A study on dead wood in european beech forest reserves

prepared by members of Work-package 2 in the Nat-Man project (Nature-based Management of beech in Europe) funded by the European Community 5th framework programme

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Publication date:
2003

Document version
Peer reviewed version

Citation for published version (APA):
Hahn, K., & Christensen, M. (2003). *A study on dead wood in european beech forest reserves: prepared by members of Work-package 2 in the Nat-Man project (Nature-based Management of beech in Europe) funded by the European Community 5th framework programme*. Nat-Man Working Report, No. Vol. 9

NAT-MAN
Working Report 9

A Study on Dead Wood in European Beech Forest Reserves

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Deliverable 20 of the Nat-Man Project
Produced under Work-Package 2
2003

Forest & Landscape

The report is produced by the Nat-Man Project (Nature-based Management of Beech in Europe) co-ordinated by *Forest & Landscape Denmark,* and funded by the European Community 5th Framework Programme.
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1. Introduction

This report forms part of the Nat-Man project (Nature-based Management of beech in Europe) funded by the European Community 5th Framework Programme. It focuses on dead wood quantities, dead wood size class composition and decay class composition in various European beech forest reserves, including several sites in England, Denmark, The Netherlands, France, Hungary and Slovenia where new fieldwork was carried out as part of the Nat-Man project.

The work in WP2 for this study is linked to the research in WP6 and WP7 within the Nat-Man project. The information in this report serves as a reference-point for the nature-based management of beech forests in Europe. It will be used in other parts on the Nat-Man project and will be used in other publications out of the Nat-Man project.

Dead wood is widely recognised as an important habitat for forest dwelling organisms as it provides shelter and food for many threatened species, especially invertebrates (e.g. Heliövaara and Väisänen, 1984; Kirby and Drake, 1993; Samuelsson et al., 1994, Siitonen 2001, Harmon et al. 1986), fungi (Sippola and Renvall 1999, Heilmann-Clausen 2001), bryophytes (Söderström 1988, Lesica et al. 1991, Ódor and Standovár 2001), lichens (Humphrey et al. 2002) cavity nesting birds (Sandström 1992, Mikusinski and Angelstam 1997) and small mammals (Harmon et al. 1986). However, the amount of this commodity is much lower in managed forests and plantations than in near-natural stands (Andersson and Hytteborn, 1991, Lesica et al., 1991, Samuelsson et al. 1994, Green and Peterken, 1997, Kirby et al. 1998, Jonsson, 2000, Ódor and Standovár 2001). Therefore, in the interests of conservation, efforts are being made to rise levels towards those found in natural forests (e.g. Hodge and Peterken, 1998, Harmon 2001). Unfortunately, natural-reference sites are scarce - at least in north-west Europe where no truly natural forests have survived and the few sites that have been dedicated as strict forest reserves, i.e. management by non- or minimum-intervention, have usually been untreated for less than a century (Parviainen et al., 1999). The reserves in central-eastern Europe have in some cases a longer history as strict forest reserves due to historical reasons and may serve as a better guideline for natural levels of fallen dead wood. However, the amounts of dead wood in natural forests in various regions of Europe do not only depend on former forest management, but also on soil types, climate, species composition, and disturbance regimes, which all contribute to the overall cycle of formation and decomposition of dead wood.

In this report, dead wood data from four different countries in Europe are represented and analysed with respect to quantities, size class composition and decay class composition. Such information may serve as a reference point for comparison with other European beech forest reserves, well aware of the large variation in natural growth conditions, natural disturbance types, and former management history throughout Europe.

2. Methods

2.1 Study sites

A total of 13 forest sites, covering app. 850 ha, were included in the study. These sites represent a series of minimum-intervention reserves, all supporting high forest, mainly dominated by beech (*Fagus sylvatica*) in various mixtures with ash (*Fraxinus excelsior*), elm (*Ulmus glabra*), hornbeam (*Carpinus betulus*), lime (*Tilia cordata, T. platyphyllos*), oak (*Quercus robur, Q. petrea*), silver fir (*Abies alba*), Norway spruce (*Picea abies*) or sycamore (*Acer pseudoplatanus*). The majority of the sites are in North-West Europe, but others were from Central Europe, including some near-virgin beech reserves in Hungary (Figure 1, Table 1).

Figure 1. The geographical distribution of the 13 minimum-intervention beech forest sites included in the study.

Table 1. Forest reserves included in the study, their size, position, forest type and forest history.

Site name	Area (ha)	Forest type, main soils, main species, location	Summary of past treatment
Suserup Skov, Denmark	19	NW European lowland beech forest Calcareous, well-drained, brown earth soil Beech-ash-elm-oak-(lime) 55.37 N, 11.55 W	Ex-wood pasture, grazed until c.1800; minimum treatment since 1850; non-intervention since 1927.
Strødam reservatet, Denmark	25	NW European lowland beech forest Mesotrophic brown earth soil Beech-(oak-ash) 55.97 N, 12.27 E	Ex-wood pasture, grazed until c.1770, minimum treatment since 1925, non-intervention since 1949.
Møns Klinteskov, Denmark	25	NW European lowland beech forest Calcareous soil Beech 54.96 N, 12.54 E	Ex-wood pasture and possible coppicing, minimum intervention since 1790, non-intervention since 1935.
Knagerne, Denmark	6	NW European lowland beech forest Acid brown earth soil Beech 56.13 N, 9.53 E	Old beech stand, regenerated about 250 years ago. Possibly same history as Velling Skov. Non-intervention since 1990.
Velling Skov, Denmark	24	NW European lowland beech forest Acid brown earth soil Beech 56.04 N, 9.50 E	Old beech stand, with evidence of former charcoal burning, coppice, grazing and masting pigs, non-intervention since 1990.
The Mens, England	155	NW European lowland beech forest Acid clay soils Beech-oak-holly-(birch-ash) 51.0 N, 0.5 W	Ex-wood pasture; enclosed c.1850, thinned at least once since, now old-growth and untreated.
Ridge Hanger, England	50	NW European lowland beech forest Mainly calcareous rendzina soils Beech-ash 51.0 N, 1.0 W	Ex-wood pasture/coppice, then promoted to high forest, now untreated.
Noar Hill, England	70	NW European lowland beech forest Mainly calcareous rendzina soils Beech-ash 51.1 N, 0.9 W	Ex-wood pasture/coppice, then promoted to high forest, now untreated.
Buckholt Wood, England	100	NW European lowland beech forest Calcareous brown earth soils Beech-holly-(ash) 51.80 N, 2.20 W	Ex-wood-pasture/coppice, then promoted to high forest, now untreated.
Fontainebleau (La Tillaie), France	136	NW European lowland beech forest Brown calcareous and acid podsol sandy soils Beech-oak-(ash-field maple-hornbeam-holly) 48.43 N, 2.68 E	Grassy oak forest in 8th century, and last cut over in 1372. Described in 1664 as high forest with mature beech, oak, and some hornbeam and lime. Protected since 1853; longest untreated reserve in NW Europe.
Kékes Forest Reserve, Hungary	72	Central European montane beech forest Brown earth soils on andesite, with steep scree slopes Beech-maple-ash-lime 47.87 N, 20.00 E	Uneven-aged, oldest trees 220 years old, never used for timber production, possible former uses includes burning large standing trees for charcoal.
Õserdõ Forest Reserve (Bükk Mts), Hungary	59	Central European montane beech forest Deep slightly podsolic brown earths and shallow rendzina on steep parts Beech-sycamore-mountain ash 48.05 N, 20.43 E	Stand regenerated about 160 years ago, regularly thinned until 40-50 years ago, since more or less untouched.
Alsóhegy Forest Reserve, Hungary	101	Central European montane beech forest Karst plateau Beech-hornbeam-oak-rowan-lime 48.55 N, 20.70 E	Example of traditional mittelwald - coppice with standards, left to free development between 1920-1940.

2.2 Recording methods

Dead wood quantity and size class distribution

In all four countries, line-intersect sampling (Warren and Olsen, 1964, Kirby et al 1998) was used to record the volume and length of fallen dead wood. The number and length of the line transects varied between the sites depending on the size of the area sampled and the density and patchiness of logs. At each site a number of equal length transects (covering a total distance = t) were laid out from random start points and in random directions. The number (N) of fallen dead stems attaining five cm diameter and intersecting the line was counted, and their diameter (d) in cm where they intersected the line was measured and species identified. The length (L) and volume (V) of fallen dead wood was estimated using the formulae, $L = N*pi*10^4/2*t$ (m/ha), and $V = SUM (pi^2*d^2/8*t)$ (m^3/ha).

In Denmark, estimates of volume of standing dead wood (snags) were obtained from a 10 m wide strip along the line transects. In England, estimates of snag volume were obtained from measurements (stem dbh and height) made on permanent transect or plots, which varied in size depending on the study site. In France, no estimates of standing volumes were made. In Hungary, snag volume was estimated in independent circular plots with a 30 m radius, with height and diameter (basal, 1.3 m, and top) being measured for snags > 10 cm dbh.

Standing dead wood was assigned to 10 cm size classes according to its breast height diameter at 1.3 m from the base. For fallen dead wood, diameter at the intersection was measured.

