

A Relation Between Historical Forest Use and Current Dead Woody Material in a Boreal Protected Old-Growth Forest in Finland

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Rouvinen, S., Rautiainen, A. & Kouki, J. 2005. A relation between historical forest use and current dead woody material in a boreal protected old-growth forest in Finland. *Silva Fennica* 39(1): 21–36.

Assessing the human impact on the naturalness and vegetation characteristics of protected areas is one of the key issues when designing forest conservation networks in Fennoscandia. We studied the small-scale, detailed relationship between forest utilization history and the current availability of dead woody material in a protected old-growth forest area in North Karelia, eastern Finland. From the study area of 32.4 ha, all the stumps (diameter ≥ 5 cm and height < 1.3 m, classified as natural, man-made and of undetermined origin) were measured using 25×25 m sub-plots. Standing and fallen dead trees (dbh ≥ 5 cm) were measured on 50×50 m plots in an area of 7.8 ha. The average number of stumps was 130 per ha, and over half of the stumps were classified as man-made. However, the historical documents since the 1910s showed no logging in the area: some of the largest man-made stumps probably originated from an earlier time, but most of those stumps were made considerably later. The variation in the total number of stumps (per ha) was great (range 0–560/ha, 0–16 m²/ha), with no clear clustering in space. However, clustering of man-made stumps was detected. The average volume of pooled standing and fallen trees was 84 m³/ha, with a range of 37–146 m³/ha. The other noticeable man-made disturbance besides logging was notching of aspens, which has a scatteredly significant influence on the amount of dead trees. In conclusion, the protected old-growth forest was not as a whole in a natural state but showed different degrees of human impact from virtually untouched patches to quite heavily managed patches. The results suggest that the number of man-made stumps may be a relatively quick and easy method of assessing the naturalness of woody biomass structure in the Fennoscandian boreal forests.

Keywords coarse woody debris, forest utilization, historical ecology, land-use history, nature conservation, *Picea abies*, *Pinus sylvestris*, *Populus tremula*, spatial pattern analysis.

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Received 17 May 2004 **Revised** 26 August 2004 **Accepted** 25 January 2005

1 Introduction

Finnish forests have been widely utilized, so few areas can be considered untouched by man (Lehtonen 1997, Kouki et al. 2001, Myllyntaus and Mattila 2002, Uotila et al. 2002). The first forms of utilization, e.g. the domestic use of wood, apparently had only a slight influence on forest structure. With the increasing density of human population, human influence on the forests has also been more intensive and widespread (Björn 1999). Slash-and-burn cultivation and tar burning affected large areas of forests for hundreds of years, until about the beginning of the 20th century (Heikinheimo 1915, Alho 1968, Soininen 1974). The early sawmills of the 19th century used timber from selective loggings (Helander 1949). Those loggings paved the way for modern intensive forestry, which has appeared during the 20th century.

As a consequence of human influence, natural forest characteristics have disappeared and the associated biota has at least partly become threatened (Rassi et al. 2001). To preserve the original or natural forest biodiversity, conservation areas have been established. However, the choice of representative areas for protection is difficult in many areas. This is particularly true in southern Finland, where the ecologically valuable areas are usually small-sized and isolated and bear only a limited resemblance to natural forest stand structures (Virkkala 1996, Forest... 2000).

In principle a network of reserves should be representative, complementary, and efficient, which means that it should satisfy conservation goals while minimizing costs, including those of economic expenditure, area, and number of selection units (Pressey et al. 1997). Several methods have been developed to select reserves (e.g. Margules et al. 1988, Nicholls and Margules 1993, Csuti et al. 1997, Siitonen et al. 2002), but independent of the method, inadequate databases complicate reserve selection (Possingham et al. 2000). Species inventories are often too limited to be very helpful in selecting the ecologically best set of areas, and often the structural characteristics of the forests are used instead of time-consuming species inventories (Polasky et al. 2000, Margules et al. 2002). Those forests that are natural in their

properties – ie. not influenced by human activities – are also regarded as having the highest conservation value.

The concept and the definition of the phrase “natural forest” is critical when forest stand characteristics are used to rank forests for conservation purposes. In theory, the concept of a natural forest is easy to define: a forest that has never been affected by human activity of any kind (Hunter 1996, Kuuluvainen 2002). In practice, however, the definition remains elusive. This is due both to the great natural variability of the characteristics of forest ecosystems and to the long-lasting relationship and interaction between forests and humans (Andrews 1996, Peterken 1996, Landres et al. 1998, 1999). The definition of natural forest thus requires explicit spatial and temporal bounds, and value judgments. It is quite likely indeed that there will never be a generally applicable definition of natural forest because the definition is context-, scale-, and value-dependent (Landres et al. 1998). It is also useful to regard the phrase “naturalness” as a continuous variable, ranging from completely natural to completely artificial (Anderson 1991, Peterken 1996). In this study, natural forest is defined as a forest where the natural successional dynamics have been predominant for a period of time lasting at least for several decades and there are thus no marks of human activity in the field or in the historical documents.

The conservation value of a forest stand has been assessed by many, often quite subjective, ocular methods. In Finland, for example, the valuation has been based e.g. on signs of recent forest management operations, the forest succession stage, and properties that are believed to represent the degree of naturalness of the forest, such as dead trees, old (especially old deciduous) living trees and trees with fire scars (Vanhogen ... 1992). The amount and diversity of dead wood has received particular emphasis in the valuation because dead wood hosts considerable numbers of threatened species in these habitats (e.g. Kouki et al. 2001, Siitonen 2001).

