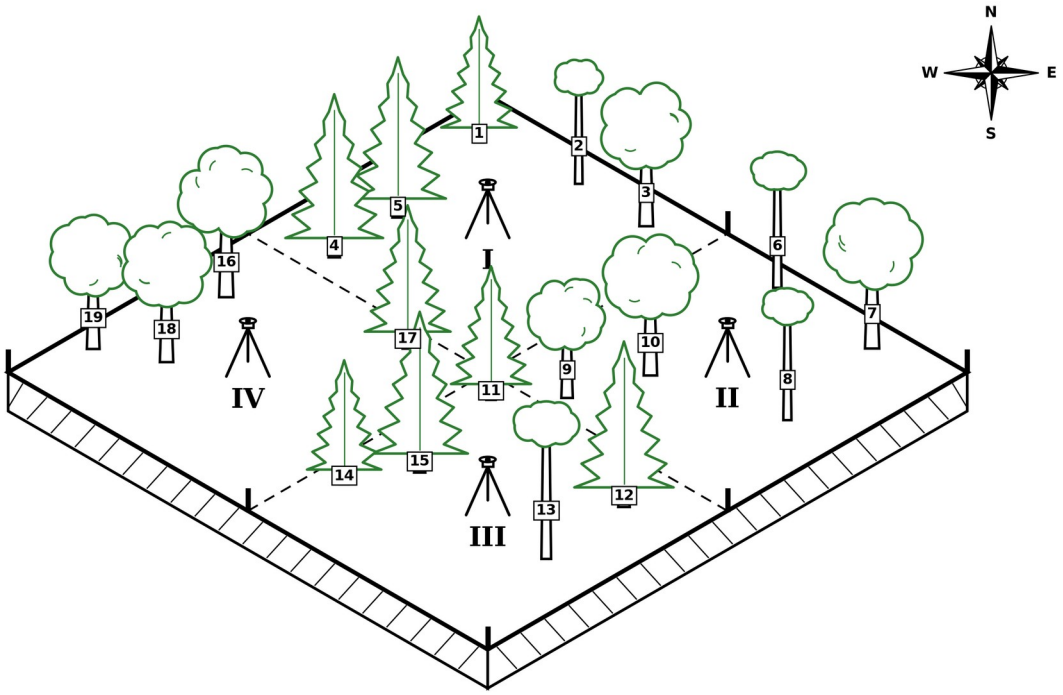
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GUIDE TO ESTABLISHING MARTELOSCOPES



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This guide was developed within the project “From Crisis to Resilience with Close-to-Nature Forest Management in Ukraine”, implemented with the financial support of the VELUX STIFTUNG foundation (Switzerland). It aims to introduce a unified methodology for establishing marteloscopes in Ukraine. It sets out the sequence of work involved in establishing a marteloscope, including site selection, plot layout, permanent marking of points in the field, tree numbering, georeferencing of trees, panoramic photography, office processing and data verification, as well as subsequent plot maintenance. The guide is intended for specialists of forest enterprises, academic staff and students in specialty H4 “Forestry”, as well as for researchers. Recommended for publication by the Academic Council of the Research Institute of Forestry and Ornamental Horticulture, NUBIP of Ukraine (minutes No. 7 of 12.10.2026).

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INTRODUCTION

Today, silvicultural practice is shifting from the management of large forest tracts towards the management of individual stands and towards silviculture focused on individual trees. This approach is consistent with the principles of close-to-nature forest management and with European standards, in particular the New EU Forest Strategy for 2030 and the guidelines of the Forest Europe process. The conservation of forests and their resilience to climate change and the consequences of war depend to a large extent on which tree a forester selects for felling and which one is left to grow. Different specialists assess the same stand differently, lacking a tool for a clear comparison of results. Marteloscopes help to solve this problem: they are special demonstration forest plots on which every tree has been measured, numbered and mapped. The marteloscope concept originated in France and was further developed in the European Integrate network coordinated by the European Forest Institute (EFI). Thanks to digital tools (the MSC Mobile app and the martelage.sylvotheque.ch platform), foresters and researchers can perform virtual tree selection and marking on a tablet or smartphone and immediately see the consequences of their decisions: how the growing stock, economic return and biodiversity indicators change.

This guide was prepared within the project “From Crisis to Resilience with Close-to-Nature Forest Management in Ukraine” with the support of the VELUX STIFTUNG foundation. It combines the approaches of EFI, the experience of the Bern University of Applied Sciences (BFH-HAFL) and the national rules of forest mensuration. The guide provides a step-by-step work procedure: from selecting and laying out the plot to measuring trees, creating spherical panoramas and verifying data. It is intended for forestry practitioners, teachers, researchers and students of forestry programmes.

1. GENERAL PROVISIONS

1.1. The concept of a marteloscope

A marteloscope is a demonstration forest plot on which all trees have been numbered, mapped and described by their main mensuration parameters (Kraus et al., 2018). A digital model is created for such a plot, in which the coordinates, tree species, diameter, height, condition and other characteristics are recorded for each tree. These data are entered into purpose-built software (https://martelage.sylvotheque.ch). The software makes it possible to carry out virtual selection of trees for felling directly in the stand and to assess immediately the economic and ecological consequences of the decisions made. A marteloscope thus combines field observation with digital tools for analysing and visualising forest stands.

The term "marteloscope" derives from the French "*martelage*" (marking, selection of trees for felling) and the Ancient Greek "skopein" (to look at, to examine). The marteloscope as a tool for studying foresters' behaviour during tree selection was first proposed in France by the Association Futaie Irrégulière (AFI) and AgroParisTech-ENGREF (Nancy) (Bruciamacchie et al., 2005; Pommerening et al., 2018). The concept was subsequently developed within the Integrate+ project and the European marteloscope network Integrate Network, coordinated by the European Forest Institute (EFI).

A classic marteloscope is a plot measuring 100 × 100 m, i.e. 1 ha in area, although its area may differ if necessary. Such plots are established in representative forest types so that they reflect the properties of a given stand as fully as possible. The location is chosen according to the training objective, for example increasing stand productivity, conserving biodiversity, developing mixed forests, etc.

A marteloscope is designed for simulating various silvicultural interventions: thinnings, final (regeneration) fellings, conversion fellings, etc. Complete data on every tree allow participants to carry out tree-selection exercises. After an exercise, they compare their decisions and assess their consequences for the structure, productivity and ecological condition of the stand. A marteloscope differs from an ordinary sample plot primarily in that it is a training plot where no trees are felled and all decisions remain virtual. The same plot can therefore be used for many years with different groups of trainees, each time comparing their approaches. This makes it possible to develop practical silvicultural decision-making skills under real conditions without harming the forest.

1.2. Tree inventory parameters and plot characteristics

The set of parameters recorded on a marteloscope follows the methodology of the European marteloscope network Integrate+ (Kraus et al., 2018) and the Swiss BFH-HAFL methodology for establishing permanent training plots (BFH-HAFL, 2022). For each tree, its location, species, condition, diameter at breast height (1.3 m), height, stem quality and the presence of tree-related microhabitats are recorded. These data make it possible to

assess both the economic and the ecological value of each tree, which is the basis of tree-selection training exercises. In addition, the social position of the tree in the stand is determined, as it is a key indicator in tree-selection training. Furthermore, information on site conditions and the mensuration characteristics of the stand is collected for the plot as a whole. The parameters recorded for individual trees and for the plot are listed in Tables 1.1 and 1.2.

Table 1.1

Parameters of an individual tree

Parameter	Purpose
Tree number	Identification of the tree in the field and in the database
Tree location (azimuth and distance from the measurement point)	Tree location mapping, analysis of the spatial structure of the stand
Tree species and condition (living/standing dead)	Stand composition, calculation of growing stock and ecological value
Diameter at breast height (1.3 m)	Distribution of trees by diameter classes, calculation of volume and economic value; trees with a diameter of 8 cm or more are recorded
Tree height	Volume calculation, assessment of tree stability
Stem quality	Assessment of the economic value of the tree
Tree-related microhabitats (cavities, injuries, dead branches, fungal fruiting bodies, etc.)	Assessment of the ecological value of the tree
Social position of the tree in the stand	Position of the tree in the vertical structure of the stand

Table 1.2

Plot and stand parameters

Parameter	Purpose
Plot description	Location, topography, forest site type, soil, climatic indicators
Stand mensuration characteristics	Composition, age, stocking, top height, management history

Parameter	Purpose
Increment	Projection of stand development before and after virtual tree selection
Timber prices	Calculation of the economic value of trees

2. FIELD WORK

2.1. Selecting a site for the marteloscope

A marteloscope is established in a stand that is representative of the region or forest enterprise in terms of species composition, age structure, forest site type and management system. The stand must suit the training objective (thinnings or final fellings, development of uneven-aged stands, selection of seed trees, etc.) so that tree selection becomes a subject of well-founded professional discussion. Preferably, the stand should be mixed and contain trees of different sizes, with varying stem quality and with tree-related microhabitats.

For the period of its use, the plot should remain free of management interventions, or any such intervention must be consistent with the purpose of the marteloscope (for example, promoting natural regeneration, developing high-value stems, etc.). No activities unrelated to forest management (for example, road construction) should be planned on the plot. The establishment of a marteloscope is agreed with the permanent forest user so that the plot is taken into account in management planning. The plot must be accessible for a group of 15–20 people, safe (free of hazardous dead trees and hanging branches along the routes of movement) and located on a slope not steeper than 20–25°, since measurements and the movement of the group become difficult on steeper slopes. Preferably, the plot should be located near a road, which makes it easier for groups to reach the training sessions.

2.2. Plot parameters

A standard marteloscope of the European Integrate+ network has an area of 1 ha and the shape of a 100×100 m square (Kraus et al., 2018). This size ensures comparability of data with other plots of the network. Where possible, the plot sides are oriented along the north–south axis, and the plot is divided into four 50 × 50 m squares numbered clockwise, starting from the north-west. In homogeneous stands, other plot sizes and shapes are acceptable (for example, a 125×80 m rectangle or a 50×50 m square), but the shorter side of the plot must not be less than the top height of the stand.