Decay phases

The decay condition of dead wood was determined using a key for a six-class scale for decay of dead wood (Van Hees et al. in press, Ódor and van Hees in press) where each stem was assigned to a decay class by test of hardness combined with a visual estimation of outline and bark (Table 2).

Sampling time

Fieldwork related to the sampling of dead wood in the forest reserves was carried out in the period June 2000 to June 2002 (Table 3).

Table 2. Description of Decay Classes (DC)

Decay Class	Bark	Twigs and branches	Softness	Surface	Shape
1	intact or missing only in small patches, > 50%	present	hard or knife penetrate 1-2 mm	covered by bark, outline intact	circle
2	*missing or < 50%*	*only branches >3 cm present*	*hard or knife penetrate less than 1 cm*	*smooth, outline intact*	*circle*
3	missing	missing	begin to be soft, knife penetrate 1-5 cm	smooth or crevices present, outline intact	circle
4	*missing*	*missing*	*soft, knife penetrate more than 5 cm*	*large crevices, small pieces missing, outline intact*	*circle or eliptic*
5	missing	missing	soft, knife penetrate more than 5 cm	large pieces missing, outline partly deformed	flat eliptic
6	*missing*	*missing*	*soft, partly reduced to mould, only core of wood*	*outline hard to define*	*flat eliptic - covered by soil*

Table 3. Overview of time of recording and sampling statistics

Site	**Time of recording**	**# transects**	**Transect length (m)**	**# circular plots (radius = 30 m)**	**Area of study (ha)**	**Total transect length/ area (m/ha)**
Suserup A	December 2001	15	50 m		11 ha	71
Strødam	November 2001	30	50 m		25 ha	60
Velling + Knagerne	November 2001	30	50 m		30 ha	50
Møn	December 2001	15	50 m		20 ha	38
The Mens	June 2001	10	50 m		17 ha	29
Ridge Hanger	May 2001	10	20 m		5 ha	40
Noar Hill Hanger	September 2000	5	50 m		7 ha	36
Buckholt Wood	June/July 2000	10	20 m		2 ha	100
Fontainebleau I	June 2000	10	25 m		1 ha	250
Fontainebleau II	June 2000	10	25 m		1 ha	250
Õserdõ	April 2001	20	60 m	20	25 ha	48
Kekes	September 2001	37	60 m	26	47 ha	47
Alsohegy	June 2002	42	60 m	46	100 ha	25

2.3 Literature review

Additional information on dead wood in other European beech forest reserves was obtained through a comprehensive literature review. The review was primarily focused on reports and publications where information on estimates of living volume, fallen dead volume, standing dead volume and total dead wood volume was available, see Appendix A for an overview.

3. Results

3.1 Dead wood quantities

Results on dead wood quantities are based on the NatMan research sites (Figure 1) as well as the literature review (see Appendix A for details on sites). The amount of dead wood differed greatly. It ranged from almost nothing to more than 550 m3/ha. Generally, the highest amounts were from mountainous beech-fir-spruce forests in central-eastern Europe. However, high levels were also recorded from other forest types where old stands had been largely destroyed by windstorms. Based on the dead wood data of the investigated sites we didn't find any simple correlation between total dead wood and living wood volume. It appears as that live volume increased there was greater variation in the total dead wood volume (Figure 2).

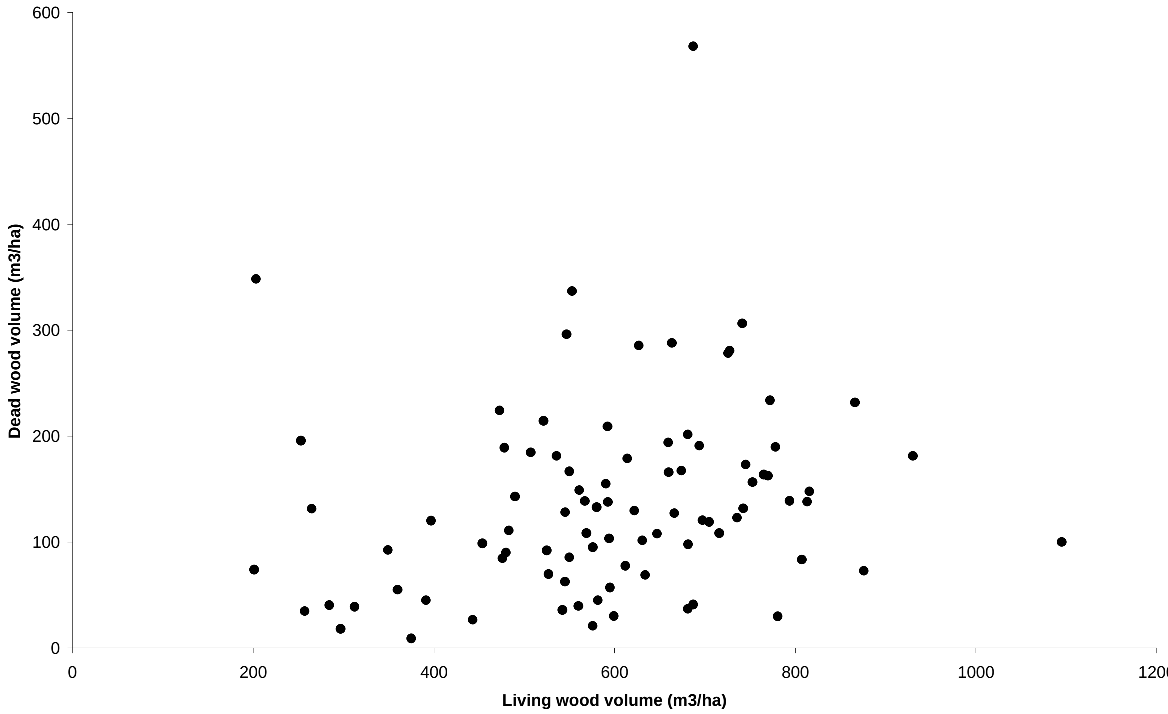

Figure 2. There is no simple correlation between living and dead wood volumes in European beech forest reserves. See Appendix A for details on sites.

The (lack of) relationship between fallen and standing dead wood volume is shown Figure 3. Most sites had a higher amount of fallen dead wood than standing dead wood. Those sites, where the amount of standing dead wood was higher than the amount of fallen dead wood, were typically those, which were mixtures with spruce and fir, as these species generally stay upright for longer after death. Certain types of disturbance were closely linked to the production of either standing dead wood (dry-out) or fallen dead wood (storm).

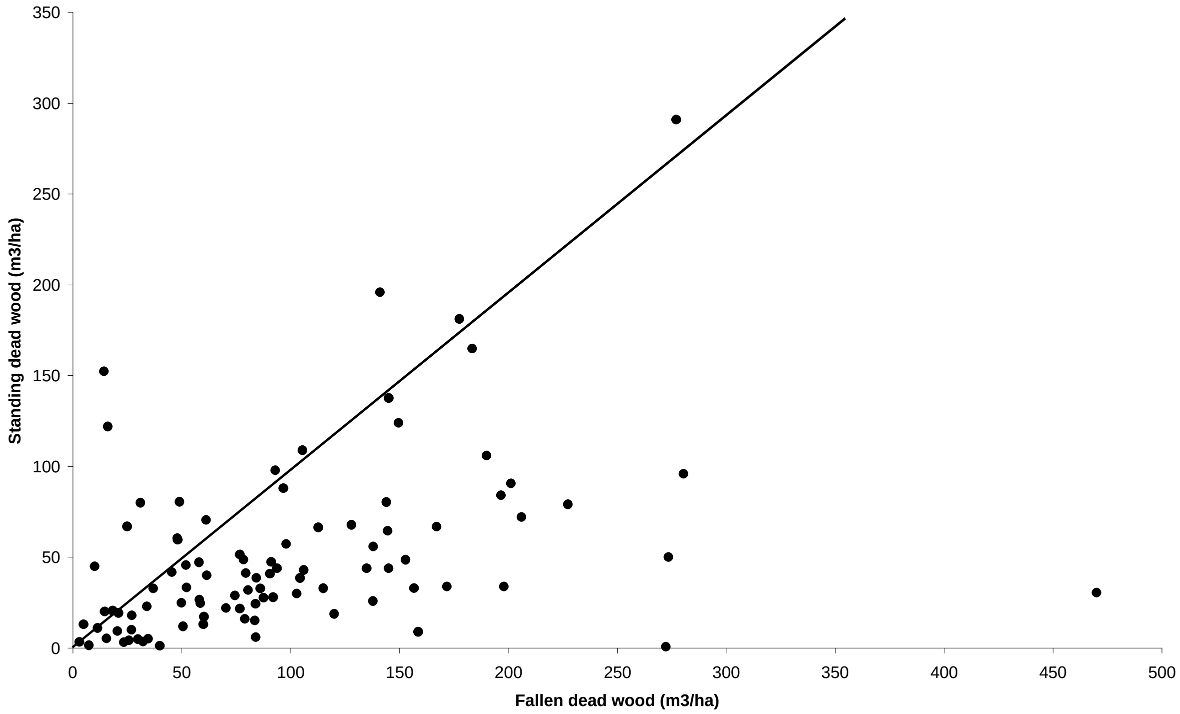

Figure 3. The relation between standing and fallen dead wood in European beech forest reserves. The full line represents the 1:1 ratio between standing and fallen dead wood. See appendix 1 for details on sites.

