3 The inventory – aims, methods and sampling design

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"It was the first time I ever worked with foreign people. I liked collaborating with the different members of the team. It was interesting to compare the Swiss inventory method we used in the Uholka-Shyrokyi Luh massif with the Ukrainian one. We got to know a lot of new parameters. The instruments are very good and well developed as they are small, lightweight and use only a minimal amount of energy. We will introduce our students to these methods and technologies. I was surprised how well everything was organised. We are not used to doing such intensive planning work. It was a good experience for all participants."

Serhiy Gavryliuk, assistant professor UNFU, Ukraine

3.1 Aims of the inventory

The general aim of the forest inventory was to obtain representative estimates of the state of the forest of Uholka-Shyrokyi Luh, which is thought to be the largest relict of primeval European beech forest. More specifically, the goal was to collect information about the number of trees, tree dimensions, growing stock, volumes of standing and lying deadwood, forest structures and regeneration density, tree species diversity, frequency of trees with microhabitats (habitat trees), and tree ages. An additional aim was to record traces of recent and former anthropogenic use or activities to assess the integrity of the forest and identify potential threats. The goal was to collect data for qualitative and quantitative descriptions and scientific analyses of the primeval forest, which could serve as a reference for comparisons with managed beech forests and forest reserves to enable the development of appropriate approaches to biodiversity conservation and forest management. Furthermore, such an inventory would provide a description of the initial state of the forest as a basis for monitoring its future development.

The inventory was planned as a joint project of WSL, UNFU and CBR, which would provide training and work experience for Ukrainian and Swiss students and foster Swiss-Ukrainian collaboration and scientific and cultural exchange.

3.2 Inventory method and sampling design

Obtaining reliable and objective information about various characteristics of the forests in the protected massif required not only a randomised (not purposive) sample so that generally acceptable statistical inferences could be made, but also a broad set of measurements and observations to allow conclusions about many different aspects of the forests to be drawn. A ground-based survey (terrestrial inventory) with field data collection on sampling plots was therefore chosen. Here the sampling plots are randomly distributed over the entire study area.

Igor Cherniuk marking the position of a sample plot centre. The sample plots are randomly distributed over the study area. Photo M. Hobi.

Requirements and materials available for planning

According to the aims of the survey, the inventory should fulfil the following requirements: it should be compatible with large area inventory data, such as the Ukrainian Forest Inventory (Ukrderzhlisproekt 2006; State Forestry Committee of Ukraine 2010) and the Swiss National Forest Inventory NFI (Brassel and Lischke 2001; Brändli 2010), and with the ongoing monitoring program in Swiss forest reserves (Brang *et al.* 2008, 2011). Thus, existing methods and definitions (Keller 2005, 2011; Tinner *et al.* 2010) should be used and, where necessary, adapted to the local conditions. The inventory should concentrate on the core and buffer zones of the reserve. The data collection should be strictly non-destructive and based on probability sampling principles (Mandallaz 2008). Sampling plots should be installed to allow re-measurement later so that future changes can be efficiently monitored. This involved establishing permanent plots to ensure the inventory is continuous. The field survey should not take more than two months because of the students' summer holidays and should be feasible with a maximum of 6 field teams. These limitations were imposed to be compatible with resource availability in general and the local capacity for accommodation of the field teams (see 4).

The following documents and data were available as a basis for planning:

- Topographic maps on a scale of 1:100 000 (Kievskaia Voenno-Kartograficheskaia Fabrika BKF 2003, sheet 183 Khust and 164 Mezhhor'e)
- A GIS data layer of the Uholka-Shyrokyi Luh massif from CBR with the functional zones, contour lines, rivers and paths
- Forest maps of the administrative units Uholka and Shyrokyi Luh with partition borders 1:10 000 and 1:25 000 (VO "Ukrderzhlisproekt" 2001, Irpin)
- Orthophotos with a ground resolution of 0.87 m from 2008 (Transcarpathian Geodesic Centre)
- Data from the 10 ha research plot in Uholka (Commarmot *et al.* 2005, 2009).

Survey perimeter

The perimeter of the inventory surrounds 99 % of the area of the Uholka-Shyrokyi Luh protected massif managed by the CBR (Table 2.1). It comprises the core and buffer zones of the massif, as well as a few enclosed areas assigned to the regulated protection and anthropogenic landscape zone (see map in the inside back cover). The small area under traditional management (anthropogenic landscape) along the southern border of the massif was excluded from the survey. In total, the area within the inventory's perimeter comprises 10 282.3 ha.

Population and target variables

The study objects, i.e. the population elements in statistical terminology, were living and dead trees, coarse woody debris, forest regeneration (seedlings and saplings), traces of anthropogenic use and of natural disturbances, the horizontal and vertical structure of the forest, and the local topographic conditions. Definitions of the population elements and assessed variables are described in detail in the field manual (Commarmot *et al.* 2010), which largely relies on those of the Swiss NFI (Keller 2005) and the Swiss forest reserve inventory (Tinner *et al.* 2009). A short overview is given below.

