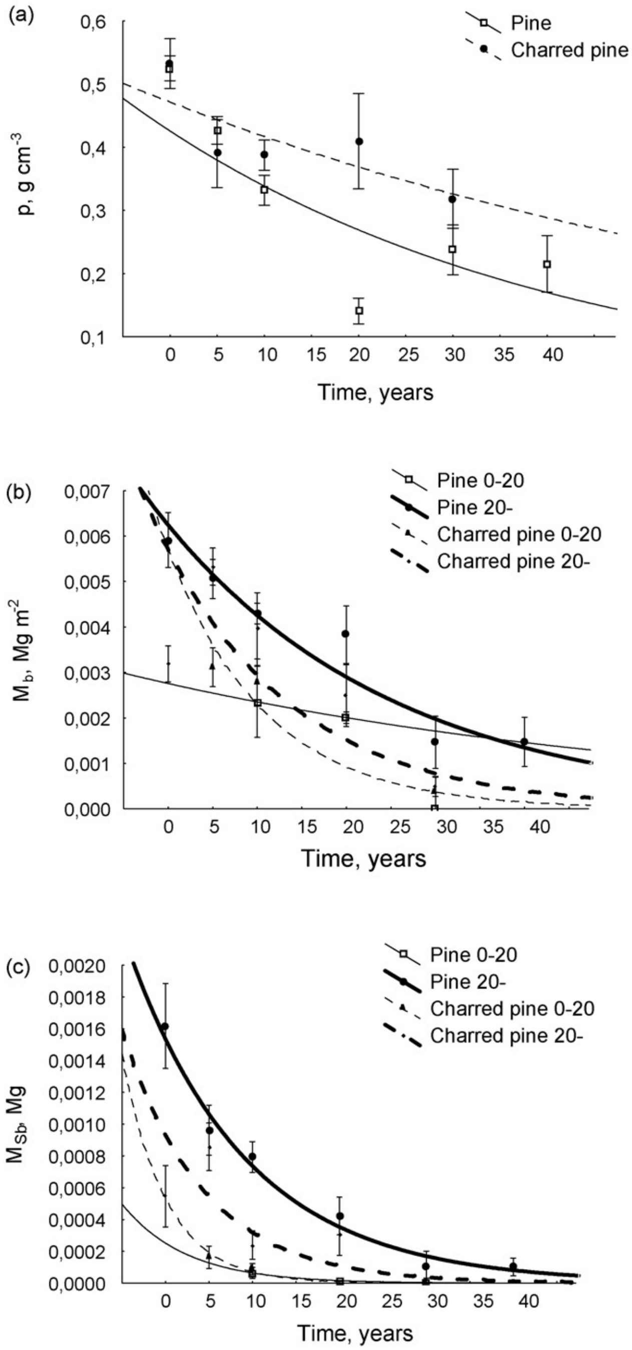

Fig. 2. Decomposition of Scots pine (***Pinus sylvestris***) stumps. Means and S.E. are shown. 0–20, 20- are diameter groups. (a) Density loss of wood on the sites with and without prescribed burning (***F*** = 8.954, ***p*** = 0.003). Effect of larger diameter was non-significant (***F*** = 0.284, d.f. = 1, ***p*** = 0.295). (b) Dynamics of specific mass of bark on the sites with and without prescribed burning (***F*** = 5.525, ***p*** = 0.020). Stumps of larger diameter were decomposed slower, ***F*** = 9.079, d.f. = 1, ***p*** = 0.003. (c) Mass loss of bark on the sites with and without prescribed burning (***F*** = 10.445, ***p*** = 0.001). Stumps of larger diameter were decomposed slower, ***F*** = 15.243, d.f. = 1, ***p*** < 0.001.

