STAND STRUCTURE ASSESSMENTS INCLUDING DEADWOOD

within the EU/ICP Forests Biodiversity Test-Phase (ForestBIOTA)

1. Introduction and approach

Stand structure including the occurrence of deadwood is regarded as one key parameter for forest biodiversity. The presented monitoring manual has been compiled based on three separate unpublished papers which were produced during the preparatory phase of the project and which are covering different aspects of stand structure and deadwood assessments:

- R. FISCHER, A. POMMERENING. 2003. Methodology for stand structure assessments in the biodiversity test phase 2003 - 2005 of EU/ICP Forests.
- G. CHIRICI, P. CORONA, M. MARCHETTI. 2003. Proposal of Deadwood Monitoring Protocol in ForestBIOTA.
- P. MEYER. 2004. ForestBIOTA: Work package 1.1. Proposal for the assessments of stand structure

The general approach within ForestBIOTA stand structure assessments is to carry out assessments with different intensities and to calculate correlations between the results of the different assessments. This will facilitate recommendations for assessment methods applicable within different surveys (e.g. Intensive Monitoring, Level I, National Forest Inventories).

2. Sampling unit configuration

2.1. Plot

The ForestBIOTA plot has to be entirely contained within the Level II plot. In the context of this submanual a "plot" always refers to the ForestBIOTA plot. The area of the plot must always be continuous and of 0.25 ha size. A division to disjunctive parts is not foressen. The plot is centered as far as possible in correspondence with the geometric center of the Level II plot. The plot should be shaped as far as possible as a square, with a side length of 50 m (see Fig. 1). Otherwise, it may be shaped as a moderate rectangle, preferably with a minimum width of 40 m (or a maximum length of 62.5 m). One side of the plot is oriented to the magnetic North if possible.

2.2. Subplots

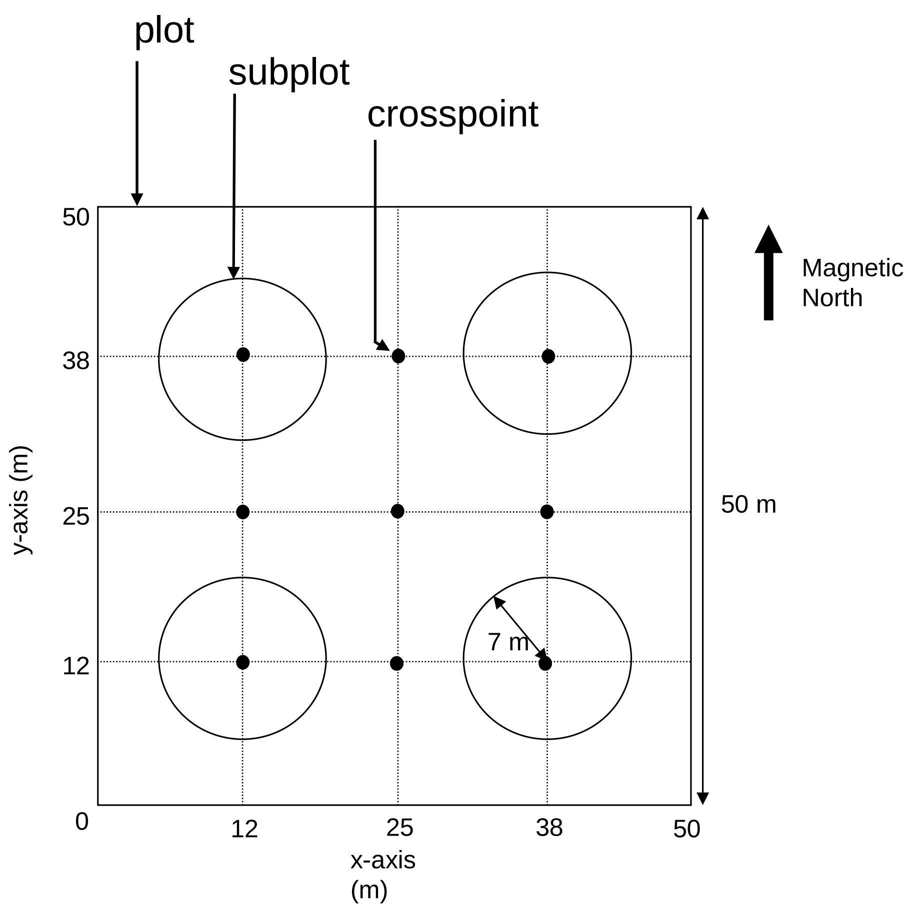
A four-subplots cluster has to be entirely contained within the plot. The four-subplots cluster is centered as far as possible in correspondence with the geometric center of the plot. Each subplot within the cluster is a circle with the radius of 7 m. The subplots should be displaced as far as possible at the corners of a square with a side length of 26 m (see Fig. 1). One side of the cluster is oriented to the magnetic North if possible.