The population of trees includes:

- living trees, whether standing or lying, with a minimum diameter at breast height (DBH) of 6 cm, measured vertical to the stem axis at a height of 1.3 m above ground (or the root collar),
- dead standing trees and snags (dead stems broken above a height of 1.3 m) with a DBH ≥ 6 cm,
- dead lying trees (complete trees with crown and root-plate) with a DBH ≥ 6 cm, and
- stumps (remaining base parts of stems) with a height between 0.5 m and 1.3 m and a minimum diameter of 6 cm.

The main attributes of interest are tree species and DBH (Fig. 3.1). Further variables indicate the horizontal layer in which the tree's crown is situated, the stem form (several variables), the crown length, microhabitats (several variables, such as cavities, cracks, broken crown and occurrence of polypores) and the degree of wood decay (5 classes). The stem heights of all snags were measured. Tree height, the height to the first green branch of the crown and the upper stem diameter 7 m above ground (D7) were measured on a sub-sample of living trees.

Lying deadwood not only includes complete trees, but also broken stems, tree fragments and broken-off parts from standing trees. The volume of lying deadwood was defined as the total volume of lying deadwood pieces with a diameter of ≥ 7 cm (over bark). Thus, a single piece of deadwood may have a section (coarser than 7 cm) accounted for in the lying deadwood volume and a section (smaller than 7 cm) not accounted for in the lying deadwood volume. Only above-ground material is included in lying deadwood.

A line intersect sampling technique was used to assess the lying deadwood (see section "sampling units" below). The variables measured in the field were: the diameter (crosswise measurements), the decay class (5 categories) and the tree species group (broadleaves and conifers) of the deadwood piece at the intersection with the transect line.

Assessing forest regeneration involved measuring living seedlings and saplings with a minimum height of 10 cm and a maximum DBH of 5.9 cm. These were classified into 3 height classes and 6 DBH classes. Further variables were the tree species and damage to the leading shoot, in particular due to browsing. Local site and stand characteristics with a potential influence on the establishment and growth of forest regeneration were also registered and included: the occurrence of rocks, stones and boulders, type of topsoil (3 categories), competing vegetation, and shading.

Root-plates and canopy openings (gaps) were chosen as indicators for natural disturbances (Fig. 3.3). Root-plates were categorised as: root-plates with soil material, root-plates without soil material and decomposed former root-plates (recognizable as small mounds). Canopy gaps were classified into 6 size classes (estimated).

Fig. 3.1. Mykola Korol measuring the DBH of a large beech tree. The DBH was measured at a height of 1.3 m above ground. Photo R. Tinner.

The vertical and horizontal forest structures were assessed with two categorical variables (expert judgements): the degree of crown cover in the upper, medium and lower layers of the stand, and the type and degree of canopy closure (aggregation of tree crowns in the upper canopy layer).

Any traces of anthropogenic use observed were classified into 10 categories (see 6, Table 6.2). The traces were not quantified, for instance, by the number of occurrences of traces on plots or by their size and relevance. Nevertheless, it is still possible to assess and monitor the amplitude and spatial distribution of anthropogenic use (and activities) from the data.

The site factors assessed in the inventory were the topographic characteristics: altitude, slope, aspect, and relief (5 categories).

Sampling units (sample plot design)

Data from the 10 ha forest research plot in Uholka was used to evaluate the optimum size of the sampling units (sample plots) for trees and forest regeneration. The sample plot design chosen is shown in Fig. 3.2.

Trees (DBH ≥ 6 cm) and root-plates were sampled on circular plots with a fixed size of 500 m^2 (horizontal radius of 12.62 m). Slope correction was applied to ensure a uniform horizontal plot area of 500 m^2. The expected average number of (living and dead) stems per plot was 15 (based on the stem density observed in the Uholka forest research plot). Larger plots were considered too difficult and error-prone, in particular on steep slopes. We did not consider varying tree inclusion probabilities (angle count sampling or concentric circles) for the sake of simplicity and robust data collection and estimation. Moreover, the stem volume was not the predominant population parameter of interest.

A sub-sample of the trees (so-called tariff trees) was selected for measuring the tree height and upper stem diameter (Fig. 3.4). The sub-sample includes all trees in the first quadrant of the plot (sector between the directions North and East, i.e. 0 and 90 degrees or 0 and 100 gon), as well as trees with a DBH of at least 60 cm (except for trees with broken stems and crowns).

The volume of lying deadwood was assessed on three transect lines, each 15 m in length. The lines start 1 m from the sample plot centre and run in the directions of 35, 170 and 300 gon.