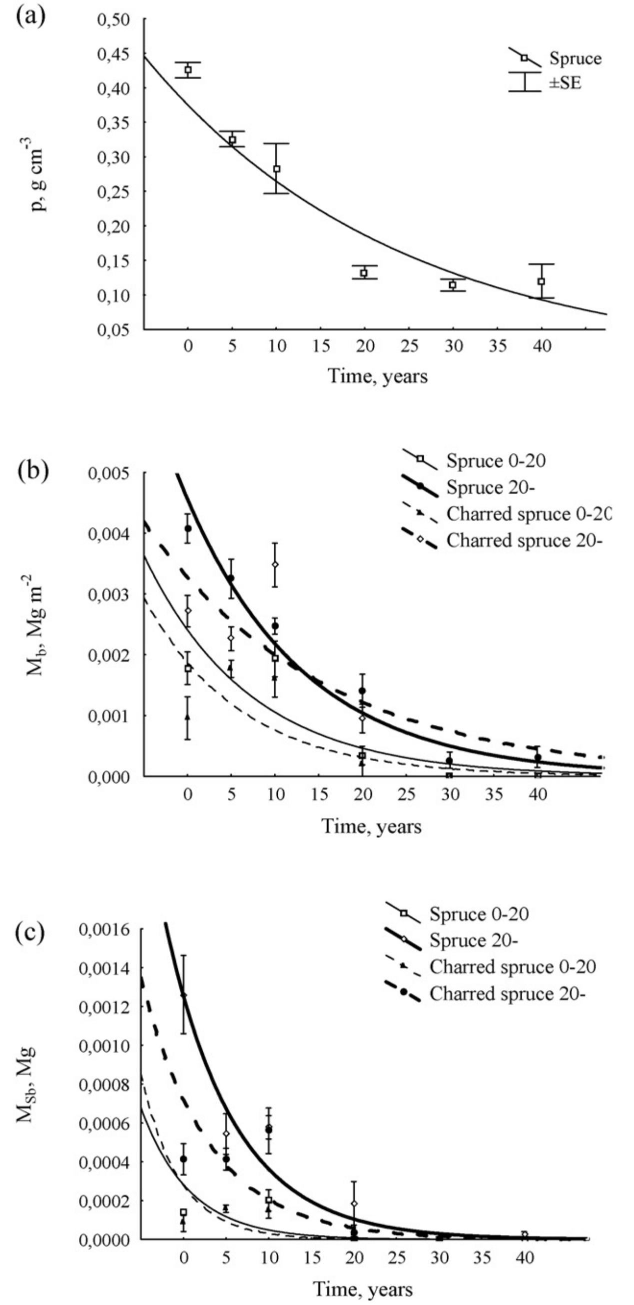

Fig. 3. Decomposition of Norway spruce (***Picea abies***) stumps. Means and S.E. are shown. 0–20, 20- are diameter groups. (a) Density loss of wood. Effects of prescribed burning and diameter were non-significant (***F*** = 0.113, ***p*** = 0.737; ***F*** = 0.708, d.f. = 1, ***p*** = 0.401, respectively). (b) Dynamics of specific mass of bark. Effect of prescribed burning was non-significant (***F*** = 0.009, ***p*** = 0.926), however, the initial specific mass was different for charred and uncharred bark (***F*** = 15.028, ***p*** = 0.0004). Stumps of larger diameter were decomposed slower, ***F*** = 25.180, d.f. = 1, ***p*** < 0.0001. (c) Mass loss of bark. Effect of prescribed burning was non-significant (***F*** = 1.318, ***p*** = 0.353) however, the initial mass was different for charred and uncharred bark (***F*** = 12.341, ***p*** = 0.001). Stumps of larger diameter were decomposed slower, ***F*** = 17.403, d.f. = 1, ***p*** < 0.0001.

Based on the time corresponding to mass loss of 30, 50 and 70%, as well as on the annual decomposition rate constants, the speed of decomposition decreased in the order of birch, spruce, pine, then pine charred (Table 1). Both values and variation of decomposition rate constants decrease from the beginning to the end of the decomposition process (Fig. 4a).

3.2. Bark

The calculated values for M_{0b} were 0.0059, 0.0037, and 0.0051 Mg m^{-2} for pine, spruce, and birch, respectively. M_{0Sb} values were calculated as 0.0016, 0.0011, and 0.0012 Mg for pine, spruce, and birch, respectively. The dynamics of both specific (M_b) and total

Table 1
Parameters of single-exponential decomposition model for wood and bark of stumps with and without fragmentation: initial wood density (ρ_0, Mg m^{-3}); initial bark specific mass (M_{0b}, Mg m^{-2}); initial bark mass of entire stump (M_{0Sb}, Mg); initial mass of all above-ground part of stump (M_{0S}, Mg); decomposition rate constants (k_W, k_{M_b}, $k_{M_{Sb}}$, k_S, year^{-1}); time in years corresponding to mass loss of 30 (t_{30}), 50 (t_{50}) and 70 (t_{70})%

