ORIGINAL PAPER

Deadwood volume assessment in the third Swiss National Forest Inventory: methods and first results

J. Böhl · U.-B. Brändli

Abstract The Swiss National Forest Inventory (NFI) is expected to provide reliable data about the current state of the Swiss forests and recent changes. Since the first Swiss NFI (1982–1986) a deadwood assessment has been part of the inventory. However, the definition of deadwood used was restricted and only parts of the total deadwood volume were assessed. A broader definition was therefore used in the second NFI (1993–1995) and coarse wood debris (CWD) was also assessed using line intersect sampling in the third NFI (2004–2006). This paper discusses the development of the definition of deadwood from the first to the third Swiss NFI, as well as the tally rules and estimators used in assessing deadwood in the ongoing third NFI. Different definitions of deadwood were applied in two Swiss regions and the resulting volume estimates were compared. The definition of deadwood appears to be crucial for the estimate of deadwood volumes, which were significantly underestimated in the first and second Swiss NFI. The minimum diameter and other limits applied must be chosen with special care. Up to 30 m³/ha of deadwood was found in Swiss forests varying with the region. There was little evidence of significant correlations between deadwood volume and such forest parameters as management, site or stand attributes. The proposed target values for the volume of deadwood have been generally reached, whereas the number of snags per hectare has not.

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Introduction

The Swiss National Forest Inventory (NFI) is designed as a multi-purpose inventory, serving as a decision-support tool for forest policies. It provides reliable information about the current state of the Swiss forests and about changes that have taken place. The inventory not only records resource indicators, such as standing timber increments and tree species composition, but also collects data on a range of forest functions (Brassel and Lischke 2001).

The increasing politicisation of environmental issues in Switzerland has resulted in a broader orientation of the NFI. Switzerland is also involved in the pan-European process concerned with the protection of forests in Europe and has endorsed the improved indicators for sustainable forest management (MCPFE 2003). Here deadwood is an important indicator of the criterion biodiversity. It is known that one-fifth of forest fauna, e.g. 1,340 central European beetle species, and more than 2,500 higher fungi species, are dependent on deadwood (Möller 1994; Schiegg-Pasinelli and Suter 2002). To obtain detailed information about deadwood, additional NFI attributes are required and further adaptations of the sampling methods are necessary.

Deadwood volume assessment in the NFI provides an example of how the requirements for information have changed since the early 1980s. During the first NFI (1983–1985), data on lying and standing deadwood

were collected if the tree species was still recognisable, if the wood was still usable and if the point at which to measure the diameter at breast height (DBH) on the sample tree was clearly identifiable. In the second NFI (1993–1995) one constraint, namely that deadwood should be usable, was dropped. After the second NFI, an impact analysis was conducted in order to identify the needs of NFI data users (Bättig et al. 2002). Deadwood was identified as an important indicator of biodiversity and carbon sequestration, but detailed information about deadwood was not recorded in the second NFI as it still had two strong constraints. The first constraint that the tree species must still be recognisable has been dropped in the second NFI. The second that the point to measure the DBH must be clearly identifiable has been retained. That means in the second NFI the assessment of lying deadwood was still restricted to lying sample trees, so that the total estimate of lying deadwood or coarse woody debris (CWD) will probably be an underestimate. Line intersect sampling (LIS) was introduced in the third Swiss NFI (2004–2007) to assess CWD volume in Swiss forests and describe the current status of CWD. It has been a widely used method to estimate CWD volume (Warren and Olsen 1964; van Wagner 1968; Brown 1974; Marshall et al. 2000; Wadell 2002) and shown to be efficient (Ståhl and Lämås 1998; Ståhl et al. 2001; Roth et al. 2003). The LIS sampling scheme was overlaid on the NFI sample plots, so that it was possible to analyse the relationships between CWD, standing deadwood and various variables collected from the standard NFI sample plots.

This paper discusses the development of the definition of deadwood from the first to the third Swiss NFI, as well as the tally rules and estimators used in assessing deadwood in the ongoing third NFI. Different definitions of deadwood were applied in two Swiss regions and the resulting volume estimates compared. The definition of deadwood appears to be crucial for the estimate of deadwood volumes, which were significantly underestimated in the first and second Swiss NFI. The minimum diameter and other limits applied must be chosen with special care.