A few recent attempts have been made to derive the degree of forest naturalness more objectively from the number of man-made stumps and from historical archives (e.g. Uotila et al. 2002). On the basis of the stumps found, it is possible to

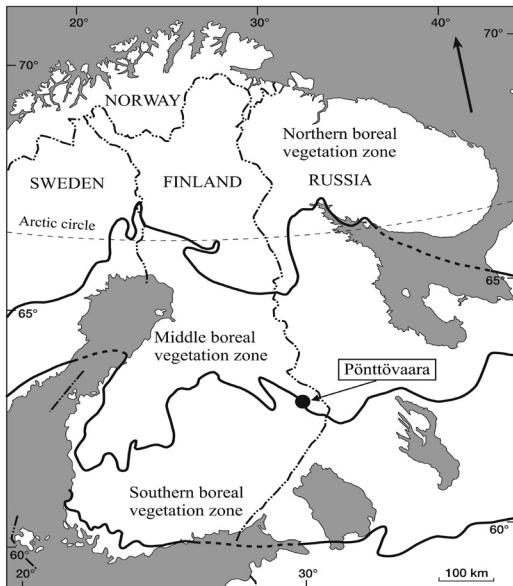


Fig. 1. Location of the study area. The borders of the vegetation zones are based on Kalela (1961) and Ahti et al. (1968).

determine at least fairly recent loggings, but due to the decaying process, the older loggings are much more difficult to detect (Nyyssönen 1956, Storaunet et al. 2000). However, especially large-diameter pine stumps may remain detectable for over a century (Rouvinen et al. 2002b) and thus make it possible to deduce the forest logging history over a prolonged period of time. Time- and space-specific forest documents include notes on loggings and other silvicultural treatment.

In this study we conduct a detailed spatial wood utilization history of a protected old-growth boreal forest area in eastern Finland and study the current availability of dead wood (CWD, coarse woody debris) material (stumps, standing and fallen dead trees) within the area. The study aims to reveal new aspects of forest structure that can be used when assessing the naturalness of a forest especially for conservation purposes. On the basis of the detailed knowledge gained of the forest area, 1) human impact on forest succession and CWD, 2) the degree of naturalness of the forest area, and 3) the value of information from different sources for defining naturalness, are discussed and suggestions are presented for assessing the naturalness of a forest.

2. Material and Methods

2.1 Study Area

The study area was situated in Pönttövaara ($63^{\circ}09'N$, $30^{\circ}59'E$) in North Karelia, eastern Finland, on the boundary of the southern and the middle boreal vegetation zones (Ahti et al. 1968) (Fig. 1). The area is included in the protection program of the Finland's Nature Conservation Act. The size of the area is 280 ha, of which 135 ha is old-growth forest (Vanhogen ... 1992). For the field studies only the core area of the old-growth forest, about 40 ha, was selected. Rouvinen and Kouki (2002) studied the variation of dead wood on a small spatial scale in the same area using a 1 ha study plot.

The area is located at approximately 190 m a.s.l. In 1992 the mean temperature was $+2.2^{\circ}C$ and the annual precipitation 726 mm (Suomen ... 1994). The area is characterized by large areas of mineral soil with scattered small-sized wet areas. In the Finnish forest site type classification (Cajander 1926) the mineral site is classified as *Myrtillus* type (mesic heath forest); the small-sized wet areas are spruce mires. The area is divided into smaller parts by one main forest road and three smaller forest roads.

The dominant tree layer is mostly composed of Scots pines (*Pinus sylvestris* L.) and Norway spruces (*Picea abies* L. Karst.). There were also scattered individual birches (*Betula pendula* Roth. and *B. pubescens* Ehrh.), aspen (*Populus tremula* L.), willow (*Salix caprea* L.), alder (*Alnus incana*) and rowan (*Sorbus aucuparia*). Of these species only birch co-occurred with pine and spruce in the dominant canopy layer. On mineral soils, the understory vegetation was comprised mainly of dwarf shrubs (*Vaccinium myrtillus* L. and *V. vitis-idaea* L.) and mosses (*Pleurozium schreberi* (Brid.) Mitt, *Hylocomium splendens* (Hedw.) Br., Sch.&Gmb. and *Dicranum* spp.). Also on the mires, dwarf shrubs (*Vaccinium myrtillus* L., *V. vitis-idaea* L., *V. uliginosum* and *Ledum palustre*) and mosses (*Sphagnum* spp. and *Polytrichum* spp.) dominated the understory vegetation.

2.2 Tree Measurements

We first established a continuous grid covering the core of the old-growth forest area. The grid was split into 50×50 m (2500 m^2) plots and further into 25×25 m (625 m^2) sub-plots (Fig. 2). Young managed tree stands, continuous mires and roads formed the borders of the study area, since only the sub-plots that were wholly on mineral soil in the old-growth forest were included in the study. The total number of measured sub-plots was 519 (32.4 ha). All the measurements were made in summer 1999.

All stumps (broken trees with height <1.3 m and diameter ≥ 5 cm) were included in the study. The measured variables of stump were mean diameter and height. Decay stage, origin class (man-made, natural or unidentified origin) and tree species were determined, and "burn status" (burned / not burned) was recorded. Only a stump that was clearly identified by tree species without digging for bark residue was classified by species; otherwise, the stump was classified as "unidentified". Each stump was located on the 25×25 m sub-plot.

