

A Swiss-Ukrainian Scientific Adventure

Inventory of the Largest Primeval Beech Forest in Europe

Editors: Brigitte Commarmot, Urs-Beat Brändli, Fedir Hamor, Vasyl Lavnyy



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Editors:

Brigitte Commarmot, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland.

e-mail: brigitte.commarmot@wsl.ch

Urs-Beat Brändli, Swiss Federal Research Institute WSL, Birmensdorf, Switzerland.

e-mail: urs-beat.braendli@wsl.ch

Fedir Hamor, Carpathian Biosphere Reserve, Rakhiv, Ukraine. e-mail: cbr-rakhiv@ukr.net

Vasyl Lavnyy, Ukrainian National Forestry University, L'viv, Ukraine. e-mail: lavnyy@gmail.com

Language revision and copy editing: Silvia Dingwall

Ukrainian translation: Vasyl Lavnyy

Maps: Martina Hobi and Meinrad Abegg

Layout: Jacqueline Annen, WSL

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Foreword

Beech forests would, without human intervention, cover large parts of the nemoral zone in Europe as climax vegetation. The beech (*Fagus sylvatica*) is one of the most successful tree species in post-glacial vegetation history, with a distribution ranging from the mountains of the Mediterranean region in the South to southern Scandinavia in the North, from the Atlantic Ocean in the West to the eastern foothills of the Carpathians and the Crimean peninsula in the East. Beech could potentially dominate most of the natural forest types within this extensive range, from sea-level to the lowlands and up to the montane belt, where the temperate climate suits them. In some areas it might even reach as far as the upper forest line. The proportion of beech forests in the current forest cover of Europe has, however, been dramatically reduced through millennia of land use. Untouched, old-growth beech forests mostly remain only in small patches in a very few inaccessible areas or sites where the historical circumstances are in some way special.

An international consensus on the preservation and sustainable management of forests was reached by the time of the 1992 World Summit in Rio de Janeiro. In this context Europe has a particular responsibility for the protection of the few remaining primeval and ancient beech forests. The largest primeval beech forest in Europe is the Uholka-Shyrokyi Luh protected massif in the Ukrainian Carpathians. This region has had a turbulent political history, which has left its mark on land use, nature conservation and forest research. The first network of protected forest areas was established in the region during the first decades of the 20th century under the Austria-Hungarian and Czechoslovakian governments. Today, the primeval forest of Uholka-Shyrokyi Luh is part of the Carpathian Biosphere Reserve (CBR), which was certified by UNESCO in 1992. In 2007, the forests of Uholka-Shyrokyi Luh, together with nine smaller primeval forest remnants in Ukraine and Slovakia, were added under the name "Primeval Beech Forests of the Carpathians" to the World Heritage List. This was the beginning of the current process of drawing up a complete serial transnational list of the primeval and ancient beech forests in Europe to be included in the World Heritage List.

Primeval forests are particularly interesting objects for forest research as they provide excellent and necessary conditions for studying and understanding the ecosystem processes in forests where no human intervention has occurred for a long time. The Carpathians are a kind of *locus classicus* for virgin beech forest studies in Europe as they include large areas of primeval forest and have a long tradition of forest research. The Uholka-Shyrokyi Luh inventory project is part of the Swiss-Ukrainian scientific cooperation on primeval forest research that started fifteen years ago. It is an outstanding example of successful bilateral cooperation and scientific teamwork. The inventory of 10 000 ha of primeval beech forest, which was carried out under adventurous conditions in real wilderness, is unique. It provides for the first time information that is really representative of a large area of primeval forest. The study is not only a valuable contribution to our understanding of natural forest dynamics, but the resulting data also provide much-needed reference values for nature conservation and natural forest management.

The research findings described here confirm the outstanding and universal value of the primeval beech forests of the Carpathians. They also emphasize how the integrity of forest ecosystems depends on the length of time they are able to develop naturally without disturbance, and thus how urgent it is to protect the few remnants of primeval and ancient beech forests in Europe. I hope this publication will encourage others to carry out similar investigations using comparable methods in other remnants of primeval forest.

Prof. Dr. Hans D. Knapp, International Academy for Nature Conservation, Isle of Vilm

Summary

International conventions and resolutions on biological diversity, sustainable forest management and climate change have led in recent decades to an increasing interest in having reference values from forests undisturbed by man. An outstanding example of such an undisturbed forest is the primeval forest of Uholka-Shyrokyi Luh within the Carpathian Biosphere Reserve (Ukraine). It is approximately 9000 ha (90 km²) in area and is thought to be the largest primeval forest of almost pure European beech (*Fagus sylvatica* L.).

In 2010, the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, the Ukrainian National Forestry University UNFU and the Carpathian Biosphere Reserve CBR carried out a sampling inventory of the Uholka-Shyrokyi Luh forest (survey perimeter 10282 ha) to obtain representative data for the main forest parameters. Given the remoteness of the area, long walking distances and difficult terrain, careful planning and organisation were required, as well as the logistic support of the local forest service. The field work was carried out by six mixed teams of Swiss and Ukrainian students and scientists, guided by three survey leaders from Switzerland and Ukraine. Two teams together shared a leader and a cook, and lived in decentralized camps, which were moved every week to minimize the walking needed to reach the sample plots. The collaboration between the Ukrainians and Swiss worked very well and was enriching for both sides. During the two-month sampling period, the teams assessed 314 sample plots laid out on a systematic grid. All living and standing dead trees ≥ 6 cm DBH (diameter at 1.3 m above ground) within the 500 m² circle plots were measured and assessed for features relevant for biodiversity. Lying deadwood was assessed with line-intersect sampling (3 lines each 15 m long per plot), and small trees (≥ 10 cm height and < 6 cm DBH) were surveyed on subplots consisting of three concentric circles 5, 10 and 20 m² in area. The stand structure and any traces of anthropogenic use were assessed on a circular interpretation area of 2500 m² around the sample plot centre.

The primeval forest of Uholka-Shyrokyi Luh shows all the typical features of an old-growth forest shaped by small-scale disturbances. The structure was mainly three-layered, and most of the gaps encountered were not larger than the crown of a canopy tree. The growing stock per ha was 582 (± 14) m³ (mean \pm standard error) and the deadwood volume 163 (± 8) m³. The ratio of standing to lying deadwood was 1:5. The maximum DBH measured was 150 cm, and 10 trees per ha had a DBH of at least 80 cm. The density of habitat trees, i.e. living trees with features such as cracks, holes, bark damage or similar that provide microhabitats, was 150 (± 8) per ha (35% of the living trees). Of all the trees recorded, 97% were beech, although 14 other tree species were identified. All species found in the tree population ≥ 6 cm DBH were also present in the regeneration.

Traces of human presence were encountered on 19% of the assessed plots (interpretation areas), mainly in the buffer and regulated protection zone of the protected massif. Most of these traces do not affect the integrity and pristine character of the forest. Nevertheless, they imply a certain pressure exerted from the nearby settlements and from the mountain pastures.

The data obtained provide good reference values for old-growth beech forests and a valuable basis for more detailed analyses and comparisons with other old-growth and managed forests. The inventory was carried out and documented in a replicable way, and can thus be repeated if desired. The plots may also be used for other non-destructive studies, e.g. on fungi.

Keywords

Fagus sylvatica, virgin forest, old-growth forest, forest structure, deadwood, reference values, Carpathian Biosphere Reserve

Резюме

ІНВЕНТАРИЗАЦІЯ НАЙБІЛЬШОГО БУКОВОГО ПРАЛІСУ ЄВРОПИ

Швейцарсько-українські наукові висліди

Міжнародні конвенції і резолюції щодо біологічного різноманіття, ведення сталого лісового господарства та змін клімату спричинили в останні десятиліття все більший інтерес до вивчення пралісів. Яскравим прикладом такого незацепленого людською діяльністю лісу є Угольсько-Широколужанський праліс в Карпатському біосферному заповіднику (Україна). Він займає площу близько 9000 га (90 км²) і вважається найбільшим пралісом, що сформувався з майже чистого бука лісового (*Fagus sylvatica* L.).

У 2010 році Швейцарський федеральний інститут досліджень лісу, снігу та ландшафтів (WSL), Національний лісотехнічний університет України (НЛТУ України) і Карпатський біосферний заповідник (КБЗ) організували вибіркочу інвентаризацію Угольсько-Широколужанського пралісу (площа за периметром 10282 га), щоб отримати репрезентативні дані про його основні параметри. Враховуючи віддаленість району, довгі піші переходи і складний рельєф місцевості, велику увагу було приділено ретельному плануванню та організації інвентаризації із залученням для допомоги місцевих працівників КБЗ. Польові роботи проводилися шістьма змішаними групами з швейцарських та українських студентів під керівництвом трьох польових менеджерів з Швейцарії та України. Дві групи, кожна зі своїм менеджером і кухарем, жили у тимчасовому таборі, який переміщувався щотижня у інше місце, щоб звести до мінімуму необхідні переходи до місць закладання пробних площ. Між українцями і швейцарцями була хороша співпраця, що приносила користь для обох сторін. Протягом двох місяців інвентаризації таксаційні групи заклали 314 кругових пробних площ на основі систематичної сітки. На цих пробних площах розміром 500 м² були заміряні всі живі й мертві стоячі дерева з діаметром ≥ 6 см на висоті 1,3 м над поверхнею ґрунту для визначення лісівничо-таксаційних показників деревостану і біорізноманіття. Лежача мертва деревина вимірювалася на лінійних трансектах (3 лінії на пробі довжиною 15 м кожна), а невеликі дерева (≥ 10 см заввишки і < 6 см за діаметром на висоті 1,3 м) були обстежені на трьох концентричних кругах площею 5, 10 і 20 м². Структура деревостану і можливі сліди антропогенного впливу оцінювалися на кругові розміром 2500 м² довкола центру пробної площі.

Угольсько-Широколужанський праліс має всі характерні риси старовікового лісу з наявністю невеликих прогалин у наметі. Структура деревостану в основному триярусна, а більшість з прогалин за площею не перевищує розмір крони пануючих дерев. Запас ростучих дерев становить 582 (± 14) м³ на гектарі (середнє значення \pm стандартна помилка), а об'єм мертвої деревини – 163 (± 8) м³/га. Співвідношення між стоячою та лежачою мертвою деревиною було 1:5. Максимальний діаметр стовбура дерев на висоті 1,3 м дорівнював 150 см, а 10 дерев на гектарі мали діаметр на висоті 1,3 м щонайменше 80 см. Щільність дерев-біотопів, тобто дерев з тріщинами, дуплами, пошкодженнями кори або іншим середовищем існування живих організмів становила 150 (± 8) шт./га (35% живих дерев). Серед деревних порід 97% всіх дерев становив бук лісовий, хоча загалом у пралісі були виявлені дерева 14 різних видів. Всі види дерев з діаметром на висоті 1,3 м ≥ 6 см також були присутні у складі самосіву і підросту.

Сліди антропогенного впливу були виявлені на 19% закладених пробних площ, в основному в зоні антропогенних ландшафтів та в буферній зоні заповідного масиву. Більшість з цих слідів не впливає на цілісність і незайманість пралісу. Однак вони свідчать про певний тиск на праліс з навколишніх населених пунктів і високогірних пасовищ.