Substratum	N	ρ_0	k_W	t_{30}	t_{50}	t_{70}	r^2
Pine charred wood	59	0.4787	0.013	28	53	76	0.626
Pine wood	100	0.4919	0.032	12	23	39	0.767
Spruce wood	311	0.4360	0.043	9	17	29	0.947
Birch wood < 20 cm in diameter	25	0.5213	0.084	5	9	15	0.842
Birch wood > 20 cm in diameter	86	0.5225	0.089	5	8	14	0.914
Substratum	N	M_{0b}	k_{M_b}	t_{30}	t_{50}	t_{70}	r^2
Bark of birch stumps > 20 cm in diameter	85	0.355	0.023	16	31	53	0.477
Bark of charred pine stumps > 20 cm in diameter	48	0.456	0.033	11	21	37	0.539
Bark of pine stumps > 20 cm in diameter	93	0.603	0.034	11	21	36	0.539
Bark of charred spruce stumps < 20 cm in diameter	28	0.150	0.040	10	18	31	0.460
Bark of charred spruce stumps > 20 cm in diameter	82	0.320	0.048	8	15	25	0.589
Bark of spruce stumps > 20 cm in diameter	171	0.419	0.058	7	12	21	0.977
Bark of birch stumps < 20 cm in diameter	25	0.820	0.065	6	11	19	0.923
Bark of pine stumps < 20 cm in diameter	7	0.501	0.068	6	11	18	0.848
Bark of spruce stumps < 20 cm in diameter	31	0.203	0.068	6	11	18	0.665
Bark of charred pine stumps < 20 cm in diameter	12	0.552	0.097	4	8	13	0.848
Substratum	N	M_{0Sb}	$k_{M_{Sb}}$	t_{30}	t_{50}	t_{70}	r^2
Bark of charred pine stumps > 20 cm in diameter	48	0.063	0.026	14	27	47	0.424
Bark of charred spruce stumps > 20 cm in diameter	82	0.041	0.049	8	15	25	0.504
Bark of pine stumps < 20 cm in diameter	7	0.138	0.068	6	11	18	0.813
Bark of pine stumps > 20 cm in diameter	93	0.157	0.075	5	10	17	0.984
Bark of charred spruce stumps < 20 cm in diameter	28	0.102	0.079	5	9	16	0.164
Bark of spruce stumps < 20 cm in diameter	31	0.153	0.081	5	9	15	0.482
Bark of spruce stumps > 20 cm in diameter	171	0.121	0.103	4	7	12	0.947
Bark of birch stumps > 20 cm in diameter	85	0.231	0.111	4	7	11	0.969
Bark of birch stumps < 20 cm in diameter	25	0.060	0.130	3	6	10	0.889
Bark of charred pine stumps < 20 cm in diameter	12	0.044	0.193	2	4	7	0.960
Substratum	N	M_{0S}	k_S	t_{30}	t_{50}	t_{70}	r^2
Above-ground part of pine stumps	153	0.015	0.048	8	15	25	0.739
Above-ground part of spruce stumps	306	0.011	0.052	7	14	24	0.896
Above-ground part of birch stumps	110	0.012	0.068	6	11	18	0.908

(M_{sb}) mass of bark varied by tree species ($F = 74.46$, $p < 0.001$ and $F = 37.455$, $p < 0.001$ for specific mass and total mass, respectively), so the data were considered separately for remaining analyses. The initial specific mass of birch bark increased with larger diameter. The initial specific mass of spruce and pine bark depended both on diameter and burning. All of the above differences indicate the need to use different parameters to model the decomposition process (Table 1, Figs. 1–3). The same differences (as for M_b and M_{sb}) were observed for the total stump bark (dynamics of M_S). Decomposition of bark of pine and spruce stumps, either with or without bark fragmentation taken into account, was slowed by burning. The exception for pine stumps with a diameter less than 20 cm may be caused by insufficient sample size (Table 1). The decomposition of birch bark did not depend on burning. The stump bark of all species was decomposed slower with larger stump diameter.

The bark of birch stumps with a diameter greater than 20 cm had the slowest decomposition, whereas the decomposition of bark of charred pine stumps less than 20 cm in diameter had the fastest decomposition. Parameters of bark decomposition change after taking fragmentation into account (Table 1).

3.3. All above-ground parts of stumps

The decomposition rate of whole stumps decreased in the following order: birch > spruce > pine (Table 1, Fig. 5). Compared to decomposition of wood and bark separately, the decomposition rate constants the whole stumps of birch significantly decreased and the decomposition rate constants of pine and spruce increased. The difference among species for whole stumps was less than difference among species for wood or bark (Fig. 4).