Before the layout, the plot is inspected to ensure that its boundaries do not cross roads, rides, watercourses or the boundaries of stands of a different type. At the same stage, the number of trees is estimated by eye: at medium stocking there are usually 300–600 trees per hectare with a diameter of 8 cm or more. The time required for field work depends on this number.

2.3. Materials and equipment

The instruments and tools required for establishing marteloscopes are listed in Table 2.1, and consumables and auxiliary equipment in Table 2.2.

Table 2.1

Instruments and tools

Instrument, tool	Purpose
Compass on a tripod	Plot layout, measuring the azimuth to each tree
Ultrasonic or laser hypsometer-rangefinder	Measuring tree heights and horizontal distances
Measuring tape (20 m or 50 m)	Laying out plot boundaries, measuring distances
Calliper, diameter tape	Measuring tree diameters
GNSS receiver or smartphone	Determining the coordinates of the plot centre and corners
Camera with tripod and panoramic head	Panoramic photography of the plot

Table 2.2

Consumables and auxiliary equipment

Material, equipment	Purpose
Ranging poles	Temporary marking of points during layout
Stakes or metal profiles	Permanent marking of corners, square centres and the plot centre
Spray paint (white and signal colours)	Tree numbering, marking the diameter measurement point, stakes and reference points
Wire brush, bark scraper, chalk	Preparing the surface for the number, marking recorded trees
Field form sheets or field tablet	Recording inventory data on the field form (Appendix 1)
Field guide to tree-related microhabitats, stem quality class scale	Identification of microhabitats and assessment of stem quality (Bütler et al., 2024)
High-visibility vests, first-aid kit	Occupational safety of the crew

2.4. Organisation of work

Field work is carried out in successive stages: plot layout, permanent marking of points, tree numbering and measurement, georeferencing of trees, height measurement, and assessment of stem quality, social position of trees and tree-related microhabitats. Each stage is completed in full within one part of the plot (a square or an inventory sector measured from one measurement point) before moving on to the next. The approximate number of crew members is given in Table 2.3.

Table 2.3

Number of crew members by work stage

Work stage	Minimum number of people	Recommended
Plot layout in the field	2	3
Permanent marking of points	2	3
Tree numbering, species identification, measurement of tree mensuration parameters, georeferencing of trees	3	4
Assessment of stem quality, identification of tree-related microhabitats	2	2

In a four-person crew, member 1 paints the tree numbers and marks the 1.3 m height with a line; member 2 moves from tree to tree with the transponder (or reflector) and a survey pole; member 3 operates the instruments (compass, rangefinder, etc.) at the centre of the 50 × 50 m square; member 4 keeps the records and checks the sequence of tree numbers and measurement results to avoid accidental errors. In a three-person crew, the roles of the person measuring from the centre and the person keeping records can be combined. The assessment of stem quality and microhabitats should be entrusted to the most experienced crew member; it is usually done by the person who approaches each tree with the transponder or pole. Tree heights and other parameters are measured after the main work cycle has been completed; if enough instruments are available, all crew members may measure heights, but only one person keeps the records.

2.5. Plot layout

The plot is laid out using an instrument for measuring horizontal angles (azimuths), such as a compass, and a tool for measuring distances (a digital rangefinder or measuring tape), together with ranging poles and stakes, in the following sequence:

1) estimate by eye (for example, by pacing) whether the plot fits within the stand;

2) lay out the outer boundaries of the plot by azimuth, with 90° interior angles, placing ranging poles every 50 m;

3) lay out the internal boundaries between the squares, also placing ranging poles every 50 m;

4) after checking the layout, replace the ranging poles with permanent stakes; paint the perimeter stakes in a bright colour;

5) locate the square centres at the intersection of their diagonals, 35.36 m from the corners (for a 50×50 m square), and mark them with stakes (Fig. 1).

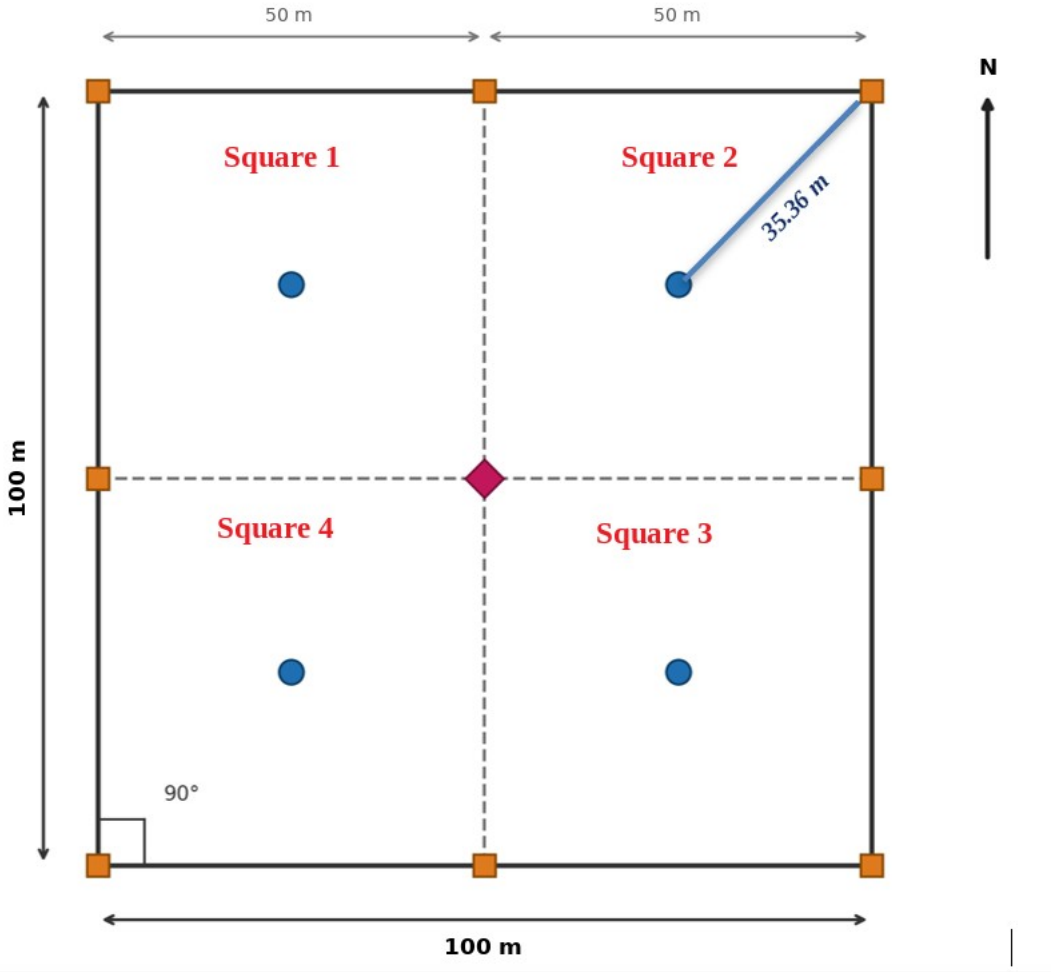


Figure 1. Layout scheme of a 1 ha marteloscope

The accuracy of the layout is checked by measuring the diagonals of the squares: in a correctly laid-out square they are equal (35.36 m). If the diagonals differ noticeably, the boundaries are corrected or laid out again. On slopes, all distances are set out as horizontal distances; otherwise the actual plot area will be smaller than intended. If the tape cannot be held horizontally, the distance is measured along the ground surface with a slope correction (Appendix 2).

The plot can also be laid out from the centre. This method is used when trees are inventoried from the centre and the corners without division into squares, and also for laying out a single square. The corners are set by polar coordinates from the centre: an azimuth and a horizontal distance equal to half the diagonal of the square (35.36 m for a 50×50 m square; 70.71 m for 100×100 m). The general sequence of work is shown in Fig. 2.

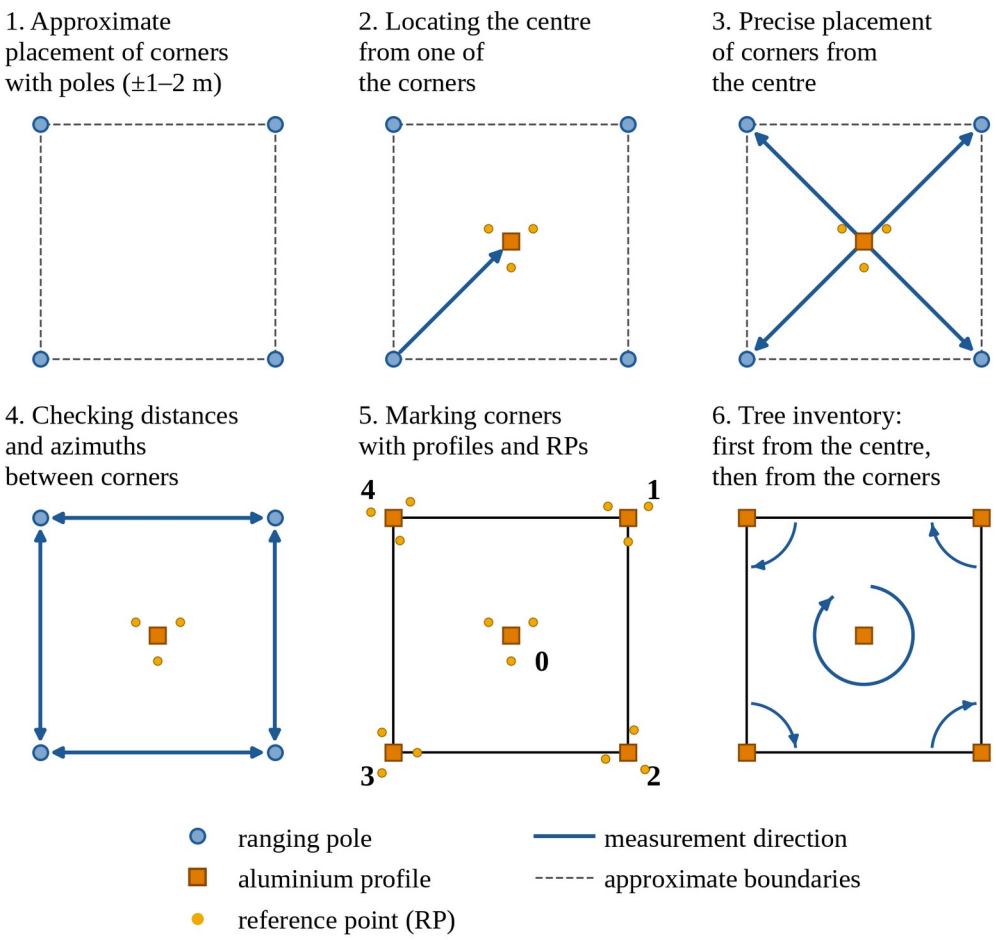


Figure 2. Sequence of plot layout from the centre by azimuths and distances

Layout from the centre is carried out in the following sequence:

1) mark the corners approximately with ranging poles (to within ±1–2 m), determining the direction with a compass and the horizontal distance with a tape (on a slope, with the correction given in Appendix 2);

2) set up the compass at one of the corners and determine the direction to the plot centre, which is at 45° to the side running from that corner;

3) in this direction, measure out a horizontal distance equal to half the diagonal and place a ranging pole at the plot centre;

4) refine the position of the centre, shifting it by 1–2 m if necessary: the centre must not be too close to a tree, and the sight lines from the centre to all corners must be clear;

5) mark the centre permanently with an aluminium (or other metal) profile, record its GNSS coordinates and their accuracy, and establish three reference points (Section 2.6);

6) determine the exact position of the corners by measuring half the diagonal of the square from the centre, with an angle of 90° between the directions to adjacent corners;

7) set up the tripod with the compass and transponder exactly above the centre profile and start the measurements.

For a 100×100 m plot, half the diagonal (70.71 m) exceeds the length of a standard 50 m tape, so it is measured in two segments via an intermediate ranging pole on the same azimuth.

2.6. Permanent marking of points in the field

The plot centre and corners are marked with U-shaped aluminium profiles driven flush with the ground surface to protect them from damage by machinery and removal by unauthorised persons. To allow each of these points to be relocated, three reference points (RP) are established for it. They are arranged in a triangle around the marked point on durable objects: at the root collar of trees that will persist for a long time, on rocks or large stones.

The marking spot is cleaned with a wire brush, and a spot of orange signal paint 10–12 cm in diameter is applied facing the marked point. For each RP, the azimuth from the point and the distance from the profile to the centre of the paint spot are measured to the nearest 1 cm, and its description is recorded: the tree number if the tree grows on the plot, or the species and diameter if it is outside the plot (Fig. 3).

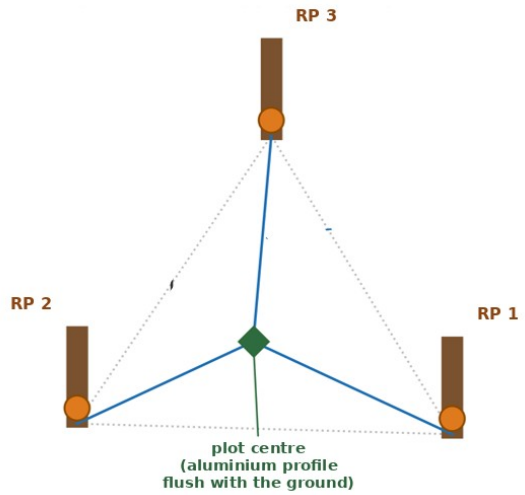


Figure 3. Referencing the centre with three reference points

2.7. Tree inventory procedure

All living and standing dead trees with a diameter at breast height (1.3 m) of at least 8 cm whose stem centre lies within the plot are recorded. Trees are inventoried by sectors, each from a measurement point (usually the centre of a square) to which all trees of the

sector are referenced (Fig. 4). If the plot has not been divided into squares, the inventory starts from the centre (all trees visible from the central point are recorded), after which the instrument is moved successively to corners 1–4 and the remaining trees that could not be recorded from the centre are measured.

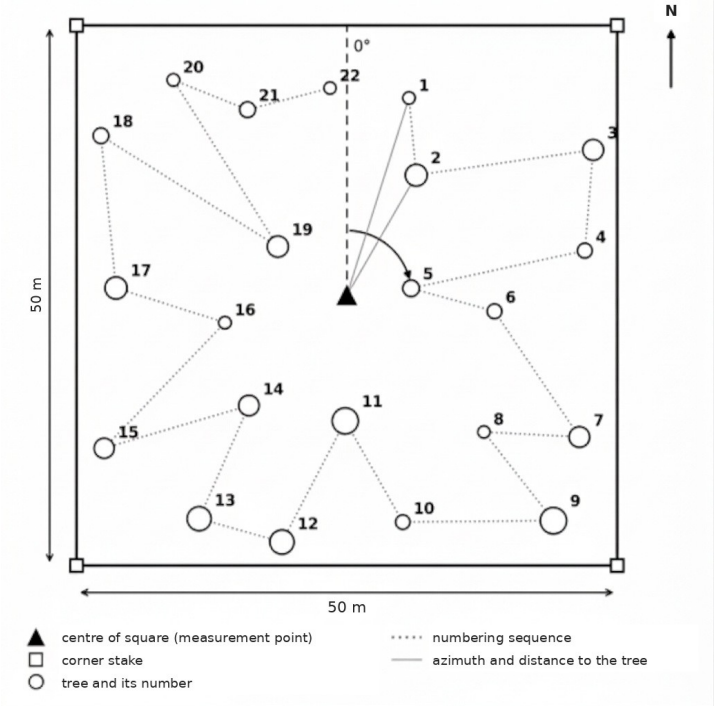


Figure 4. Order of tree numbering from the measurement point within a square

2.8. Tree numbering

Trees are numbered consecutively in the order of inventory, by increasing azimuth, starting from north (0°). The number is painted in white at eye level on the side facing the point from which the tree was recorded. The digits should be as small as possible but legible from a distance of 10 m or more. On thin stems they are written one below the other (Fig. 5). Bark covered with moss or lichens is first cleaned with a wire brush. To avoid missing a tree or recording it twice, the back of a recorded stem can be marked with chalk.



a) *b*) *c*)

Figure 5. Examples of painting a number on a stem: *a*) thick stem, number painted horizontally; *b*) thin stem, number painted vertically; c) number painted “around” the stem and not legible from a distance

2.9. Georeferencing of trees

The position of each tree is determined in polar coordinates, i.e. by the azimuth and the horizontal distance from the measurement point to the tree, which are converted into Cartesian coordinates during office processing. The distance is measured to the left edge of the stem (as seen from the measurement point), and the azimuth to the centre of the stem (Fig. 6). All crew members see the edge of the stem in the same way, so this method reduces discrepancies between measurements.

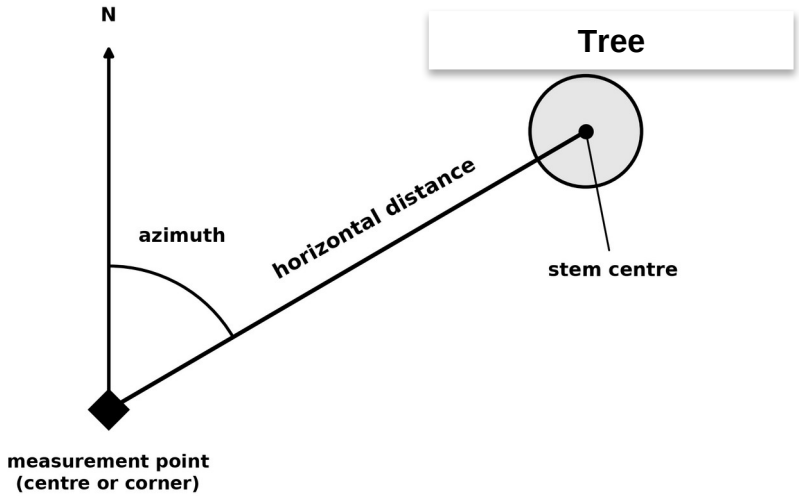


Figure 6. Scheme for measuring the azimuth and distance to a stem

The tripod with the compass and transponder is set up exactly above the centre or corner profile. The horizontal distance is measured with an ultrasonic or laser rangefinder to the nearest 1 cm, with the device held at the left edge of the stem; the height of the device above the ground does not affect the result. The azimuth is determined with the compass by sighting at the centre of the stem at a height of 1.3 m or at a pole placed in front of the stem. The tree number, azimuth and distance are entered on the field form.

2.10. Measurement of tree mensuration parameters

Measuring diameter at breast height (1.3 m)

Diameter is measured at 1.3 m above the root collar to the nearest 0.5 cm. Two mutually perpendicular diameters are measured on each tree: the first with the calliper pointing towards the measurement point, the second perpendicular to it. Both values are entered on the form, and their mean is calculated during office processing. Diameter can also be determined from the stem circumference measured with a tape, converted during office processing using the formula:

$$d = C / \pi, \quad (2.1)$$

where d is the diameter, cm; C is the stem circumference at 1.3 m, cm; π ≈ 3.1416.

Rules for measuring diameter in difficult cases are shown in Figure 7 (Düggelin et al., 2020).