Отримані дані інвентаризації є добрим порівнянням для інших старовікових лісів бука та цінною основою для більш детального аналізу та порівняння з іншими старовіковими і господарськими лісами. Інвентаризація була проведена і задокументована таким чином, щоб можна було знайти всі пробні площі у майбутньому. Тому при необхідності вона може бути повторена через певний проміжок часу. Крім того, закладені пробні площі можуть бути використані для інших неруйнівних досліджень, наприклад, для вивчення грибів.

Ключові слова

Fagus sylvatica, праліс, структура деревостану, еталонне значення, мертва деревина, міжкультурне співробітництво, Карпатський біосферний заповідник.

Abbreviations

a.s.l.	above sea level
BFH	Berne University of Applied Sciences
CBR	Carpathian Biosphere Reserve
DBH	diameter at breast height (measured 1.3 m above ground)
D7	upper stem diameter (measured 7 m above ground)
ETHZ	Swiss Federal Institute of Technology Zürich
ha	hectare (= 10 000 m ² or 0.01 km ²)
HAFL	School of Agricultural, Forest and Food Sciences
N	number (e.g. number of trees or plots)
NFI	National Forest Inventory
SE	standard error
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFU	Ukrainian National Forestry University
WSL	Swiss Federal Institute for Forest, Snow and Landscape Research
ZHAW	Zurich University of Applied Sciences, School of Life Sciences and Facility Management

Note on the terms “primeval”, “virgin” and “old-growth” forest:

We use the terms “primeval” and “virgin forest” as synonyms for a “forest undisturbed by man”, i. e. where there has been no known significant human intervention, or where the last significant human intervention was so long ago that the natural species composition and processes have re-established (MCPFE 2007). In contrast, the term “old-growth forest” may include forests previously managed but which have been left to develop naturally. They thus show some old-growth characteristics, such as mixed tree ages and development phases with senescent and dead trees, as well as standing and lying deadwood in all decay stages.

MCPFE Ministerial Conference on the Protection of Forests in Europe 2007: State of Europe's forests 2007. The MCPFE report on sustainable forest management in Europe. MCPFE Liaison Unit Warsaw, Poland.

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1 Introduction

Brigitte Commarmot, Urs-Beat Brändli, Fedir Hamor, Vasyi Lavnyy

“The endless horizons, unspoilt nature, clear streams and the beech trees standing guard over the breathtaking natural world were well complemented by the warmth and friendship that the Ukrainians emanated. Perhaps it is the philosophy of life – ‘everything in due course’ – that has allowed the forests to last so long.”

Daniel Oertig, student HAFL, Switzerland

European forests have been used and altered by humans for thousands of years, with the most rapid changes occurring during the Middle Ages (KÜSTER 1998). The expansion of human settlements not only led to the forest area diminishing fast, but also to more intensive use of the remaining forest. Wood continued to be the main resource for heating, energy and construction far into the 19th century, and the increasing demand was met by exploiting and clear-cutting forests even in remote areas. Forests were also used for grazing, leaves were cut as fodder and litter was collected as bedding for livestock and humans.

Only scattered relicts of primeval forest, also known as virgin or primary forest, have survived in mountainous areas, mainly in the geographic regions of the Carpathians, the Balkans and the Alps (LEIBUNDGUT 1982; MAYER *et al.* 1989; KORPEL’ 1995; PRŮŠA 1985; DIACI 1999; GIURGIU *et al.* 2001; BRÄNDLI AND DOWHANYTSCH 2003; HAMOR *et al.* 2008). These virgin forest relicts have a high value for biodiversity conservation (PAILLET *et al.* 2009), but they are also unique objects for ecological and forest research as they provide unique opportunities for studying the complex natural structures, processes and ecosystem functions of forests undisturbed by man.

The value of such old-growth forests was already recognized in the 19th century, when the first forest reserves were established in Poland and the Czech Republic (ZIELONY 1999; HORT *et al.* 1999). Since then, most European countries have protected and set aside near-natural forests as reserves where old-growth structures can, in the long run, develop again. It may take centuries, however, before such formerly managed forests become like virgin forests again and provide the same kind of ecosystem functions as the long-lost primeval forests.

In recent decades, various international conventions and resolutions on biological diversity, sustainable forest management and climate change have been passed and have led to an increasing demand for reference values from undisturbed forests. The Ukrainian Carpathians harbour some of the largest remnants of primeval forest of European beech (*Fagus sylvatica* L.). If humans had not interfered, beech forests would today cover extensive areas of Central Europe, from the Alps

Typical appearance of the primeval beech forest of Uholka-Shyrokyi Luh, with uneven-sized beech trees, lying deadwood, regeneration, and a multilayered structure. Photo V. Chumak.



Fig. 1.1. Sign with information about the 10 ha research plot of CBR and WSL in the Uholka administrative unit. Photo U.-B. Brändli.

across the lower mountain ranges down to the lowlands. The Carpathian relicts of primeval beech forest are therefore of special interest for research. In 1998, WSL initiated a co-operation with the Carpathian Biosphere Reserve (CBR) and other Ukrainian institutes to study the structure and diversity of virgin forests. In 2000, a 10 ha research plot (Fig. 1.1) was established in the primeval forest of Uholka (COMMARMOT *et al.* 2005). Since then, detailed measurements have been carried out every five years to follow the natural forest dynamics. This research plot allows insights into the small-scale spatial structures and their dynamics, and also into the interactions between individual trees and different species, but it cannot be considered representative of the approx. 14 000 ha of primeval beech forest still preserved in the Krasna Massif of the Ukrainian Carpathians (HAMOR *et al.* 2008). Large-scale systematic (random) sampling was therefore needed to obtain representative data from these forests.

At the conference “Natural Forests in the Temperate Zone of Europe – Values and Utilisation”, which was jointly organised by the WSL and the CBR in 2003 (COMMARMOT and HAMOR 2005), the idea was born to carry out such a large-scale virgin forest inventory. During the next few years, this idea was further developed and discussed with possible partners and sponsors in Ukraine and Switzerland, and presented at a conference at CBR in 2008 (COMMARMOT *et al.* 2008). With financial support from the State Secretariat for Education, Research and Innovation SERI, Switzerland, it was at last possible to start the project. In 2010, WSL, CBR and the Ukrainian National Forestry University (UNFU) carried out a sampling inventory over the whole forest area in the Uholka-Shyrokyi Luh protected massif

within the CBR, 8800 ha of which are thought to be primeval forest (BRÄNDLI and DOWHANYTSCH 2003; BRÄNDLI *et al.* 2008; SUKHARYUK 2005). To our knowledge, this is the first systematic inventory of such a large virgin forest area in Europe. In this report, we describe the sampling design and the parameters assessed, the planning and organisation of the field work, and the management and analysis of the data collected in the terrestrial survey. We also present findings about basic forest characteristics, habitat structures, site factors and anthropogenic traces. The report is intended to give an overview of the inventory methods and basic calculations we used and to serve as a reference and basis for more thorough analyses and inventories in future. Not included in this report are detailed structural analyses and comparisons with other reserves or managed forests, as they are the topics of separate scientific papers.

The report is intended for scientists working with data from this inventory, forest ecologists, biologists, conservationists and other people interested in reference data from virgin forests. Researchers planning to carry out a similar inventory should also find it useful.

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2 The Uholka-Shyrokyi Luh protected massif – an overview

Fedir Hamor, Urs-Beat Brändli

“The work in the forest was fascinating, physically demanding, but very satisfying. The view into the forest was enthralling, especially in the more inaccessible areas where there was a lot of deadwood and an untouched natural environment. The work was physically challenging due to the topography, with very steep slopes and gullies, and because of the time it took to walk there.”

Jonas Stillhard, student ZHAW, Switzerland

2.1 Location and site conditions

The Uholka-Shyrokyi Luh massif is one of the eight protected massifs¹ united in the CBR. It is situated in central Transcarpathia, the south-westernmost region of Ukraine (Fig. 2.1). It belongs to the beech forest belt on the southern slopes of the Polonyny Carpathians (Krasna mountain range), and comprises the upper basin of the Luzhanka, Velyka Uholka and Mala Uholka rivers at altitudes ranging from 400 to 1400 m a.s.l. (Fig. 2.2). The Uholka-Shyrokyi Luh massif covers an area of around 16 000 ha, of which 10 400 ha are under direct management of the CBR, while the other 5600 ha are managed by the state forest enterprises. The massif is divided into two parts of similar size: the administrative unit of Uholka, adjacent to the villages Velyka Uholka and Mala Uholka, and the unit of Shyrokyi Luh, 12 km north of the Shyrokyi Luh village.

The relief of the Uholka-Shyrokyi Luh massif is very fragmented and divided by several narrow valleys formed by mountain streams. The massif consists mainly of flysch formations of the Cretaceous and Paleogene periods, with Jurassic limestone, calcareous conglomerates, marls and sandstone. A unique landscape feature of the Uholka part of the massif is the limestone ridge, which is part of the great tertiary limestone range that stretches from the West to the South Carpathians. Limestone rocks form up to 60 m high cliffs and contain numerous karst caves, the longest of which is over 1 km long. The Shyrokyi Luh area is practically free of limestone. Clastic sedimentary rocks, such as alevrolits (siltstone), sandstone and conglomerates, dominate, sometimes forming high cliffs. The topsoil of the massif consists of acidic brown soils of variable granulometric composition and depth.

The Uholka-Shyrokyi Luh massif lies in the Atlantic-continental climatic region of the Ukrainian Carpathians, with inflowing Atlantic air masses. The mean annual temperature measured at the meteorological station of CBR in Uholka at 430 m altitude is 7.7°C, the mean July temperature 17.9°C, and the mean January temperature –2.7°C (averages for the years 1990–2010). The

View from the “polonina” (mountain pasture) on top of Menchul looking towards the South-West. Photo L. Mini.

¹ The term “massif” is used for the CBR protected areas and does not correspond with the geological term.

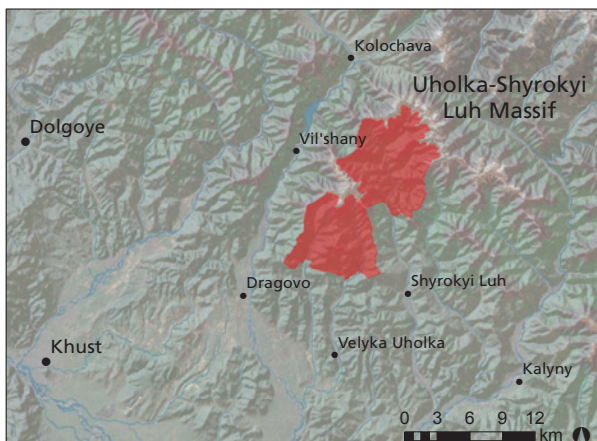


Fig. 2.1. Location of the Uholka-Shyrokyi Luh massif. Source: ArcGIS Map Service <http://www.arcgis.com>, "World Shaded Relief" and "World Imagery".

absolute minimum measured was -25.1°C (on January 13, 1987), and the maximum 35.3°C (on July 15, 2001). The mean annual precipitation from 1980–2010 was 1134 mm, 50–60 % of which fell during the vegetation period (May to October). The snow cover is usually 40–60 cm, in some places reaching as much as 100 cm.