3.2 Size class distribution

The size-class distribution of fallen dead wood was determined for 14 sites in Denmark, England, France and Hungary. The characteristics of the sites in each country are discussed below.

For the Danish sites (Figure 4), the results show that most sites have a lack of dead wood in the two largest diameter classes, but in Suserup, the whole diameter range is represented, supporting the steady state of the forest described by Emborg et al. (2000). For Strødam and Knagerne, the general pattern is a lower level of dead wood and a lack of the largest diameter classes. This relates to the former management of the forest as well as the slightly more sandy soils here. Velling represents a newly established forest reserve, which is illustrated by the lack of large diameter classes and the steep decrease in volume with increasing diameter class. However, due to great variation in the soil conditions from poor sandy and dry soils to rich spring-dominated soils, it expected that the future diameter distribution of dead wood would be close to that of Strødam. For Møn, the diameter distribution of dead wood is rather low and the maximum diameter attained is rather low compared to the other forest reserves, but rather high (37%) compared to the living volume. The reason for lower quantities is the extreme soil conditions, with a very this soil layer on top of the pure chalk.

The size-class distributions for fallen dead wood in four sites recorded in England are shown in Figure 5. Buckholt Wood contained only small diameter pieces and the total fallen dead wood volume for this site was very low. The stand was only middle-aged and dead wood input had been restricted to small-sized branches and trunks killed by exclusion. The Mens contained more fallen dead wood and included some middle-sized trunks and small diameter pieces. The area was an old-growth stand, which had lost some canopy beech oak during windstorms in the last 15 years. The final two sites at Noar Hill and Ridge Hanger, had some of the highest levels of fallen dead wood recorded, and included many middle and some large diameter trunks. These sites had supported old-growth stands dominated by beech, but were largely blown apart during an exceptional windstorm in October 1987. Further trees were lost at both sites during storms in 1990 and the next decade.

Figure 6 shows the size-distribution of fallen dead wood as recorded in the two plots at Fontainebleau Forest Reserve, France (see Mountford 2002). Both contained moderate-high levels of fallen dead wood, fallen trunks and branches across many of the diameter classes, and supported old-growth beech stands that had broken up during windstorms in 1967, 1987, 1990 and 1999. These storms damaged trees in both plots by uprooting and snapping. Plot 1 suffered mainly during the storm of 1999, whereas plot 2 suffered major storm-damage in 1967 and occasional damage in the storms thereafter. Thus, the volume of fallen dead wood in plot 1 was far higher at the time of sampling in summer 2000 (256 v 142m^3 ha^{-1}). Although the level in plot 2 was more moderate, it had remained relatively stable from 1982 when it was measured as 145m^3 ha^{-1} (Koop and Hilgen, 1987). During the same period, the volume in plot 1 had increased nearly three times from 92 to 256m^3 ha^{-1}. This demonstrates that the ultimate maximum of fallen dead wood achieved by a mature stand, is related to time it takes to break-up. If canopy trees die and fall progressively, then the maximum level is moderate but sustained over a longer period. Whereas, if a stand collapses almost over night in a severe windstorm, this will achieve a higher maximum level of fallen dead wood, but this will be relatively short-lasting.

For the Hungarian sites Kékes and Oserdo (Figure 7) a wide diameter range is represented for dead wood. In Kékes the proportion of small trees (below 35 cm) is high, while in Oserdo the proportion of large logs (above 65 cm) is much higher. It is supposed that there are two important reasons of this difference: (1) the productivity of the Oserdo site is much higher, and (2) it is a formerly managed forest of which a considerable part of the trees of the upper canopy have reached the collapsing stage now. Kékes is a non-intervention stand on a steep slope with very low productivity, which has never been cut. Also these are the reasons that the amount of dead wood is higher in Oserdo than in Kékes. The amount of logs is much lower in Alsóhegy than in the other two sites, and the majority of the logs are small (below 25 cm). This stand was more intensively managed in the last decades (mainly by irregular coppice) than the other two sites.

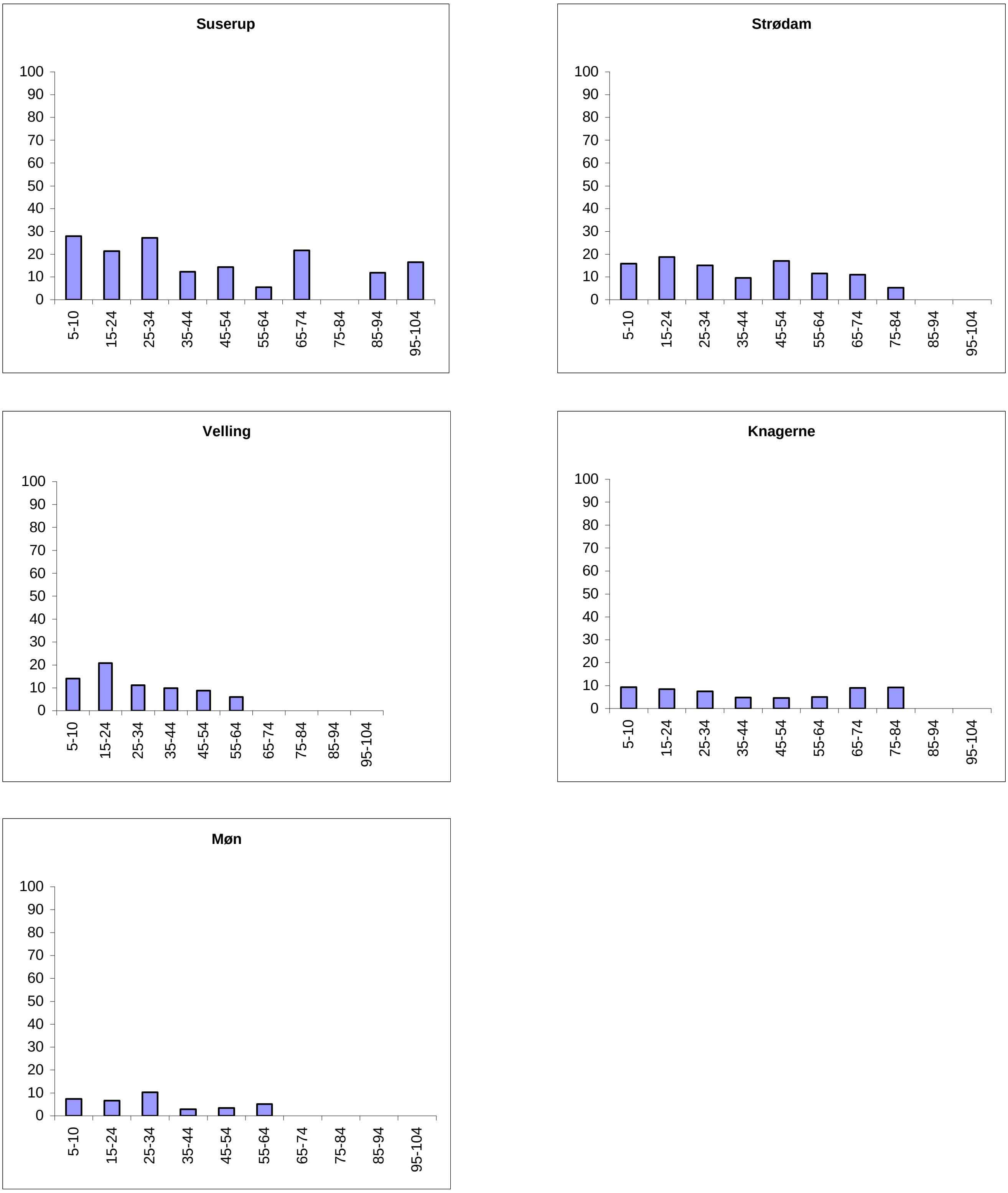

Figure 4. The diameter size class distribution of dead wood in 10 cm classes for the Danish beech forest reserves Suserup, Strødam, Velling, Knagerne and Møn. Horizontal axis = diameter classes (cm), vertical axis= dead wood volume (m^3/ha).