The decay stage classification was based on the hardness of the wood, which was modified from Renvall (1995):

- 1) Wood hard. Pushed knife penetrates only a few mm into the wood.
- 2) Wood fairly hard. Knife penetrates ca. 1–2 cm into the wood.
- 3) Wood fairly soft. Knife penetrates fairly easily ca. 2–5 cm into the wood.
- 4) Wood soft. The whole blade of the knife easily penetrates into the wood.
- 5) Wood very soft. Almost completely decomposed and disintegrates easily between the fingers.

Besides these, we used the sixth (6th) stage for badly burned, charred hollow stumps, which have lost most of their wood.

A stump was classified as man-made if the breaking face was straight, indicating felling by axe or saw. In this case the felled log was not usually found. If a felled log (or mound) was found beside the stump, the stump was classified as natural. Characteristic for a young natural stump is a splintery breaking face. The remaining stumps, including e.g. stumps in an advanced

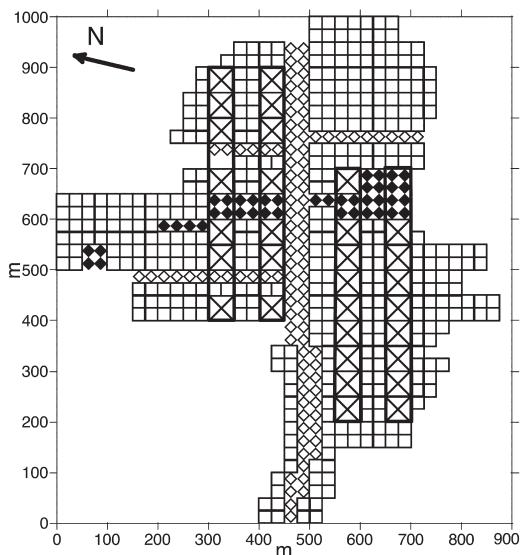


Fig. 2. Study design for field measurements. Small open squares represent 25×25 m sub-plots for stumps and large ticks 50×50 m plots for standing and fallen dead trees. Note that stumps were mapped in the 25×25 m sub-plots also within the 50×50 m plots. White diamonds represent the road area and black diamonds represent mires.

stage of decay and badly charred stumps, were classified as of unidentified origin. A total of 4211 stumps were recorded.

Due to the time limit on the fieldwork, only a sub-sample of the standing and fallen trees was measured. We placed four 50×500 m parallel transects, which were divided into 50×50 m plots to study standing dead trees (height ≥ 1.3 m and diameter at breast height (dbh) ≥ 5 cm) and fallen logs (diameter ≥ 5 cm) (Fig. 2). The plots coincided with the sub-plots determined for the measurements of stumps. On each side of the main road, two transects were located parallel to the road. Of the total of 40 plots, 31 were on mineral soil, 5 on spruce mires and 4 on forest road areas. Only trees situated on plots of mineral soil were included in this study. Diameter (dbh) was measured for all dead trees, but height was measured for broken standing dead trees and for fallen logs with a broken stem. Tree species was determined, and the decay classification was made using the same stages as with the stumps

(decay stages 1–5). The number of dead trees measured was 2420, of which 645 (27%) were standing and 1775 (73%) fallen.

Living trees were measured on one relascope plot (Bitterlich 1984) within each 50×50 m plot (relascope factor=1). The relascope plot was situated in the middle of the plot. The number of stems within the relascope plot was counted by tree species and the diameter of the basal area median tree was measured.

2.3 Analysis Methods

The available historical documents were used to find out the history of logging and other silvicultural treatment of the study area. The documents are filed in the Provincial Archives in Joensuu, in National Land Survey Office of North Karelia in Joensuu and in Forest and Park Service in Ilomantsi. Lehtonen (1997) has studied the fire history of the area by dendrochronological methods.

The volumes of standing and fallen dead trees (height >1.3 m) were estimated using Laasasenaho's (1982) volume equations. The volumes of stumps in decay stages 1–5 were estimated using the formula of cylinder. In decay class 6, the volume of the stump was assumed to be one fourth of the volume estimated for a whole stump of the same dimensions.

To estimate the living tree volumes, diameter distributions were first derived from the relascope sample measurements. We used the three-parameter approach of Weibull-distribution in estimating the diameter distributions of living trees. The measured basal areas and the diameter of basal area median tree were used in the estimation of the parameters (for details, see e.g. Maltamo 1997). The heights of trees in each diameter class were obtained using a height model made in the same area (Rouvinen unpubl. material: see Rouvinen and Kouki 2002). Finally, Laasasenaho's (1982) two parameters volume equations, using dbh and height as independent variables, were applied.

The pattern of the spatial autocorrelation of the basal areas of stumps and volumes of dead trees on the quadrat scale was investigated using omnidirectional semivariance analysis (Cressie 1991). The semivariance is the sum of squared

differences in the basal area (stumps) or volumes (dead trees) between all possible pairs of samples separated by a given distance, arranged in distance classes. The range that the spatial autocorrelation reaches can be considered to reflect the size of the block/cluster that occurs in the data (e.g. Meisel and Turner 1998). The semivariogram estimator is defined by (Cressie 1991):

$$\hat{\gamma}(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(x_i) - z(x_i + h))^2 \quad (1)$$

where $N(h)$ is the number of pairs of points separated by a distance h , and $z(x_i)$ and $z(x_i + h)$ are the values of variables (basal areas or volumes in this case) measured at locations separated by the distance h .