2.2 Main plant associations

Over 96% of the Uholka-Shyrokyi Luh protected massif is covered with forests. Natural (old-growth) forests make up 9980 ha, 8800 ha of which are primeval forests (BRÄNDLI and DOWHANYTSCH 2003; SUKHARYUK 2005). Most of these are more-or-less pure beech forests. Beech forms a continuous forest belt from 400 m a.s.l. up to the upper timber line (1250–1350 m). The characteristic herbaceous plants of the massif are ephemeral and early spring species, such as *Anemone nemorosa*, *A. ranunculoides*, *Leucojum vernum*, *Dentaria bulbifera*, *D. glandulosa*, *Galantus nivalis*, *Isopirum thalictroides*, *Corydalis solida*, *C. hallery* and *Heleborus purpurascens*.

The forest vegetation has been classified into 10 forest formations (alliances) and 77 plant associations (STOJKO *et al.* 1982; classification according to SHELIAH-SOSONKO 1991). Moist and humid pure beech forests growing on mega- and mesotrophic soils are the most widespread forest formations. Over 70% of the primeval



Fig. 2.2. Valley of the Luzhanka river. Photo R. Iseli.

forest sites are *Fagetum dentariosum* (Fig. 2.3) or *Fagetum asperulosum*, with the latter the most productive of the Ukrainian Carpathian beech formations. On sites where beech is less competitive, mixed communities are formed, such as *Querceto petraeae-Fagetum*, *Carpineto-Fagetum* or *Acereto-Fagetum*.

In the administrative unit of Shyrokyj Luh, where the climate is somewhat colder than in Uholka, the mesotrophic associations *Abieto-Fagetum* and *Abieto-Piceeto-Fagetum* also occur in a few areas at high altitudes, as do the humid associations *Fageto-Abietum* and *Piceeto-Fageto-Abietum* on the rocky slopes of the Tetry and Yalynkovatyi areas. The monodominant association *Piceetum myrtilosum* is preserved in several small islands as well. In addition to the dominant beech forests, associations such as *Fageto-Aceretum pseudo-platani*, *Ulmeto-Fraxineto excelsioris-Aceretum pseudo-platani*, *Fraxinum excelsioris* or *Betuletum pendulae* may also be found.

Due to the region's specific ecological conditions, many relict and endemic plant species, as well as rare associations, such as the *Caprineto-Fagetum spiraeosomercurialidosum* with a significant share of thermophile species, are preserved on the limestone cliffs in the Uholka unit of the massif. *Ulmeto-Fraxineto-Aceretum* occurs at the foot of the cliffs, with relict species such as *Lunaria rediviva* and *Phyllitis scolopendrium*. Many rare associations are found in the Grebin and Mala



Fig. 2.3. *Cardamine glanduligera*, characteristic species of the *Fagetum dentariosum*. Photo B. Commarmot.

Kopytsia areas. These are the only sites in Ukraine where the *Fageto-Tilietum platyphyllae sesleriosum heufferianae* is protected (Fig. 2.4). *Fagetum taxosohederosum*, *Fagetum taxoso-sesleriosum* and *Fagetum taxoso-myrtilosum* forest sites can be found sporadically distributed on limestone slopes. Uholka is the second largest area in Ukraine containing the Tertiary relict species *Taxus baccata*, and the only site in the East Carpathians where *Juniperus sabina* is found.

2.3 History of land use

Transcarpathia's borders have changed so frequently over the centuries that industrialisation and intensive forest use began relatively late. Much of the mountain forest remained untouched until the 18th century. Some forests were not used for timber until even later because they were kept as hunting grounds for the aristocracy or because they contained no suitable water stretches for rafting or other forms of transport for getting the timber out of the forest. The remote beech forests in the Uholka-Shyrokyj Luh area are one such example (BRÄNDLI *et al.* 2008). The intense livestock pasturing practised for centuries on the mountain meadows had, however, a negative impact on the forest ecosystems and depressed the upper forest line by 100–200 m in altitude in some places (Fig. 2.5). Thus, the present forest line seems to be man-

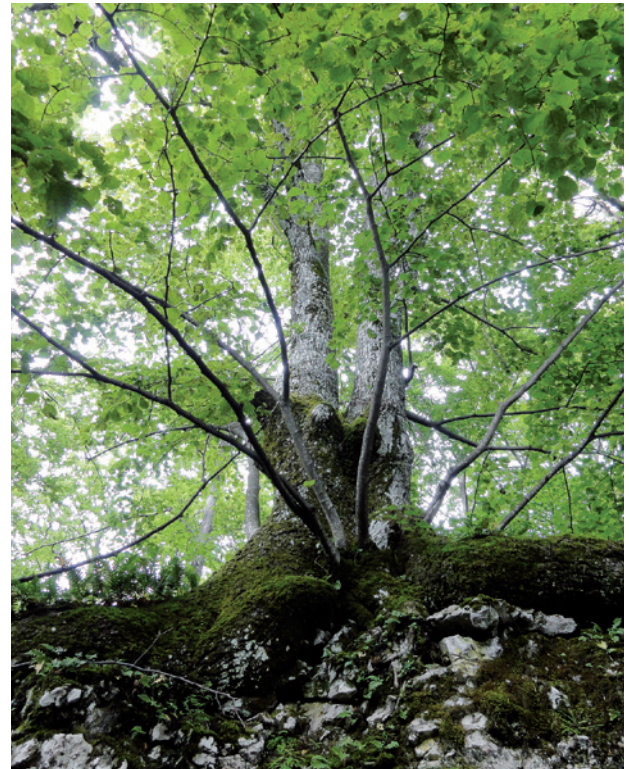


Fig. 2.4. *Tilia platyphyllos* Scop. on a limestone cliff in Uholka. Photo L. Mini.



Fig. 2.5. The upper forest line is 100–200 m lower than it would be without the intense livestock pasturing practised for centuries on the mountain meadows. Photo M. Brüllhardt.



Fig. 2.6. Traditional subsistence farming in the anthropogenic landscape zone of the Uholka-Shyrokyi Luh protected massif. Photo O. Nadyeina.

made. Today, the Uholka-Shyrokyi Luh massif is still interlaced with footpaths leading from the villages close-by through the forests up to the mountain meadows.

In 1936, the first forest reserve 1024.5 ha in area was established in the Luzhanka river basin, thanks to the efforts of the prominent Czech botanists A. Zlatnik and A. Gilitzer, to conserve the primeval beech forests and the relict Norway spruce (*Picea abies* Karst) association. After the Transcarpathian region was separated from Czechoslovakia and became part of the Soviet Union, the Uholka reserve was established in 1958 and the Shyrokyi Luh in 1964. They were incorporated in the newly founded Carpathian Reserve in 1968 and 1979, respectively.

In 1992 the Carpathian Reserve was designated a UNESCO Biosphere Reserve, the Carpathian Biosphere Reserve CBR, comprising eight geographically separate massifs and a total area of 53 630 ha, 14 600 ha of which are primeval forests. Today, most of these forests are included in the UNESCO World Heritage Site “Primeval Beech Forests of the Carpathians and the Ancient Beech Forests of Germany”.

2.4 Management of the protected massifs

CBR has a 10-year management plan for all the massifs, which includes a detailed forest description with data on forest taxation, maps and the division of the massifs into functional zones (Table 2.1). The plan defines the level of logistic, financial and staff support, specifies conservation measures, defines the tolerated pressure on ecosystems and restricts the use of natural areas. It also specifies the sanitary measures (including salvage logging) to be applied for particular forest diseases and insect infestations, and outlines how infrastructure should be developed.

Any activity that could have a negative impact on the local natural and historical-cultural features is forbidden within the protected massifs of CBR. The regime for using the natural areas in the functional zones corresponds to the Seville Strategy (UNESCO 1996) and the Madrid Action Plan (UNESCO/MAB 2008) for biosphere

reserves. All potential human impact is restricted within the core zone, where natural processes occur without any intervention. The buffer zone allows some conservation measures for restoring natural ecosystems and protecting them from harmful effects. The anthropogenic landscapes zone is the area where traditional land management is practiced (Fig. 2.6). The zone with regulated protection comprises two 50 m wide buffers on both sides of the main corridors leading through the core zone, where measures to maintain the corridors, e.g. to clear away fallen trees, are allowed. Today, every year approximately 1400 m³ of timber are logged in the anthropogenic landscape zone and partially within the buffer zone of the Uholka-Shyrokyi Luh massif, 25 tons of hay are mown, and 700 cattle pastured (average for the years 2007–2011).

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Table 2.1. The functional zoning of the Uholka-Shyrokyi Luh massif under CBR management (Proekt orhanizatsii terytorii Karpats'koho biosferneho zapovidnyka 2002).

Administrative unit	Total area [ha]	Area according to functional zones [ha]			
		Core zone	Regulated protection zone	Buffer zone	Anthropogenic landscape zone
Shyrokyi Luh	5654	3871	175	1436	172
Uholka	4729	3246	248	1065	170
Total	10 383	7 117	423	2501	342



3 The inventory – aims, methods and sampling design

Adrian Lanz, Urs-Beat Brändli, Brigitte Commarmot, Christian Ginzler

“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 (Kievskaja Voenno-Kartograficheskaja Fabrika BKF 2003, sheet 183 Khust and 164 Mezhor'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 \geq 6 cm,
- dead lying trees (complete trees with crown and root-plate) with a DBH \geq 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 \geq 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 judgments): 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 \geq 6 cm) and root-plates were sampled on circular plots with a fixed size of 500 m² (horizontal radius of 12.62 m). Slope correction was applied to ensure a uniform horizontal plot area of 500 m². 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 m² for saplings between 10 cm and 39.9 cm height, 10 m² for saplings with a height between 40 and 129.9 cm, and 20 m² for saplings with a minimum height of 130 cm and up to a DBH of 5.9 cm.

A circular interpretation area of 2500 m² (concentric with the main sample plot for trees) was used to assess

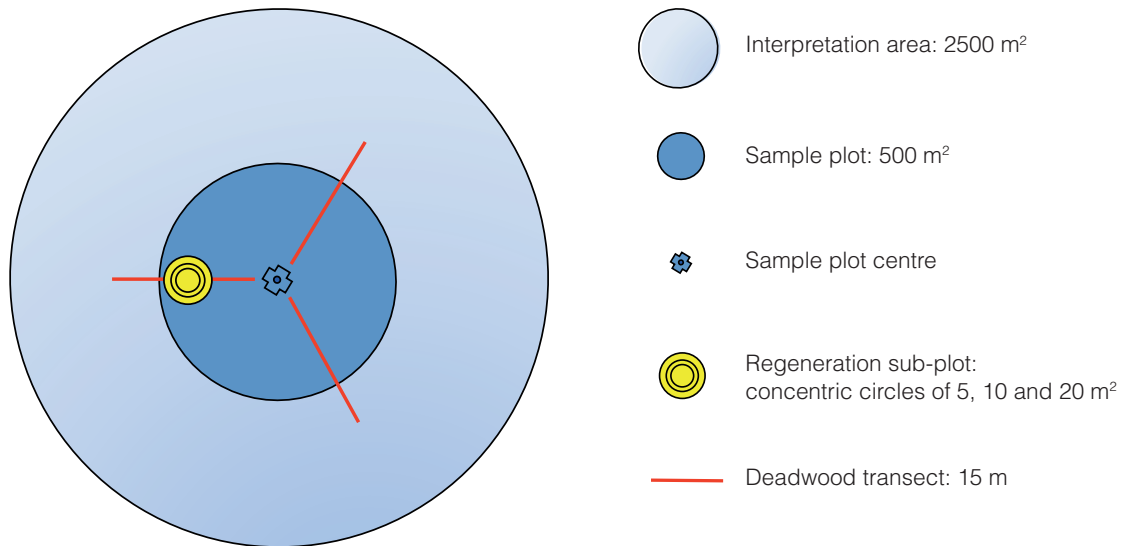


Fig. 3.2. Sample plot design.