Up to 30 m^3/ha of deadwood was found in Swiss forests varying with the region. In addition, the occurrence and distribution of deadwood and their relationships to different forest variables are explored. There was little evidence of correlations between deadwood volume and such forest parameters as management, site or stand attributes. The proposed target values for the volume of deadwood have been generally reached, whereas the number of snags per hectare has not.

Method

LIS in the forestry literature

Line intersect sampling was introduced into forestry by Warren and Olsen (1964) to estimate the amount of logging residue present on the forest floor. The method is best described as a strip sample of infinitesimally small width (i.e. a transect line), which runs through a population of needle-shaped objects. A diameter measurement is taken from every piece of CWD that intersects the fixed transect line to estimate the volume per unit area. van Wagner (1968) developed a formula that only requires a diameter measurement at the point of intersection to estimate the volume of CWD per unit area:

$$\hat{V} = \frac{\pi^2}{8L} \sum_{i=1}^{N} d_i^2 \tag{1}$$

where $\hat{V}$ is an estimate of the volume per unit area, L is the length of the transect line and d_i is the diameter of the CWD pieces perpendicular to the longitudinal axis of the individual piece at the point of intersection. van Wagner stated that $\hat{V}$ is an unbiased estimator of the CWD volume per unit area if the pieces are cylindrical and not tilted from the plane and if all pieces are randomly oriented. van Wagner (1982) proposed the use of more than one transect line running in different directions to neutralise the effect of non-random piece orientation. Correction factors for populations that are tilted from the plane are provided by Brown and Roussopoulos (1974). De Vries (1986) and Marshall et al. (2000) extended van Wagner's formula to allow an estimate per unit area for any quantifiable property of interest:

$$\hat{X} = \frac{\pi}{2L} \sum_{i=1}^{N} \frac{x_i}{l_i} \tag{2}$$

where x_i is the attribute of interest of the individual CWD piece and l_i is the length of that piece. If one chooses the volume of the CWD pieces as the attribute of interest and applies the Huber formula for the x_i:

$$x_i = \frac{d_i^2 \pi}{4} l_i \tag{3}$$

then Eq. 2 reduces to Eq. 1.

Kaiser (1983) provided further insights into LIS. He considered the population as fixed and made no assumption about the orientation of the CWD pieces. The only randomness that arises in Kaiser's approach

is the random location of the transect line. In addition, he provided design-unbiased estimators for objects of arbitrary shape, so the method was no longer restricted to needle-shaped objects. Gregoire and Valentine (2003) followed Kaiser's approach to develop an unconditional estimator for CWD volume. They maintained that the transect line should be randomly placed on the area of interest and that diameter measurements should be taken along the transect line to obtain a design-unbiased estimator of the CWD volume. In addition, they suggest that, under circumstances where the diameter measurement perpendicular to the longitudinal axis of the pieces is easier to obtain, the conditional estimator as given by De Vries and van Wagner may be used.

Applying LIS in the third Swiss NFI

The estimator proposed by van Wagner is preferred in the Swiss NFI. Field tests have shown that the diameter perpendicular to the longitudinal axis of the pieces is easier to obtain than a diameter measurement along the transect line. In order to achieve results that can be reproduced, it is also preferable to choose a fixed arrangement of the transect lines. Therefore, the layout of the transect lines is the same on every NFI plot. Equation 1 is used to estimate the volume of CWD on forest floors.

During the fieldwork preparations we realised that the time needed to setup a total horizontal line length of 30 m on a standard NFI sample plot can be kept to a minimum if multiple short lines are used. We tested using an equilateral triangle as a layout, as proposed by van Wagner (1982), but due to Switzerland's alpine topography, this turned out to be far too time consuming. Other layout designs were also considered (Howard and Ward 1972; Kleinn 1994; Linnell Nemec and Davis 2002). The most efficient layout in terms of time we found was the fan. This layout was also proposed by Bell et al. (1996) to be used in LIS to minimise sampling error. By overlaying a fan of three fixed transect lines on our standard NFI sample plots, we reduced the risk of a possible orientation bias. It was also an optimal sampling scheme as it minimised the time needed to setup the lines at each sample plot with a total length of 30 m horizontally.