3 Results

3.1 Documents and Previous Studies

According to old maps (Pielisjärven... 1901, Ilomantsin... 1906), the study area is not situated in the slash-and-burn cultivation areas. The dendrochronological analysis of trees with fire scars revealed that the last forest fire occurred in year 1824, and before the last fire the fire interval had been only 30–40 years (Lehtonen 1997). This suggests that in the study area, slash-and-burn cultivation had been applied, but this is not shown in the old maps, or – perhaps more likely – that the fires had spread from nearby slash-and-burn cultivation areas and burnt the area (see also Pitkänen and Huttunen 1999, Pitkänen et al. 1999). Many large pines seem to have survived at least the last fire, while other tree species mainly originated from after the last fire (Rouvinen, unpubl. data).

The available documents on the Pönttövaara area showed that there were no loggings during a period beginning from the 1910s, even though surrounding areas were logged, mainly in the 1960s and 1970s (Leimausluettelot... 1932, 1947, 1950, 1960, 1968, 1977, 1988). The only silvicultural treatment recorded was the notching of aspens in 1977 (Suoritetut... 1977).

The main forest road split the area in 1954, and three smaller forest roads were built later when logging of the surrounding forested areas

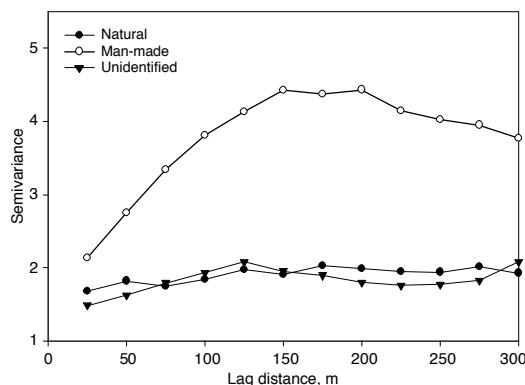


Fig. 3. Spatial autocorrelation for basal area of stumps of man-made, natural and unidentified origins.

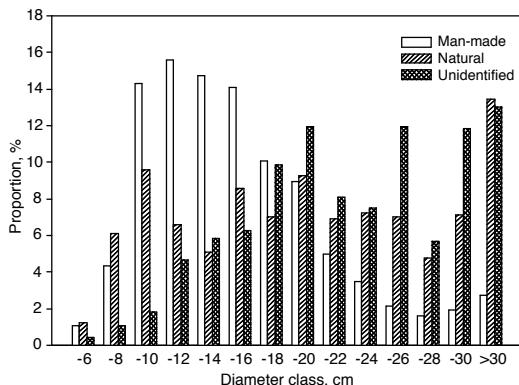


Fig. 5. Diameter distributions of stumps with man-made, natural and unidentified origins.

advanced. A solitary farm (now abandoned) was established in the 1890s on Nikkiläinvaara hill, about 2 km from the study area, but the surrounding region has generally been very sparsely populated (Pitkänen et al. 1999).

3.2 Field Data

3.2.1 Stumps

There were on average 129.8 stumps per ha, of which 61% were classified as man-made, 23% as natural and 16% as of unidentified origin (Table 1). There was great variation in the number of stumps between the 25 × 25 m sub-plots. A total of 107 sub-plots (21%) were without any man-made

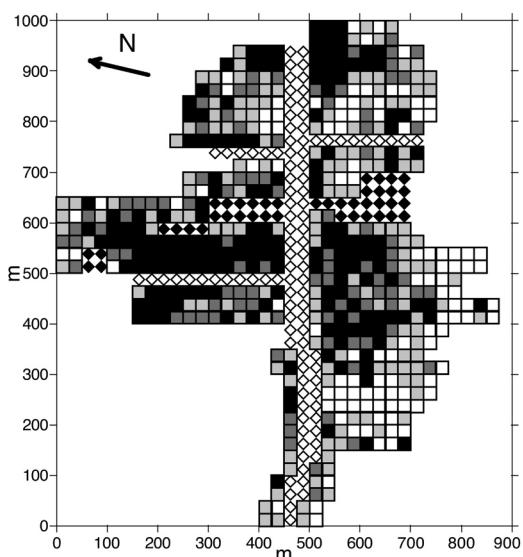


Fig. 4. Spatial distribution of man-made stumps. White squares represent sub-plots without any man-made stumps (107 sub-plots). Light grey represents sub-plots with more than zero but less than one m²/ha (146), dark grey sub-plots with 1–2 m²/ha (94), and black sub-plots with more than 2 m²/ha (172) of the basal area of man-made stumps. The symbols for the road area and mires are as in Fig. 2.

stumps, 126 (24%) without natural stumps and 235 (45%) without stumps of unidentified origin. The semivariance analysis showed that there was no spatial autocorrelation between sub-plots in the amount of natural and unidentified origin stumps (Fig. 3). Man-made stumps, however, showed a distinct spatial autocorrelation up to 150 m distances. Further visual interpretation of the map showed that the spatial pattern of man-made stumps is mainly due to several clusters situated near the roads (Fig. 4).

The diameter distribution of man-made stumps was unimodal, with an average of about 16 cm, whereas distributions of natural and unidentified origin stumps was more even (Fig. 5). The height distribution of stumps showed the same patterns (results not shown): for man-made stumps distinct unimodal distribution with an average of about 24 cm, and for natural and unidentified origin stumps more even distribution with averages of about 46 and 72 cm, respectively.

Table 1. Number of stumps within the study area, stumps/ha. In parenthesis the values are given in m²/ha. The values are based on the 25×25 m sub-plots.