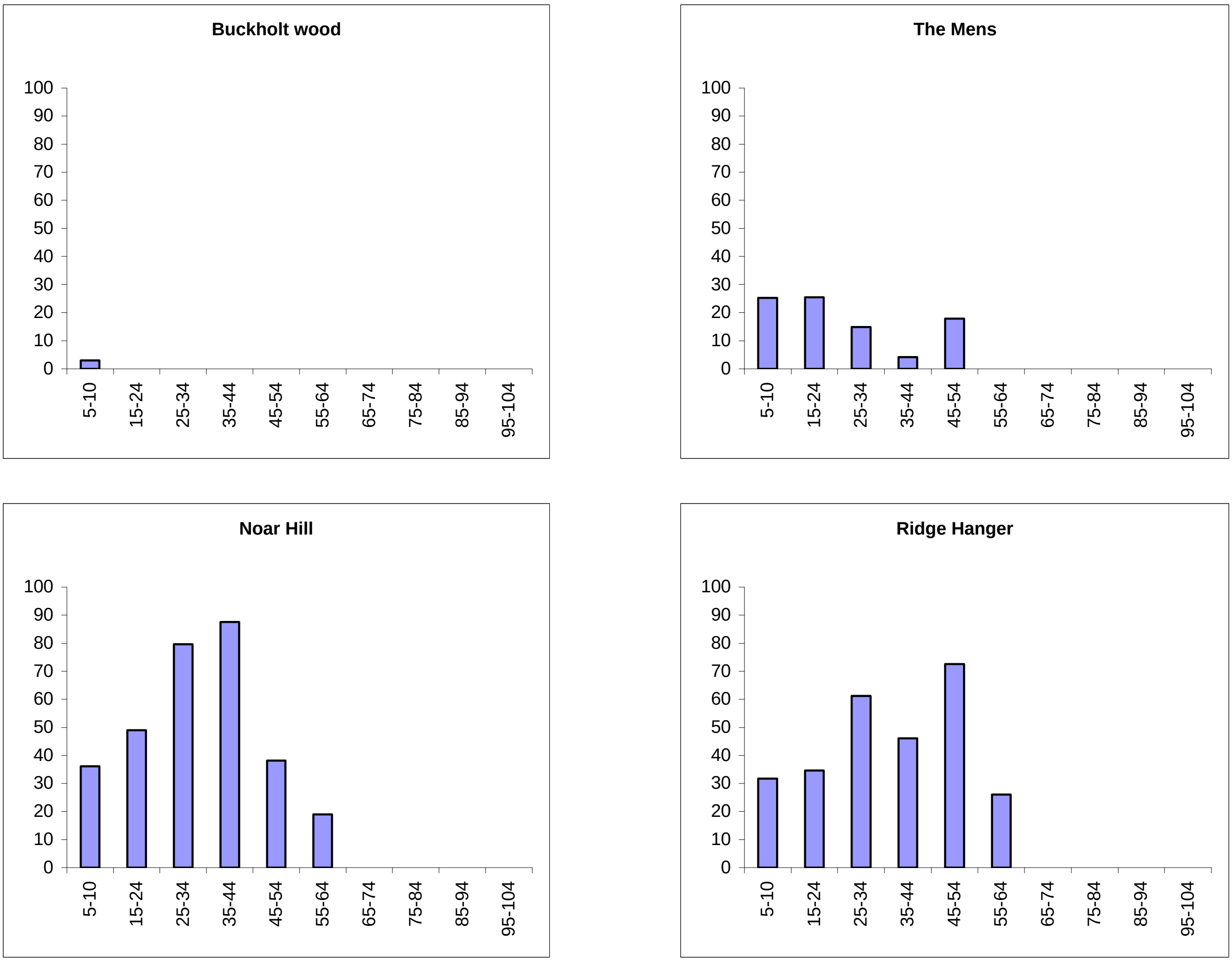

Figure 5. The diameter size class distribution of dead wood in 10 cm classes for the English beech forest reserves. Horizontal axis = diameter classes (cm), vertical axis= dead wood volume (m^3/ha).

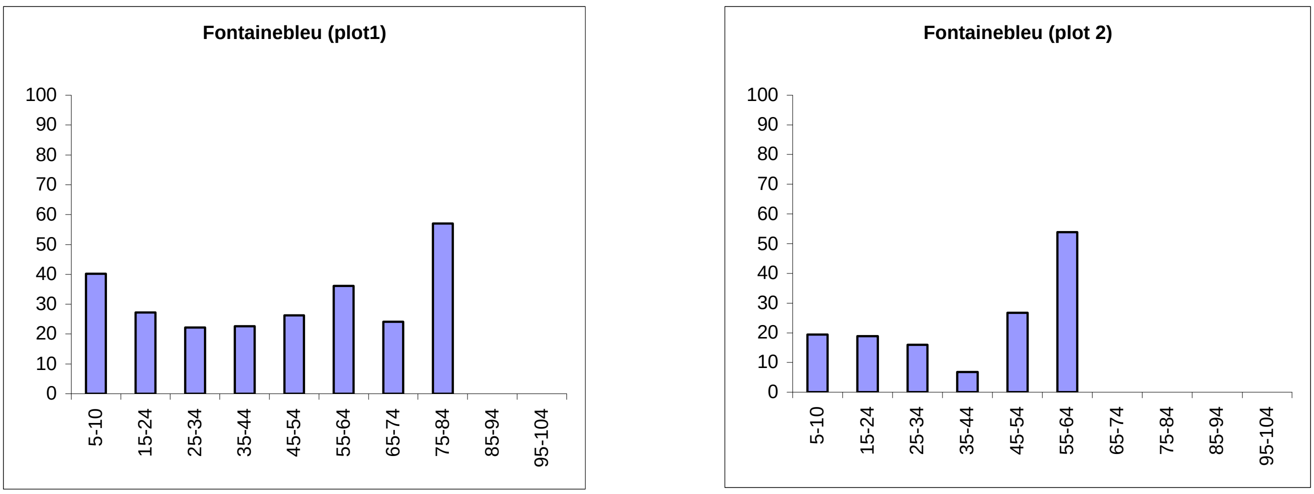

Figure 6. The diameter size class distribution of dead wood in 10 cm classes for the French beech forest reserves. Horizontal axis = diameter classes (cm), vertical axis= dead wood volume (m^3/ha).

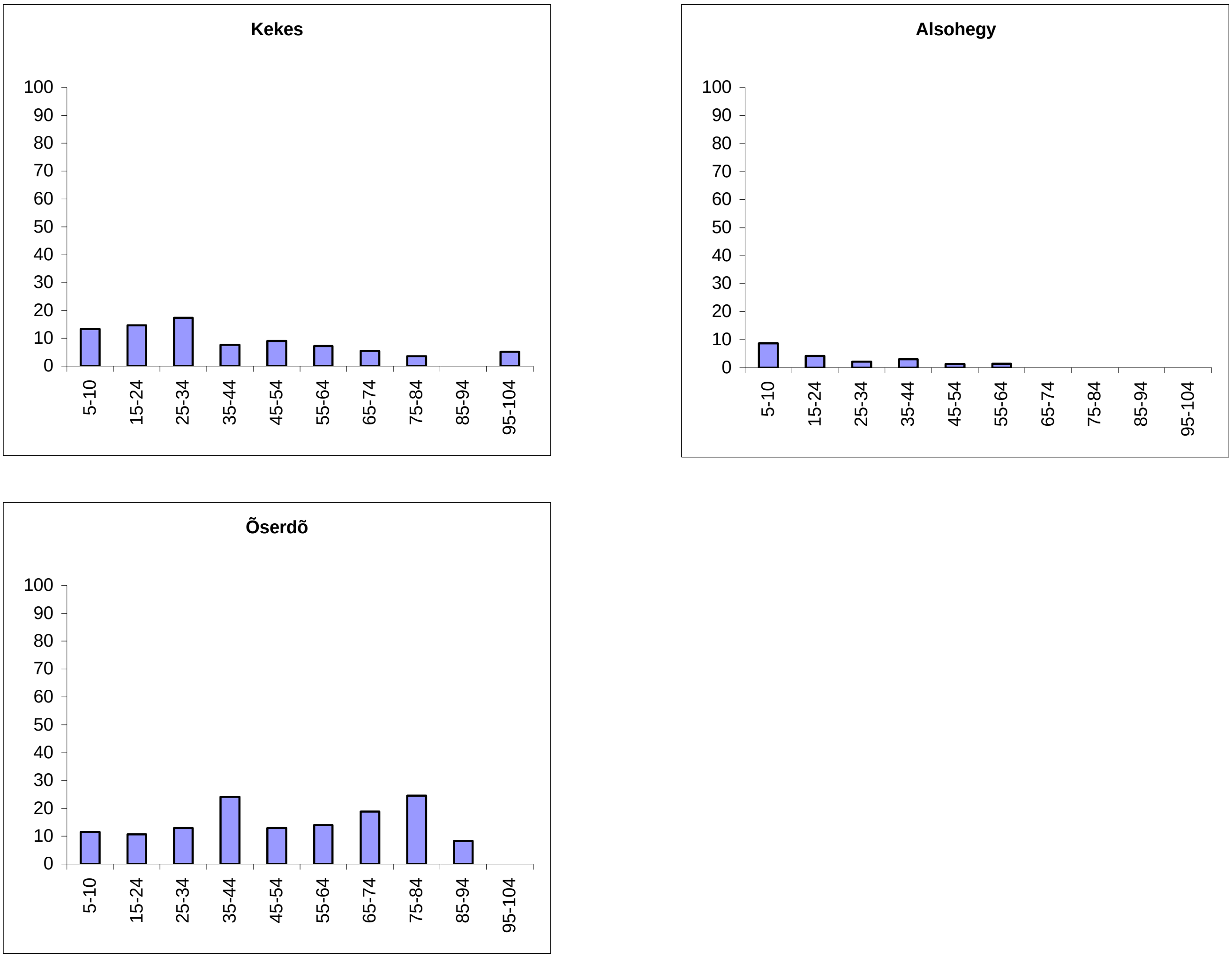

Figure 7. The diameter size class distribution of dead wood in 10 cm classes for the Hungarian beech forest reserves. Horizontal axis = diameter classes (cm), vertical axis= dead wood volume (m^3/ha).