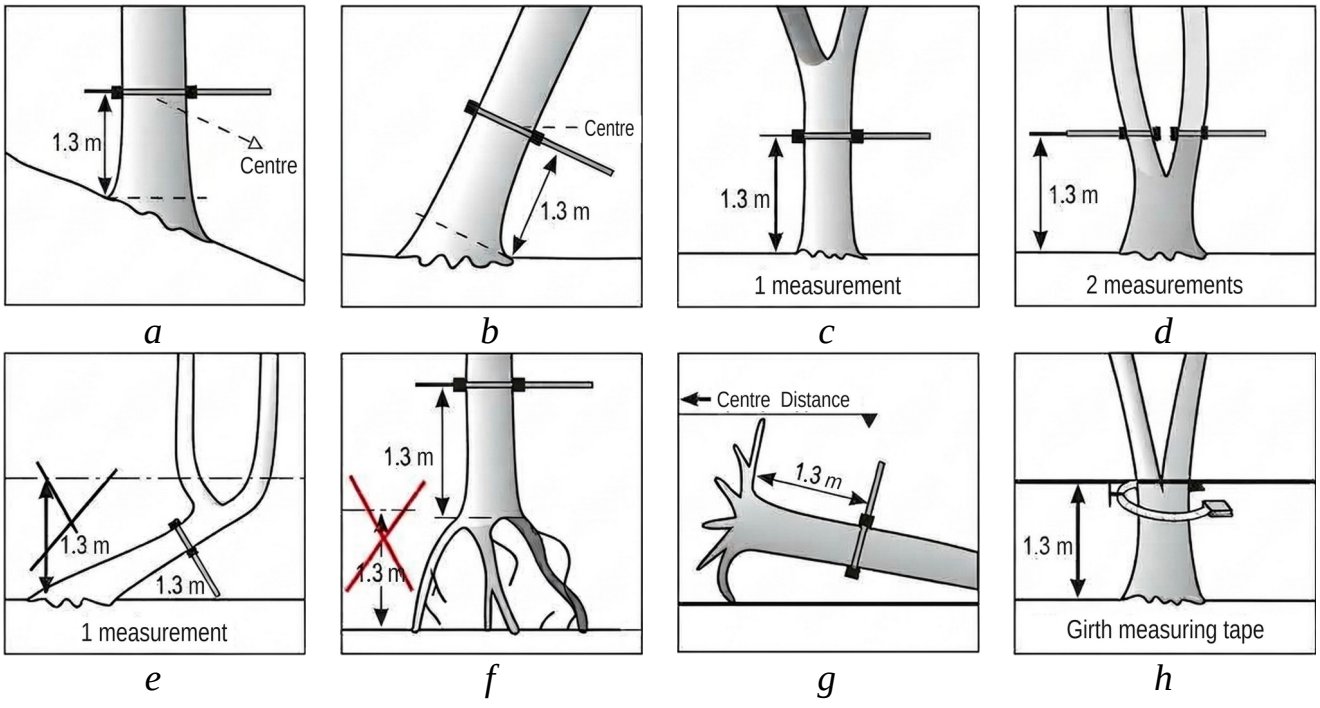


Figure 7. Rules for measuring diameter at 1.3 m in difficult cases: *a* – tree on a slope (1.3 m is measured from the uphill side); *b* – leaning tree (1.3 m is measured along the stem axis, and the calliper is applied perpendicular to the axis); *c* – fork above 1.3 m (one measurement); *d* – fork below 1.3 m (each stem is measured as a separate tree); *e* – stem curved at the base (1.3 m is measured along the stem); *f* – tree with high buttress roots (1.3 m is measured from where the buttresses merge into the stem); *g* – living fallen tree (1.3 m is measured along the stem from the root collar); *h* – fork at 1.3 m (diameter is determined below the fork by girth measurement)

If a swelling, burl or branch occurs at the measurement point, the diameter is measured above and below the defect and the mean is calculated.

The diameter measurement point is marked with a painted line. During the repeat inventory, carried out every 5–10 years, the diameter is measured at the same point, which makes it possible to determine the actual increment.

Measuring tree height

Tree height is measured with an ultrasonic or laser hypsometer (or another available instrument) to the nearest 0.1 m. The height measurement scheme is shown in Figure 8. When measuring, sight precisely at the top of the tree rather than at a side branch; otherwise the height will be underestimated.

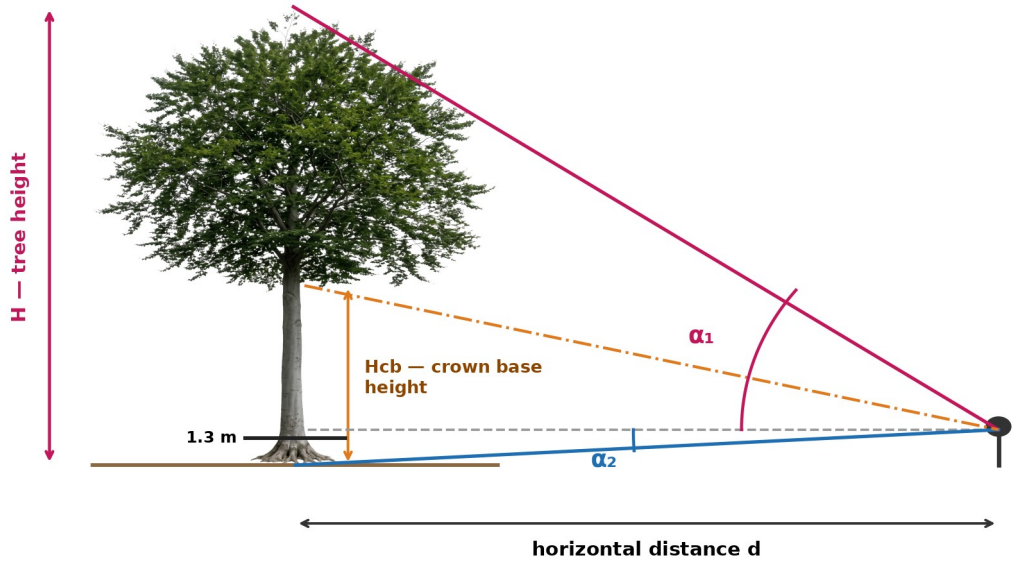


Figure 8. Scheme for measuring tree height

Measuring the height of every tree is labour-intensive, and the height of some trees is difficult to determine; it is therefore acceptable to measure the height of 15–30 trees of each species, distributed proportionally across diameter classes, with most trees selected in the central diameter classes and fewer in the extreme ones (for example, 15 trees can be distributed across diameter classes as follows: 1, 2, 3, 3, 3, 2, 1). From these data a height curve is constructed, which is used to determine the height of the remaining trees from their diameter at 1.3 m. The more trees are measured, the more accurate the height curve. Height curves are constructed separately for each tree species. An example of a height curve is shown in Figure 9.

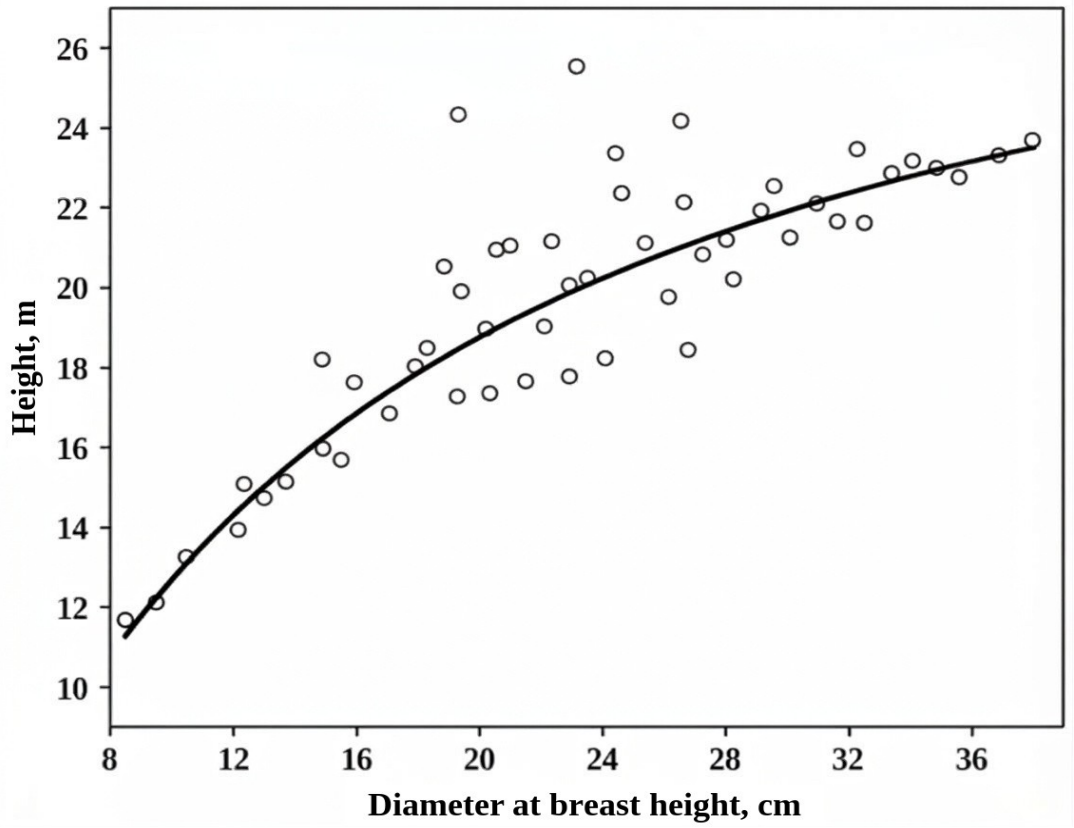


Figure 9. Constructing a height curve and determining the height of individual trees

2.11. Assessment of stem quality, social position of the tree and tree-related microhabitats

Stem quality, the social position of the tree and tree-related microhabitats are assessed visually. To keep the assessments comparable, they are carried out over the whole plot by the same trained person or the same pair of crew members. The assessment is made at the same time as tree numbering and measurement, and the results are entered on the field form as codes in the “Notes” column (Appendix 1).

Stem quality. Quality is assessed on the lower (butt) part of the stem, since this part determines the value of the tree. The stem is inspected from all sides and, according to the presence and size of defects (knots, sweep, rot, cracks, mechanical damage, butt swelling), assigned to one of four classes: A, B, C or D (Appendix 3). If a stem shows features of two classes, it is assigned to the lower one. The quality class, together with species and diameter, is used to calculate the economic value of the tree (Kraus et al., 2018).

Social position of the tree. The position is determined according to the Kraft classification (Kraft, 1884) by comparing the crown of the tree with the crowns of neighbouring trees: whether it rises above the canopy, whether it forms part of the upper storey, and whether it receives direct light (Appendix 4). The Kraft class is determined only for living trees; standing dead trees are indicated in the condition column.

Tree-related microhabitats. Tree-related microhabitats (TreMs) are structural features of a tree that serve as places for other organisms to live, feed or breed: cavities, injuries and exposed wood, dead branches in the crown, growths, fungal fruiting bodies, epiphytes, sap and resin flows (Kraus et al., 2016; Larrieu et al., 2018). Microhabitats are recorded in the following sequence:

1) the tree is inspected from all sides, from the root buttresses to the top; the crown is examined with binoculars in good light;

2) each microhabitat found is assigned to the corresponding type (Appendix 5) and its presence is recorded on the form;

3) a microhabitat is counted only if its size is not below the threshold given in the field guide (Bütler et al., 2024);

4) if a tree has no microhabitats, a dash is entered on the form to distinguish an inspected tree from a missed one.