If such a configuration is not feasible because the plot has a design different from that suggested at 2.1, or because large parts of a subplot contain installed Level II measurement equipment, the four subplots should be arranged within the plot in such a way that distances between the subplot centers and plot borders are maximized.

2.3 Crosspoints

Nine cross points are placed within the plot following the outline of Figure 1. Four cross points are located within the centers of the subplots. If such a configuration is not feasible because the plot has a design different from that suggested at 2.1, or because crosspoints are located on installed Level II measurement equipment, one ore more crosspoints should be displaced within the plot in such a way that distances between the crosspoints and plot borders are maximized.

Figure 1: Sampling unit configuration.



3. Parameters assessed

Table 1 gives an overview on the stand structural parameters assessed within ForestBIOTA

Table 1: Stand structural parameters assessed within ForestBIOTA

Inventoried attribute	Survey unit
Deadwood	
Standing deadwood (dead standing trees, including snags with broken off stem)	plot
Dead downed trees	plot
Lying dead wood pieces	subplot
Stumps	subplot
Stand structure	
Tree coordinates **or**	plot
Structural group of four	crosspoints
Simple estimates	plot
Qualitative features	plot

Deadwood sampling should be carried out before stand structural assessments in order to avoid destruction as much as possible

4. Measurement and estimation procedures

4.1 Simple estimates

Before measuring stand structural parameter estimate at first the following simple structural parameters.

survey unit: plot.

sampling rule: simple estimates are carried out for all plots. They should give a mean estimation for the total plot area.

inventoried attributes:

4.1.1 Canopy closure

- Estimated percentage coverage of tree layer > 5 m in 5% steps. The maximum value is 100% as multiple coverage is not considered separately.

4.1.2 Coverage of the tree layers and tree species

- List of tree species (minimum 10% cover) with estimated percentage cover in 5% steps for each tree layer > 5m (if distinguishable tree layers exist)
- The estimated average top height in meter and the estimated total cover (in 5% steps) of each tree layer should be recorded. In single layered stands the total coverage of the layer=conopy closure. As layers may overlap, the sum of the coverage of the layers may be higher than the canopy closure.
- List of all additional tree species less than 10 % cover occurring without percentage cover.

(The purpose of this parameter is to test the quality of such simple estimates. Thus this parameter must be estimated in the field and not deducted from the database!)

4.1.3 number of tree layers > 5m

1. one layer
2. two layers (each min of 10 % coverage)
3. multilayered (each min of 10 % coverage)
4. irregular

4.1.4 Type of tree species mixture

1. monoculture (>90% tree cover consists of main tree species)
2. single tree wise mixture
3. group wise mixture
4. mixture by layers
5. irregular, none of the above

4.2 Qualitative features

survey unit: plot.

sampling rule: simple estimates are carried out for all plots. They should give a mean estimation for the total plot area.

inventoried attributes:

4.2.1. Ancient forest site

1. forested since > 300 years
2. forested since > 200 years
3. forested since > 100 years
4. afforested in the past 100 years
5. no information

4.2.2. Intensity of forest management

1. no sign of management, natural development
2. signs of past management, abandoned to natural development
3. managed

4.2.3. Management type of forest

1. high forest
2. coppice without standards
3. coppice with standards
4. plantation

4.2.4. Management method

1. clear cut
2. clear cut with reservoirs
3. selective cut
4. shelterwood

4.3. Standing deadwood (minimum DBH ≥ 5 cm)

survey unit: plot.

sampling rule: a dead tree or a snag is inventoried if its DBH is ≥ 5 cm and its stem base lies within the boundary of the plot. Do not measure recently harvested wood that is assumed to be removed soon. In contrast to stumps snags are required to have a height of ≥1.3 m.

inventoried attributes: DBH (with or without bark); height (highest part); species; decay level; for snags, also snag height (the height of stem truncation) and stem diameter at half snag height (only in the case of snag height ≤ 4 m).

volume estimation at plot level [V_{st_tr}]: the volume of each inventoried dead tree is estimated by standard two-way volume equations or tables (see Chapt. 5.1); in the case of snag, if the snag height is > 4 m, the snag volume is estimated by applying a reduction factor to the intact volume obtained by standard two-way volume equations or tables (see Chapt. 5.1, with the adoption of a height-DBH relationship obtained from surrounding trees of the same species); if snag height is ≤ 4 m, the snag volume in m^3 is estimated by Huber's formula (see formula [1] at Chapt. 5.2); dead tree and snag volumes in m^3 are then summed up at plot level and transformed in m^3ha^{-1} by an expansion factor of 4.

4.4. Dead downed trees (minimum DBH ≥ 5 cm)

survey unit: plot.

sampling rule: a downed tree (in one piece or in more pieces unambiguously recognizable as a single tree) is inventoried if the thickest part of its stem lies within the boundary of the plot.

inventoried attributes: DBH (with or without bark); total length; species; decay level.

volume estimation at plot level [V_{down_tr}]: volume of each downed tree is estimated using the standard two-way volume equations or tables (see Chapt. 5.1); tree volumes in m^3 are then summed up at plot level and transformed in m^3ha^{-1} by an expansion factor of 4.