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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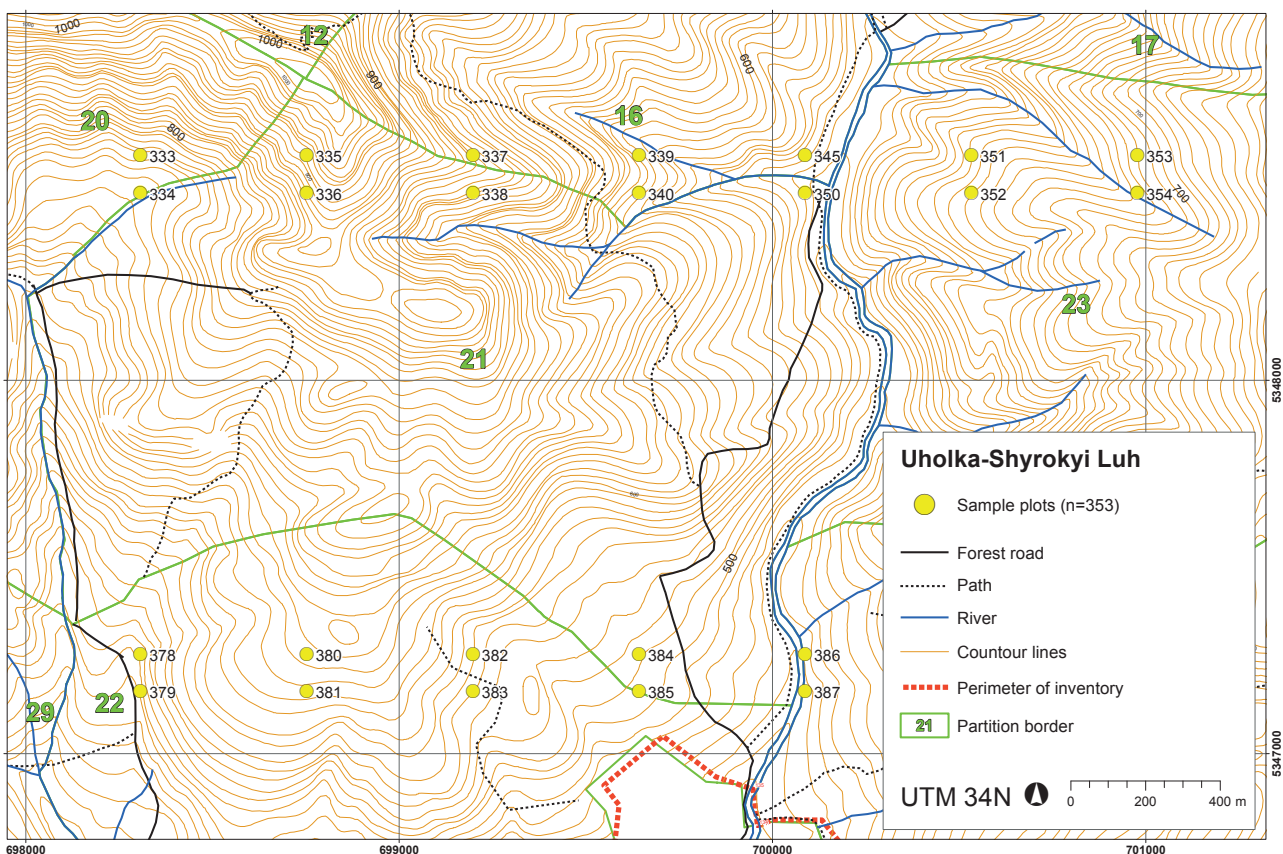


Fig. 3.6. Sampling design with clustered plots arranged on a rectangular grid. Extract from the overview map on a scale of 1:20 000.

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4 Planning and management of the field survey

Martina L. Hobi, Brigitte Commarmot, Ruedi Iseli, Mykola Korol

“During the sometimes tough work, we gained insights into how different people collaborate under such special circumstances. We had the opportunity to learn more about different traditions and ways of living and about interpersonal relationships.”

Volodymyr Trotsiuk, student UNFU, Ukraine

4.1 Pilot inventory 2009

Preparations for the inventory started in winter 2008. A stepwise procedure was adopted, with a pilot inventory in July 2009 and the main inventory in July and August 2010 (Fig. 4.1). The project organisation and division of tasks between WSL, UNFU and CBR are described in Appendix 1.

During the pilot inventory in summer 2009, the two main leaders of the 2010 field work tested the inventory methods (in particular the field manuals and field forms), the field equipment (e.g. the usability and accuracy of the GPS system), and the time needed for the measurements and assessments. They also explored the project area and inspected possible accommodation facilities, the condition of footpaths and river crossings, and the available infrastructure. This was done in close collaboration with the local forest officers. In total, 18 sample plots distributed within the whole perimeter were localised and measured during the pilot inventory. The results allowed the field manual and field forms to be improved, as well as the detailed maps for orientation. The time analysis showed that a reasonable goal would be to assess 1.5 to 2 sample plots per day and team if walking distances and logistics were optimised by having decentralised camp sites and the logistic support of locals.

4.2 Main inventory 2010

The logistics of organising the inventory posed a considerable challenge due to the remoteness of the area, the long walking distances involved and the difficult terrain, about which we had very little information. Access by car was only possible at three points on the southern border of the survey perimeter in Uholka and Shyrokyi Luh. Within the perimeter, there were only a few small footpaths used by the rangers and the main tracks to the mountain pastures, which were wide enough for horses. Good organisation and preparation were essential, as was the support of the local forest service, without which it would not have been possible to carry out the inventory.

The different preparatory tasks consisted of two main types: methodological and logistic preparation (Table 4.1).

Transporting material to the campsite with a horse-drawn sledge. Photo M. Brüllhardt.

Table 4.1. Methodological and logistic preparation.

Methodological preparation	Logistic preparation
Revision and translation of field manuals and field forms	Accommodation and infrastructure
Preparation of maps and orthophotos	Safety measures
Data handling, storage and quality	Support of locals for transport, meals, etc.
Instruments and equipment	Weekend program
Instruction of field teams	Handling of finances
	Recruitment of survey teams
	Operational planning and coordination of survey teams

Field equipment and orientation in the field

The field manuals (COMMARMOT *et al.* 2010) were translated into Ukrainian by scientists at UNFU, and field forms were prepared in German, English and Ukrainian. As electricity was available at only a few places outside the perimeter and the power supply was not reliable, field computers could not be used. All the data collected had to be written on paper forms (six different forms were used) and entered into the computer afterwards. For this an access data-base with entry masks based on the field forms was created. The limited access to electricity and the long walking distances also restricted the choice of measurement instruments and equipment. A list of all the field equipment used for field work can be found in Appendix 2.

The available topographic maps were on a scale of 1:100 000. They were useful to obtain a general orientation, but more detailed maps were needed for reaching the sample plots. Maps based on GIS-data from CBR were therefore created for the whole area and printed on water-resistant paper. Orthophotos with a ground resolution of 0.87 m from 2008 provided background data. The images were very useful when figuring out which areas are covered with forest and for finding the way along the forest boundary. Point symbols, such as the sample plots, additional objects for orientation (e.g. shelters and bridges), and campsites were mapped. The line symbols plotted were rivers, forest paths, forest partition borders and the perimeter of the biosphere reserve. Some information about topography was pro-



Fig. 4.1. Preparation of the pilot inventory. Scientists of WSL, UNFU and the Ukrainian Research Institute of Mountain Forestry with satellite images and GPS, discussing how best to find the way in the field. Left to right: Vasyi Lavnyy, Yuriy Shparyk, Christoph Düggelein, Christian Ginzler. Photo U.-B. Brändli.

vided by 100-m contour lines, but they proved to be not very accurate. All the maps were based on the coordinate system UTM 34N. The Universal Transverse Mercator (UTM) grid uses a 2-dimensional Cartesian coordinate system, where coordinates in each zone are measured to the North and East in meters. Two different versions of the maps were used in the field: an overview map on a scale of 1:20 000 (Fig. 3.6), which covered the whole perimeter, and 32 sub-maps on a scale of 1:8000.

To find the sample plots, the survey teams mainly used a Garmin GPS as a navigation instrument, on which all the plot coordinates (that is a point 20 m south of the sample plot centre) had been saved in advance. Since the accuracy of the GPS system in the massif is only up to 5–7 m, the last 20 meters had to be measured with a compass (Wyssen MERIDIAN MI-4007) and measuring tape (COMMARMOT *et al.* 2010). This ensured that the exact location of the plot centre was randomly selected and not chosen in the field by the survey teams. The walking route to the sample plot needed to be well planned, especially as not all the entries on the map (e.g. footpaths) were up to date (Fig. 4.2). In some cases access to the sample plots was hindered by steep slopes, windthrow areas, blackberry thickets, or creeks. This meant that indirect routes were inevitable.

The best help for orientation in the field was the system of rivers and ridges. It was always easier to walk along ridges since large amounts of deadwood tended to accumulate on the valley floors. Once the plot centre was found, the more accurate Trimble GPS was used to measure the actual coordinates of the plot centre as precisely as possible. The collected data was later improved by post-processing.

Recruitment and instruction of field teams

As the field work was to be carried out by Swiss and Ukrainian students, the survey period was limited to two months (summer holidays). Based on the experience with the pilot inventory, it was decided to work with six survey teams simultaneously. The Swiss students were recruited from the Department of Environmental Systems Science at ETHZ, the Institute of Natural Resource Sciences at ZHAW in Wädenswil, and the School of Agricultural, Forest and Food Sciences at BFH in Zollikofen. All the Ukrainian students were recruited at the UNFU. The students had not only to be well versed in forest ecology and the identification of tree species, but also to have good language skills, and be physically and mentally healthy and robust, enthusiastic about working in remote areas, hard working and precise, open-minded, tolerant and flexible.



Fig. 4.2. Survey team on the way to a sample plot. Photo A. Khomiuk.



Fig. 4.3. Distributing material and equipment at the base camp in Mala Uholka. Photo B. Commarmot.



Fig. 4.4. Campsite of two survey teams in the Shyrokyi Luh unit of the protected massif. Photo D. Oertig.

The field teams were instructed before the start of the sampling inventory. Instruction days (one in Switzerland and one in Ukraine) were organised to acquaint the participants with the measuring methods and instruments. These days were also important for the team members to get to know each other. All the participants received the field manual before the start of the survey. The first two days in Uholka were spent with further training and organising the field equipment (Fig. 4.3). Most of the questions and uncertainties could be discussed and solved during these and the following few days, when all the teams were staying at the base camp. After one month, some of the field team members were replaced and the new participants were instructed for one day in Shyrokyi Luh.