	Man-made	Natural	Unidentified	Total
Mean	79.4 (1.8)	29.8 (1.2)	20.6 (1.0)	129.8 (4.0)
Median	32 (1.1)	16 (0.8)	16 (0.4)	112 (3.5)
Range	0–512 (0–15.1)	0–288 (0–10.0)	0–128 (0–12.4)	0–560 (0–16.2)
CV	1.22 (1.17)	1.02 (1.17)	1.29 (1.47)	0.76 (0.69)

Over 90% of man-made stumps were classified as belonging to decay stage 5 (wood very soft) (Table 2). This decay stage was also the most abundant in natural stumps, whereas the badly burned, charred stumps (decay stage 6) comprised the biggest class of unidentified origin stumps.

Burned stumps were found in every origin class (man-made, natural or unidentified origin) and decay stage. However, over half of the burned stumps (58%) were classified as of unidentified origin and decay stage 6. At least one burned stump was found on 254 (49%) of the measured sub-plots.

Because most of the stumps were in an advanced stage of decay, the determining of tree species was difficult. In particular, man-made and unidentified origin stumps were hard to identify: in both types less than 5% were identified by tree species. Nearly 70% of natural stumps were identified by species. Pines accounted for about 5% and birches for about 50% of the identified species in each origin class. Spruces accounted for some 45% of the identified species in man-made and unidentified origin stumps, and about 35% in natural stumps. Both natural and man-made aspen stumps were found: the proportion was about 10% and 1% of the species identified stumps, respectively.

3.2.2 Standing and Fallen CWD

The average volume of CWD was 84.2 m³/ha, of which 42% was standing and 58% fallen CWD (Table 3). Between plots, the variation in volumes of standing CWD was greater than in fallen CWD. CWD volume (standing + fallen, standing, fallen) was not spatially autocorrelated up to 150 m distances (Fig. 6). After 150 m distance, CWD volume exhibited increasing semivariance throughout the study range.

Table 2. Proportion of stumps in different decay stages, %. For explanation of the different decay stages, see Material and methods.

	Man-made (n = 2575)	Natural (n = 968)	Unidentified (n = 668)	Total (n = 4211)
Stage 1	0.8	1.2	6.7	1.8
Stage 2	1.1	4.2	4.6	2.4
Stage 3	1.3	12.8	3.0	4.2
Stage 4	4.0	25.9	4.1	9.0
Stage 5	91.3	54.3	28.3	72.8
Stage 6	1.5	1.6	53.3	9.8
Total	100	100	100	100

The number of fallen trees decreased towards larger diameter classes (Fig. 7). The same decreasing trend was also detected in standing dead trees, but it was not so pronounced as in fallen trees, and the largest diameter class (diameter ≥40 cm) had even more trees than the smaller size-classes, probably due to its wider class range, having no upper limit. In addition, there was clearly a higher number of standing dead trees compared to fallen trees in the largest diameter class. Out of the total 31 plots, 24 had standing dead tree(s) and 15 had fallen dead tree(s) with a diameter ≥40 cm.

Pine predominated in total and standing CWD volume, with proportions of 54% and 84%, respectively (Table 3). Pine was also abundant in fallen CWD (32%), but the volume of unidentified tree species (35%) was higher. Dead wood of pine, spruce and unidentified tree species was found on every plot and birch dead wood on 28 (90%) plots. Dead aspens were found on only 19 (61%) plots.

On average, the two least decayed stages composed over 90% of the volume of standing CWD (Table 4). In fallen CWD, the trees in a more advanced stage of decay predominated: nearly 80% of fallen trees were classified as belonging to decay stages 3–5.

Table 3. Amount of CWD by tree species, m^3/ha (total volume, and volume of dead standing and fallen trunks separately). The values are based on the $50 \times 50 \text{ m}$ plots situated on mineral soil. In addition to the given tree species, one stem of standing dead alder, one stem of standing dead rowan and one stem of fallen dead goat willow were found in the study area.

	Pine	Spruce	Birch	Aspen	Unidentified	Total
<i>Total</i>						
Mean	45.4	10.6	4.0	7.1	17.1	84.2
Range	4.4–113.6	2.2–35.2	0.0–13.3	0.0–51.9	2.3–37.6	37.0–145.9
CV	0.74	0.74	0.78	1.75	0.59	0.36
<i>Standing</i>						
Mean	29.7	2.5	1.2	2.1		35.5
Range	3.0–95.1	0.1–9.0	0.0–5.5	0.0–19.5		8.0–96.3
CV	0.78	0.90	1.28	2.20		0.61
<i>Fallen</i>						
Mean	15.7	8.1	2.8	5.0	17.1	48.7
Range	0.0–61.1	0.6–26.2	0.0–7.8	0.0–41.0	2.3–37.6	21.9–84.9
CV	0.97	0.75	0.75	1.79	0.59	0.30

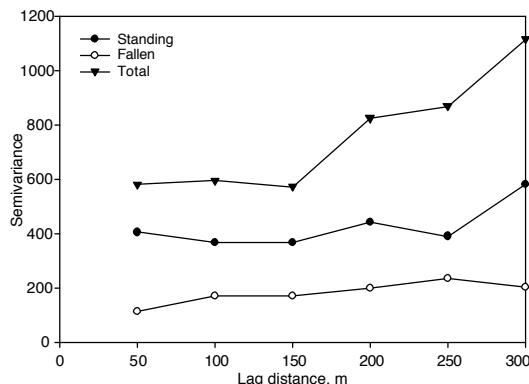


Fig. 6. Spatial autocorrelation for standing, fallen and total (standing and fallen trees combined) CWD volume.