4.5. Other lying deadwood pieces (diameter at thicker end ≥ 5 cm)

survey unit: subplot.

sampling rule: a lying wood piece is inventoried if its diameter at thicker end is ≥ 5 cm and its thicker end lies within the boundary of the subplot. If the piece contains several branches, than all branches are considered and measured as separate deadwood pieces if their diameter is ≥ 5 cm at the thicker end.

inventoried attributes: total length of the piece from the thicker end until the point where the diameter drops below a diameter ≤ 3cm; median diameter (diameter at half length); species; decay level.

volume estimation at subplot level [V_{lying}]: volume of each inventoried piece is estimated by Huber's formula (see formula [1] at Chapt. 5.2); wood pieces volumes in m^3 are then summed up at subplot level and transformed in m^3ha^{-1} by an expansion factor of 65.

4.6. Stumps (diameter at the level of cut ≥ 10 cm, height < 1.3m)

survey unit: subplot.

sampling rule: a stump is inventoried if its diameter at the level where the tree was cut (or where the stem broken off) is ≥ 10 cm and if more than 50% of the stump lies within the boundary of the subplot.

inventoried attributes: diameter of the stump (with or without bark) at the level where the tree was cut; stump height; species; decay level.

volume estimation at subplot level [V_{stump}]: volume of each inventoried stump is estimated by formula [2] at Chapt. 5.3; stump volumes in m^3 are then summed up at subplot level and transformed in m^3ha^{-1} by an expansion factor of 65.

4.7. Tree coordinates (DBH > 5 cm)

survey unit: plot.

sampling rule: Coordinates of all trees with DBH > 5 cm are measured. If the number of these trees is > 300 on 0.25 ha, the measurement of tree coordinates can be omitted and structural group of four assessments may be conducted instead. Please take contact with the data centre in this case.

inventoried attributes: tree species, tree number, DBH, x and y coordinates of the tree center [m].

calculation of diversity indices: Based on the measured tree coordinates, tree species and DBH the following indices will be calculated by the data centre after data submission: Clark Evans Index (see Chapt. 5.6), Pilou Index (see Chapt. 5.7), Contagion Index (see Chapt. 5.8), Mingling Index (see Chapt. 5.9), Diameter differentiation (see Chapt. 5.10), Standard deviation of DBH (see Chapt. 5.11), Shannon Index (see Chapt. 5.12), Simpson Index (see Chapt. 5.13). If enough tree height measurements are available, also the species profile index can be calculated (see Chapt. 5.14).