Safety measures

Due to the remoteness of the area and the lack of mobile phone coverage within large parts of the survey perimeter, special safety precautions had to be taken. All the participants had one day of training in first-aid with professionals before the beginning of the inventory. Possible dangerous situations and rules of conduct in the field were discussed with all the survey teams and also given to them in written form. One of the most important rules was to take no risks and to adapt behaviour to the capabilities of the weakest team member. The sampling team decided as a group whether a sampling plot could be measured or had to be classified as inaccessible because of steep slopes or dangerous rocks. All teams were equipped with first-aid kits, emergency phone numbers and alarm whistles to alert other teams working nearby if necessary to get help. Additional medical equipment was stored at the camp sites. The local forest officers and rangers repaired river crossings and built some additional simple bridges. Luckily, no major accident happened during the inventory.

Accommodation and infrastructure

During the planning phase of the inventory, 19 possible accommodation sites (huts and camp sites) suitable for two to three survey teams were selected, and 17 were finally used (see map in the inside back cover). A camp site had to have water, be accessible with horses, have a large enough flat and dry area to set up tents, and not be at risk of getting hit by falling trees or branches in windy weather. The three forest huts "Plesha", "Shcherbanova Poljana" and "Pidshchavna" were repaired in advance so that they could be used as accommodation (Fig. 4.4). Two base camps were set up. The one at the Mala Uholka forest centre of CBR had a power supply and several rooms that could be used for accommodation and as offices for administration and data entry. The one at the CBR control point in Shyrokyi Luh also had some rooms we could use, but it did not have electricity, so a generator had to be installed.

Operational planning and coordination of the survey teams

It was decided to work first with all teams in Uholka, before moving to Shyrokyi Luh during the second month of the inventory. This procedure had the advantage that sampling could be completed in at least one of the two more-or-less secluded administrative units, even if the conditions were such that not all the planned 353 sample plots could be assessed. Initially the plan was to start with a thinned sampling grid, which could be made more compact later if there was still enough time. However, this strategy was rejected as the walking distances would have been too long and the accommodation would have had to be changed too often.

The research area was divided into sampling divisions according to where accommodation was available, and to the topography of the area. Walking distances could thus be minimised and sampling plots revisited on successive days if this was necessary to complete the work. The number of sample plots within each division corresponded to the estimated work capacity of two teams per week. With this design, two teams could each use the same accommodation or camp site and work in the same area. Each of these pairs of team groups was accompanied by one of the leaders or the assistant leader of the survey. This person was then responsible for coordinating the sampling within the particular division and for supervising the work of the two teams. In addition, the group leaders were also responsible for coring one tree per plot for age analysis.

The survey teams consisted of one Ukrainian and one Swiss student each. The common language of the groups was either English or German. The two main leaders of the inventory understood Ukrainian as well as English and/or German. The groups stayed at a specific camp site for one week, returning to the base camp on Friday evenings with all their material. Local people helped with horses to transport material to and from the camp sites, and a cook stayed with the groups during the week, taking care of food and guarding the personal belongings of the students (Fig. 4.5). The local forest officers were very involved in organising the camp sites, improving the infrastructure, organising local helpers and being on call for any unforeseen circumstances.

Work progress varied according to the topography, forest structure and weather conditions. This meant continuous planning was necessary and the sampling divisions had to be adapted from week to week. Since mobile phone reception was very poor, the coordination of the field teams was very challenging. An exchange of information between the field groups was only possible on weekends. Thus, the whole program of all the teams had to be fixed at the beginning of the week and later changes were almost impossible. All the logistic support also had to be arranged over the weekends.



Fig. 4.5. Marija Bohdan preparing breakfast for the survey teams. Photo D. Oertig.

Data entry and data quality

During the whole inventory, two Ukrainians stayed at the base camps, typing the data from the field forms into the data-base. Thus, the completeness of the forms and the data could be continuously checked and unclear entries could be discussed with the field teams. This, together with the intensive instruction and the continuous supervision of the survey teams by the field-work leaders, helped to ensure the data was of high quality. Due to the limited time available, it was not possible for a different team to measure a certain percentage of sample plots a second time, which would have allowed a better estimate of the data accuracy. The data quality could, however, be verified to some extent on the 18 sample plots measured during the pilot inventory in 2009 and re-measured in 2010.

Time management and work performance

The inventory period (July 5 to August 27, 2010) included 39 working days. 12 of these days were not spent on surveying the sample plots due to the instruction of the survey teams and the logistics of setting up and changing camps, or because of bad weather with heavy rain and thunderstorms (Table 4.2). This left only 27 days for measuring and assessing the sample plots. Since there were six survey teams, this resulted in 162 working days for assessing the planned 353 plots.

Table 4.2. Distribution of working days.

Working on plots	27
Coordination and changing camps	7
Instruction of groups	3
Bad weather	2
Total number of working days	39

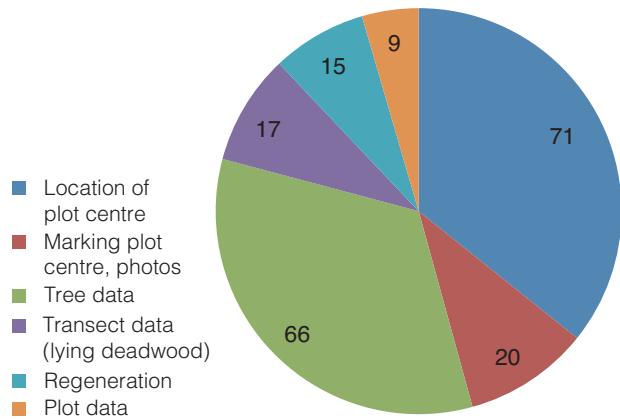


Fig. 4.6. Average time needed (in minutes) to assess a sample plot, including the time taken to walk to the plot from the campsite or last plot. The time does not include getting back to the camp in the evening.

Only two sample plots, located on the northern border of the protected massif, could not be assessed due to lack of time. A further 37 plots were either inaccessible or considered too dangerous for the survey teams. These were mainly plots in steep ravines with slopes of more than 100 %. Thus a total of 314 sample plots were surveyed, i.e. on average approximately two plots per day and team, which corresponded well with the estimated time needed. Finding the 39 plots that turned out to be inaccessible also consumed a large amount of time.

On average, 198 minutes were needed to reach and assess one sample plot. Approximately one third of this time was needed to walk to the plot (Fig. 4.6), one third for the measurements and assessments of the sample trees, and one third for all the other assessments (lying deadwood, regeneration, forest structure, topography, anthropogenic traces), including marking the plot centre, taking photos and recording all relevant information to facilitate relocation of the plot in the future. The calculated average time per sample plot does not include the time needed to return from the last plot of the day to the camp. As it was almost impossible to take the same route back, the teams had to ensure they had enough time to reach the campsite before dark.

Whenever possible, the teams tried to finish work on a plot before the end of the day so that they did not have

to visit the same plot twice. This resulted in long working days, which were not finished when back at the camp. There, the material had to be checked and the field forms copied by taking photos of them. The field work for the next day also had to be planned and prepared. It was not unusual for the teams to work for 10–12 hours a day.

Weekend program

Several joint weekend activities were organised to provide a break from work and an opportunity for the groups to meet and share experiences. These included excursions in Transcarpathia to find out more about the way of life of the people living in the region and about some other intercultural projects going on, as well as visits to the city of L'viv, the university town where the Ukrainian participants in the inventory were studying. As the workload was heavy and the field work physically strenuous, the weekends were almost too short, and the need for a change of scene sometimes conflicted with the need for relaxation and recreation. Nevertheless, the joint weekend activities were important for socialising and team building.

Financial issues

A difficult task during the inventory was the management of finances. All the payments to the local people for meals, transport and other support had to be made in cash (by each of the team leaders), as well as the payments for weekend activities. This meant organising enough opportunities and time to obtain cash. This

form of payment also complicated the book keeping, for which a separate member of the administrative support group was responsible.

Intercultural collaboration

The collaboration between the Ukrainians and the Swiss worked very well and was enriching for both sides. All survey teams were highly motivated and committed to meeting the goals of the inventory (Fig. 4.7). The different cultural and scientific backgrounds of the team members, the different habits and ways of organising things rarely led to discord, but tended rather to be inspiring and have a positive effect on the work. The support of the local forest service and local families was encouraging and crucial for the success of this project. All participants contributed to creating a good atmosphere, which helped everybody keep going even when conditions were difficult and hard. The close and intensive collaboration of the Ukrainian and Swiss students has led to many maintaining contact and even friendships with each other.

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Fig. 4.7. Field crew of the forest inventory in Shyrokij Luh: survey teams and forest officers from Shyrokij Luh and Uholka. Photo M. Brüllhardt.



		<p>4.4.6 Bemerkungen:</p> $\frac{13,5}{36,5} = 28$	
<p>4.2.1.3 Azimut [°]</p> <p>74</p>	<p>4.2.1.4 Azimut [°]</p> <p>75</p>	<p>4.2.1.4 Richtung 1 Grenzlinie [gon]</p> <p>376</p>	<p>4.2.1.5 Richtung 2 Grenzlinie [gon]</p> <p>175</p>
<p>4.3.3.1 Kamera-Nr. <u>2</u></p> <p>4.3.3.2 Anzahl Fotos (alle Fotos auf dieser PF) <u>6</u></p>		<p>4.3.4.4 Beschreibung Objekt</p>	
<p>4.3.4.5 Foto Objekt ja/nein</p>		<p>4.3.4.5 Foto Objekt ja/nein</p>	

5 Data management and statistical evaluation

Meinrad Abegg, Martina L. Hobi, Edgar Kaufmann, Adrian Lanz

“What a unique experience it was to wander through the forest, and to see and feel the dynamics in action, while at the same time becoming immersed in a new culture! We returned home enriched with memories, new friendships and scientific data.”

Luca Mini, student ZHAW, Switzerland

5.1 Storage and handling of the data

The data of the inventory is stored and maintained at WSL, but the Ukrainian partners also have a copy of the data-base. The data is stored in two schemas (applications) of a relational data-base. The first one contains the raw data copied from the field forms (Fig. 5.1). Any modification of the raw data to correct errors in the transcription from the forms is documented in a table. After plausibility checks, the raw data was transferred to a second application used for data analysis. All derived variables, such as the basal area or the volume of trees, are saved in this second application, again with all changes to the data documented in a separate table. Several indicator variables for frequently used subsets of trees and plots have been defined in the tables to ease data extraction and analysis. Typical examples of such subsets are sub-populations of trees, such as living and dead trees, the sample of stumps or the domain of accessed plots in the survey.