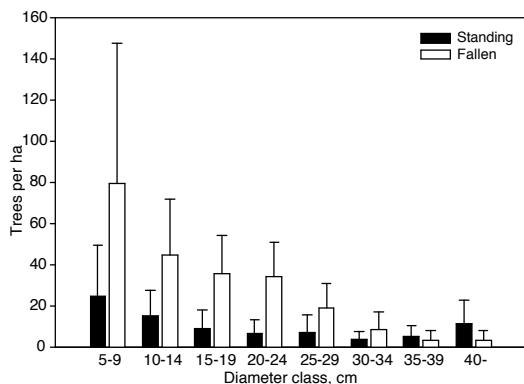


Fig. 7. Diameter distributions of standing and fallen dead trees. Bars indicate standard deviation among plots.

3.2.3 Dead Trees vs Human Impact

The number of cut trees on the ground was 2.5 stems per ha ($0.6 \text{ m}^3/\text{ha}$). This was very low compared to the number of man-made stumps in the same area, 83.7 stumps per ha, indicating that nearly all cut trees had been removed. It is, of course, possible that not all cut trees in the data on fallen trees were classified as cut, due to their advanced stage of decay.

At least one notched aspen was found on 14 of the 31 plots, the total number of notched aspens being 59 (7.6 stems per ha) and the total volume

33.3 m^3 ($4.3 \text{ m}^3/\text{ha}$). The notched aspens formed a significant proportion of the dead aspens, the total number of dead aspens being 128 (16.5 stems per ha) and the total volume 54.8 m^3 ($7.1 \text{ m}^3/\text{ha}$). On the 19 plots where dead aspens were found, the average volume of notched aspens in proportion to the total volume of dead aspens was 48%, ranging from 0% (5 plots) to 100% (2 plots). On the same 19 plots, notched aspens formed on average of 8% of the total volume of dead trees (standing and fallen combined) (range 0–26%).

The estimated volume of stumps was $1.2 \text{ m}^3/\text{ha}$ (range = 0.1 – $2.7 \text{ m}^3/\text{ha}$, CV = 0.55) in the plots

Table 4. Decay stage distribution of standing and fallen CWD, m³/ha. The values are based on the 50×50 m plots situated on mineral soil. For explanation of the different decay stages, see Material and methods.

	Decay stage 1	Decay stage 2	Decay stage 3	Decay stage 4	Decay stage 5
<i>Standing</i>					
Mean	17.1	15.7	2.6	0.1	
Range	3.1–48.1	0.8–42.1	0.0–10.7	0.0–1.2	
CV	0.63	0.85	1.25	2.06	
<i>Fallen</i>					
Mean	3.1	7.9	12.3	11.6	13.8
Range	0.0–11.8	0.8–29.4	1.1–38.7	1.9–26.3	0.8–41.0
CV	1.02	0.82	0.70	0.60	0.73

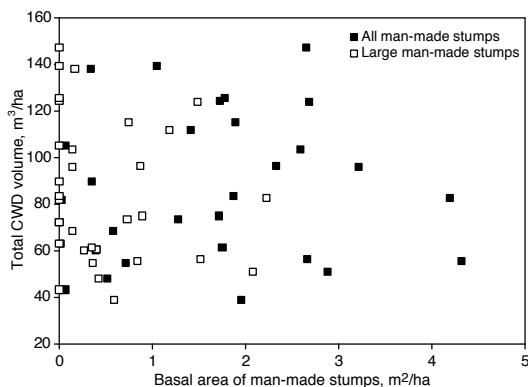


Fig. 8. Total CWD volume in relation to basal area of man-made stumps. Large man-made stumps are larger than 20 cm in diameter.

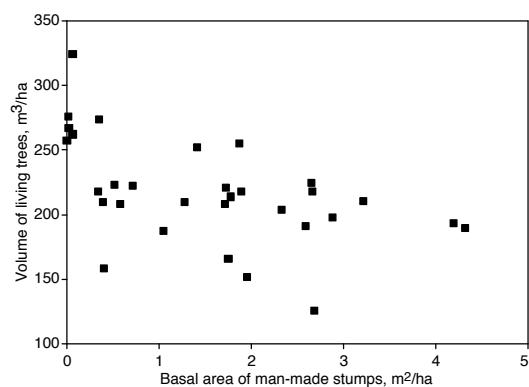


Fig. 9. Volume of living trees in relation to basal area of man-made stumps.

where standing and fallen CWD was measured, raising the definitive volume of CWD to 85.4 m³/ha (range = 39.1–147.3 m³/ha, CV = 0.36). One third (i.e. 0.4 m³/ha) of the volume of stumps originated from man-made stumps. Thus, man-made CWD volume (cut trees, notched aspens and man-made stumps combined) was 5.3 m³/ha (range = 0.01–36.1 m³/ha, CV = 1.57).

There was no significant dependence between the basal area of man-made stumps and the total CWD volume (Spearman's correlation coefficient = 0.10, p = 0.58) (Fig. 8). The basal area of the large man-made stumps (diameter >20 cm) and the total CWD volume showed a negative correlation, but the relation was not statistically significant (Spearman's correlation coefficient = -0.28, p = 0.13).

3.2.4 Living vs Dead Trees

The volume of living trees varied from 125.7 to 324.1 m³/ha with an average of 217.4 m³/ha (CV = 0.18). Spruce predominated in terms of volume of living trees (56%), with a smaller proportion of pine (35%) and birch (9%). Dead wood comprised on average 28% (range 12–50%, CV = 0.30) of the total volume of trees (dead and living trees combined). No dependency was found between the volume of dead and living trees (Spearman's correlation coefficient = 0.05, p = 0.77). However, there was a negative correlation between the basal area of man-made stumps and the volume of living trees (Spearman's correlation coefficient = -0.57, p = 0.001) (Fig. 9).