As the distribution and variance of CWD in Swiss forests were unknown, it was not possible to evaluate the optimal line length per sample plot beforehand to obtain a specific standard error for the estimate. Field tests of the LIS in different parts of Switzerland led us expect it would take approximately 7 min per sample plot to carry out the LIS. Since the costs of the

inventory had to be kept to a minimum, we could not afford a longer line length.

To correct piece tilt, we decided to measure the angle of every CWD piece with the horizontal. Although van Wagner (1982) stated that the resolving error from piece tilt may not even be worth correcting, Brown and Roussopoulos (1974) found that piece tilt errors can be significant, especially in fresh loggings. We therefore added the correction factor $1/\cos(\alpha)$, where α is the angle of tilt of an individual piece away from the horizontal line. Though the factor is close to 1 at low angles, every measured diameter is corrected by it.

The line-intersect method collects a sample of circular cross-sections. Thus, there is a risk that non-circular cross-sections from odd-shaped pieces will introduce an error into the estimate. We decided to adopt the simplest method of handling occasional non-circular cross-sections by estimating one representative diameter from the average of two measurements that are orthogonal to each other. The diameter measurements from every intersected CWD piece are taken at the point of intersection.

The results of the Swiss NFI are related to the horizontal map area. Therefore, the length of the transect line has to be corrected to take the slope angle into account. The length of the transect lines is corrected in the field so that all transect lines have the same horizontal length. Brown (1974) provides a correction factor for ground slope:

$$L' = L\sqrt{1 + \left(\frac{\text{slope}(\%)}{100}\right)^2} \tag{4}$$

where L' is the length of the transect line in the field. With this correction for sloping terrain, together with the correction factor for piece tilt and two diameter measurements for every intersected piece, the local estimator for CWD volume per unit area used at the plot level is

$$\hat{X}_j = \frac{\pi^2}{8L_j} \sum_{i=1}^{N} \left(\frac{(d_{1i} + d_{2i})}{2}\right)^2 \frac{1}{\cos(\alpha_i)} \tag{5}$$

where $\hat{X}_j$ is the estimate of CWD volume in m³/ha for the individual sample plot j, L_j is the total horizontal length of the transect lines in metre, d_{1i} and d_{2i} are the two diameter measurements of the intersected pieces in centimetre, and α_i is the piece tilt of each intersected piece in degrees. In the case of NFI sample plots, data from all three transects within each plot are added together and extrapolated as per ha estimate of the CWD volume in each sample plot.

Tally rules for CWD assessment

A detailed field protocol of the LIS can be found in Chap. 8 of the third Swiss NFI field survey manual (Böhl 2005). The Swiss NFI defines CWD as deadwood on the forest floor with an intact structural integrity and a minimum diameter of 7 cm measured perpendicular to the longitudinal axis of the piece at the point of intersection. CWD includes downed trees, parts of trunks and branches, branches that are no longer connected to a living tree trunk and uprooted stumps. Living material, separated bark, rooted stumps, standing trees and dead branches still connected to standing trees are not included. Harvested logs that will obviously be removed from the forest are also not included.

An individual CWD piece is included in the sample if it meets the definition of CWD and if the longitudinal axis of the piece intercepts one of the transect lines. Theoretically, one piece cannot intercept a single transect line more than once. In practice, however, there are odd-shaped pieces that may intercept a transect line more than once. The same problem may occur if both parts of a forked piece intercept the transect line. In these cases, a CWD piece is seen as a collection of pieces connected with each other. Therefore, a CWD piece that is intercepted more than once, either by one transect line or by different transect lines, is tallied as often as it is intersected by the transect lines. Figure 1 shows a typical situation. The CWD piece is intercepted twice by the transect line. Therefore, the diameters of every point of intersection are recorded if they are greater than or equal to 7 cm.

After recording the diameter, the piece tilt from the horizontal at every point of intersection is measured by attaching a goniometer to the CWD piece at the point of intersection.

Design of the Swiss NFI

The third Swiss NFI covers the entire forest area of the country, irrespective of the land's legal status. It uses double sampling for stratification design to collect information on forests in Switzerland in a reproducible manner (Köhl 1994). Approximately, 160,000 primary sample plots are evaluated by photo interpretation. Besides an assessment of general landscape data, a forest definition is applied, which results in a forest/ non-forest decision for each of the primary sample plots. The secondary sample consists of approximately 6,500 permanently established field plots in Switzerland's forest area. On the permanent sample plots a variety of measurements are recorded by field crews. Details can be found in the Manual for the Field Survey (Stierlin et al. 1994; Keller 2005).