3.3 Decay class distribution

The decay-class distribution of fallen dead wood was determined for four sites in Denmark and three sites in Hungary. The characteristics of the sites in each country are discussed below.

When reading the figures, it is important to be aware of the fact that the transition phases naturally are of unequal length (preliminary results of WP7). Here it is found that decay class (DC) 1 and 2 are rather short with a maximum of 10 years in total - whereas DC 3, 4 and 5 represent long-lasting phases - often more than 5-10 years each. Just as with the diameter class distribution, the absence of dead wood in the latest decay phases strongly indicates a break in the continuity of dead wood supplies, typically due to a combination of recent harvesting of large timber and dead wood removal.

In Denmark (Figure 8), Suserup, Strødam and Møn represent sites with a long history of non-intervention, whereas Velling and Knagerne are more recent reserves. This is reflected in the absence of dead wood in decay phase 5 and 6 for Velling and Knagerne. The decay class distribution is clearly influenced by irregular disturbance events. An example of this is the supposed 'overrepresentation' of DC 4 and 5 in Suserup, caused by a severe windstorm in 1967.

From the Hungarian sites (Figure 9) all of the decay phases are represented with relatively high amounts of dead wood in Oserdo and Kékes showing a relatively long non-intervention history in them. The proportion of well-decayed logs (DC 4 to 6) is lower in Kékes. In this site most of the logs disintegrate in later stages because of the steep slope and high rock cover, and occur only as fine organic woody material among the outcrops. In Alsóhegy later stages are underrepresented because of recent management activities.

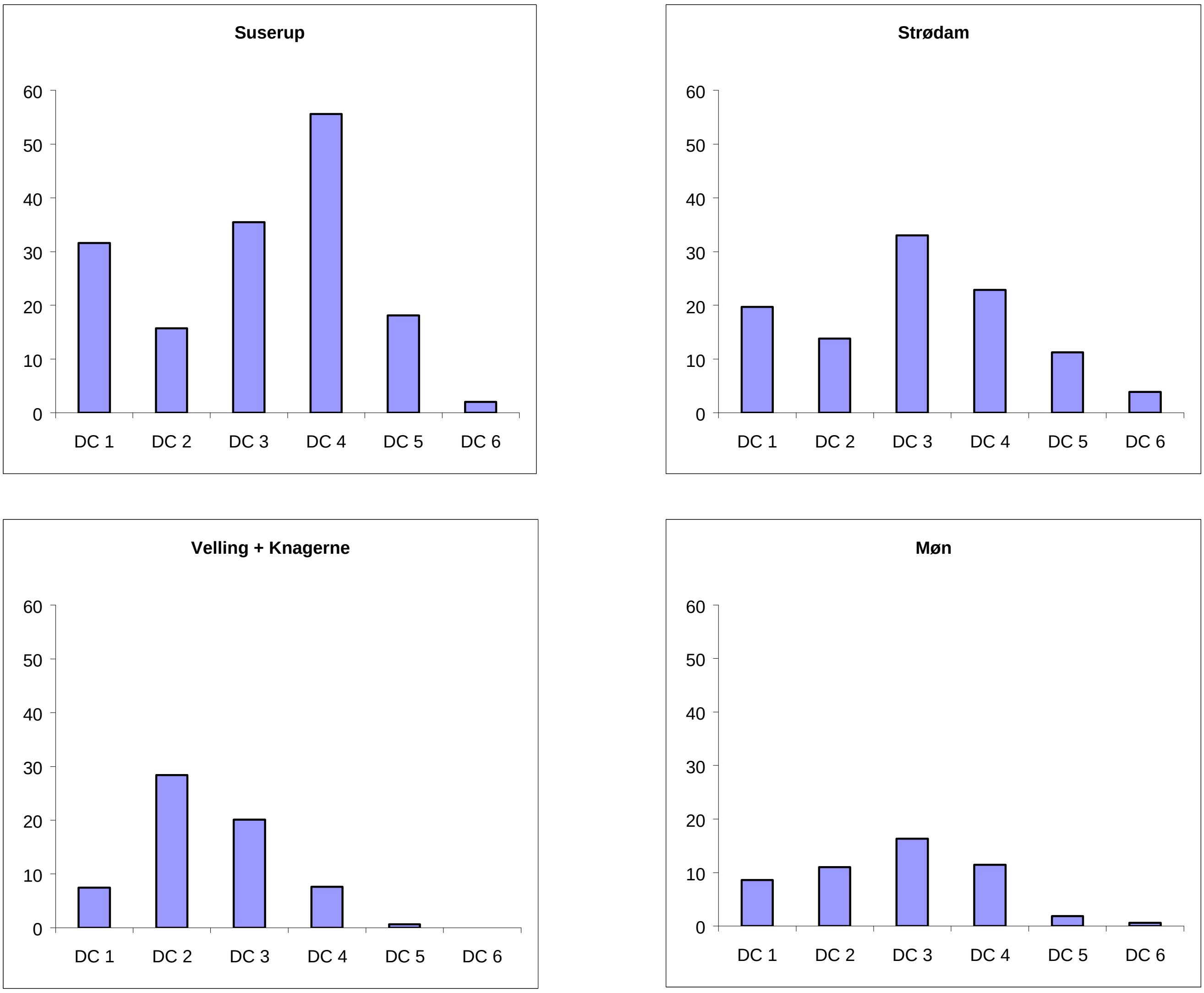

Figure 8. The decay class distribution (decay class 1-6) in relation to dead wood volume in the Danish beech forest reserves Suserup, Strødam, Velling, Knagerne, and Møn. Horizontal axis = decay classes (see Table 2 for explanation), vertical axis= dead wood volume (m^3/ha).

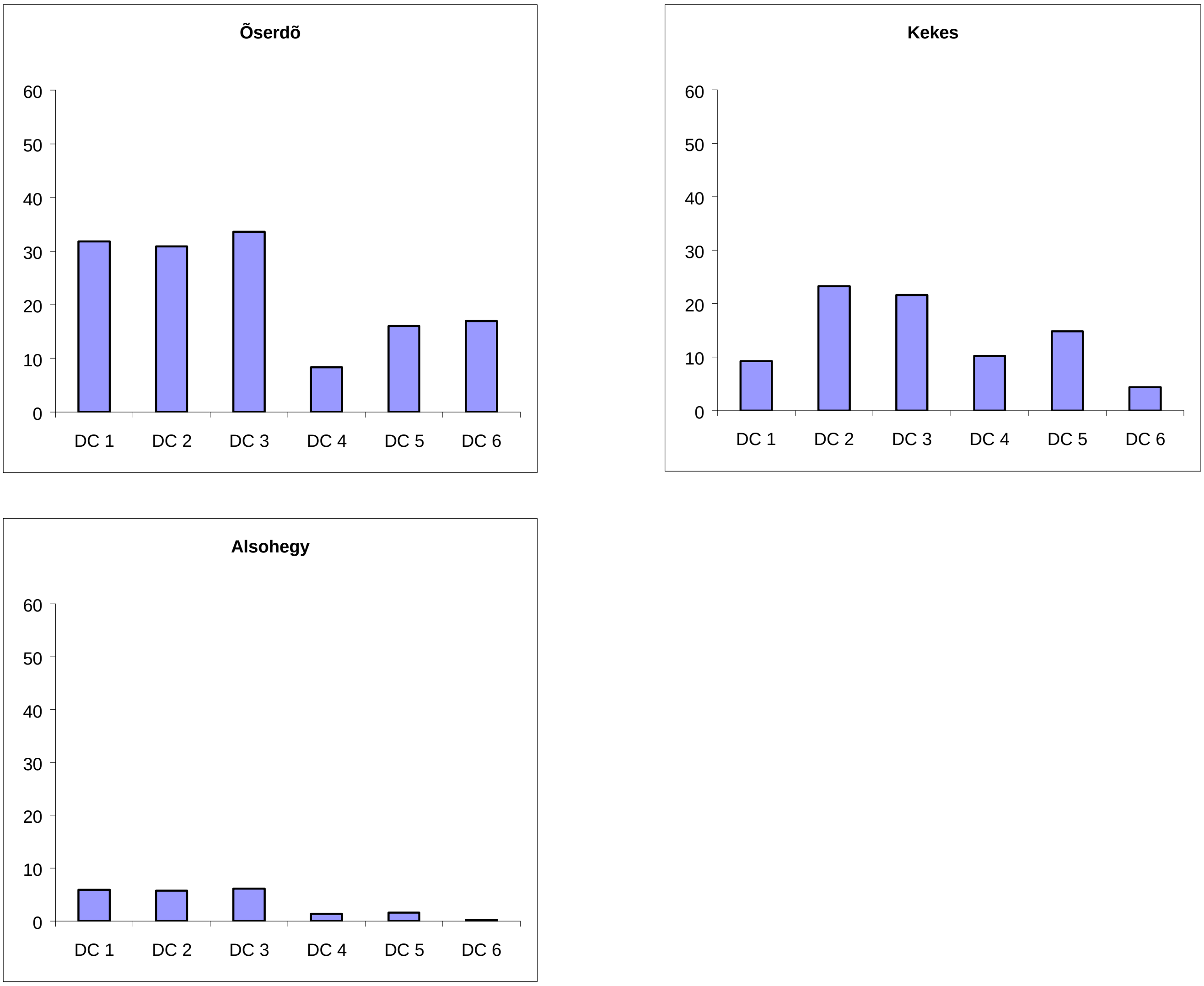

Figure 9. Decay class distribution (decay class 1-6) in relation to dead wood volume in Hungarian beech forest reserves Õserdõ, Kekes and Alsohegy. Horizontal axis = decay classes (see Table 2 for explanation), vertical axis= dead wood volume (m^3/ha).