In broadleaved stands, microhabitats are recorded in the leafless season, when the crown is clearly visible (Zudin et al., 2022). The software calculates the ecological value of a tree from the number and types of its microhabitats.

2.12. Panoramic photography of the plot

Spherical panoramas (photospheres) allow a marteloscope to be viewed remotely: a trainee sees the stand as if standing at the shooting point and can examine every numbered tree. The panoramas are uploaded to the plot record in the network database together with the inventory data. The required equipment is listed in Table 2.4 and shown in Figure 10.

Table 2.4

Equipment for panoramic photography

Equipment	Purpose
Camera with a wide-angle lens	Shooting a series of frames
Tripod with panoramic head	Rotating the camera around the nodal point at a fixed angular step

Equipment	Purpose
Ranging pole	Indicating north
Spare batteries and memory cards	Extended shooting (one panorama requires 86 frames)

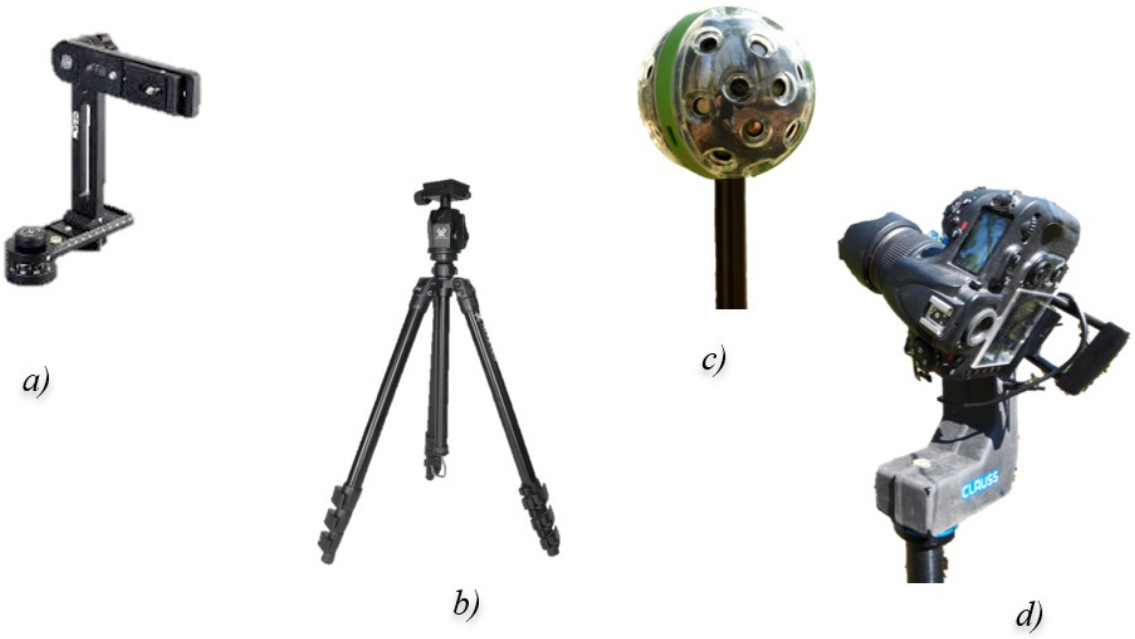


Figure 10. Equipment for panoramic photography: *a)* panoramic head; *b)* tripod; *c)* spherical camera with 36 lenses; *d)* camera on a robotic panoramic head

Shooting panoramas

Panoramas are usually taken at the centres of the squares and at the plot centre (5 points in total). The shooting point is shifted if:

− the nearest tree is closer than 3 m and its stem does not fit entirely into the frame;

− the point falls in a dense patch where the view is blocked by thick branches and foliage.

A shifted point is referenced in the same way as trees, by the azimuth and horizontal distance from the centre of the square. Without such referencing, the panorama cannot be matched with the stand map.

At each point, shooting is carried out in the following sequence:

1) set up the tripod with the panoramic head and level it using the spirit level;

2) place a ranging pole to the north (azimuth 0°) so that it appears in the first frame;

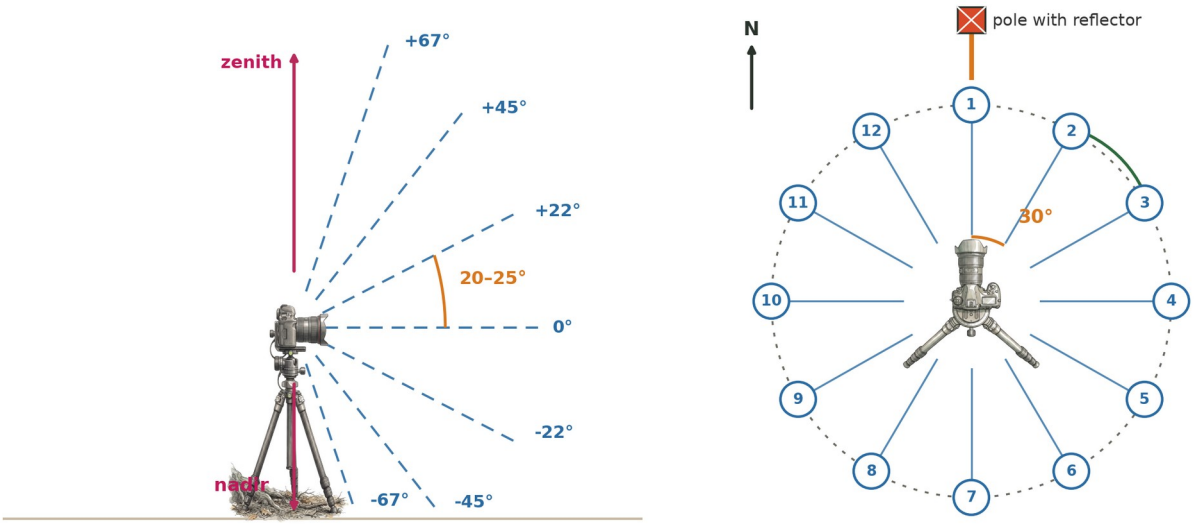
3) rotating the camera clockwise in 30° steps, shoot a full rotation of 12 frames;

4) tilt the camera down by 20–25° and shoot another rotation of 12 frames; repeat this twice more, increasing the tilt each time;

5) in the same way, shoot three rotations of 12 frames with the camera tilted upwards;

6) finish with two frames: one pointing straight up and one straight down.

In total, one panorama requires 86 frames (12 frames × 7 rows + 2 vertical frames) (Fig. 11).



a) *b*)

Figure 11. Panoramic shooting scheme: *a*) side view; *b*) top view

The following rules are observed during shooting:

– after each rotation, the operator steps behind the camera so as not to appear in the frame;

– instruments, backpacks and measuring tapes are removed from the camera's field of view;

– shoot in even light, ideally under complete cloud cover: at a sunny midday, the sharp contrast between light and shade will leave some frames over- or underexposed; manual exposure mode is therefore preferable.

Processing panoramic images

Frame series are stitched into a spherical panorama using photosphere software (for example, PTGui, Hugin, PanoramaStudio, Panoweaver). The frame series of each shooting point is processed separately.

Before stitching, all frames in the series are brought to the same colour and brightness; otherwise the seams between frames will be visible in the finished panorama. Adjustments are made in photo-editing software (Adobe Lightroom, Adobe Camera Raw, darktable, RawTherapee, etc.) in the following sequence:

1) review the series and check that it is complete (86 frames) and contains no blurred or missing frames;

2) on one frame, set the white balance using a neutral area of the image (for example, grey bark or the ranging pole) and adjust the exposure;

3) reduce the brightness of overexposed areas, especially the sky in canopy gaps, and brighten shadows that are too dark;

4) remove chromatic aberrations (colour fringing along the edges of stems against the sky);

5) synchronise identical settings across all frames in the series; do not adjust frames individually, as adjacent frames would then differ in brightness;

6) export the frames as TIFF or maximum-quality JPEG, retaining the EXIF metadata from which the stitching software determines the lens parameters.

Lens-induced image distortion is not corrected at this stage, as it is taken into account by the stitching software.

Frames are stitched in specialised software (PTGui, Hugin, PanoramaStudio, Panoweaver, etc.) in the following sequence:

1) load the frame series of one point and check that the software has correctly identified the focal length and lens type;

2) run the automatic search for control points (identical details in adjacent frames) and the optimisation, during which the software aligns the frames (Fig. 12);

3) check the alignment accuracy: the mean error should not exceed 5 pixels; delete the control points with the largest errors and repeat the optimisation; if the error remains large, there is a gap between frames in the series or the tripod moved during shooting;

4) level the horizon and orient the panorama so that the ranging pole placed in the first frame indicates north;

5) mask unwanted objects in the frames (the operator’s shadow, tripod, instruments) so that the stitching lines avoid them.