Sample plots used in the Swiss NFI consist of two concentric circles and a 50 × 50 m interpretation area (Fig. 2). Every tree (lying, standing, dead or alive) with a minimum DBH of 12 cm is sampled within the smaller circle, which has an area of 200 m². The larger circle has an area of 500 m², within which every tree with a minimum DBH of 36 cm is measured. The three transects used to assess the CWD are established at each plot location. Each transect line originates at a distance of 1 m from the centre of the sample plot and extends at an angle of 35, 170 and 300gon. That way, the three transect lines together form a fan. The length of each transect is 10 m horizontal distance. The reason for selecting a distance of 1 m between the centre of the sample plot and the starting point of transects is that multiple measurements are recorded at the centre of the sample plots according to standard NFI field
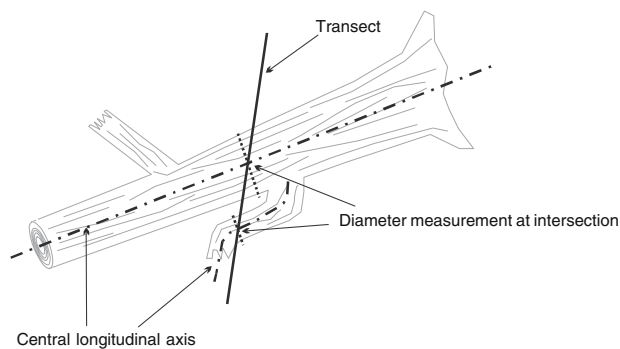

Fig. 1 Illustration of the tally rules for CWD in the Swiss NFI. Diameter measurements are taken at every point of intersection of the central longitudinal axis of a CWD piece and the transect line
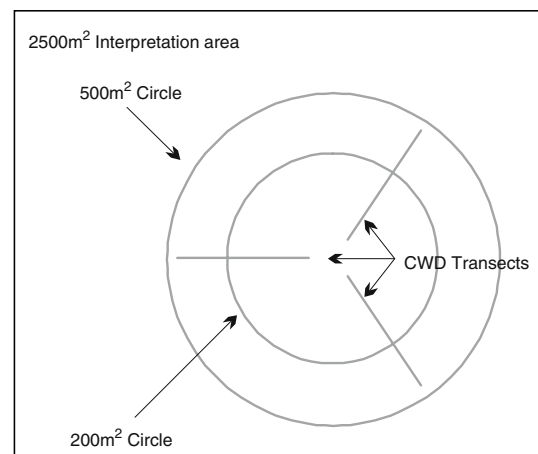

Fig. 2 Layout of the terrestrial sample plot components of the Swiss NFI. The CWD transects have been overlaid on the existing terrestrial sample plot

protocol. Therefore, the risk that CWD pieces will be displaced is high.

The volume of a dead standing sample tree is derived through tariff functions. In the third NFI we also record the height of broken snags to reduce the volume of single trees with snapped crowns. Since tariff functions for the ongoing third NFI have not yet been developed, we used the tariff functions of the previous NFI for unbroken snags and calculated the volume of a frustum for sample trees with snapped crowns. The mean volume of broken snags is about 29% less then the tariff volume of these snags. Since about 40% of the snags have broken crowns, the volume estimate of standing deadwood is reduced by 13.5%.

To obtain a local estimate of the standing deadwood volume, the single tree volume of a sample tree is multiplied with a representation factor that converts the single tree volume into volume per hectare. The volume per hectare values are summed up to a plot value that represents the local estimate for standing deadwood in m³/ha (Kaufmann 2001).

The NFI is optimised to provide reliable estimates for the five production regions in Switzerland (Köhl 1994) which are a geographical breakdown of Switzerland by site (growth, geology and climate) and production conditions (silviculture, harvesting method). Most plots in the production regions Jura (forest area of 201,000 ha) and Plateau (forest area of 227,000 ha) have already been visited by field crews during fieldwork undertaken for the third NFI. The plots of the Plateau region are mostly located on very productive sites in the submontane vegetation belt (beech forests). The plots of the Jura region represent productive sites in the montane vegetation belt (beech and fir-beech forests). The production regions are defined and used by the Swiss Federal Forest Statistics.