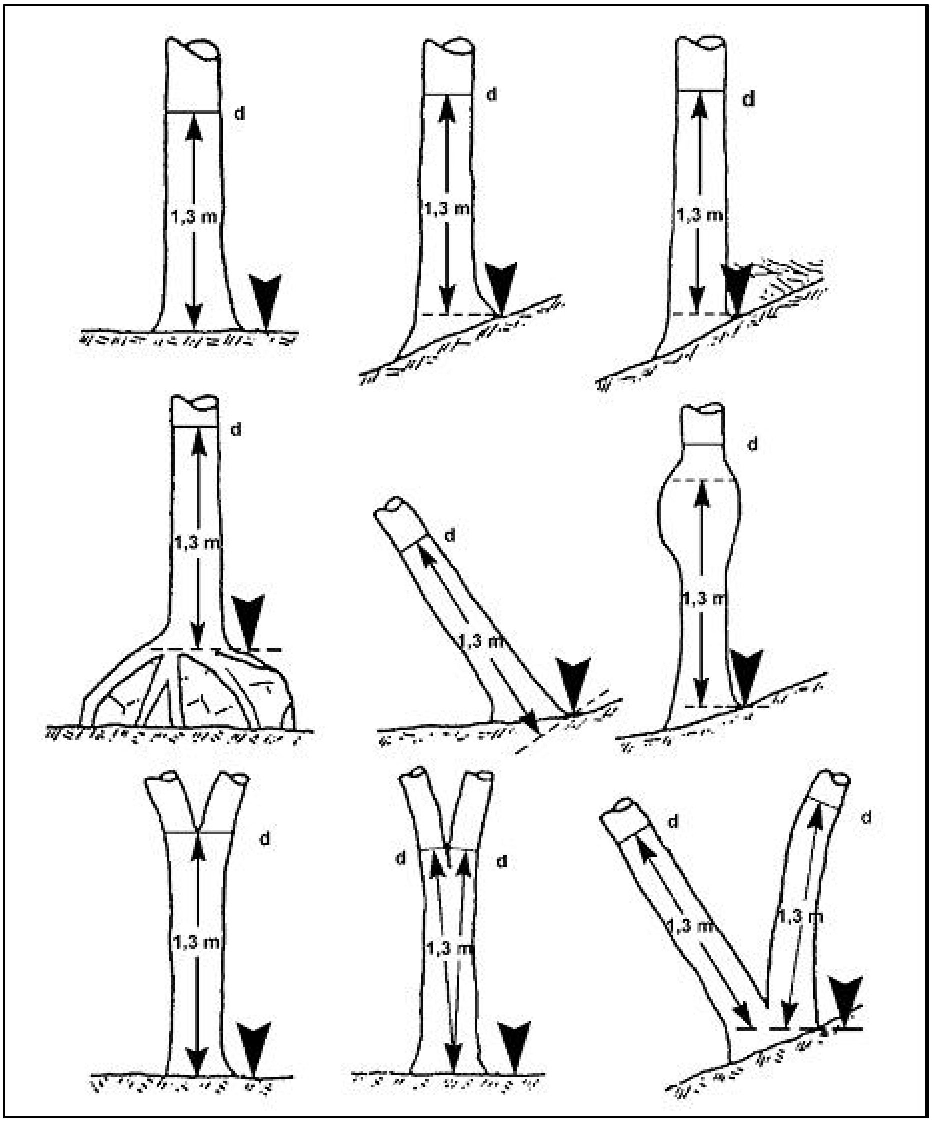


Figure 2: Measurement of DBH (from: Bundesministerium der Justiz, 2000)

4.8. Structural group of four assessments (DBH > 5 cm)

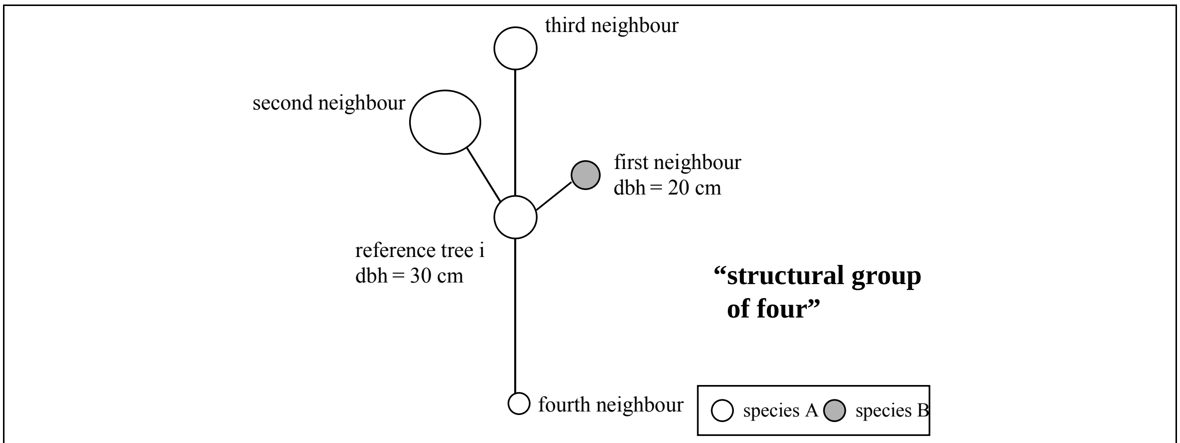
survey unit: crosspoints.

sampling rule: If no tree coordinates are known, and the number of trees with DBH > 5 cm is > 300 per 0.25 ha clustered field sampling of “structural group of four” can be carried out instead of coordinate measurement and after consultation with the data centre. It includes only trees with DBH > 5cm. In these cases however all trees of the plot must be registered nevertheless (tree number, species, DBH of the standard Level II data bank can be used).

inventoried attributes: Samples of 4 clustered “structural groups of four” (see Fig. 3 and 4) are placed at 9 – 12 crosspoints of the grid-network. This amounts to 4 clusters and maximally 16 sample trees per crosspoint. Multiple measurements of the same trees do not affect the independence of the samples (Hui and Albert 2004).

The field assessment is carried out as follows:

- the four nearest neighbours to the crosspoint are defined (reference trees)
- the four nearest neighbours to each reference tree are defined
- the dbh of the first neighbour is determined
- species and angle > standard angle of all four neighbours are determined



attribute of stand structure	calculated example	interpretation for i	number of neighbours
species mingling	$M_i = \dfrac{0+0+0+1}{4} = 0.25$	one of the four neighbours is of a different species	4
dbh-differentiation	$T_{i1} = 1 - 20/30 = 0.33$	reference tree 33% larger than neighbour 1	1
contagion	$W_i = \dfrac{1+1+0+0}{4} = 0.5$	two of the angles between the 4 neighbours and the reference tree are smaller than the standard angle (random arrangement)	4

Figure 3: Inventory method “structural group of four”. For the formulas see Chapt. 5. For calculating the species mingling, three neighbours are considered, for the dbh-differentiation one neighbour is needed as a minimum and for the contagion, four neighbours are required (from: Pommerening 2002, after Albert and Gadow, 1998).