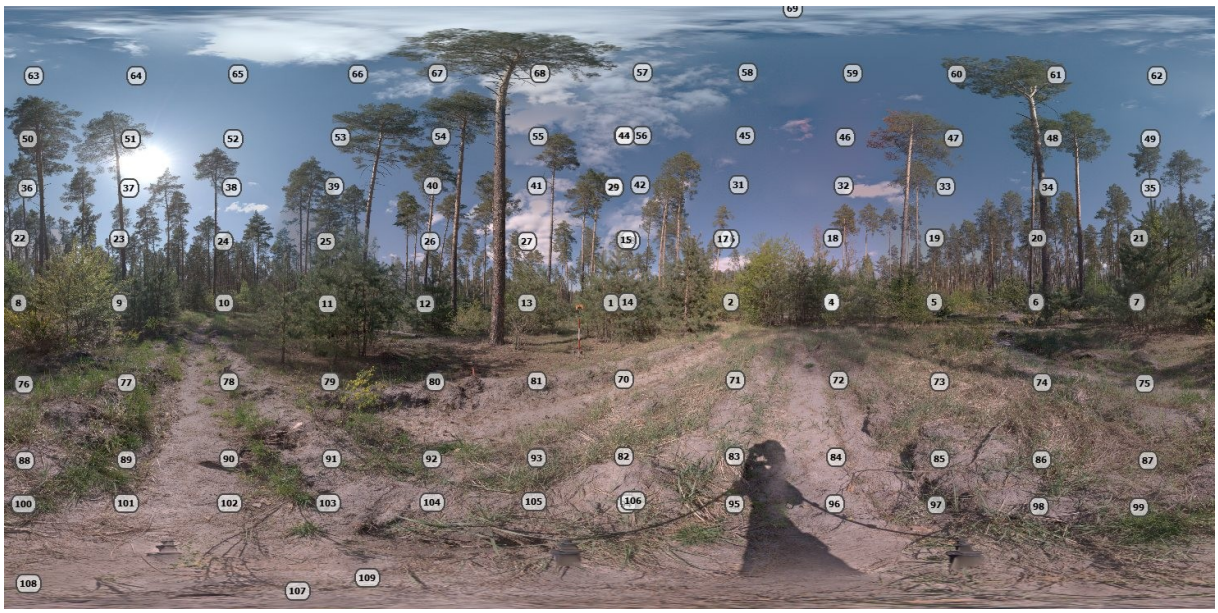


Figure 12. Automatic stitching of a frame series using control points

The stitched panorama is finalised and published in the following sequence:

1) areas that could not be fixed by masking (for example, the area under the tripod) are retouched in an image editor (Adobe Photoshop, Affinity Photo, GIMP);

2) the panorama is saved in equirectangular projection with a 2:1 aspect ratio, corresponding to 360° × 180° coverage, in JPEG format;

3) check that the file contains spherical panorama metadata (XMP GPano): stitching software writes them automatically, but image editors may delete them, and without these metadata, software and platforms do not recognise the image as a sphere;

4) the finished panoramas are viewed in dedicated spherical panorama software (PTGui Viewer, FSPViewer, etc.) to check for breaks along the stitching lines and for correct orientation; for publication, the platform https://martelage.sylvotheque.ch is used, where the panorama is uploaded to the page of the respective plot (Fig. 13), as well as online services for hosting spherical panoramas: Kuula (https://kuula.co), Momento360 (https://momento360.com), Google Maps (as a geotagged 360° photo).

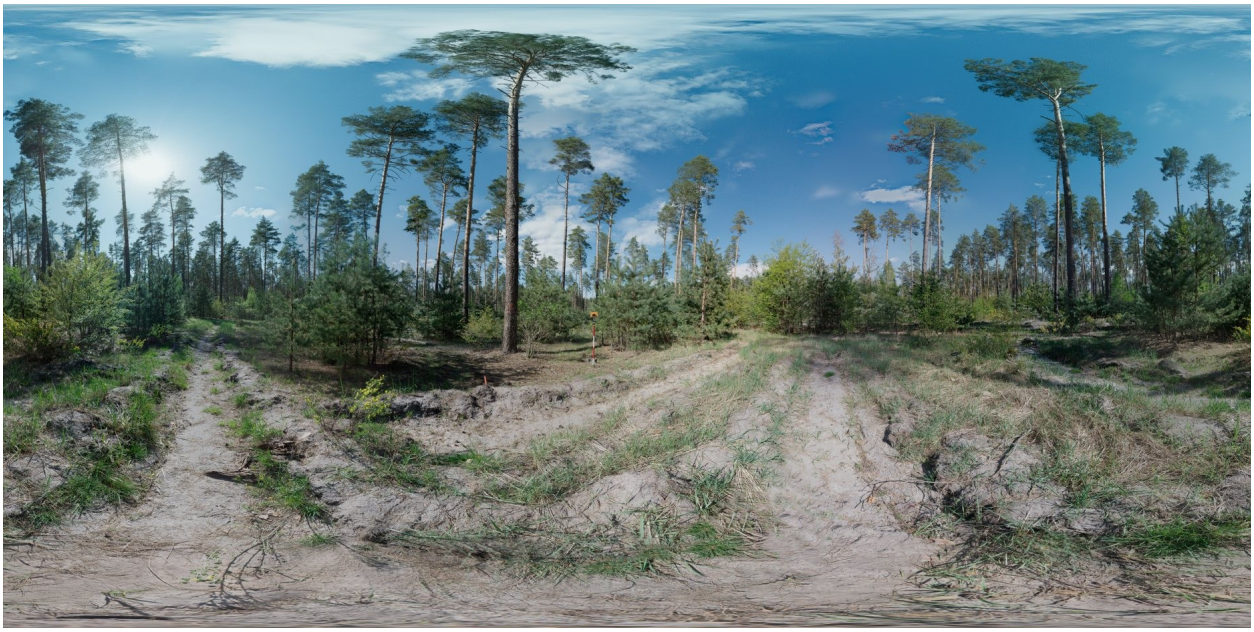


Figure 13. Finished spherical panorama of a shooting point

It is recommended to process panoramas on the day of shooting. If a series fails to stitch because of a gap between frames, the problematic row can be reshot while the lighting conditions and the state of the stand have not changed.

3. OFFICE WORK

Office work is carried out immediately after the field inventory is completed, while the crew still remembers the specific features of the plot and can return to it for verification if necessary. Its aim is to transfer the field data into electronic form, check them, calculate tree coordinates and stand mensuration parameters, and prepare the data for upload to the martelage.sylvotheque.ch platform.

Office work is carried out in the following sequence:

1) field data entry;
2) data checking and correction;
3) calculation of tree coordinates;
4) calculation of mensuration parameters;
5) preparing and uploading data to the platform;
6) compiling the plot description and archiving the data.

3.1. Field data entry

Data from the field forms (Appendix 1) are entered into a spreadsheet (Microsoft Excel, LibreOffice Calc, etc.) according to the following rules:

−each column uses the same units and recording format, and the decimal separator is the same throughout the table;

−tree species, condition, stem quality class, Kraft class and microhabitats are recorded as codes (Appendices 3–5), and the code key is given on a separate worksheet;

−a cell is left empty only when the parameter was not determined (for example, tree height under sample-based measurement); zero is never entered in place of a missing value.

The table structure is given in Table 3.1. Calculated fields are filled in with formulas rather than manually.

Table 3.1

Structure of the data entry table

Field	Recording format	Example
Measurement point	code: 0 – plot centre, 1–4 – corners or square number	0
Tree number	integer	107
Tree species	code	QR
Condition	living, standing dead	living
Diameter d, cm	number to the nearest 0.5	38.5
Height, m	number to the nearest 0.1	27.4

Field	Recording format	Example
Azimuth, °	integer from 0 to 359	58
Horizontal distance, m	number to the nearest 0.01	22.04
Stem quality class	code A–D (Appendix 3)	B
Kraft class	code I–V (Appendix 4)	II
Tree-related microhabitats	codes of forms and types (Appendix 5)	1; 3
Note	text	leaning tree

Field forms are not destroyed after data entry: they are scanned and stored together with the spreadsheet.

3.2. Data checking and correction

Before calculations, the data are checked for completeness and logical consistency. The checks are performed with spreadsheet tools (sorting, filters and conditional formatting) or with artificial intelligence tools. The mandatory checks are listed in Table 3.2.

Table 3.2

List of data checks

Parameter	Error indicator	Action
Tree numbers	Duplicate numbers or gaps in numbering	Check against the field form and, if necessary, in the field
Number of records	Does not match the number of numbered trees	Find missing records; if necessary, re-survey the plot
Codes	Code not in the code list	Check against the field form
Diameter	Below the inventory threshold (8 cm) or above 150 cm	Check the record; re-measure if necessary
Height	Below 1.3 m or above the maximum for the species in the region	Check whether a neighbouring tree was sighted by mistake
Height-to-diameter ratio (H/D)	Outside 40–120 (H and D in metres)	Check diameter and height
Azimuth	Outside 0–359°	Correct the record
Distance	Greater than half the diagonal of the square or plot	Check the measurement point and distance
Quality class, Kraft class	Assigned to a standing dead tree	Check tree condition
Tree location map	Trees outside the plot, overlaps or unnatural clusters	Check azimuth and distance

The most effective check is a tree location map plotted from the calculated coordinates (Appendix 6). Errors in azimuths and distances are immediately visible on it: trees fall outside the plot or form unnatural clusters. The map is compared with the plot scheme and, if necessary, with the situation in the field.

3.3. Calculation of tree coordinates

Tree positions determined in the field as polar coordinates (azimuth and horizontal distance from the measurement point) are converted into the Cartesian coordinates of the plot. The origin of the coordinate system is placed at the south-west corner of the plot, with the X axis pointing east and the Y axis pointing north. The coordinates of the measurement points for a 100×100 m plot are given in Table 3.3.

Table 3.3

Coordinates of measurement points on a 100 × 100 m plot

Measurement point	X_0, m	Y_0, m
Plot centre (0)	50	50
Centre of square 1 (north-west)	25	75
Centre of square 2 (north-east)	75	75
Centre of square 3 (south-east)	75	25
Centre of square 4 (south-west)	25	25
Corner 1 (north-east)	100	100
Corner 2 (south-east)	100	0
Corner 3 (south-west)	0	0
Corner 4 (north-west)	0	100

Tree coordinates are calculated using the formulas:

$$X = X_0 + L \cdot \sin Az, \quad (3.1)$$

$$Y = Y_0 + L \cdot \cos Az, \quad (3.2)$$

where X_0, Y_0 are the coordinates of the measurement point, m; L is the horizontal distance from the measurement point to the tree, m; Az is the azimuth to the tree, °.

In a spreadsheet, the formulas are written as =X0+L*SIN(RADIANS(Az)) and =Y0+L*COS(RADIANS(Az)). For example, for a tree located at an azimuth of 58° and a distance of 22.04 m from the plot centre, X = 50 + 22.04 · sin 58° = 68.69 m, Y = 50 + 22.04 · cos 58° = 61.68 m.

The azimuth is taken to the centre of the stem and the distance to its side surface, so the resulting coordinates correspond to the stem axis and require no correction. Azimuths

measured with a compass are magnetic. If the plot is oriented to true north, the local magnetic declination, determined from geomagnetic models, is added to them.