4. Discussion

The higher decomposition rate constants of deciduous European boreal tree species as compared with coniferous species agree with previous findings (Yatskov et al., 2003; Mäkinen et al., 2006). The decomposition constants determined in this study for the entire above-ground parts of stumps are higher than decomposition constants for logs reported by Yatskov et al. (2003): 0.048 vs. 0.027 (SD = 0.005); 0.052 vs. 0.026 (0.003); 0.068 vs. 0.054 (0.013) year^{-1} for pine, spruce and birch, respectively. This may be explained by closer positioning of stumps to the soil; stumps thus retain more moisture than elevated logs and can be more easily attacked by decomposers. However, further research is needed because different methodologies (used to determine mass vs. density of bark, different vs. the same decomposition constants for wood and bark) were used in comparable studies. In some studies no differences in decomposition of stumps and logs have been found (Janisch et al., 2004). Stumps and logs differ not only by their decomposition rates but also by initial characteristics of substrate. The experimentally determined initial bulk density of cut stumps in this study is higher than the initial bulk density reported for logs in Finland (Hakkila, 1966; Mäkinen et al., 2006): 0.525 vs. 0.390–0.460; 0.436 vs. 0.380–0.420; 0.547 vs. 0.450–0.500 Mg m^{-3} for Scots pine, Norway spruce and birch, respectively. This is not unexpected, because wood from the base of trunks and stumps is denser due to its support functions (Polubojarinov, 1976).

Bark loses its mass almost two times faster than wood. This observation does not agree with our initial hypothesis, nor with theoretical assumptions and experiments *in vitro* (Rypaček, 1957;

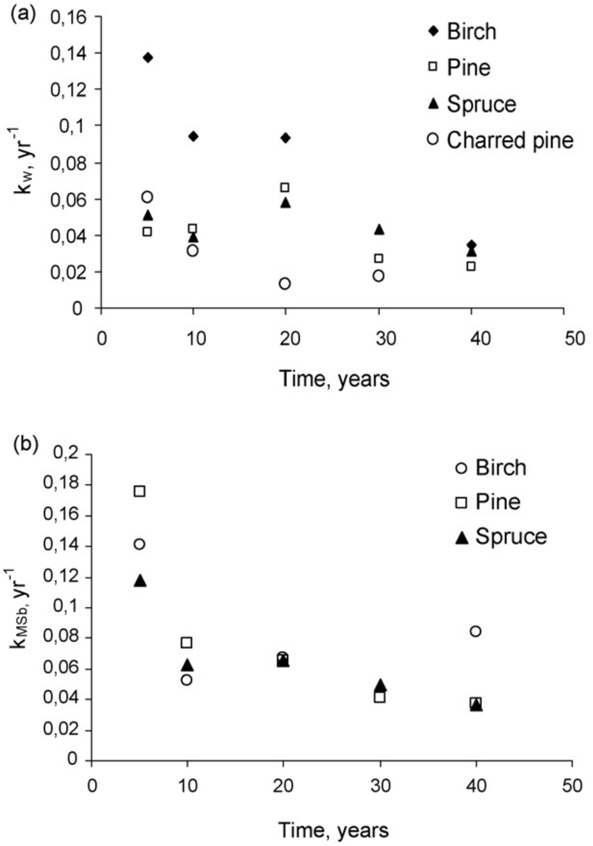

Fig. 4. Annual decomposition rate constants of (a) wood ($\boldsymbol{k}_W$), calculated using Eq. (5), and (b) all above-ground stumps ($\boldsymbol{k}_S$) averaged by time periods.

Käärik, 1974; Parameswaran et al., 1976). Further exploration of differences in decomposition of bark under laboratory and natural conditions is a subject for further research.

Fragmentation significantly influences decomposition of bark. The bark loss of all tree species, taking into account fragmentation, is much faster when the bark is destroyed by either mechanical damage or wood inhabiting insects. This confirms our initial hypothesis. This observed tendency for stumps will not necessarily be corroborated for logs and snags. For example, almost completely decomposed birch logs and snags in can very often be found with almost intact bark. For logs and snags of conifers, the pattern may be similar to that for stumps.

Decomposition of bark as partial CWD, but not as partial litter, has been studied via density loss (Krankina and Harmon, 1995; Yatskov et al., 2003; Ganjegunte et al., 2004; Janisch et al., 2004); decomposition rate constants have been calculated for combined substrate: wood and bark. However, accurate density estimates are difficult to make for highly decomposed thin bark (Polubojarinov, 1976); in such sampling, variation in the presence of bark is not completely accounted for, causing a biased estimation of decomposition rate constants. The suggested approach for studying mass loss of bark using mass per surface area allows tracking and accurate modeling of the decomposition of bark during all periods of the chronosequence. Our results suggest that considering wood and bark together as one substrate can result in a less accurate portrayal of decomposition pattern.