5.2 Evaluation routines

The statistical software R (R Development Core Team 2008) was used to develop evaluation routines. Two functions were programmed, which can be easily parameterised to produce basic result tables. One function handles tables with one subgroup at the tree level (e.g. diameter classes) and one subgroup at the plot level (e.g. functional zones of the reserve). The function is able to read and combine data from different data-base tables, such as the plot table, the regeneration table and the tree table. The other function reads data from the regeneration table only and allows two subgroups. Both functions produce point and error estimates, which are stored in a separate result table. The target variable (e.g. basal area), the tree population to be analysed (e.g. living trees), the sub-populations (e.g. diameter classes), the sub-domain of interests (e.g. management zones) and the definition of forest land under investigation (e.g. accessible forest) can be defined in a flexible way. The estimators are those given in MANDALLAZ (2008, p. 65–69) under a non-



Fig. 5.1. Vasyly Lutsyshyn and Volodymyr Savchyn in the CBR check-point office in Shyrokyi Luh, typing data from the field forms to the data base. Photo B. Commarmot.

stratified, one-phase, one-stage cluster random sampling scheme. The two adjacent sample plots in the double rows of the inventory (Fig. 3.6) should be treated as a cluster of two plots when estimating population parameters. The estimators are as follows:

As a first step, tree variables are summarised to plot values, the so-called local density $Y(x_l)$, which is always standardised to a per hectare value. In formula [1] below, the sum is over the $N(x_l)$ trees in plot l of cluster x . f_i is the extrapolation factor to obtain hectare values (in our case usually 20), and X_i is the value of the target variable X for tree i . X can be e.g. the tree volume or take the value of 1 for the estimation of the number of stems.

$$[1] \quad Y(x_l) = \sum_{i=1}^{N(x_l)} X_i f_i$$

The number of plots per cluster $M(x)$ within the area of interest is then calculated according to formula [2], and the average number of plots per cluster \bar{M}_2 (usually 2 in this inventory) according to formula [3], where I_F is an indicator variable indicating whether the plot x_l lies in the domain of interest F , and n_2 the number of clusters used for the estimation.

$$[2] \quad M(x) = \sum_{l=1}^M I_F(x_l)$$

$$[3] \quad \bar{M}_2 = \frac{1}{n_2} \sum_{x \in S_2} M(x)$$

The local density for the cluster $Y_c(x)$ is simply the arithmetic mean of the plot densities [4]:

$$[4] \quad Y_c(x) = \frac{\sum_{l=1}^M I_F(x_l) Y(x_l)}{M(x)}$$

Finally, the following estimators are used to calculate the estimate for the (unknown) mean spatial density \hat{Y}_c of the target variable X in the area of interest F [5] and the variance of the estimate $\text{Var}(\hat{Y}_c)$ [6]:

$$[5] \quad \hat{Y}_c = \frac{\sum_{x \in S_2} M(x) Y_c(x)}{\sum_{x \in S_2} M(x)}$$

$$[6] \quad \widehat{\text{Var}}(\hat{Y}_c) = \frac{1}{n_2(n_2-1)} \sum_{x \in S_2} \left(\frac{M(x)}{\bar{M}_2} \right)^2 (Y_c(x) - \hat{Y}_c)^2$$

$Y(x_l)$ Local density at plot level.

i : Tree (1 ... N).

X_i : Value of target variable for tree i .

f_i : Extrapolation factor of the i^{th} tree to obtain hectare values.

x : Cluster (1 ... n_2).

x_l : Plot l in cluster x (1 ... M).

- $M(x)$: Number of plots n in cluster x .
- $I_F(x_i)$: Indicator variable, indicating whether the plot x_i lies in the domain of interest (F).
- \bar{M}_2 : Average number of plots per cluster falling into the domain of interest (F).
- $Y_c(x)$: Local density at the cluster level.
- \hat{Y}_c : Estimated local density in the domain of interest (point estimate).
- $\widehat{Var}(\hat{Y}_c)$: Variance (error) of the estimated local density.
- s_2 : Set of clusters (sample) used for the estimation.
- n_2 : Number of clusters used for the estimation.

Confidence intervals are based on the standard error of the estimate, which is the square root of the variance. To test for differences in the estimators between two sub-domains of interest, a two sample t-test with unequal variances was used.

The total of the target variable X , i.e. the total timber volume in the reserve, is computed by multiplying the above mean spatial density of the variable (and likewise the standard error) with the area of interest (F).

The point estimator for the ratio of two variables X and Z (e.g. the volume of beech in relation to the total volume of all tree species) is simply the ratio of the two estimates. The formula for estimating variance is slightly more complicated (MANDALLAZ 2008, p. 68).

5.3 Volume estimation

Volume of living trees

To create a tariff function to estimate the volumes for all trees with an intact stem (not broken), we computed, in a first step, the individual stem volumes V_1 of the 1054 trees with additional measurement of the stem height H according to formula [7] (Kaufmann, unpublished):

$$[7] \quad V_1 = 0.03427 + 0.35690 * DBH^2 * H - 0.02497 * DBH^3 * H$$

The volumes V_2 of the 520 trees were computed with additional measurements of the stem height H and the upper stem diameter $D7$ according to formula [8], which was developed for the Swiss NFI (KAUFMANN 2001, p. 163):

$$[8] \quad V_2 = 0.002542 + 2.56612 * DBH^2 - 3.67034 * D7^3 + 0.39446 * D7^2 * H + 0.03567 * DBH^3 * H$$

In a second step, the volumes of these 1574 trees were used to calibrate a function that predicts the tariff volume (TV) for all trees measured [9]. The tariff volume is defined as the stem volume from the ground to the

stem top, including the bark. The explanatory variables are the DBH of the stem, the altitude of the plot (ALT, m a.s.l.), the presence of a stem bifurcation (BF, an indicator variable) and the crown length (CL, categorical variable in three classes):

$$[9] \quad TV = \exp(-9.88133 + 3.03787 * \ln(DBH) - 0.002725617 * \ln^4(DBH) - 0.000387604 * ALT - 0.11263 * BF - 0.044796 * CL)$$

The coefficients were estimated by nonlinear regression analysis.

Finally, to calculate the total volume including branch wood with a minimum diameter of 7 cm, a certain percentage was added to the stem volume (Fig. 5.2). This percentage was assumed to be equal to the proportion observed on average in Swiss forests (Duc *et al.* 2010). Thus, the branch volume of beech trees was estimated to be 17% of the stem volume. For all other deciduous tree species, the value 7% for sycamore (*Acer* sp.) was chosen, as this species accounts for the largest share of the basal area of the admixed species. Branch volumes were only added to trees with a complete crown.



Fig. 5.2. The volume of a tree includes the stem volume from the ground to the stem top and branch wood with a minimum diameter of 7 cm. Photo L. Denzler.



Fig. 5.3. Dead tree with intact stem and crown. The volume of such a tree was estimated in the same way as that of a living tree. Photo U.-B. Brändli.



Fig. 5.4. The volume of a snag was calculated as a cylinder, using the measured snag height and the modeled diameter at half the snag height. Photo B. Commarmot.

Volume of dead standing trees, snags and stumps

To calculate the volume of dead standing trees, four cases were distinguished:

- a) Dead trees with intact stems and crowns (Fig. 5.3):
The volume was calculated according to the tariff function TV (see formula [9] above), plus the addition for branch volume.
- b) Dead trees with an intact stem but only stubs of branches: The volume was calculated according to the tariff function TV [9] (without branch wood).
- c) Snags (stem broken above 1.3 m height, Fig. 5.4):
The snag volume V_s [10] was calculated according to COMMARMOT *et al.* (2005) as a cylinder, using the measured snag height H_s and the modeled diameter at half the snag height $D_{0.5H_s}$. Based on the trees where both the DBH and the upper stem diameter $D7$ were measured, a simple linear model was calculated to predict the $D7_{mod}$ from the DBH [11]. The DBH and $D7_{mod}$ were then used to estimate the diameter decrease per m tree height DD_m [12], and to calculate the diameter at half the snag height $D_{0.5H_s}$ [13].

$$[10] \quad V_s = \pi \left(\frac{D_{0.5H_s}}{2} \right)^2 H_s$$

$$[11] \quad D7_{mod} = 0.8834 * DBH - 0.01912$$

$$[12] \quad DD_m = \frac{DBH - D7_{mod}}{5.7}$$

$$[13] \quad D_{0.5H_s} = DBH - \left(DD_m \left(\frac{H_s}{2} - 1.3 \right) \right)$$

V_s : Volume of the snag [m³].

H_s : Measured height of the snag [m].

$D_{0.5H_s}$: Modelled diameter at half the snag height [m].

DBH : Measured diameter at 1.3 m above ground [m].

DD_m : Modelled diameter decrease per meter [m].

$D7_{mod}$: Modelled diameter of the tree at a height of 7 m [m].

This approach to volume estimation is based on the assumption that the diameter decrease per m from the stem base to the top of the stem is constant and equal to that between 1.3 m and 7 m height. As the mean snag height was 5.25 ± 0.01 m (see 6.4), we

think that any error arising from this assumption is negligible. Another simplification was to apply the cylinder formula, which slightly underestimates the stem volume (KRAMER and AKÇA 1995).

- d) Stumps < 1.3 m height: The volume was computed according to formula [10] as a simple cylinder, with the height of the stump and its diameter halfway up, which were both measured in the field.

Volume of lying deadwood

The volume of lying deadwood assessed with line intersect sampling (3.2) was calculated according to BÖHL and BRÄNDLI (2007):

$$[14] \quad Y(x_l) = \frac{1}{h_l} \sum_{k=1}^{h_l} \frac{\pi^2}{8L_k} \sum_{i=1}^{N(k)} \left(\frac{D1_i + D2_i}{2} \right)^2 \frac{1}{\cos \alpha_i}$$

$Y(x_l)$: Estimated lying deadwood [m³/ha] on sample plot x_l .

h_l : Number of transects on sample plot x_l .

L_k : Horizontal length of the k^{th} transect [m].

$D1_i, D2_i$: Diameter of deadwood piece i [cm] measured crosswise

α_i : Inclination of the deadwood piece [gon].

$N(k)$: Number of deadwood pieces on the k^{th} transect line.

The volume was stored as a plot variable (represented volume of deadwood per ha), and in a separate table as volume per ha represented by each piece of deadwood. This meant the lying deadwood could be classified for the evaluation.

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6 Main results

Brigitte Commarmot, Meinrad Abegg, Urs-Beat Brändli, Martina L. Hobi, Mykola Korol, Adrian Lanz

“This was a very good project. The steep slopes, regeneration, deadwood and windthrow areas presented difficulties. I thought such an inventory would not be possible – but we did it.”

Vasyl Kostyshyn, PhD student UNFU, Ukraine

6.1 Presentation and statistical interpretation of the results

In this chapter, we present some basic findings about the current status of the primeval forest of Uholka-Shyrokyi Luh. All results relate to the areas accessible within the perimeter (assessed plots; see 4), given separately for the two administrative units Uholka and Shyrokyi-Luh, as well as for the entire massif. In some cases, they are also presented separately for the different functional zones of the protected massif.

The results summarised in the following tables are statistical estimates of unknown population parameters, such as the average volume of living and dead trees per hectare or the total number of stems per diameter class. The estimates are subject to sampling errors, i.e. sample-to-sample variations, which originate in the randomised sample selection. For this reason, all estimates are given with standard errors so that confidence intervals for the unknown population parameter can be computed at any desired level. For a 95% confidence level, for instance, the lower and upper confidence limits are $X - 2 * SE(X)$ and $X + 2 * SE(X)$, while $X - SE(X)$ and $X + SE(X)$ are the confidence limits at the 68% confidence level (X denotes the estimate, and $SE(X)$ its standard error). The correct interpretation of such a confidence interval is: Assuming repeated samples have been randomly collected according to the same sampling design, the unknown population parameter would be within the above mentioned confidence interval limits in 95% (68%) of these samples (COCHRAN 1977; SÄRNDAL *et al.* 1992).