Results and discussion

Methodological aspects

After 1 year of fieldwork and experience with applying LIS in the field, the method appears to be practicable and easy to apply even under difficult conditions, such as wind throw on the sample plot. As Table 1 shows,

Table 1 Time needed to apply the LIS in the field

Region	Mean time consumption (minutes)	Standard deviation
Jura	5.5	3.03
Plateau	4.7	4.66

the time needed to apply the method is between 5 and 6 min per sample plot depending on the production region. We were expecting about 7 min per sample plot from our field tests of the LIS.

As the number of sample plots in the third NFI is fixed, the time needed to apply the LIS can only be reduced by using shorter lines, which would be at the cost of a higher standard error. Table 2 shows the standard error of the LIS estimate with a total line length of 30 m and the standard error of a LIS estimate using only a total line length of 10 and 20 m. To obtain the 10 m estimate, we randomly drew one of the three lines per sample plot and calculated an estimate of the CWD volume and its standard error. In analogy we calculated the 20 m estimate and the standard error. As Table 2 shows, a reduction of the total line length from 30 to 10 m would result in an approximately 60% rise in the standard error of the estimate. A reduction of the total line length from 30 to 20 m would result in a increase in the standard error of approximately 20%.

Another methodological issue is the influence of the definition of deadwood. With the results of the CWD assessment, we were able to examine how much deadwood lying on the forest ground would not have been assessed, due to the restriction on sample trees, if LIS had not been used. As Table 3 shows, the volume of deadwood on the ground assessed with LIS is about 3–4 times as much as that of the dead lying sample tree assessment, depending on the dimension of the

Table 2 Expected increase in standard error when shorter lines are used

Total length of transect lines per sample plot (m)	Estimate (m³/ha)	Standard error (%)
10	19.27	8.66
20	19.77	6.42
30	19.39	5.31

Table 3 Differences in the estimates of lying deadwood when different definitions of deadwood are used

Method	Line intersect sampling				Lying dead sample tree assessment		
Diameter of deadwood	≥7 cm	≥12 cm	≥20 cm	≥40 cm	≥12 cm	≥20 cm	≥40 cm
Deadwood (m³/ha)	19.40	15.10	10.56	5.36	3.72	3.09	1.76
Standard error	1.04	0.99	0.94	0.83	0.34	0.33	0.26
Plots with deadwood (%)	59	33	14	3	13	7	3

deadwood. The constraint, ''sample tree'', is clearly very severe and CWD was considerably underestimated in the first and second Swiss NFIs. Table 3 also shows that the minimum diameter chosen for the assessment is crucial. Applying a minimum diameter of 7 cm instead of 12 cm would result in an approximately 28% higher estimate. The estimate would almost double if a minimum diameter of 7 cm instead of 20 cm is used.

The rather high standard errors of the estimates in Tables 2 and 3 indicate that the volume of deadwood varies greatly. Figures 3 and 4 show the distribution of plot values of CWD and standing deadwood. On approximately 40% of the sample plots no CWD was found. The 10% sample plots with the highest CWD stocks contain more than 50% of the CWD volume in the Swiss forests. The clustered appearance of deadwood is expected because of wind-throw and other natural events. Figure 4 illustrates how rare standing deadwood is in Swiss forests. On more than 77% of the sample plots no standing deadwood was found. Given deadwood is likely to occur in clusters due to wind throw and similar events, adaptive cluster sampling could be an efficient alternative to plot-sampling and LIS when assessing deadwood (Ståhl et al. 2001).