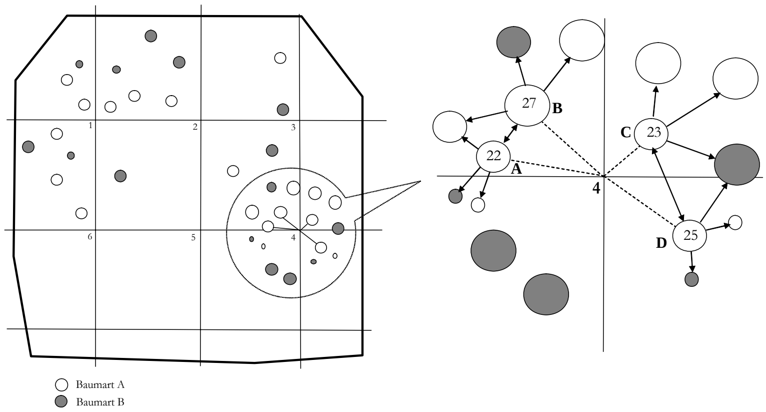


Figure 4: Design of a clustered assessment of a "structural group of four". Trees A – D are the four nearest neighbours to the reference point 4. A regular "structural group of four" sample is taken from all four trees (adapted from Hui & Albert 2004).

calculation of diversity indices:
Based on the "structural group of four assessments" the following indices will be calculated by the data centre after data submission: Contagion Index (see Chapt. 5.8), Mingling Index (see Chapt. 5.9), Diameter differentiation (see Chapt. 5.10).

Based on the Standard Level II data (tree number, species DBH of all trees) the following indices are calculated: Standard deviation of DBH (see Chapt. 5.11), Shannon Index (see Chapt. 5.12), Simpson Index (see Chapt. 5.13).

If enough tree height measurements are available, also the species profile index can be calculated (see Chapt. 5.14).

An example for calculations is given in the Annex.

5. Formulas

5.1. Volume equations/tables

Volumes of dead trees (standing or downed) is estimated by standard two-way equations or tables (*V = f (DBH, height, species)*). If available, the use of volume equations/tables adopted by National Forest Inventory is recommended.

5.2. Huber's formula

$$v = \frac{\pi}{4} d^2_{0.5l}\, l \qquad [1]$$

where: v = volume; $d_{0.5l}$ = diameter at half length; l = length.

5.3. Formula for estimating the volume of a stump

$$v = \frac{\pi}{4} d^2 h \qquad [2]$$

where: v = volume; d = diameter at the level where the tree was cut; h = height.

5.6 Clark Evans Index (Clark and Evans, 1954).

This index gives the relation between measured and expected distance to the nearest neighbour. It is a measure for regular or clustered horizontal distribution. A clustered distribution will give values below 1 whereas a complete hexagonal distribution produces the maximum value of 2.15.

$$CE = \frac{\text{observed mean distance between neighbour trees}}{\text{expected mean distance between neighbour trees}} = \frac{\frac{1}{n}\sum_{i=1}^{n} r_i}{0{,}5\sqrt{10000/N}} \qquad [5]$$

with r_i = distance of tree $_i$ to next neighbour
N = number of trees per ha
n = number of sample trees

5.7 Pilou Index for non-randomness (Pielou, 1959).

This index gives the average distance from random sample points to the nearest tree. Values above 1 indicate a clustered distribution, whereas lower values a regular distribution. The information derived should be comparable to the Clark Evans Index.

$$PI = \pi \frac{n}{A} \frac{1}{k} \sum_{1}^{k} r_i^2 \qquad [6]$$

with n = stem number per plot
A = plot area
k = number of sample points
r_i = distance from sample point to nearest tree

5.8 Contagion Index (Gadow et al. 1998)

The 'contagion variable' or 'neighbourhood pattern' defines the degree of regularity of the distribution of tree positions in a forest. Unlike e.g. the index of Clark and Evans it is a single tree parameter. Assuming complete regularity of the positions of the *n* nearest neighbours around a reference tree *i*, the expected standard angle α_0 between two neighbours would be equal to 360°/n. For example $\alpha_0 = 90°$ in a constellation involving four neighbours. Each pair of nearest neighbours shares two angles summing up to 360° with the α angle being defined as the smaller one of the two. The contagion is defined as the proportion of α angles < 90° between n=4 trees around a reference tree.

$$W_i = \frac{1}{4}\sum_{1}^{4} w_j \qquad [7]$$

with $w_i = 1$ if α angle j < 90°

$w_i = 0$ otherwise

5.9 Mingling Index (Gadow and Füldner, 1995)

This index describes the probability that none of the three nearest trees belongs to the tree species of the centre tree. Index values are possible between 0 and 1. High values point to single tree wise mixtures and values close to 0 indicate group wise occurrences of a certain tree species. Indices are calculated for single trees and can then be aggregated for single tree species on a plot.

$$MI_i = \frac{1}{3}\sum_{j=1}^{3} v_{ij} \qquad [8]$$

with $v_{ij} = 0$ in case that neighbour $_j$ belongs to same species and

$v_{ij} = 1$ in case that neighbour $_j$ belongs to same species.