4 Discussion

During recent years many attempts have been made to reconstruct ancient or natural forest structures, based on and combining different data sources, such as pollen and charcoal analysis, dendroecological sampling, and written historical sources (e.g. Henry and Swan 1974, Hörnberg et al. 1999, Moore et al. 1999, Motzkin et al. 1999, Swetnam et al. 1999, Dey and Guyette 2000, Ericsson et al. 2000, Axelsson 2001). Although human impact is difficult to measure adequately (Östlund 1999), the historical knowledge gained is a prerequisite for nature conservation, restoration and forest management aimed at maintaining biological diversity in forest ecosystems. Especially in Fennoscandia, such analyses are needed when potential new conservation areas are evaluated and when forest restoration methods are designed and implemented. Our study evaluates the importance and usefulness of detailed CWD analysis for assessing the forest naturalness.

4.1 Dead Wood Characteristics

The history of the study area represents a situation that is probably common in many protected old forests in Finland (see e.g. Uotila et al. 2002). The average volume of dead trees was typical for old boreal coniferous forests termed "natural" or "near-natural", and it was significantly higher than is usually found in comparable managed old forests (e.g. Fridman and Walheim 2000, Siitonens 2001, Uotila et al. 2001, Rouvinen 2002, Rouvinen et al. 2002a). However, man-made stumps occurred frequently within the area, indicating that there may be high amount of CWD even if there has been logging in the forest. Thus, a high amount of CWD does not always indicate that the forest stand is in its natural state (see also Uotila et al. 2001, Rouvinen et al. 2002a).

Standing dead trees formed a high proportion of the total CWD volume, which seems to be a common feature of old boreal forests, especially in pine dominated forests (Siitonens 2001). Most of the standing dead trees were in the early or intermediate stages of decay, because trees in the more advanced decay stages tend to fall. Fallen

CWD was distributed in all the decay stages, indicating the continuity of CWD in the studied area. Although the decay stage of trees can be seen only as a rough approximation of the time elapsed since tree death (Dynesius and Jonsson 1991, Rouvinen 2002), the variation in decay stage distribution can be regarded as indicative of the temporal variation in tree mortality, or tree felling, telling the CWD history of the forest (Stokland 2001). Thus, when fallen dead trees are present in all decay stages, trees have died and fallen, or been felled, over a long period. The low temporal variation of mortality that we deduced from decay stages is in accordance with previous studies of the mortality patterns of spruce (Jonsson 2000, see however Jonsson and Dynesius 1993) and pine (Rouvinen et al. 2002b).

Although the amount of CWD varied clearly among the plots, spatial autocorrelation patterns did not indicate clustering of CWD on the studied scale. In the same study area, Rouvinen and Kouki (2002) detected clustering of both standing and fallen dead trees on a finer scale. Many studies in old boreal forests termed "natural" and "near-natural" have shown that the spatial pattern of CWD is generally clustered on small spatial scales and shifting towards a more regular pattern when larger areas are analysed (Edman and Jonsson 2001, Kuuluvainen et al. 2001, Rouvinen and Kuuluvainen 2001, Karjalainen and Kuuluvainen 2002, Rouvinen et al. 2002a). The small-scale clustering of CWD is concluded to reflect a small-scale disturbance pattern of the forest stand. Although not detected in our coarse-scale study, probably due to forest utilization history, it is reasonable to assume that, in the absence of fire, small-scale disturbances are a driving force of forest succession in the area.

Regarding the size-class distributions of CWD, small-diameter trees predominated numerically. The number of fallen dead trees decreased toward larger diameter classes, as detected in previous studies of boreal Fennoscandian forests (e.g. Kuuluvainen et al. 1998, Karjalainen and Kuuluvainen 2002, Rouvinen et al. 2002). In comparing standing dead trees with fallen dead trees, the diameter distribution was more even, and many trees were in the large size classes. The most probable explanation for the high number of large standing trees is that many pines had survived the last forest

fire(s) and after death had remained standing for a prolonged period of time. In addition, based on the man-made stump data of this study and the living tree data of Rouvinen and Kouki (2002), it seems that medium-sized trees were given preference in logging.

The direct effect of human activity on the amount of CWD present is rather minor: about 6% of CWD volume originating from cut trees, notched aspens and man-made stumps. The elevating effect of human action on CWD is seen most pronouncedly in the volume of dead aspen. It is reasonable to suppose that, without notching, the proportion of dead aspens would not be as high as it is today and that the decay stage distribution of aspens would be more diverse (Kouki et al. 2004). The effect of past loggings is minor, probably because nearly all the cut trees have been removed: man-made stumps formed only about 0.5% of the total CWD volume. Our result is in agreement with the study by Rouvinen et al. (2002a), who found that man-made CWD formed 2–5% of the total CWD volume in old boreal Fennoscandian forests selectively logged a long time ago. However, in stands classified as natural, Rouvinen et al. (2002a) reported that the proportion of man-made CWD was <0.5%.