After the calculation, it is checked that the coordinates of all trees lie within the plot (for a 100×100 m plot, from 0 to 100 m on both axes), and a tree location map is plotted (Appendix 6).

3.4. Calculation of mensuration parameters

The inventory data are used to calculate parameters of individual trees and of the stand as a whole.

Basal area of each tree at 1.3 m:

$$g = \pi \cdot D^2 / 40{,}000, \quad (3.3)$$

where g is the basal area, m²; D is the mean diameter of the tree, cm.

Heights of trees that were not measured are determined from height curves constructed separately for each tree species from the measured trees.

Stem volume is determined from the current official reference data (stem volume tables) for the respective tree species.

Stand parameters are calculated for the plot and converted to a per-hectare basis: number of trees, basal area, growing stock, species composition by volume, mean diameter, mean height and the distribution of trees by diameter classes (usually 4 cm). The mean stand diameter is determined as the quadratic mean diameter, i.e. the diameter of the tree of mean basal area:

$$D_g = \sqrt{(\Sigma\, D_i^2 / N)}, \quad (3.4)$$

where D_i is the diameter of the i-th tree, cm; N is the number of trees.

The per-hectare value is calculated using the formula:

$$A_{ha} = A \cdot 10{,}000 / S, \quad (3.5)$$

where A_{ha} is the value per hectare; A is the value on the plot; S is the plot area in horizontal projection, m².

Parameters are calculated separately for living and standing dead trees. The values obtained are compared with the stand description from the forest inventory: large discrepancies may indicate errors in the data.

3.5. Preparing and uploading data to the platform

For upload to the martelage.sylvotheque.ch platform, the data are converted into the format required by the platform. When preparing the data:

− codes for tree species, quality classes and microhabitats are matched to the platform codes;

− units of measurement and the decimal separator are checked;

− a description of the plot and stand is prepared.

After the upload, it is checked that the number of trees on the platform matches the number of records in the table, the tree location map on the platform is compared with the map produced during office work, and the data of several trees are spot-checked.

3.6. Plot description and data archiving

A description is compiled for each marteloscope, stating:

− the plot name and location (forest enterprise, forest district, compartment, sub-compartment);

− the coordinates of the plot centre and corners determined with a GNSS receiver, and their accuracy;

− the size, shape and orientation of the plot, the layout method and the numbering of squares;

− the date of establishment, the crew and the instruments used;

− the azimuth and distance measurement scheme (magnetic or true azimuths, to which part of the stem measurements were taken);

− the stand mensuration characteristics and site conditions;

− the height curve equations and the reference data used for volume calculation.

All plot materials (scans of field forms, spreadsheets, change log, description, panoramas) are stored in one folder with a consistent file-naming structure. The original table is never modified: all corrections are made in a working copy.

4. COMMON ERRORS

Most errors made when establishing a marteloscope arise from departures from the work sequence or a lack of checks at individual stages. Errors made in the field often come to light only during office processing, when correcting them requires another visit to the plot. The most important thing is therefore to prevent them during the field work itself. Common errors, their consequences and ways of preventing them are given in Table 4.1.

Table 4.1

Common errors in establishing a marteloscope and how to prevent them

Error	Consequences	How to prevent
Plot layout		
Boundaries laid out by eye, without checking angles and diagonals	Plot area differs from the intended area; data are not comparable with other plots	Check the diagonals of the squares or the azimuths and distances between corners (deviation not more than ±1° and ±2%)
On a slope, distances set out along the surface without slope correction	Actual plot area is smaller than intended; per-hectare values are underestimated	Hold the tape horizontally or apply the slope correction (Appendix 2)
Centre placed next to a stem or where the corners cannot be seen from it	The instrument has to be moved; some trees are missed	Shift the centre by 1–2 m so that the sight lines to all corners are clear
Permanent marking of points		
Reference points placed on short-lived objects, or their azimuth, distance and description not recorded	Lost profiles cannot be relocated	Place RPs at the root collar of long-lived trees, on rocks or large stones; record the azimuth, distance and description of each RP
Profile (marker) protrudes above the ground surface	The profile (marker) is damaged by machinery or removed by unauthorised persons	Drive the profile (marker) flush with the ground surface
Tree inventory and numbering		
Trees recorded without a clear order	Some trees are missed or recorded twice; incorrect tree numbers and growing stock	Record by sectors from the measurement point in order of increasing azimuth; mark the back of recorded stems with chalk
Trees on the plot boundary incorrectly assigned	Number of trees over- or underestimated	Assign a tree to the plot if the stem centre lies within it
Number not painted facing the measurement point, too small, or “around” the stem	Number cannot be read from the measurement point or during training exercises	Paint the number at eye level, facing the measurement point, at a size legible from 10 m

Error	Consequences	How to prevent
Georeferencing of trees		
Mixed measurement schemes: azimuth taken sometimes to the centre, sometimes to the edge of the stem	Systematic shift of trees on the map	Use a single scheme throughout the plot and record it in the plot description
Tripod not set up above the profile or not levelled	Shift of all trees of the sector on the map	Set up the tripod exactly above the profile and check the level before starting measurements
Measurement point not recorded, or magnetic and true azimuths mixed	Trees on the map are shifted or mirrored	Record the measurement point for each tree; state the azimuth type in the plot description
Diameter and height measurement		
1.3 m measured from the downhill side, or calliper not applied perpendicular to the stem axis	Diameter overestimated	Follow the measurement rules for difficult cases (Fig. 7)
Diameter measurement point not marked	Repeat inventory gives incorrect increment	Mark the measurement point with a painted line on every tree
Height determined by sighting at a side branch instead of the top	Height underestimated by 1–3 m	Measure from a point where the top is clearly visible, at a distance roughly equal to the tree height
Assessment of stem quality, social position and microhabitats		
Assessments made by different people	Assessments of different trees are not comparable	Assign the assessment to the same trained person or the same pair of crew members
Microhabitats recorded in the leaf-on season or without binoculars	Microhabitats in the crown are missed; the ecological value of trees is underestimated	In broadleaved stands, record in the leafless season and examine the crown with binoculars
Panoramic photography		
The operator or instruments appear in the frame; gaps between frames	The panorama contains unwanted objects or fails to stitch	Step behind the camera after each rotation, remove instruments from view, keep a 30° step in all rows; process panoramas on the day of shooting
Records and office work		
Records kept alternately by different crew members	Missed rows; errors due to different handwriting	Assign record-keeping to one person
Data entry errors; zero entered instead of a missing value	Incorrect mensuration parameters	Check entered data against the field forms; perform the checks listed in Table 3.2

Error	Consequences	How to prevent
Corrections made directly in the original table	Original data are lost; errors cannot be traced	Work with a working copy; record every correction in a change log

To detect errors in good time, at the end of each working day the number of numbered trees is compared with the number of records on the field forms, and the records are reviewed for gaps. Any shortcomings found are corrected the next day while the crew is still working on the plot.

5. PLOT MAINTENANCE

A marteloscope retains its training value only as long as the markings on the plot remain legible and the data reflect the actual state of the stand. To this end, the plot is inspected regularly, the markings are renewed and the data are updated. The measures and their frequency are given in Table 5.1.

Table 5.1

Plot maintenance measures

Measure	Frequency	Scope of work
Plot inspection	Annually, and after storms, heavy snowfall and fires	Checking profiles, stakes, reference points, tree numbers and access to the plot; recording changes in the stand
Renewal of markings	Every 2–3 years	Repainting reference points, tree numbers and diameter measurement marks
Data update	After every change in the stand	Flagging removed trees in the database and on the platform
Repeat inventory	Every 5–10 years	Re-measurement of diameters and sample height measurement, recording of ingrowth trees, updating panoramas

The plot is inspected every year, preferably before the start of the training season, and additionally after storms, heavy snowfall, fires or other events that may have damaged the stand. The inspection covers:

−the presence and condition of the aluminium profiles, stakes and reference points;

−the legibility of tree numbers and diameter measurement marks;

−the condition of access to the plot and the presence of hazardous trees and hanging branches along the routes used by groups;

−changes in the stand: windthrow, windbreak, dieback, fellings.

The inspection results are entered in the plot log. Lost profiles are relocated from the reference points using the recorded azimuths and distances.

The paint on reference points, tree numbers and diameter measurement marks is renewed every 2–3 years, or more often if necessary. Numbers are repainted in the same colour and at the same place so as not to change the numbering.

All changes in the stand are reflected in the database and on the martelage.sylvotheque.ch platform. A removed tree (windthrown, dead, felled) is not deleted from the table but flagged as removed, stating the year and reason for removal. This preserves the history of the plot and makes it possible to analyse changes in the stand. If a

forest management intervention has been carried out on the plot, the felled trees are flagged in the same way and the panoramas are reshot if necessary.

A repeat inventory is carried out every 5–10 years. Diameters are measured exactly at the marked measurement points, which makes it possible to determine the actual increment of trees and of the stand; heights are measured on a sample basis and the height curves are refined. Trees that have reached the inventory threshold (8 cm) in the meantime are recorded as ingrowth: they are given the next free numbers, their azimuth and distance from the measurement point are determined, and they are entered in the database. Repeat inventory results are stored separately from previous ones so that the state of the stand can be compared across years.

REFERENCES

BFH-HAFL. (2022). *Einrichtung einer waldbaulichen Dauerbeobachtungs- und Trainingsfläche (PPSS)* [presentation]. Berner Fachhochschule, Hochschule für Agrar-, Forst- und Lebensmittelwissenschaften HAFL.

Bruciamacchie, M., Pierrat, J.-C., & Tomasini, J. (2005). Modèles explicatif et marginal de la stratégie de martelage d'une parcelle irrégulière. *Annals of Forest Science, 62*(7), 727–736. https://doi.org/10.1051/forest:2005070.

Bütler, R., Lachat, T., Krumm, F., Kraus, D., & Larrieu, L. (2024). *Field guide to tree-related microhabitats: Descriptions and size limits for their inventory in temperate and Mediterranean forests* (2nd ed.). Swiss Federal Institute for Forest, Snow and Landscape Research WSL.