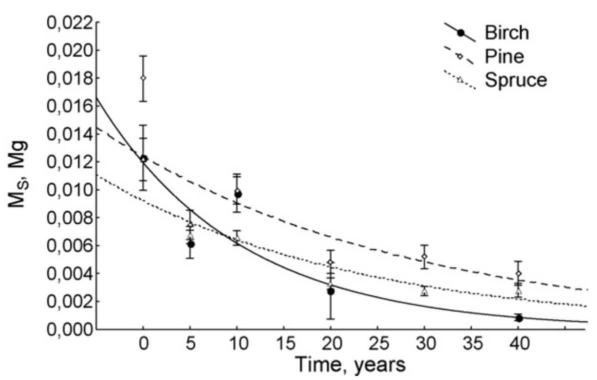

Fig. 5. Mass loss of above-ground stumps. Means and S.E. are shown. Mass of wood was estimated based on stump bulk density and volume; mass of bark was estimated based on mass per surface area and surface area of remained bark.

Our results showed that prescribed burning does not change the initial properties of wood except for the bark of conifers. The decomposition process is slower in charred pine stumps as compared to uncharred ones. The decomposition of charred spruce bark is also slower as compared to uncharred bark. The decomposition rate constants of birch wood and bark do not change on burned sites compared to unburned ones.

Evidence of any effect of burning on the decomposition of CWD is scarce and ambiguous. Wei et al. (1997) found that decomposition of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) CWD is faster on harvested as compared to fire-killed sites. Authors attribute this to the degree of contact between CWD and the ground, an important factor influencing decomposition processes. CWD after harvesting generally has complete contact with the ground, whereas CWD following a wildfire takes a long time to fully contacting the ground. The decomposition of buried wood was faster in burned than in unburned watersheds in tallgrass prairie (O'Lear et al., 1996). The authors hypothesize that the indirect effects of annual fire (i.e. causing changes in the composition of soil flora and fauna) may override the short-term effects of fire (i.e. causing changes in soil temperature and moisture) on belowground decomposition.

The ecological effects of burning are complex. Charcoal is very resistant to decomposition. When a black fragmented surface is heated, a positive effect on decomposition occurs if decomposer organisms penetrate under the charcoal layer. Evaporation increases, suggesting a negative effect on decomposition. At high temperatures pyrolysis begins and consequently pH decreases. The brown rot woody debris has been reported to have pH values of 3.0–3.5, whereas white rot woody debris is characterized by pH of 4.5–5.0. The low pH creates conditions favorable for brown rot fungi; these are more active consumers of wood (Soloviev et al., 1992). The wood of dead conifers is typically decomposed by both white and brown rot fungi; thus burning facilitates the dominance of brown rot fungi and promotes decomposition. It may explain variations of the burning effect by periods of time (Figs. 1–4). Wood of deciduous species is decomposed mainly by white rot fungi (Rayner and Boddy, 1988); consequently a changing pH would not influence species composition of decomposer organisms. Further research is needed to reveal the effects of prescribed burning and wildfire on decomposition of CWD. Effects of wildfire could be different in connection with severity of fire, abundance and position of dead wood, stand structure and many other factors.

The slightly negative effect of larger size of stumps on wood decomposition rates was seen only for birch. Bark of all species decomposed slower in proportion to diameter. The CWD size is assumed to affect decomposition rate in both direct and indirect ways—by influencing moisture, temperature and aeration of the substrate and by influencing the characteristics of substrate itself. A recent review showed that diameter explained substantial variation in *k* though diameter-*k* relationships for logs have been reported as positive, negative and non-existent (Mackensen et al., 2003). This inconsistent evidence for the effect of size on decomposition rate of CWD could be explained by different range of diameters examined and by other factors influencing a very complex decomposition process.

5. Conclusions

Studying decomposition of wood and bark separately using a suggested method for bark (mass loss per surface area) revealed differences in initial characteristics, decomposition rate and factors controlling the decomposition process. Our results suggest that using bulk density for wood and mass per surface area for bark, taking into account fragmentation of bark and making adjustments of *k* on burned sites can increase the accuracy in estimates of decomposition rate constants. Such refinements could aid in identification of ecosystems and management scenarios necessary to maximize carbon storage and conserve biodiversity. Prescribed burning for restoration purposes decreases decomposition rates and consequently ensures greater persistence of stumps for maintaining biodiversity in intensively managed forests.

Acknowledgements

The research was supported by Metla (Finnish Forest Research Institute); Metsäteho Ltd., and Metsämiesten Säätiö. We thank Ilkka Taponen and Juhani Makinen for help during the fieldwork; Kimmo K. Kolari for assistance in literature search; Victor Soloviev for fruitful discussions and critical comments on the results and Carla Burton for linguistic corrections. Comments by two anonymous reviewers significantly improved the manuscript.

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