4. Discussion

4.1 Dead wood quantities

The amount of dead wood present is often a combination of former forest management, stand development stage, and the pattern caused by irregular, natural disturbances. To sort these complicated figures out combined models of dead wood productions, patterns in time and space and decomposition rates would be needed and should be applied to different forest ecosystems around

Europe. However, this report provides some background information to help answer these questions.

It was found that the total dead wood volume in the beech forest reserves studied varied by about 500 m^3/ha. For the sites studied in Nat-Man, the average was 136 m^3/ha across the 14 samples. This demonstrates that there is no one level of natural dead wood, rather that level differs greatly from site to site. This is related to the general cycle of dead wood levels in natural stands (Table 4). As a stand progresses into maturity the volume of dead wood tends to increase; it then peaks during and immediately after the break-up of the old-growth stand; and then falls to a minimum during the stem exclusion stage as the replacement stands develops towards maturity. The scale of stands within natural beech forests probably differs on a regional and local scale. Natural disturbance patterns are probably larger in NW Europe than elsewhere on the continent, because severe windstorms are more common here (e.g. Peterken 1996). In Central and East Europe, stand dynamics are typically small-scale, but even here quite large-scale disturbances can occur occasionally.

Table 4. Trend in dead wood levels in natural beech forest stands in Europe.

Development stage	**Dead wood level**	**Comments**
Stand initiation	Medium to very high	Dead wood is residual from the previous old-growth stand. The amount depends on the biomass accrued in the previous stand and the scale and intensity of the break-up of the old-growth stand. The abundance of snags v logs depends on the type of disturbance: drought kills trees standing, whereas windstorms usually uproot or snap trees.
Stem exclusion	Low	Much of the dead wood decays within a few decades. The longevity depends on the size of logs/snags (larger material decays less rapidly), the rapidity with which snags fall (logs decay faster than snags), and the presence of slow-decaying material (beech decays much faster than oak). During the stem exclusion stage there is little input and most that is input is small and decays rapidly.
Understorey reinitiation	Low-medium	By this age a few larger (and more persistent) branches/trunks become dead wood and levels increase somewhat.
Old-growth	Medium	By this age even more large branches/trunks become dead wood and levels increase further. More large aerial dead wood occurs, notably in large senescent trees.
Canopy break-up	Medium-high	When old-growth stands break-up dead wood levels increase, often dramatically because mature beech trees are prone to damage and death through windstorms, drought and senescence.

4.2 Size class distribution

The data recorded for the Nat-Man study shows that the size class distribution of dead wood varied between countries, forest reserves within each country, and in some cases within particular forest reserves. The three main factors influencing the size class distribution were stand age, site productivity, local disturbance, and management history. Large logs were found on fertile sites that had mature stands. Here, trees had been able to grow large and produce large trunks when they fell. In several cases, individual large trees or parts of stands had been blown down prematurely by windstorms, sometimes in combination with other debilitating agents (e.g. drought, water logging, animal damages and fungi). Possibly, differences in the speed of decomposition also influenced the size class pattern. Large logs could be missing in stands, which were recovering after past felling. It was also possible that at some sites the sampling missed the few large logs that were present. In a few cases, the sites had extreme growth conditions, e.g. dry calcareous or sandy sites, where trees could not attain large diameters.

4.3 Decay class distribution

It is expected that a forest, which has remained unmanaged, would contain dead wood in all decay phases due to a biological decomposition of the dead wood. It is also expected that the dead wood in such a stand would be distributed in the various decay phases, so that the volume in the earlier decay phases is higher and vice versa in the later decay phases due to the physical breakdown of the matter. However, the decay phases are not constructed to reflect decay phases of equal length, but rather to be simple and correct to use under field conditions. When reading the figures, it is important to be aware of the fact that the transition phases naturally are of unequal length (preliminary results of WP7). Here it is found that decay class (DC) 1 and 2 are rather short - app. 10 years in total - whereas DC 3, 4 and 5 represent long-lasting phases – often more than 10 years each. Just as with the diameter class distribution, the absence of dead wood in the latest decay phases strongly indicates a break in the continuity of dead wood supplies, typically due to a combination of recent harvesting of large timber and dead wood removal.

5. Perspectives

The amount of dead wood is one of the major topics in the discussion on sustainable forest management. In the process of developing Pan-European indicators for sustainable forest management (MCPFE meetings) dead wood is included as indicator 4.5 *'Volume of standing deadwood and of lying deadwood on forest and other wooded land classified by forest type'* (MCPFE 2002). This raises the important question *'What is the amount of dead wood in our natural forest ecosystems?'*

6. Acknowledgements

Thanks to Erzsébet Szurdoki, László Gálhidy, Anne Maren Ingemann Madsen, Jacob Heilmann-Clausen, Jaris Bigler, Thomas Vrska, Peter Meyer, and Ruben Walleyn for help with fieldwork and unpublished data.

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Appendix A

Site name	Country	Year recorded	Site area (ha)	Latitude N	Longitude E	Altitude (m)	Main tree species	Living tree volume (m3/ha)	*Minimum dbh recorded (cm)*	Snag & standing dead trees volume (m3/ha)	*Minimum dbh recorded (cm)*	Fallen log volume (m^3/ ha)	*Minimum dbh recorded (cm)*	All CWD volume (m3 -1)	Dead/living volume (%)	*Reference/recorders*
Strødam Reserve	DK	2001	25	55,97	12,27	20-25	Fa, Qu	490	all	39	5 cm	104	5 cm	143	29%	NAT-MAN results
Suserup Skov	DK	2001	10,6	55,37	11,55	10-30	Fa,Qu, Fr, Ul	674	3 cm	9	5 cm	159	5 cm	168	23%	NAT-MAN results
Knagerne	DK	2001	5,6	56,13	9,53	70-90	Fa		all	47	5 cm	58	5 cm	105	-	NAT-MAN results
Velling Skov	DK	2001	24	56,04	9,50	50-100	Fa	349	all	22	5 cm	70	5 cm	92	26%	NAT-MAN results
Møns Klinteskov	DK	2001	25	54,96	12,54	80-110	Fa	201	all	25	5 cm	50	5 cm	74	37%	NAT-MAN results
Buckholt Wood	GB	2000	650	51,80	-2,20		Fa, Fr	-	-	3	3 cm	3	5 cm	6	-	NAT-MAN results
Dendles Wood	GB	1998	29	50,40	-4,00		Fa, Qu, Cs	-	-	66	3 cm	113	5 cm	179	-	NAT-MAN results
Denny Inclosure	GB	1996	25	50,80	-1,50		Fa, Qu	-	-	91	1 cm	201	5 cm	292	-	Mountford et al. 1999
Ridge Hanger	GB	2001	20	51,00	-1,00		Fa, Fr	-	-	1	5 cm	272	5 cm	273	-	NAT-MAN results
The Mens	GB	2001	154	51,00	-0,50		Fa, Qu	-	-	28	6 cm	88	5 cm	115	-	NAT-MAN results
Toy's Hill	GB	1999	154	51,30	0,30		Fa, Be, Qu	-	-	31	5 cm	470	5 cm	501	-	Mountford 2000
Noar Hill	G B		7	51,10	-0,90		Fa, Fr	-	-	-	-	-	-	-	-	NAT-MAN results
Lady Park Wood I (old-growth)	GB	1995	35	51,80	-2,70		Fa, Fr, Qu, Ti	-	-	22	5 cm	77	5 cm	99	-	Green & Peterken 1997
Lady Park Wood II (old-growth)	GB	1995	35	51,80	-2,70		Fa, Fr, Qu, Ti	-	-	32	5 cm	81	5 cm	112	-	Green & Peterken 1997
Lady Park Wood III (old-growth)	GB	1995	35	51,80	-2,70		Fa, Fr, Qu, Ti	-	-	42	5 cm	46	5 cm	87	-	Green & Peterken 1999
Lady Park Wood V & IV (old-growth)	GB	1995	35	51,80	-2,70		Fa, Fr, Qu, Ti	-	-	20	5 cm	15	5 cm	35	-	Green & Peterken 1997
Coed Ithel-Weir	GB	1994	?	51,60	2,70		Fa, Qu, Ti	-	-	11	5 cm	11	5 cm	22	-	Green & Peterken 1997
Pijpebrandje	NL	1999	36	52,25	5,72	50	Fa, Qu	312	5 cm	21	10 cm	18	10 cm	39	12%	NAT-MAN results
Zoinenwoud	BE	2000	10,5	50,77	4,45	90	Fa	794	?	19	7 cm	120	7 cm	139	17%	De Keersmaeker et al. 2002
La Tillaie I	FR	1982	34	48,43	2,68	140	Fa, Qu	478	?	44	9,5 cm	145	9,5 cm	189	40%	Koop & Hilgen 1987, Baren & Hilgen 1984
La Tillaie I	FR	2000	36	48,43	2,68	140	Fa	253	5 cm	68	10 cm	128	10 cm	196	77%	NAT-MAN results
La Tillaie II	FR	1982	34	48,43	2,68	140	Fa, Fr	397	?	28	9,5 cm	92	9,5 cm	120	30%	Koop and Hilgen 1987
La Tillaie II	FR	2000	36	48,43	2,68	140	Fa, Qu	265	5 cm	41	10 cm	91	10 cm	131	50%	NAT-MAN results
Vilm N	DE	1997	20	54,32	13,53	2-10	Fa,Qu, Ac, Ca	561	7 cm	43	7 cm	106	7 cm	149	27%	Schmaltz & Lange 1999
Heillige Hallen	DE	1997	25,6	52,20	13,25	120-140	Fa	507	35 cm	88	35 cm	97	20 cm	185	36%	Tabaku & Meyer 1999
Hünstollen	DE	1996	55,5	51,75	10,08	370-420	Fa, Fr, Ac	576	7 cm	5	7 cm	16	7 cm	21	4%	Meyer 1999 and Meyer pers. comm.