Ecological aspects

The first results of the third Swiss NFI presented in this paper concern the forests of the regions Jura and Plateau, which together make up one-third of the Swiss forest area. These regions are of special interest as they comprise most of the potential high-value habitats for saproxylic species[1] in Switzerland (saproxylic hotspots). On the basis of a European literature review, Bütler et al. (2005) found that the European consensus was that there should be at least 20–40 m³/ha of deadwood for European forest communities. They propose a target value of 20 m³/ha deadwood for Switzerland. As Table 4 shows, the average deadwood volume of the Jura (29.3 m³/ha) and the Plateau (23.9 m³/ha) exceeds the target value. Compared to the second NFI, the volume of lying dead sample trees in Jura and Plateau has increased from 1.0 m³/ha (Brändli and Ulmer 1999) to 3.7 m³/ha (Table 3). This is only partly the result of the winter storm Lothar of December 26, 1999, as the annual Sanasilva Inventory documents a continuous increase in deadwood since 1994 (Brändli 2005). For economic and ecological reasons fewer dead trees are harvested. The volume of

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[1] Saproxylic species: species depending on dead or decaying wood during a part of their life cycle.
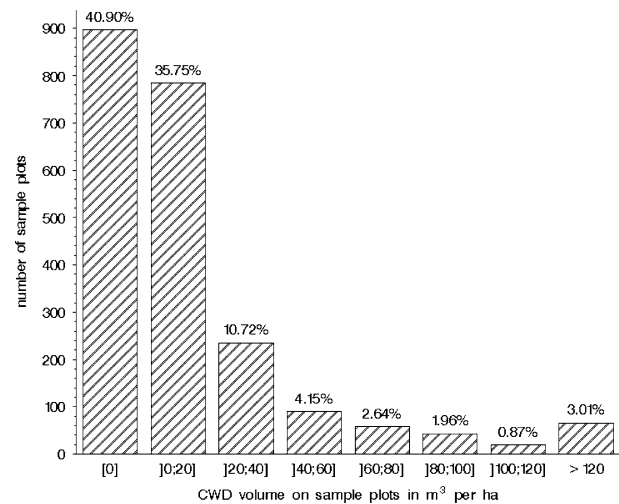
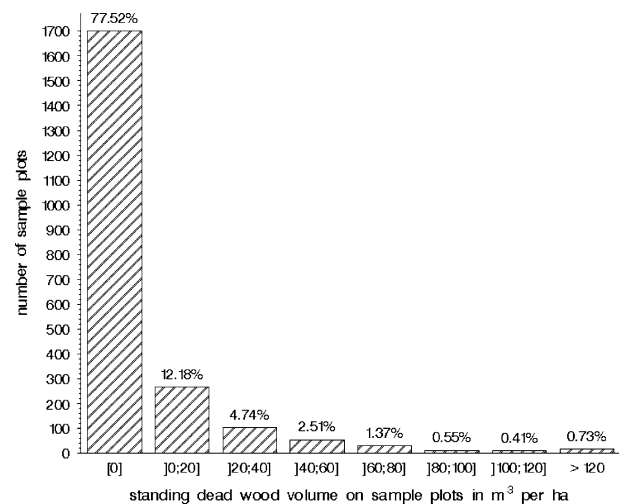**Fig. 3** Distribution of CWD volume plot values

Fig. 4 Distribution of standing dead volume plot values

deadwood in Swiss forests is, nevertheless, still much less than in comparable virgin beech forests in the Ukrainian Carpathians, which have 27 to 255 m³/ha of deadwood, with an average of 111 m³/ha deadwood (Commarmot et al. 2005). Similar amounts of deadwood have been recorded in other European virgin and natural forests (Brändli 2005).

Our data (Figs. 3, 4) support the hypothesis that deadwood is patchily distributed in both managed and virgin forests. For ecological accounting purposes, standing deadwood (snags) of larger dimensions (diameter) are said to be particularly important. Bütler (2003) proposes at least 14 standing snags per hectare with a DBH of more than 20 cm in sub-alpine forests. For the managed forests of the Jura and Plateau, the target of environmental policy is five snags per hectare

Table 4 Results of the deadwood assessment of the third Swiss NFI in the Jura and the Plateau