As could be expected, past loggings have reduced the volume of living trees. Since the last selective logging probably took place only 30–40 years ago (P. Väänänen, forest technician, Forest and Park Service, pers. comm.), the influence on living trees is clear. If the logging had happened a longer time ago, the influence on the volume of living trees would presumably have been non-significant, since the forest would have had a long time to gain volume (Kumpulainen and Veteläinen 2000, see however Sippola et al. 2001). However, there was no significant correlation between the basal area of man-made stumps and CWD volume. Apparently the number of cut trees was so low and the cut trees were so small in diameter that the effect of logging on the long-term input of CWD was negligible (see also Karjalainen and Kuuluvainen 2002). In addition, the volumes of living and dead trees were not related. The result is consistent with Rouvinen et al. (2002a), who found no correlation between the volumes of dead and living trees in boreal Fennoscandia (see however Sippola et al. 1998). The

lack of relationship can be related to lack of site type variability, but also to the stochastic character of small-scale disturbances, i.e. the death of single trees or small groups of trees, which is typical of old boreal Fennoscandian forests (Rouvinen et al. 2002b).

4.2 Historical Documents and Their Reliability

Historical documents may provide a good supplement to observations and measurements in the forest and interpretation of the results (Marks and Gardescu 2001). In state-owned forests in Finland, such as our study area, the detailed documented period goes back to the beginning of the 20th century (Sippola et al. 2001, Uotila et al. 2002). However, these documents/archives may have obvious deficiencies, for example, all treatment may not have been recorded, or some of the written sources may have been destroyed/lost (see also Östlund 1999).

In our study area the most pronounced discrepancy between archives and field data was that there were many man-made stumps although there were no notes on logging in the historical documents. Some of these stumps, especially large-diameter pine stumps, probably originate from the undocumented period (i.e. before the 1910s). The smaller stumps (diameter 10–20 cm) in an advanced decay stage cannot be that old. These stumps are probably associated with the large-scale loggings practised around the Pöntövaara area in the 1960s and 1970s: at that time it was common practice to fill in wood lacking from incomplete timber sales by cutting suitable trees from nearby forest stands (P. Väänänen, forest technician, Forest and Park Service, pers. comm.). This assumption is supported by the spatial pattern of stumps: there were clusters of man-made stumps near the roads. The stumps that were classified as man-made and badly charred originate from the time period before year 1824 and thus indicate the longevity of traces of human activity in the forest. Probably these were pine stumps impregnated with resin, which prevents decay. In general, pine decays more slowly than spruce and deciduous trees (Krankina and Harmon 1995, Tarasov and Birdsey 2001) and can persist as a

solid standing or fallen tree, or as a stump, for a prolonged period of time, typically over 100 years (Rouvinen and Kouki 2002, Rouvinen et al. 2002b).

Overall, without well-planned fieldwork, deducing the degree of naturalness of forest seems to be a difficult task (see also Uotila et al. 2002, Berglund 2004). From the amount, diversity and spatio-temporal availability of man-made stumps it is possible to derive the forest utilization history or, at least, part of it. Thus, counting the man-made stumps may be a relatively quick and easy method to assess the naturalness of woody biomass structure in a forest. However, it must be remembered that the data on man-made stumps usually only tracks the recent forest utilization history and the time limit depends on stump decay rates (see also Introduction). In addition, using the stump data with the "CWD profile" (*sensu* Stokland 2001), we can probably achieve better understanding of a forest stand history and thus deduce the degree of naturalness of a forest.

4.3 Human Impact and Forest Succession

The forest was not as a whole in a natural state according to our definition of natural, but it showed different degrees of human impact (i.e. naturalness), from virtually untouched patches to quite heavily managed patches. Loggings have created conditions for the availability of growth factors of the remaining tree stems and also for tree regeneration. However, these gaps do not correspond to natural gaps, because the decaying wood has been removed. In addition, the loggings have not created pits and mounds, which are characteristics of uprooted trees. Both decaying wood and pits and mounds are important for tree regeneration (e.g. Hofgaard 1993, Kuuluvainen and Rouvinen 2000, Ulanova 2000). The notching of aspens has also created gaps and probably increased the current CWD volume, but due to the use of herbicides, natural aspen regeneration based on root sprouting has ceased. Increased browsing pressure by moose (*Alces alces*) has also negatively affected the amount of small and medium-sized aspens (Kouki et al. 2004). In addition, there seems to be a successional trend in tree species composition in the study area, since the

CWD is rather strongly dominated by pine, while the current living stand is dominated by spruce. This spruce dominance is a common feature in many protected Fennoscandian forests, usually interpreted as a result of fire prevention (Linder 1998). However, when deducing successional trend from tree species composition between living and dead trees, we must remember that pine has a lower decay rate than spruce (Krankina and Harmon 1995, Tarasov and Birdsey 2001).

Despite these deviations from complete naturalness (i.e. natural forest), the conservation value of the study areas cannot be doubted: the high conservation value can be seen from the occurrence of several rare and threatened forest-dwelling species in the area (Pajari 1995). It would be very important to know, however, whether the populations of the most demanding species have declined due to past cutting operations and whether there are specific cutover points in terms of naturalness that seriously affect these species. It also remains unclear what effects the spatial structure of the dead wood have on these species. All these questions seem to be of prime importance when designing and establishing a forest conservation area network. Man-made stumps and their spatial distribution seem to provide a good surrogate for analyzing these effects on the conservation value of a particular forest area.

Acknowledgements

We should like to thank Marja Kuskelin and Ari Vaara for their assistance in data collection, as well as Bengt Gunnar Jonsson, Ken Olaf Storau-net and two anonymous reviewers, who made valuable comments on the earlier version of the manuscript. Our thanks are also due to Rosemary Mackenzie, who revised the English language. This study was financed by the Faculty of Forestry, University of Joensuu, and the Academy of Finland (Finnish Centre of Excellence Programme 2000–2005, project no. 64308 and 203786).

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