Site name	**Country**	**Year recorded**	**Site area (ha)**	**Latitude N**	**Longitude E**	**Altitude (m)**	**Main tree species**	**Living tree volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Snag & standing dead trees volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Fallen log volume (m^3/ha)**	***Minimum dbh recorded (cm)***	**All CWD volume (m3/ha)**	**Dead/living volume (%)**	***Reference/recorders***
Lüssberg	DE	1997	29,1	52,85	10,25	101-150	Fa, Qu	375	*7 cm*	2	*7 cm*	7	*7 cm*	9	3%	*Meyer 1999 and Meyer pers. comm.*
Vogelherd	DE	1996	10,6	51,75	10,58	480-500	Fa	443	*7 cm*	3	*7 cm*	23	*7 cm*	27	6%	*Meyer 1999 and Meyer pers. comm.*
Königsbuche	DE	1996	26,5	51,75	10,42	200-250	Fa, Qu, Pi	612	*7 cm*	17	*7 cm*	60	*7 cm*	77	13%	*Meyer 1999 and Meyer pers. comm.*
Lohn	DE	1996	37,3	52,95	10,42	51-100	Fa	687	*7 cm*	1	*7 cm*	40	*7 cm*	41	6%	*Meyer 1999 and Meyer pers. comm.*
Bannwald Napf	DE	1994	139,6			1350	Pi, Fa, Ab	483	*all*	80	*all?*	31	*all?*	111	23%	*Hanke 1998*
Waldhaus	DE	1991	96,6	49,85	10,48	370-445	Fa	480	*?*	6	*?*	84	*?*	90	19%	*Kölbel 1999*
Platzer Kuppe	DE	1991	24,2	50,22	9,98		Fa	595	*?*	23	*?*	34	*?*	57	10%	*Kölbel 1999*
Kalkberg	DE	1991	23,8	50,25	9,88		Fa	681	*?*	10	*?*	27	*?*	37	5%	*Kölbel 1999*
Hoher Knuck	DE	1991	109,2	49,95	9,40		Fa, Qu	576	*?*	16	*?*	79	*?*	95	16%	*Kölbel 1999*
Schwarzwihrberg	DE	1991	24,4	49,35	12,37		Fa, Pi	876	*?*	13	*?*	60	*?*	73	8%	*Kölbel 1999*
Niddahänge I	DE	1988	19,8	50,42	9,00	517-700	Fa, Ac, Fr	542	*>7 cm*	4	*>20 cm*	32	*>20 cm*	36	7%	*Hocke 1996*
Niddahänge II	DE	1988	20,8	50,42	9,00	517-700	Fa, Fr, Ac	599	*>7 cm*	4	*>20 cm*	26	*>20 cm*	30	5%	*Hocke 1996*
Hoxfels	DE	1986	55	49,47	6,87	230-413	Fa	297	*?*	13	*?*	5	*?*	18	6%	*Heupel 2002*
Hoxfels	DE	2000	55	49,47	6,87	230-413	Fa	360	*?*	45	*?*	10	*?*	55	15%	*Heupel 2002*
Barbia Gora	PL	1992	35	49,57	19,55	920-1045	Fa, Ab, Pi	553	*>7 cm*	196	*>7 cm*	141	*>7 cm*	337	61%	*Szwagrzyk et al. 1995*
Gorce NP, Lopuszna I	PL	1991	0,6	49,55	20,12	990-1025	Fa, Pi, Ab	614	*> 6 cm*	44	*>6/8 cm*	135	*?*	179	29%	*Jaworski et al. 1995*
Gorce NP, Lopuszna II	PL	1991	0,5	49,55	20,12	990-1025	Pi, Fa, Ab	694	*> 6 cm*	98	*>6/8 cm*	93	*?*	191	28%	*Jaworski et al. 1995*
Gorce NP, Lopuszna II	PL	1991	0,5	49,55	20,12	990-1025	Fa, Ab, Pi	742	*> 6 cm*	71	*>6/8 cm*	61	*?*	132	18%	*Jaworski et al. 1995*
Bieszczady Mts, Moczarne II	PL	c.1994	0,33	49,10	22,72	930-1160	Fa, Ac	545	*>8 cm*	12	*>8 cm*	51	*>8 cm*	62	11%	*Jaworski et al. 1995b*
Bieszczady Mts, Moczarne I	PL	c.1994	0,25	49,10	22,72	930-1160	Ac, Fa	391	*>8 cm*	18	*>8 cm*	27	*>8 cm*	45	12%	*Jaworski et al. 1995b*
Bieszczady Mts, Rabia Skala I	PL	c.1994	0,25	49,10	22,72	930-1160	Ac, Fa	257	*>8 cm*	5	*>8 cm*	30	*>8 cm*	35	13%	*Jaworski et al. 1995b*
Swietokrzyski NP I	PL	1992	451	50,88	20,88	560-570	Fa, Ab	521	*>8 cm*	109	*>8 cm*	105	*>8 cm*	214	41%	*Jaworski et al. 1999*
Swietokrzyski NP II	PL	1992	451	50,88	20,88	560-570	Fa, Ab	203	*>8 cm*	165	*>8 cm*	183	*>8 cm*	348	172%	*Jaworski et al. 1999*
Milesice	CZ	1972	9,63	48,98	13,83	1070-1125	Pi, Fa, Ab	476	*10 cm*	27	*10 cm*	58	*10 cm*	85	18%	*Vrska et al 2001a*