Düggelin, C., Abegg, M., Bischof, S., Brändli, U.-B., Cioldi, F., Fischer, C., & Meile, R. (2020). *Schweizerisches Landesforstinventar: Anleitung für die Feldaufnahmen der fünften Erhebung 2018–2026* (WSL Berichte 90). Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL.

Kraft, G. (1884). *Beiträge zur Lehre von den Durchforstungen, Schlagstellungen und Lichtungshieben*. Klindworth.

Kraus, D., Bütler, R., Krumm, F., Lachat, T., Larrieu, L., Mergner, U., Paillet, Y., Rydkvist, T., Schuck, A., & Winter, S. (2016). *Catalogue of tree microhabitats: Reference field list* (Integrate+ Technical Paper). European Forest Institute.

Kraus, D., Schuck, A., Krumm, F., Bütler, R., Cosyns, H., Courbaud, B., Larrieu, L., Mergner, U., Pyttel, P., Varis, S., Wilhelm, G., Witz, M., Zenner, E., & Zudin, S. (2018). *Seeing is building better understanding: The Integrate+ marteloscopes* (Integrate+ Technical Paper No. 26). European Forest Institute.

Larrieu, L., Paillet, Y., Winter, S., Bütler, R., Kraus, D., Krumm, F., Lachat, T., Michel, A. K., Regnery, B., & Vandekerkhove, K. (2018). Tree related microhabitats in temperate and Mediterranean European forests: A hierarchical typology for inventory standardization. *Ecological Indicators, 84*, 194–207. https://doi.org/10.1016/j.ecolind.2017.08.051.

Pommerening, A., Pallarés Ramos, C., Kędziora, W., Haufe, J., & Stoyan, D. (2018). Rating experiments in forestry: How much agreement is there in tree marking? *PLOS ONE, 13*(3), Article e0194747. https://doi.org/10.1371/journal.pone.0194747.

Zudin, S., Heintz, W., Kraus, D., Krumm, F., Larrieu, L., & Schuck, A. (2022). A spatially-explicit database of tree-related microhabitats in Europe and beyond. *Biodiversity Data Journal, 10*, Article e91385. https://doi.org/10.3897/BDJ.10.e91385.

APPENDICES

Appendix 1

Field form for referencing and measuring trees

Plot: _____ Date: _____ Measurement point: _____ Recorder: _____

Table 1. Referencing record

Coordinate	Point name	Azimuth	Distance	Notes
X				
Y				

Table 2. Tree measurement record

No.	Tree species	Cond.	Dist.	Azim.	Diam./ circ.	Ht	Stem quality class	Kraft class	TreMs	Notes
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										
19										
20										
21										

Notes: mechanical damage, frost cracks, other defects and features of trees.

Appendix 2

Slope corrections for determining horizontal distances

All distances in plot layout are set as horizontal distances. If the tape cannot be held horizontally, a slope distance L corresponding to the required horizontal distance d is measured along the slope surface:

$$L = d / \cos \alpha = d \cdot k, \qquad \text{(A2.1)}$$

where d is the horizontal distance, m; L is the slope distance, m; α is the slope angle, °; k is the correction factor. A slope distance is converted back to a horizontal distance using d = L · cos α. The gradient in per cent equals tan α × 100.

For example, for a horizontal distance of 35.36 m (half the diagonal of a 50 × 50 m square) on a 15° slope, 36.61 m is measured along the surface.

The slope angle is determined separately for each line, since it may differ in different directions from the centre. On a broken slope, the line is divided into segments of uniform angle and the correction is applied to each segment.

Table A.2.1

Slope distance as a function of horizontal distance and slope angle

Slope angle α, °	Gradient, %	k = 1/cos α	cos α	Horizontal distance, m							
				10	**20**	**25**	**30**	**35.36**	**40**	**50**	**70.71**
				Slope distance, m							
1	1.7	1.0002	0.9998	10.00	20.00	25.00	30.00	35.37	40.01	50.01	70.72
2	3.5	1.0006	0.9994	10.01	20.01	25.02	30.02	35.38	40.02	50.03	70.75
3	5.2	1.0014	0.9986	10.01	20.03	25.03	30.04	35.41	40.05	50.07	70.81
4	7.0	1.0024	0.9976	10.02	20.05	25.06	30.07	35.45	40.10	50.12	70.88
5	8.7	1.0038	0.9962	10.04	20.08	25.10	30.11	35.50	40.15	50.19	70.98
6	10.5	1.0055	0.9945	10.06	20.11	25.14	30.17	35.55	40.22	50.28	71.10
7	12.3	1.0075	0.9925	10.08	20.15	25.19	30.23	35.63	40.30	50.38	71.24
8	14.1	1.0098	0.9903	10.10	20.20	25.25	30.29	35.71	40.39	50.49	71.40
9	15.8	1.0125	0.9877	10.12	20.25	25.31	30.37	35.80	40.50	50.62	71.59
10	17.6	1.0154	0.9848	10.15	20.31	25.39	30.46	35.91	40.62	50.77	71.80
11	19.4	1.0187	0.9816	10.19	20.37	25.47	30.56	36.02	40.75	50.94	72.03
12	21.3	1.0223	0.9781	10.22	20.45	25.56	30.67	36.15	40.89	51.12	72.29
13	23.1	1.0263	0.9744	10.26	20.53	25.66	30.79	36.29	41.05	51.32	72.57
14	24.9	1.0306	0.9703	10.31	20.61	25.77	30.92	36.44	41.22	51.53	72.87
15	26.8	1.0353	0.9659	10.35	20.71	25.88	31.06	36.61	41.41	51.76	73.20
16	28.7	1.0403	0.9613	10.40	20.81	26.01	31.21	36.78	41.61	52.01	73.56
17	30.6	1.0457	0.9563	10.46	20.91	26.14	31.37	36.98	41.83	52.28	73.94
18	32.5	1.0515	0.9511	10.51	21.03	26.29	31.54	37.18	42.06	52.57	74.35
19	34.4	1.0576	0.9455	10.58	21.15	26.44	31.73	37.40	42.30	52.88	74.78
20	36.4	1.0642	0.9397	10.64	21.28	26.60	31.93	37.63	42.57	53.21	75.25
21	38.4	1.0711	0.9336	10.71	21.42	26.78	32.13	37.88	42.85	53.56	75.74
22	40.4	1.0785	0.9272	10.79	21.57	26.96	32.36	38.14	43.14	53.93	76.26
23	42.4	1.0864	0.9205	10.86	21.73	27.16	32.59	38.41	43.45	54.32	76.82
24	44.5	1.0946	0.9135	10.95	21.89	27.37	32.84	38.71	43.79	54.73	77.40
25	46.6	1.1034	0.9063	11.03	22.07	27.58	33.10	39.02	44.14	55.17	78.02
26	48.8	1.1126	0.8988	11.13	22.25	27.82	33.38	39.34	44.50	55.63	78.67
27	51.0	1.1223	0.8910	11.22	22.45	28.06	33.67	39.69	44.89	56.12	79.36
28	53.2	1.1326	0.8829	11.33	22.65	28.31	33.98	40.05	45.30	56.63	80.08
29	55.4	1.1434	0.8746	11.43	22.87	28.58	34.30	40.43	45.73	57.17	80.85
30	57.7	1.1547	0.8660	11.55	23.09	28.87	34.64	40.83	46.19	57.74	81.65

Appendix 3

Stem quality classes

The class is determined from the lower (butt) part of the stem. If a stem shows features of two classes, it is assigned to the lower one.

Table A.3.1

Features of stem quality classes

Class	Stem features	Indicative timber use
A	Straight, low taper, knot-free and without visible defects; bark smooth, with no signs of rot, cracks or mechanical damage	High-quality sawlogs, raw material for slicing and peeling (veneer)
B	Straight or slightly curved; occasional small sound knots or other minor defects with little effect on timber quality	Medium- to high-quality sawlogs
C	Noticeable sweep, numerous or large knots, butt swelling, minor mechanical damage or limited rot	Low-quality sawlogs, construction timber
D	Severe sweep, forks, extensive rot, major damage or other defects that make sawlogs impossible to obtain	Industrial wood, firewood

Note. Classes A–D correspond to the assessment system of the Integrate+ marteloscope network (Kraus et al., 2018).

Appendix 4

Kraft classification of the social position of trees

Table A.4.1

Kraft classes

Class	Name	Features
I	Predominant	Clearly taller than the upper canopy. Rare in even-aged stands, mostly at early stages of development
II	Dominant	Fully form the upper canopy; good height growth and a large crown evenly developed on all sides
III	Co-dominant	Still part of the upper canopy, but their crowns are weaker and less even than those of dominant trees
IV	Suppressed	Not part of the upper canopy; the crown does not receive full direct light but is still in contact with the crowns of class I–III trees
V	Completely suppressed	The crown is not in contact with the crowns of dominant and co-dominant trees; the top is usually overtopped by the branches of neighbouring trees

Note. In uneven-aged and multi-storeyed stands, the tree's membership of the middle or lower storey is additionally recorded if necessary.

Appendix 5

Main forms and types of tree-related microhabitats

The classification follows the hierarchical typology of tree-related microhabitats (Larrieu et al., 2018). A description of each type and the threshold sizes from which a microhabitat is counted are given in the field guide (Bütler et al., 2024).

Table A.5.1

Forms and main types of tree-related microhabitats

No.	Form	Main groups and types
1	Cavities	Woodpecker breeding cavities; rot holes in the trunk and at the base; water-filled hollows in bark or forks; holes and galleries of wood-boring insects
2	Injuries and exposed wood	Bark loss; exposed sapwood or heartwood; longitudinal cracks; split or broken trunk; broken top; scars from fire, lightning or a falling neighbouring tree
3	Crown deadwood	Dead branches and dead limbs; dead top
4	Growths	Witches' brooms; clusters of epicormic shoots; burrs; cankers
5	Fruiting bodies of fungi and slime moulds	Perennial polypores; annual polypores; agarics; myxomycetes
6	Epiphytic and epixylic structures	Mosses, lichens and ferns on the trunk; ivy and other lianas; mistletoe; bird and ant nests; soil accumulation in forks
7	Exudates	Sap flows; resin flows

Appendix 6

Tree location map on the platform martelage.sylvotheque.ch