5.10 Diameter differentiation (Gadow and Füldner 1995)

This index is based on the ratio between the thinner and thicker dbh of two neighbouring trees. Index values are possible between 0 and 1. High values point to bigger differences in dbh of neighbour trees, whereas values close to 0 indicate a low diameter differentiation.

$$T = \frac{1}{n}\sum_{i=1}^{n}(1 - r_i) \qquad [9]$$

with r_i = (thinner dbh)/(thicker dbh) of tree pair $_i$

n = number of measured tree pairs

5.11 Standard deviation of dbh

This is computable from already available Level II data sets. The measure has been shown to be a strong index for horizontal stand structure by Neumann and Starlinger (2001).

5.12 Shannon index of diversity (Shannon, 1948).

The Shannon index is an ecological standard measure for diversity. It can be calculated based on the Level II data set by proportion of stem numbers or basal area.

$$SH = \sum_{i}^{N}(-\log_2 \pi_i)\pi_i \qquad [10]$$

with: π_i = relative abundance of the *i*th species

N = number of species

5.13 Simpson index of diversity (Simpson, 1949)

It can be calculated based on the Level II data set by proportion of stem numbers or basal area. It can be calculated based on the Level II data set by proportion of stem numbers or basal area.

$$SI = \sum_{i}^{N} (1 - \pi_i)\pi_i \qquad [11]$$

with: π_i = relative abundance of the *i*th species

N = number of species

5.14 Species profile index (Pretzsch 1996)

This index is a Shannon index calculation for the proportion of trees in different stand layers. For the calculation the forest stand under study is subdivided into three different vertical height bands:

band 1: 100 - 80 % of maximal tree height (h_{max})
band 2: 80 - 50 % of h_{max}
band 3: 50 - 0 % of h_{max}

Each tree is classified into one of the three bands according to the height of its tip. For each band *j* the relative frequency p_{ij} of each species *i* is calculated in terms of the total number of trees N in the stand:

$$p_{ij} = \frac{n_{ij}}{N} \qquad [12]$$

with n_{ij} = number of trees of species *i* in height band *j*

The species profile index A is then calculated as:

$$A = -\sum_{i=1}^{S} \sum_{j=1}^{B} \begin{cases} p_{ij} \cdot \ln p_{ij} & if \quad p_{ij} > 0 \\ 0 & otherwise \end{cases} \qquad [13]$$

with S = number of different tree species

B = number of height bands = 3

The maximal possible A value varies according to tree species and bands. It can be calculated as

$A_{max} = \ln(S*B)$

In order to compare different stands a relative A value is calculated according to

$A_{rel} = A / A_{max}$

As the index requires labour intense measurements of all tree heights an alternative to be discussed is the measurement of a few tree heights as cardinal points in the stand and subsequently the assignment of each tree to the three bands through estimate via height curves or tree wise estimate in the stand.

Rare species contribute to the index over-proportionally. The value of the index increases the more species occur and the more equally they are distributed over the three height bands. The maximal value of A, A_{max}, depends on the number of species S and the number of height bands.

5.15 Estimation of lying deadwood and stumps at plot level

Lying deadwood and stump volume figures estimated from each of the four subplots can be averaged to provide the statistics at the plot level.

If X_i is the volume figure (in m^{3}ha^{-1}) estimated on the i-th subplot, then the averaged overall value at the plot level (X_{pp}, in m^{3}ha^{-1}) is equal to

$$X_{pp} = \frac{1}{4}\sum_{i=1}^{4} X_i \qquad [14]$$

with a variance ((m^{3}ha^{-1})^2) equal to

$$s^2_{X_{pp}} = \frac{\sum_{i=1}^{4}\left(X_i - X_{pp}\right)^2}{12} \qquad [15]$$

5.16. Estimation of total deadwood volume at plot level

Total deadwood volume at plot level (TV_{dead}, in m^{3}ha^{-1}) is equal to the sum of volumes from standing deadwood (V_{st_tr}, see § 4.3), dead downed trees (V_{down_tr}, see Chapt. 4.4), lying deadwood pieces (V_{lying}, see Chapt. 4.5 and 5.15) and stumps (V_{stump}, see Chapt. 4.6 and 5.15).