Site name	**Country**	**Year recorded**	**Site area (ha)**	**Latitude N**	**Longitude E**	**Altitude (m)**	**Main tree species**	**Living tree volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Snag & standing dead trees volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Fallen log volume (m3/ha)**	***Minimum dbh recorded (cm)***	**All CWD volume (m3/ha)**	**Dead/living volume (%)**	***Reference/recorders***
Milesice	CZ	1996	9,63	48,98	13,83	1070-1125	Pi, Fa, Ab	567	*10 cm*	47	*10 cm*	91	*10 cm*	139	24%	*Vrska et al 2001a*
Boubín	CZ	1996	46.62	48,97	13,80	930-1110	Pi, Fa, Ab	772	*10 cm*	67	*10 cm*	167	*10 cm*	234	30%	*Vrska et al 2001b*
Mionsí	CZ	1994	171,07	49,53	18,65	620-950	Fa, Ac, Ab	590	*10 cm*	57	*10 cm*	98	*10 cm*	155	26%	*Vrska et al 2000*
Razula	CZ	1972	23.52	49,35	18,38	600-812	Fa, Ab, Pi	550	*?*	152	*?*	14	*?*	167	30%	*Vrska et al 2001d*
Razula	CZ	1995	23.52	49,35	18,38	600-812	Fa, Ab, Pi	592	*?*	65	*?*	144	*?*	209	35%	*Vrska et al 2001d*
Salajka	CZ	1994	21.86	49,40	18,42	715-815	Fa, Ab, Pi	473	*10 cm*	80	*10 cm*	144	*10 cm*	224	47%	*Vrska et al. 1998*
Zakova hora	CZ	1974	38,10	49,65	16,00	730-808	Fa, Pi, Ac	536	*?*		*?*		*?*	181	34%	*Vrska et al. 1999*
Zakova hora	CZ	1995	38,10	49,65	16,00	730-808	Fa, Pi, Ac	580	*?*	30	*?*	103	*?*	133	23%	*Vrska et al. 1999*
Zofin	CZ	1975	97,72	48,67	14,70	735-825	Fa, Ab, Pi	666	*10 cm*	49	*10 cm*	78	*10 cm*	127	19%	*Prusa 1982, 1985a*
V Kluci	CZ	1973	??	49,32	15,52	635-680	Fa, Ul, Ac	681	*10 cm*	46	*10 cm*	52	*10 cm*	98	14%	*Batelka 1975*
V Kluci	CZ	2000	??	49,32	15,52	635-680	Fa, Ac, Fr	681	*10 cm*	49	*10 cm*	153	*10 cm*	201	30%	*Odehnalova 2001*
Polom	CZ	1973	19,34	49,78	15,75	545-625	Pi, Fa, Ab, Ac	545	*?*	51	*?*	77	*?*	128	24%	*Vrska et al. 2000*
Polom	CZ	1995	19,34	49,78	15,75	545-625	Pi, Fa, Ac, Fr	593	*?*	44	*?*	94	*?*	138	23%	*Vrska et al. 2000*
Kyjov	SK	1963	53.4	48,88	22,05	730-790	Fa, Ac, Fr	550	*7*	33	*all*	52	*all*	86	16%	*Saniga & Schütz 2001*
Kyjov	SK	1973	53.4	48,88	22,05	730-790	Fa, Ac, Fr	631	*7*	40	*all*	62	*all*	102	16%	*Saniga & Schütz 2001*
Kyjov	SK	1983	53.4	48,88	22,05	730-790	Fa, Ac, Fr	622	*7*	81	*all*	49	*all*	130	21%	*Saniga & Schütz 2001*
Kyjov	SK	1993	53.4	48,88	22,05	730-790	Fa, Ac, Fr	659	*7*	56	*all*	138	*all*	194	29%	*Saniga & Schütz 2001*
Rozok	SK	1979	67.1	48,98	22,63	610-650	Fa	716	*6*	24	*all*	84	*all*	108	15%	*Saniga & Schütz 2001*
Rozok	SK	1989	67.1	48,98	22,63	610-650	Fa	778	*6*	33	*all*	157	*all*	190	24%	*Saniga & Schütz 2001*
Rozok	SK	1999	67.1	48,98	22,63	610-650	Fa	816	*6*	33	*all*	115	*all*	148	18%	*Saniga & Schütz 2001*
Havesova	SK	1979	171.3	49,02	22,25	540-590	Fa	697	*7*	41	*all*	79	*all*	121	17%	*Saniga & Schütz 2001*

Site name	Country	Year recorded	Site area (ha)	Latitude N	Longitude E	Altitude (m)	Main tree species	Living tree volume (m3/ha)	*Minimum dbh recorded (cm)*	Snag & standing dead trees volume (m3/ha)	*Minimum dbh recorded (cm)*	Fallen log volume (m3/ha)	*Minimum dbh recorded (cm)*	All CWD volume (m3/ha)	Dead/living volume (%)	*Reference/recorders*
Havesova	SK	1989	171.3	49,02	22,25	540-590	Fa	705	*7*	33	*all*	86	*all*	119	17%	*Saniga & Schütz 2001, Korpel 1997*
Havesova	SK	1999	171.3	49,02	22,25	540-590	Fa	736	*7*	39	*all*	84	*all*	123	17%	*Saniga & Schütz 2001*
Dobroc	SK	1958	101,82	48,68	19,67	700-1000	Ab, Fa, Pi	866	*?*	34	*all*	198	*all*	232	27%	*Saniga & Schütz 2001b*
Dobroc	SK	1978	101,82	48,68	19,67	700-1000	Ab, Pi, Fa	727	*?*	84	*all*	197	*all*	281	39%	*Saniga & Schütz 2001b, Korpel 1997*
Dobroc	SK	1988	101,82	48,68	19,67	700-1000	Pi, Ab, Fa	726	*?*	72	*all*	206	*all*	278	38%	*Saniga & Schütz 2001b*
Dobroc	SK	1998	101,82	48,68	19,67	700-1000	Pi, Fa, Ab	741	*?*	79	*all*	227	*all*	306	41%	*Saniga & Schütz 2001b*
Stuzica 4	SK	1991	218	49,07	22,53	730-770	Fa, Qu	569	*7*	60	*all*	48	*all*	108	19%	*Korpel 1997*
Stuzica 5	SK	1991	442	49,07	22,53	790-830	Fa, Qu	647	*7*	60	*all*	48	*all*	108	17%	*Korpel 1997*
Sitno	SK	c.1991	45,49	48,42	18,98	760-790	Fa, Ac, Qu,	594	*?*	29	*all*	74	*all*	103	17%	*Korpel 1997*
Rastun	SK	c.1993	18,00	48,60	16,27	550-620	Fa, Qu, Ac	527	*7*	33	*all*	37	*all*	70	13%	*Korpel 1992, Korpel 1997*
Badin	SK	1957	30,70	48,67	19,00	710-770	Fa, Ab	745	*?*	34	*all*	172	*all*	173	23%	*Saniga & Schütz 2001a*
Badin	SK	1970	30,70	48,67	19,00	710-770	Fa, Ab, Ac	770	*?*	138	*all*	145	*all*	162	21%	*Saniga & Schütz 2001a*
Badin	SK	1977	30,70	48,67	19,00	710-770	Fa, Ab, Ac	753	*?*	124	*all*	150	*all*	156	21%	*Saniga & Schütz 2001a*
Badin	SK	1987	30,70	48,67	19,00	710-770	Fa, Ab, Ac	663	*?*	96	*all*	280	*all*	288	43%	*Saniga & Schütz 2001a, Saniga 1999*
Badin	SK	1997	30,70	48,67	19,00	710-770	Fa, Ab, Ac	627	*?*	50	*all*	273	*all*	286	46%	*Saniga & Schütz 2001a, Saniga 1999*
Rothwald	AU	1977	300	47,78	14,83	940-1500	Fa, Ab, Pi	547	*1 cm*	106	*1 cm*	190	*1 cm*	296	54%	*Mayer & Neumann 1981 ao.*
Dobra	AU	1970	6	48,58	15,40	390-550	Fa, Ul, Ti, Ac	582	*8 cm*	-	*?*	-	*?*	45	8%	*Mayer & Reimoser 1978*
Bükk, Õserdõ	HU	2001	59,3	48,05	20,43	800-900	Fa, Ac, Fr	765	*2 cm*	26	*>2 cm*	138	*>10 cm*	164	21%	*NAT-MAN results*
Kekes	HU	2002	54,8	47,87	20,00	750-950	Fa	454	*2 cm*	15	*>2 cm*	84	*>10 cm*	99	22%	*NAT-MAN results*
Alsohegy	HU	2002	112,8	48,55	20,70	470-550	Ca, Qu, Fa	284	*2 cm*	19	*>2 cm*	21	*>10 cm*	40	14%	*NAT-MAN results*
Perucica	BA	c.1978	786	43,27	18,75	1100-1600	Ab, Fa, Pi	1095	*all*	100	*all*	-	*all*	100	9%	*Leibundgut 1982*
Rajhenaski Rog	SI	1985	51,3	45,66	15,02	850-960	Ab, Fa	813	*5 cm*	122	*5 cm*	16	*5 cm*	138	17%	*Hartman 1987*
Pecka	SI	1980	60,2	45,75	15,00	800-910	Ab, Fa	930	*all*	181	*?*	178	*?*	181	19%	*Leibundgut 1982*
Pecka	SI	1999	60,2	45,75	15,00	800-910	Fa, Ab	687	*5 cm*	291	*5 cm*	277	*5 cm*	568	83%	*Debeljak 1999*

Site name	**Country**	**Year recorded**	**Site area (ha)**	**Latitude N**	**Longitude E**	**Altitude (m)**	**Main tree species**	**Living tree volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Snag & standing dead trees volume (m3/ha)**	***Minimum dbh recorded (cm)***	**Fallen log volume (m3/ha)**	***Minimum dbh recorded (cm)***	**All CWD volume (m3/ha)**	**Dead/living volume (%)**	***Reference/recorders***
Krokar	SI	c. 1996	72,8	45,54	14,78	850-1190	Fa, Ab	634	*?*	-	*?*	-	*?*	69	11%	*Joze 1997*
Bukov Vrh	SI	1998	9,25	45,99	13,89	1200-1300	Fa, Ab, Ac	525	*5 cm*	67	*5 cm*	25	*?*	92	18%	*Kovac 1999*
Strmec	SI	2001	15,55	45,62	14,82	900	Fa, Ab, Pi, Ac	660	*10 cm*	-	*?*	-	*?*	166	25%	*NAT-MAN results*
Mirdita	AL	1997	c. 3500	42,02	20,15	1370-1430	Fa	560	*7 cm*	5	*7 cm*	35	*20 cm*	40	7%	*Tabaku & Meyer 1999*
Puka	AL	1997	c. 3500	42,02	20,15	1370-1430	Fa, Ab	781	*7 cm*	9	*7 cm*	20	*20 cm*	30	4%	*Tabaku & Meyer 1999*
Rajca	AL	1997	c. 2000	41,23	20,12	1400-1450	Fa	807	*7 cm*	25	*7 cm*	59	*20 cm*	83	10%	*Tabaku & Meyer 1999*