| | Volume of deadwood | | | | | | Number of standing dead trees | | | |
| | Lying (CWD) (m³/ha) | | Standing (m³/ha) | | Total (m³/ha) | | DBH ≥ 20 cm (n/ha) | | DBH ≥ 40 cm (n/ha) | |
	Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Site attributes										
Production regions										
Jura	22.29	1.75	7.00	0.68	29.29	1.88	7.80	0.76	1.30	0.18
Central Plateau	16.63	1.14	7.24	0.94	23.86	1.48	6.10	0.73	1.80	0.25
Altitude										
Up to 600 m	17.71	1.53	7.41	1.09	25.13	1.88	6.71	0.89	1.56	0.25
601–800 m	20.56	1.85	7.57	0.96	28.12	2.08	7.69	0.99	1.87	0.33
Over 800 m	20.91	2.09	6.32	0.73	27.24	2.21	6.65	0.81	1.36	0.24
Plot slope										
0–20%	13.62	1.15	7.07	1.37	20.68	1.79	6.09	1.08	1.70	0.32
20–40%	15.39	2.05	6.92	1.36	22.31	2.46	6.07	1.14	1.63	0.37
40–60%	17.93	2.00	4.05	0.73	21.98	2.13	4.84	0.86	0.85	0.26
Over 60%	29.51	2.65	9.34	0.86	38.85	2.79	9.89	0.99	1.88	0.26
Stand attributes										
Forest type										
Conifer forest, pure	15.06	1.91	4.91	0.77	19.97	2.06	4.32	0.72	0.88	0.22
Conifer forest, mixed	18.40	1.70	8.64	1.12	27.04	2.04	8.77	1.00	1.84	0.34
Broadleaf forest, mixed	21.93	2.30	10.22	2.01	32.15	3.05	9.32	1.60	2.50	0.48
Broadleaf forest, pure	20.31	2.21	5.39	0.87	25.71	2.38	5.76	0.95	0.97	0.20
Stand damage										
<10% heavily damaged	17.68	1.09	6.09	0.48	23.77	1.19	6.23	0.51	1.18	0.13
≥10% heavily damaged	33.61	4.37	13.58	3.93	47.19	5.88	11.05	2.83	4.95	0.98
Managment attributes										
Distance to road										
Up to 50 m	17.47	1.47	6.25	1.04	23.71	1.80	5.94	0.84	1.60	0.25
51–100 m	22.89	2.67	7.28	1.16	30.16	2.91	6.41	0.92	1.61	0.33
101–200 m	19.93	2.29	7.52	0.98	27.45	2.49	8.05	1.26	1.17	0.29
Over 200 m	19.05	2.31	8.80	1.29	27.85	2.64	9.14	1.43	1.92	0.4
Last intervention										
Maximum 10 years ago	21.06	1.56	5.79	0.91	26.85	1.81	5.30	0.74	1.35	0.22
11–20 years ago	12.33	1.70	8.25	1.38	20.57	2.19	7.19	1.47	1.68	0.42
21–30 years ago	15.98	3.03	9.85	1.79	25.82	3.52	11.12	1.92	1.72	0.54
30 and more years ago	21.07	4.44	11.20	1.61	32.26	4.72	12.83	2.21	1.45	0.42
Ownership										
Public with fiscal sovereignty	22.70	1.88	5.38	0.62	28.08	1.98	5.57	0.67	1.42	0.21
Public without fiscal sovereignty	18.84	1.69	7.65	0.87	26.49	1.90	7.84	0.92	1.88	0.29
Private	16.38	1.79	8.41	1.42	24.79	2.28	7.54	1.12	1.43	0.31

Est estimate, *SE* standard error

with a DBH of at least 40 cm (Hahn et al. 2005). The actual amount is only 1.3 snags per hectare in the Jura and 1.8 snags per hectare in the Plateau (Table 4). This indicates that there is a significant lack of ecologically high-value deadwood in Swiss forests in the submontane and montane vegetation belt. What influences the occurrence and amount of deadwood in forests? We expected correlations between attributes describing sites, stands and human activities, but found in general little evidence for this hypothesis (Table 4). Above average deadwood volumes can be found in damaged stands and in stands where the last intervention was more than 30 years ago due to the effect of natural hazards and higher mortality. Stands that were used

within the previous 10 years had an unexpectedly high volume of lying deadwood, probably due to harvesting losses. The forest type "pure conifer forest" has the smallest amount of deadwood of all forest types, probably because the higher prices for spruce timber led to these forests being more intensively harvested. The low amount of deadwood in pure broadleaf forests might be because broadleaf trees are robust against windthrow. The highest amount of deadwood, especially standing deadwood, was found in mixed broadleaf forests. One explanation is that many shallow rooting spruce trees could not compete with deeper rooting broadleaves during the hot summer in 2003 and died due to water deficiency. Such isolated spruce