Confidence intervals can be used to test whether the observed difference between the estimates for two different populations (e.g. the tree population of Uholka and the tree population of Shyrokyi Luh) is statistically significant. If the confidence intervals of the two estimates do not overlap, we conclude that the difference between the two population parameters is significant at the given probability level, and that otherwise the difference is not significant.

In this survey, 314 sample plots 500 m² in size were assessed, with a total surface area of 15.6 ha. Thus, the sampling intensity in this survey is 0.15% (the entire study area measures 10282.3 ha). On average, each sample plot represents an area of 29.1 ha.

6.2 Topography and anthropogenic traces

Local distribution and topographic characteristics of the plots studied

The 314 assessed sample plots are distributed almost equally over the administrative units of Uholka (46%) and Shyrokyi Luh (54%). 71% are in the core zone of the massif (Table 6.1).

The distribution of plots according to altitude, slope, aspect and relief (Fig. 6.1) reflects differences in topography and site conditions between the two administrative units, which may influence the growth conditions

Table 6.1. Number of plots assessed in the administrative units and functional zones.

	Uholka	Shyrokyi Luh	Whole study area
Core zone	98	124	222
Buffer zone	36	36	72
Other zones	11	9	20
All zones	145	169	314

and species composition of the forest. On average, the terrain in Uholka is at lower altitudes, less steep and more south exposed than that in Shyrokyi Luh. In Uholka, the average altitude of the plots is 778 ± 22 m and the average slope 46 ± 2 %, and in Shyrokyi Luh it is 908 ± 18 m and 55 ± 1 %, respectively. It should be noted that the steepest plots were classified as inaccessible and are therefore not represented in these values. The lowest sample plot assessed is in Uholka at 460 m a.s.l., and the highest in Shyrokyi Luh at 1270 m. In both territories, 80 % of the plots are on the middle slopes, and only a few are on hilltops or ridges (upper zone of slope with water and nutrient run-off), or on the foot slopes, where water and nutrients are most plentiful. Whereas in Shyrokyi Luh the plots are almost evenly exposed to the different aspects, only a few plots in Uholka are north exposed (north-west to north-east).

Traces of human activities

The anthropogenic traces assessed include all kind of traces from discarded cigarette packets to traces of recent or former logging. Traces of human activities were found on 19% of all plots (interpretation area, 2500 m² in size). They were three to four times more

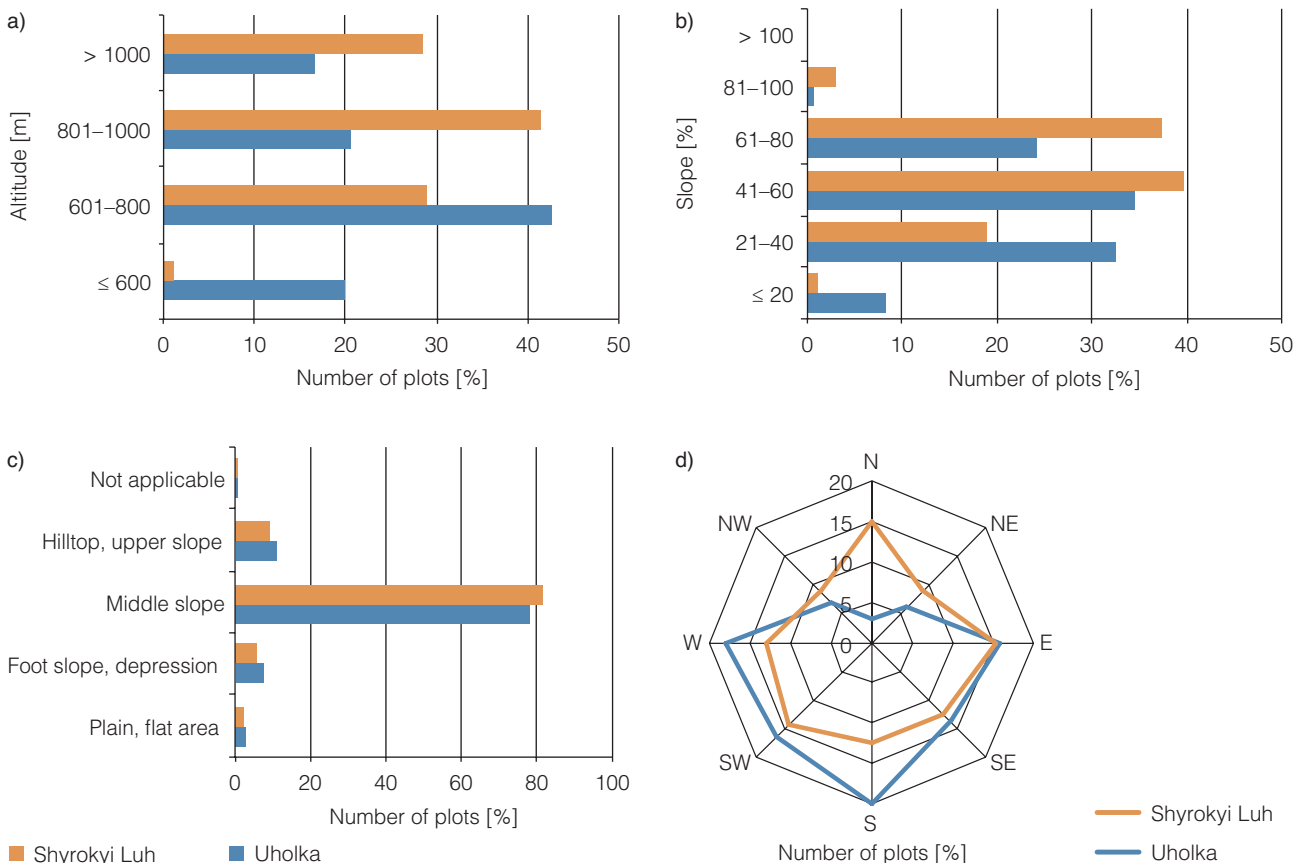


Fig. 6.1. Relative frequency of a) altitude, b) slope, c) relief and d) aspect of the assessed plots in the administrative units Uholka and Shyrokyi Luh. Total number of plots = 314.

Table 6.2. Anthropogenic traces found in the different functional zones. Number of plots (2500 m² in size) with anthropogenic traces.

Type of anthropogenic trace	Core zone	Buffer zone	Other zones	Whole study area
Timber cutting	7	6	4	17
Timber not removed	2	1	0	3
Timber removed	1	4	2	7
Not identifiable	2	1	1	4
Not specified	2	0	1	3
Roads or paths	10	19	3	32
Footpaths	9	6	1	16
Trampling tracks (e.g. by horses)	0	8	2	10
Wheel tracks	1	5	0	6
Livestock grazing, pasturing	0	12	0	12
Fire, traces of burning	1	2	0	3
Buildings or other constructions	1	0	0	1
Plantation	1	0	0	1
Litter, waste	6	10	1	17
Anthropogenic damage to trees	4	5	1	10
Research, monitoring	4	2	2	8
Other traces (gas pipeline)	0	1	0	1
Some anthropogenic traces	25	30	6	61
In % of all plots in respective zone	11	42	30	19
Total number of plots assessed	222	72	20	314

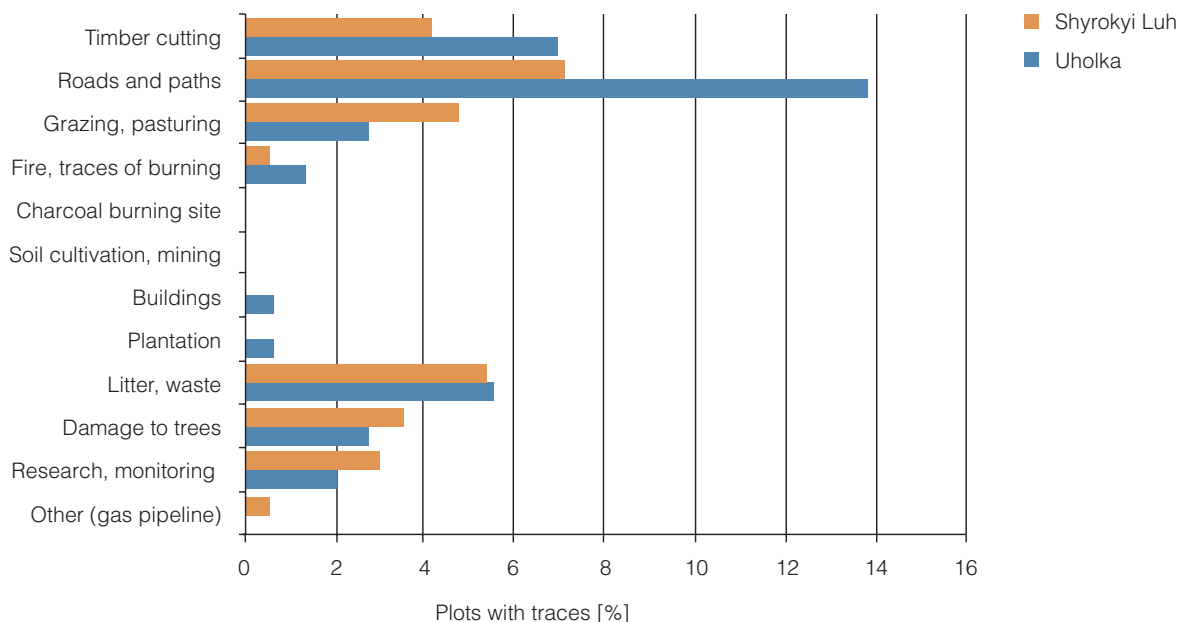
Fig. 6.2. Percentage of plots with anthropogenic traces found in the two administrative units. Total number of plots assessed = 314 (145 in Uholka, 169 in Shyrokyi Luh). Plot size = 2500 m².



Fig. 6.3. Small footpath used by locals and forest rangers in the Uholka-Shyrokyi Luh massif. A fallen tree across the path has been sawn through to facilitate access. Photo V. Chumak.

frequent in the buffer and regulated protection zone than in the core zone (Table 6.2), where traces were detected on only 11% of the plots. They also tended to be more frequent in Uholka than in Shyrokyi Luh (Fig. 6.2). This is mainly due to the higher density of roads and paths, in particular in the southern part of the Uholka administrative unit.

“Roads and paths” were the most frequent anthropogenic traces found (Table 6.2). Paths consisted mainly of small footpaths (Fig. 6.3), but in the buffer and regulated protection zone there were also wider tracks used for packhorses, horse-drawn vehicles or off-road trucks. Traces of timber cutting were noted on 17 of the 314 plots, 7 of which were inside the core zone. This does not necessarily mean, however, that timber was actually removed from the forest, although it clearly was from one plot in the core zone. In other places, trees that had fallen across a path had been sawn through to facilitate access, with the timber left on site (Fig. 6.3). Other anthropogenic traces found were waste, (anthropogenic) damage to trees, and in the buffer zone also traces of livestock grazing (mainly by sheep and goats, Fig. 6.4).