TV_{dead} can be considered as the sum of true measured values (i.e., standing deadwood and downed tree deadwood) and values estimated by sampling (i.e., lying deadwood and stumps). Assuming no covariance between V_{lying} and V_{stump}, the standard error (in m^{3}ha^{-1}) of TV_{dead} is equal to

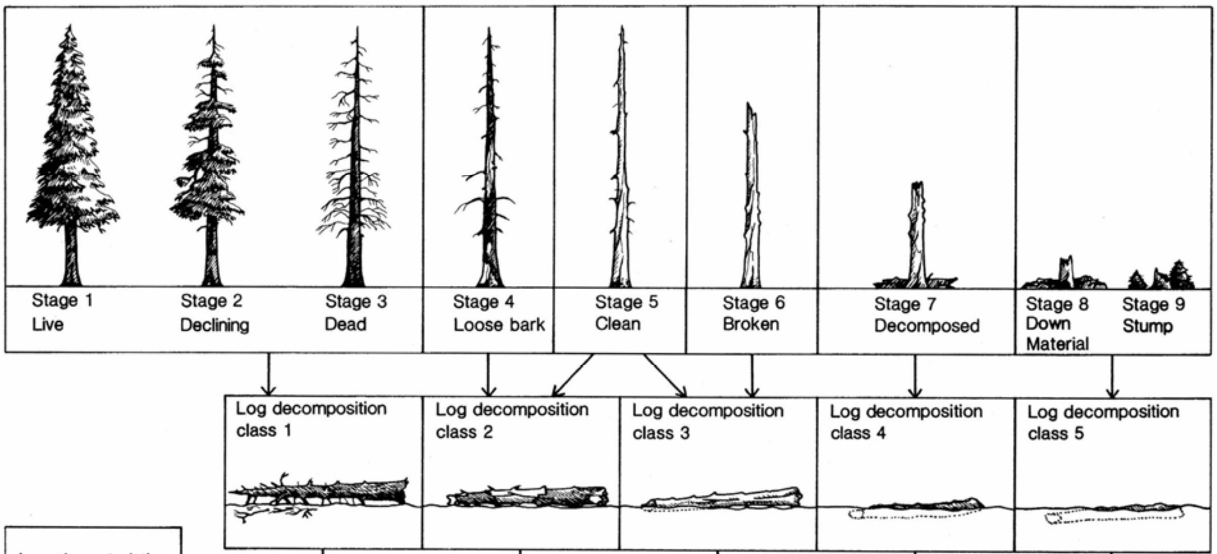
$$s_{TV_{dead}} = \sqrt{s^2_{V_{lying}} + s^2_{V_{stump}}}$$

where $s^2_{V_{lying}}$ and $s^2_{V_{stump}}$ are, respectively, the variances of V_{lying} and V_{stump}, estimated according to formula [15] (see Chapt. 5.15).

Deadwood volume with a diameter > 10 cm and 5 – ≤ 10 are reported separately.

6. Decay assessment

Decay levels are assessed according to the five decomposition classes following Figure 6.



Log characteristics	Log decomposition class 1	Log decomposition class 2	Log decomposition class 3	Log decomposition class 4	Log decomposition class 5
Bark	intact	intact	trace	absent	absent
Twigs < 3 cm	present	absent	absent	absent	absent
Texture	intact	intact to partly soft	hard, large pieces	small, soft, blocky pieces	soft and powdery
Shape	round	round	round	round to oval	oval
Color of wood	original color	original color	original color to faded	light to faded brown or yellow	faded to light yellow or gray
Portion of log on ground	log elevated on support points	log elevated but sagging slightly	log is sagging near ground	all of log on ground	all of log on ground

Figure 6: Decay classes following Hunter (1990)

7. References

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Annex

Description of inventory method structural group of four and examples of applied indices (from Pommerening 2002)

Table 2: Forest yield data of the stands Manderscheid 198, Manderscheid 187 and Ammeloe 14e. In the schematic pictures beech trees appear white, oaks dark grey, Douglas firs light grey and Scots pine black. B.area = basal area per hectare [m^2], N number of trees per hectare, Vol = volume per hectare [m^3]