Regeneration was sampled on three concentric circular plots located 10 m from the centre of the main plot (to the West): 5 m^2 for saplings between 10 cm and 39.9 cm height, 10 m^2 for saplings with a height between 40 and 129.9 cm, and 20 m^2 for saplings with a minimum height of 130 cm and up to a DBH of 5.9 cm.

A circular interpretation area of 2500 m^2 (concentric with the main sample plot for trees) was used to assess

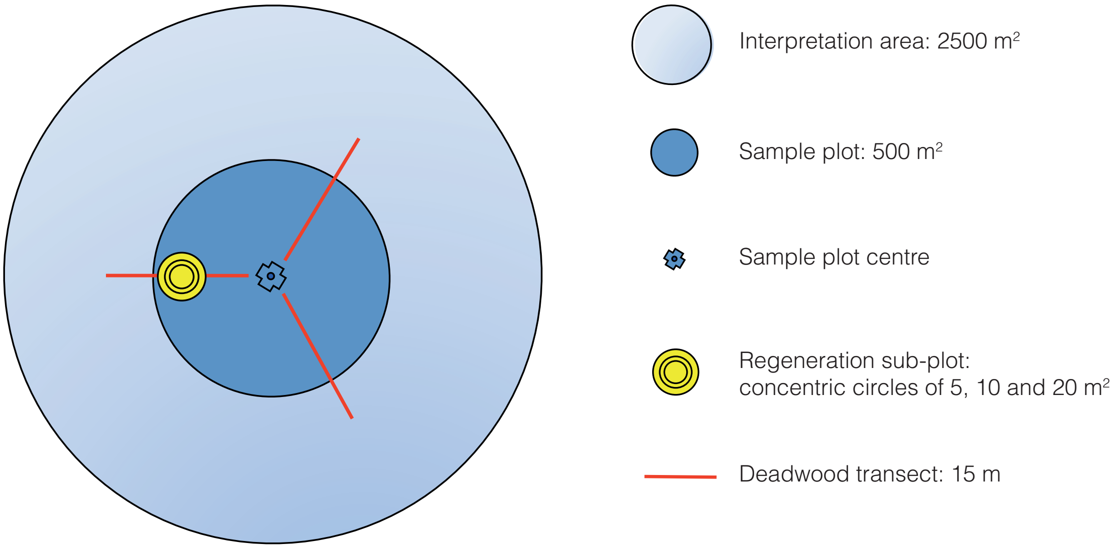

Fig. 3.2. Sample plot design.

Fig. 3.3. Root-plates were assessed as indicators of natural disturbances, but also as habitat features. Photo M. Hobi.

Fig. 3.4. Martin Brüllhardt measuring the height of a tree. The height was measured on only a sub-sample of trees. Photo A. Khomiuk.

the horizontal and vertical structure of the forest, as well as the occurrence of anthropogenic traces and topographic variables. If a canopy gap was located directly above the centre of a sample plot (point decision), it was noted and its size recorded.

The centre of the main sample plot and the centre of the regeneration sub-plot were marked with a small oak pole. The co-ordinates were registered with a GPS device (Trimble GeoXH or Juno SB). To facilitate the relocation of sample plots in future surveys, photographs were taken from the centre of the sample plot in four different directions and one from downslope towards the centre. In addition, any eye-catching objects close-by (e. g. a rock or a tree with a large canker, Fig. 3.5) were registered with polar coordinates (distance and azimuth from the plot centre), as were all trees measured on the plot.

Distribution of sample plots (sampling grid)

Based on long experience with the Swiss NFI in landscapes with similar topographic conditions, and taking into account the remoteness of the area with difficult terrain conditions and long walking distances, work performance of two sample plots per team and day was assumed to be possible. This led us to conclude that a sample size of approximately 350 plots should be planned.

The sampling design chosen was a non-stratified, systematic cluster sampling. Each cluster consisted of two sample plots, with a distance of 100 m between the two plots in a cluster. Clusters were arranged on a rectangular grid (systematic sampling), with side lengths of 445 m and 1235 m (Fig. 3.6). This design resulted in 353 sample plots. The starting point for the grid was randomly chosen.

Fig. 3.5. To facilitate the relocation of sample plots in future surveys, any eye-catching objects close-by, such as this tree with a large canker, were documented with their distance and azimuth from the plot centre. Photo U.-B. Brändli.