snags were not harvested. Concerning site factors, we found no correlation between deadwood and altitude in the Jura and Plateau, but on steep slopes, where harvesting costs are very high, the volume of deadwood is higher and reaches nearly double that as on flat terrain. The distance away from the nearest forest road does not, surprisingly, appear to correlate with the deadwood amount found on NFI plots. Forest in the Jura and Plateau have a high access density and seem to be managed independently of the relatively short logging distances. NFI plots near forest roads generally have almost the same amount of deadwood as other plots, and there seems to be no indication of special security measures for safety reasons along such public roads. Regarding forest ownership, we expected to find more deadwood in public forests with fiscal owners (political communities, cantons, confederation) as a result of ecological policy. Such forests tend, we found, to obtain more lying deadwood, probably due to harvesting losses, but fewer snags than other forests, perhaps they are more intensively exploited for economical reasons.

Overall the occurrence of deadwood does correlate with several site, stand and management attributes. Higher volumes of deadwood, especially snags, can be found in damaged forests, on steep slopes, in seldom used forests and in broadleaf forests with conifers. But it is not possible to interpret the amount of deadwood only by NFI attributes. On the basis of data from the second NFI and using multivariate data analyses, Bütler et al. (2005) created statistical models with similar types of parameters to those discussed in this paper. Even though they included many more parameters, they were still able to explain only 14% (R^2 Jura) and 28% (R^2 Plateau) of the deadwood variance.

Conclusion

Methodological aspects

Line intersect sampling is an efficient and reliable method to estimate CWD. It takes less time than we had originally expected. Moreover, the simplicity of the method meant that the field crews did not have to ask concerning the LIS application. As shown in the results, using a line length of more than 30 m is not expected to lead to a drastic reduction in the standard error of the estimate. Under the conditions we described above, we recommend a total line length per sample plot of 20–30 m. The most critical point of a CWD assessment is defining deadwood. We showed that having a particular constraint in the definition of

deadwood can result in a significant change in the estimate of the volume. The minimum diameter applied is also crucial. Even deadwood of low dimensions can add a significant amount to the assessed deadwood volume. Deadwood is not scattered uniformly over the area and the higher the minimum diameter is, the more plots there will be without any deadwood. We recommend using a rather small minimum diameter. Apart from the time needed to walk to the plot, most time needed for the assessment is spent establishing the transect lines. Measuring diameters does not take much time. Thus it is unlikely that the costs of an assessment with a minimum diameter of 7 cm will be much higher than an assessment with a minimum diameter of 12 cm, but including smaller diameters would lead to significantly more information being obtained.

Ecological and political aspects

Standing and lying deadwood, stumps and heaps of branches have been used to describe the structural diversity of Swiss forests since the second NFI (Brändli 2001). The introduction of LIS in the third NFI has made it possible for the first time to estimate the entire volume of deadwood in Swiss forests. As shown on the basis of NFI data, different definitions of deadwood and different sampling methods (e.g. different minimum diameters) may result in contradictory ecological interpretations of the current state of the Swiss forest habitats as target values for deadwood are met or not. The results of the Swiss NFI are often referred in the discussions of the environmental policy. Thus, having information about methods is as important as the results themselves.

The definition of ecological target values for deadwood in managed forests is also very important. At present such target values are set on the basis of little sound scientific information, as little is yet known about the influence of volume and quality of deadwood on biodiversity. The deadwood volumes in the forests of the Swiss regions Jura and Plateau exceed the minimum target values currently set, for lying deadwood but not for snags with a DBH of more than 40 cm, even in damaged stands. One conclusion for the sustainable management of Swiss forests is the need to increase the number of thick snags and to test the target values.

The amount and quality (diameter) of deadwood can only be roughly explained using models based on NFI attributes (Bütler et al. 2005). Some expected correlations with natural disturbances (e.g. storm damage, drought, stability of broadleaves) and human disturbances (e.g. last silvicultural intervention) could however be found. Especially on steep slopes harvest-

ing costs exceed benefits. There are indications that economics (e.g. timber prices) and phytosanitary measures (e.g. bark-beetle prevention) may explain the current volumes of deadwood in Swiss forest better than ecological policy of the forest manager. Thus if more standing dead trees of larger dimensions are required public financial incentives will be needed to reach that target.

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