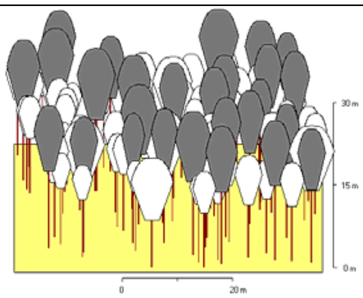
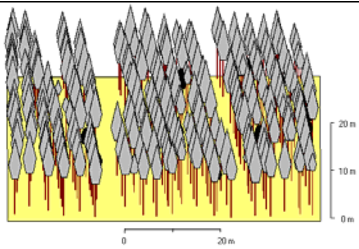
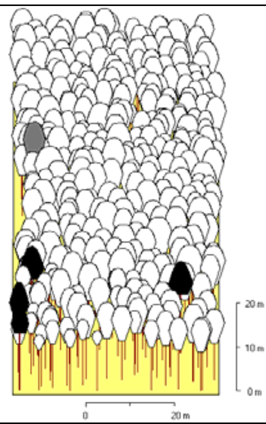
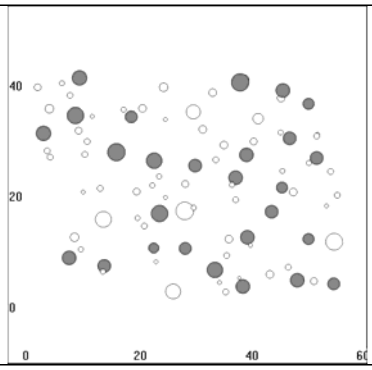
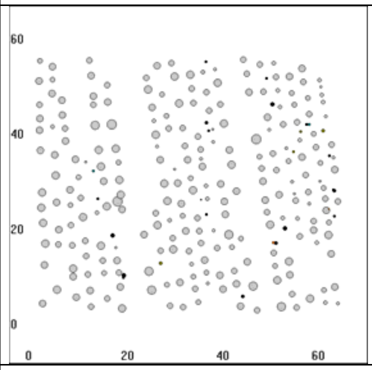
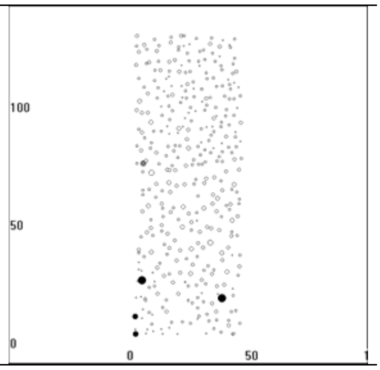
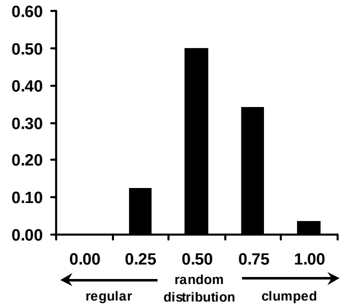
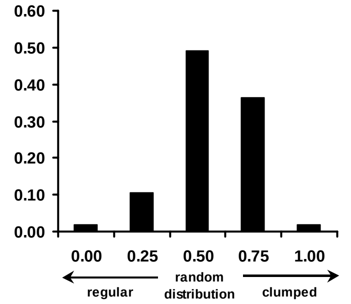
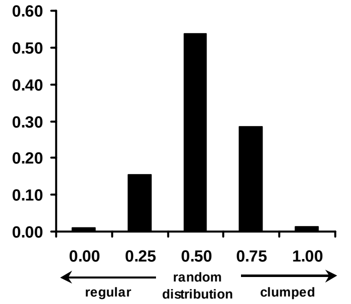
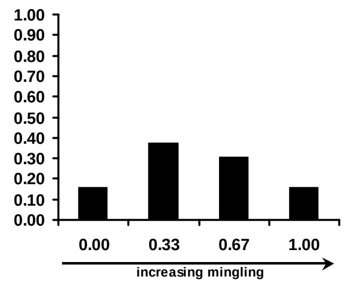
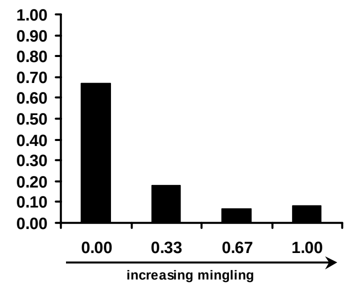
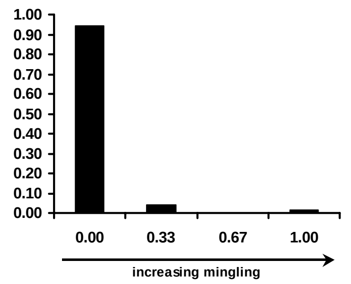
compartment	Manderscheid 198				Manderscheid 187				Ammeloe 14e			
schematic picture												
survey	1996				1996				1996			
natural production		B. area	N	Vol		B. area	N	Vol		B. area	N	Vol
	Oak	16.31	112	293.86	Doug. Fir	27.30	660	246.86	Beech	18.76	546	211.14
	Beech	10.95	253	140.64	Scots pine	0.53	53	2.86	Oak	0.21	3	3.03
	-	-	-	-	Other	0.20	23	0.69	Scots Pine	1.07	6	13.72
	Total	27.26	365	434.5	Total	28.03	736	250.41	Total	20.04	555	227.89
age	118 years				24 years				53 years			
area	0.24 ha				0.36 ha				0.65 ha			

Table 3: A quantitative description of the structure of the three sample stands by means of variables and correlation functions. The label of the ordinates of contagion, mingling and T1 distributions is relative frequency. The label of the ordinates of the correlation functions is correlation. In the square plots beech trees appear white, oaks dark grey, Douglas firs light grey and Scots pine black

compartment	Manderscheid 198	Manderscheid 187	Ammeloe 14e
square plots			
Clark &Evans	**1.0073**	**1.3508**	**1.2481**
contagion	**0.5710**	**0.5646**	**0.5342**
Shannon	**0.6165**	**0.4249**	**0.0997**
mingling	**0.4886**	**0.1888**	**0.0307**
T1	**0.4173**	**0.2495**	**0.2145**
contagion distribution			
mingling distribution			
T1 distribution (=diameter diffentiation)