The decision about how to distribute the sample plots was based on the following considerations:

– The administrative units of Uholka and Shyrokyi Luh are of similar size, and the forest (structure) can be expected to be basically homogeneous over the whole study area. Thus, a pre-stratification was not judged appropriate. This does not, however, exclude the use of strata (and other auxiliary information) in the estimation stage of the inventory (post-stratification).
– The systematic distribution of plots leads, in general, to a higher precision of the estimates and to lower inventory costs than with independent random point sampling because the plots are distributed better over the study area. Other advantages of systematic sampling are the shorter walking distances involved and the faster location of plot coordinates. Walking distances are shorter on rectangular grids than on quadratic grids (Schmid-Haas 1993). A relation of up to 4:1 between the longer and shorter side of rectangular grids is acceptable (Dvorak 2000), as otherwise correlations between plots may become an issue and should be addressed when estimating sampling errors.
– Cluster sampling obviously reduces the cost (walking distances) of the inventory compared to an inventory with the same number of single plots. However, the cost reduction is achieved at the expense of less precise estimates. The optimum design is difficult to predict, even with extensive pre-experience and data from pilot studies. The design chosen has two sampling plots per cluster, and is based on cost and population estimates obtained from data collected earlier on the local forest research plot (Commarmot *et al.* 2005, 2009), in a pilot inventory in 2009 and during a field visit. An operational advantage was that two survey teams could work within alarm distance of each other, which would be important if an accident or emergency occurred (see 4).

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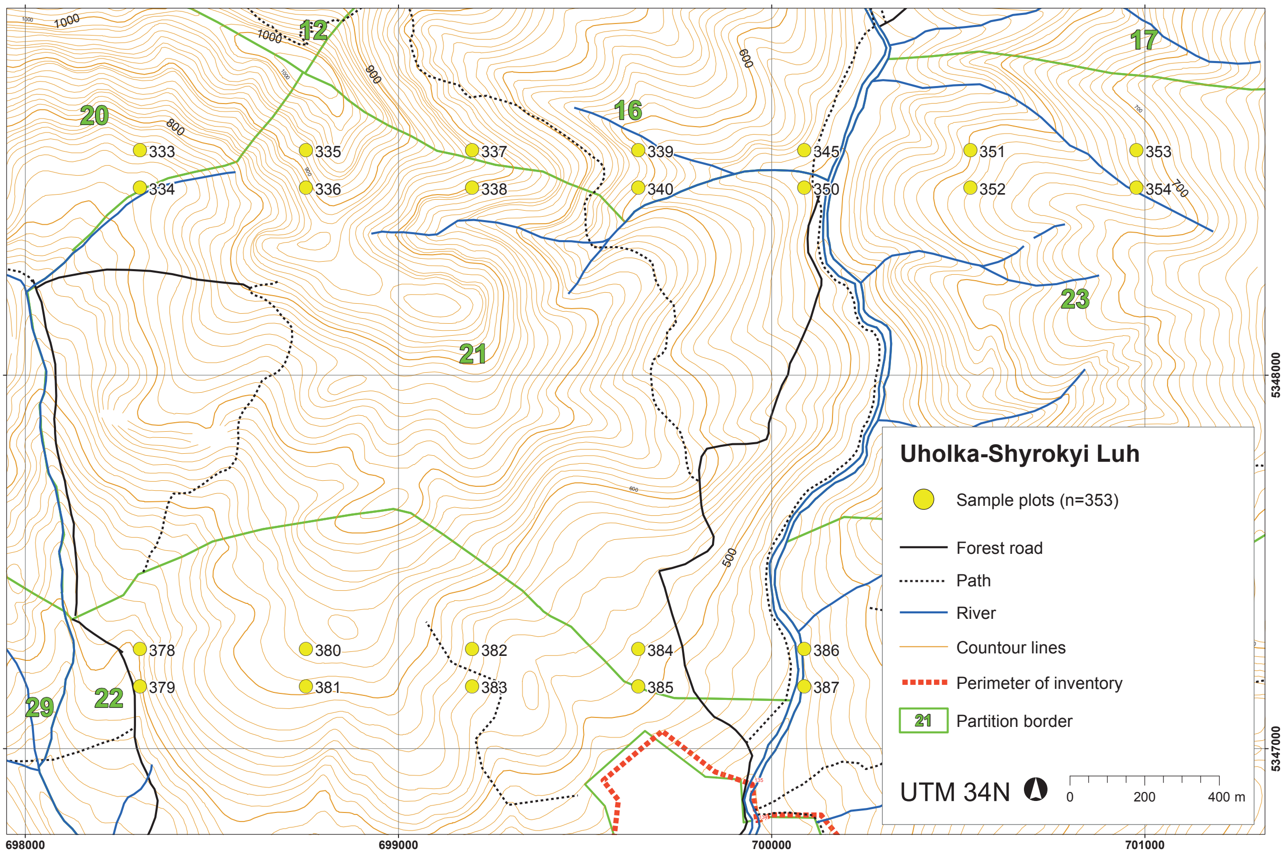

Fig. 3.6. Sampling design with clustered plots arranged on a rectangular grid. Extract from the overview map on a scale of 1:20 000.

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