Apart from paths and items to do with “research and monitoring”, most anthropogenic traces were found close to the settlements of Mala and Velyka Uholka, along the upper forest line and along the main routes to the mountain pastures in Shyrokyi Luh (see maps in Appendix 3). All in all, the impact of anthropogenic use – at least in the core zone of the reserve – appears to



Fig. 6.4. Sheep and goats on the way to the mountain pasture. Photo B. Hasspacher.

be very small, although the traces found suggest that the area is frequented quite often.

6.3 Tree species diversity and forest structure

The current forest composition and structure allow some inferences to be drawn about the forest dynamics and (natural or anthropogenic) disturbances. The tree species and structural diversity of a forest are also important for biodiversity, as they provide different habitats and diverse light conditions.

Tree species diversity

A total of 6779 living trees and 460 dead standing trees and snags ≥ 6 cm DBH were assessed on the 314 sample plots. On average, there are 435 (± 12) living trees per ha in the study area (Table 6.4), most of which are beech (*Fagus sylvatica* L.). The proportion of tree species other than beech is less than 3% (Table 6.3), and slightly higher in Uholka than in Shyrokyi Luh. In total, 15 tree species were identified on the plots, two of them only in saplings less than 1.3 m tall (for the list of all species recorded, see Appendix 4). The most frequent admixed species are: sycamore (*Acer pseudoplatanus* L.), silver fir (*Abies alba* Mill.), elm (*Ulmus glabra* Huds.) and European hornbeam (*Carpinus betulus* L.), which are all relatively shade tolerant, at least when young (ELLENBERG *et al.* 1992; EWALD 2007). Very light-demanding species typically occurring in early successional or pioneer phases, such as poplars (*Populus* sp.) or willows (*Salix* sp.), were found very rarely, and then only along the forest edge or close to a river. Apart from a few Norway spruce (*Picea abies* Karst.) trees planted beside huts, all species found are of natural origin.



Fig. 6.5. Sycamore (*Acer pseudoplatanus* L.) saplings. Tree species other than beech were more frequent in the regeneration than in the tree population ≥ 6 cm DBH. Photo B. Reineking.

Sycamore has the widest distribution of all the admixed species within the study area, occurring from less than 500 m altitude up to the upper forest line (Fig. 6.5). Norway maple and elm were also found up to altitudes of 1000 m or more, whereas the other admixed broadleaved species were mainly found at lower alti-

Table 6.3. Tree species composition (percentage of basal area; living trees ≥ 6 cm DBH).

	Uholka % \pm SE	Shyrokyi-Luh % \pm SE	Whole study area % \pm SE
Beech (<i>Fagus sylvatica</i> L.)	96.5 \pm 1.0	97.9 \pm 0.9	97.3 \pm 0.7
Sycamore (<i>Acer pseudoplatanus</i> L.)	1.4 \pm 0.6	0.5 \pm 0.3	0.9 \pm 0.3
Norway maple (<i>Acer platanoides</i> L.)	0.1 \pm 0.1	0.2 \pm 0.2	0.1 \pm 0.1
European Hornbeam (<i>Carpinus betulus</i> L.)	0.8 \pm 0.4	0.5 \pm 0.4	0.6 \pm 0.3
Elm (<i>Ulmus glabra</i> Huds.)	0.8 \pm 0.7	0.0 \pm 0.0	0.4 \pm 0.3
Ash (<i>Fraxinus excelsior</i> L.)	0.1 \pm 0.1	0.0 \pm 0.0	0.1 \pm 0.0
Silver fir (<i>Abies alba</i> Mill.)	0.0 \pm 0.0	0.8 \pm 0.6	0.5 \pm 0.3
Other species	0.3 \pm 0.1	0.1 \pm 0.1	0.2 \pm 0.1
All species	100.0 \pm 0.0	100.0 \pm 0.0	100.0 \pm 0.0

tudes in Uholka, and to a lesser extent also in Shyrokyi Luh. Silver fir occurs only on a limited area in the northern part of Shyrokyi Luh above 750 m a.s.l. Maps showing the distribution of the sample plots with the most widespread tree species can be found in Appendix 5.

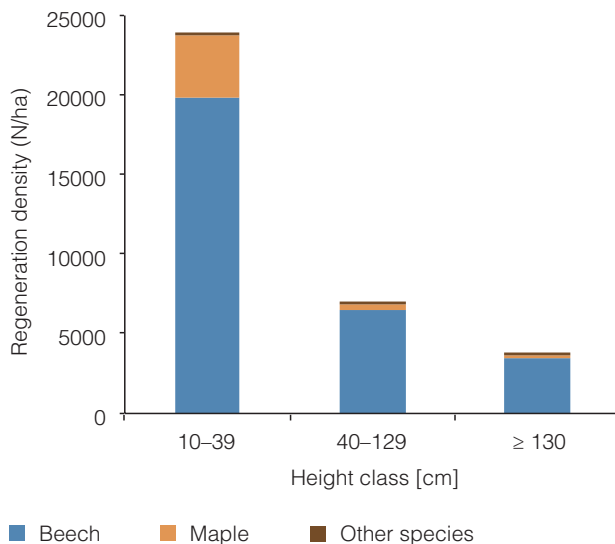


Fig. 6.6. Regeneration density according to height class and tree species. Maple = *Acer pseudoplatanus* and *Acer platanoides*. Total number of saplings (all height classes) < 6 cm DBH = 34 642 (\pm 3859) per hectare.

All species present in the tree population \geq 6 cm DBH were also found in the regeneration (in total, 1277 saplings \geq 10 cm tall and < 6 cm DBH were assessed). The percentage of tree species other than beech decreases from 17% in the regeneration class 1 to 7% in class 2 and 4% in class 3 (Fig. 6.6). This finding shows that beech is very competitive and may outlive longer suppression periods than most of the other species found. On average, there were more than 34 000 seedlings and saplings per hectare (3 per m^2), 69% of which were less than 40 cm tall.

Browsing damage to the leading shoot caused by red deer (*Cervus elaphus* L.) or roe deer (*Capreolus capreolus* L.) was very rarely found. Only 0.1% (\pm 0.1%) of all 10 to 129 cm high saplings had been browsed during the previous year. Although saplings other than beech were browsed about four times as often as beech (0.4% \pm 0.2% of the admixed species), the current populations of red and roe deer do not seem to have a negative impact on the regeneration density. It appears that most of the admixed species are able to maintain their albeit very low share in the distribution of the tree population.

Forest structure

On average, the number of living trees in the virgin forest of Uholka-Shyrokyi Luh was 435 (\pm 12) per ha, the basal area 37 (\pm 1) m^2 , and the growing stock (volume of living trees) 582 (\pm 14) m^3 (Table 6.4). Deadwood (standing and lying) made up 22% of the total volume

Table 6.4. Main characteristics of forest structure. (Calliper limit = 6 cm DBH. The volumes include branch wood \geq 7 cm diameter.) Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* $P \leq$ 0.05, ** $P \leq$ 0.01, *** $P \leq$ 0.001).

Population	Parameter		Uholka Mean \pm SE	Shyrokyi Luh Mean \pm SE	Whole study area Mean \pm SE
Living trees \geq 6 cm DBH	Number of trees [N/ha]	standing	411.0 \pm 19.4	448.1 \pm 15.3	431.0 \pm 12.2
		lying	3.6 \pm 1.2	4.4 \pm 1.1	4.0 \pm 0.8
		total	414.5 \pm 19.4	452.5 \pm 15.2	435.0 \pm 12.2
	Basal area [m^2 /ha]	standing	35.3 \pm 1.2	37.3 \pm 1.0	36.3 \pm 0.8
		lying	0.2 \pm 0.2	0.3 \pm 0.1	0.3 \pm 0.1
		total	35.5 \pm 1.2	37.5 \pm 1.0	36.6 \pm 0.8
	Volume [m^3 /ha]	standing	582.7 \pm 21.5	574.6 \pm 17.4	578.4 \pm 13.6
		lying	3.9 \pm 2.8	3.7 \pm 1.2	3.8 \pm 1.5
		total	586.6 \pm 21.4	578.3 \pm 17.2	582.1 \pm 13.5
Deadwood	Number of trees [N/ha]	standing ¹⁾	26.6 \pm 3.8	32.2 \pm 2.6	29.6 \pm 2.2
		lying ²⁾	1.9 \pm 0.8	1.0 \pm 0.4	1.4 \pm 0.4
	Volume [m^3 /ha]	standing ¹⁾	30.4 \pm 5.7	23.3 \pm 2.9	26.6 \pm 3.1
		lying ³⁾	150.1 \pm 11.2	123.8 \pm 10.0	135.9 \pm 7.5
		total	180.5 \pm 12.9	147.1 \pm 10.7 *	162.5 \pm 8.4

¹⁾ Dead trees and snags

²⁾ Only complete trees with crown and rootplate, and with DBH \geq 6 cm

³⁾ Total volume of lying deadwood (including the complete trees) with a diameter \geq 7 cm, assessed with line intersect sampling



Fig. 6.7. Small-scale mosaic of multilayered forest with regeneration of beech growing in a small gap. Photo U.-B. Brändli.

(living and dead) of 745 m^3 per ha. These values lie within the range of values given for primeval beech forests in the north-western Carpathians of Slovakia (KUCBEL *et al.* 2012; KORPEL' 1995). Tree density, basal area and growing stock did not significantly differ between the administrative units of Uholka and Shyrokyi Luh. The total deadwood volume was slightly higher in Uholka than in Shyrokyi Luh, although the difference is statistically of little significance ($p = 0.05$).

The horizontal and vertical forest structure can be described in terms of the canopy closure, the degree of crown cover in the different canopy layers and the estimated gap sizes (see 3.2). In general, the virgin beech forest of Uholka-Shyrokyi Luh is rather dense, with only small gaps in the canopy (Fig. 6.7). The upper canopy layer was mainly fairly loose (with few gaps the size of a canopy tree) or closed (Fig. 6.8a). The canopy was described as scattered on less than 20% of the plots, which had several gaps large enough for more than one canopy tree to fit. 61% of the sample plot centres did not lie in a gap (Fig. 6.8b) and only 16% were in gaps larger than 200 m^2 (corresponding to a

radius of 8 m). Some gaps larger than 5000 m^2 were also found, indicating the albeit rare occurrence of medium- to large-scale disturbances, e.g. caused by wind. The vertical forest structure was mainly three-layered (in two thirds of the sample plots), which means that the degree of cover of the upper, medium and lower canopy layer was $\geq 20\%$ each. A one-layered structure (where only one of the canopy layers had a coverage of at least 20%) was found in only 7% of the plots (Fig. 6.8c). The structural diversity was slightly more pronounced in Shyrokyi Luh than in Uholka, where there were fewer plots with a closed canopy and the vertical structure was better developed (Fig. 6.8).

The diameter distributions, showing the number of living trees per 4-cm diameter classes, differed slightly between Uholka and Shyrokyi Luh, although the general trend of the curves is similar (Fig. 6.9). The rotated sigmoid type of diameter distribution is commonly observed in primeval forests (Fig. 6.10). This type, where the highest density of trees is in the smallest diameter class, with a second small peak in the mid-diameter range, is clearly visible in the curve for Uholka, and less

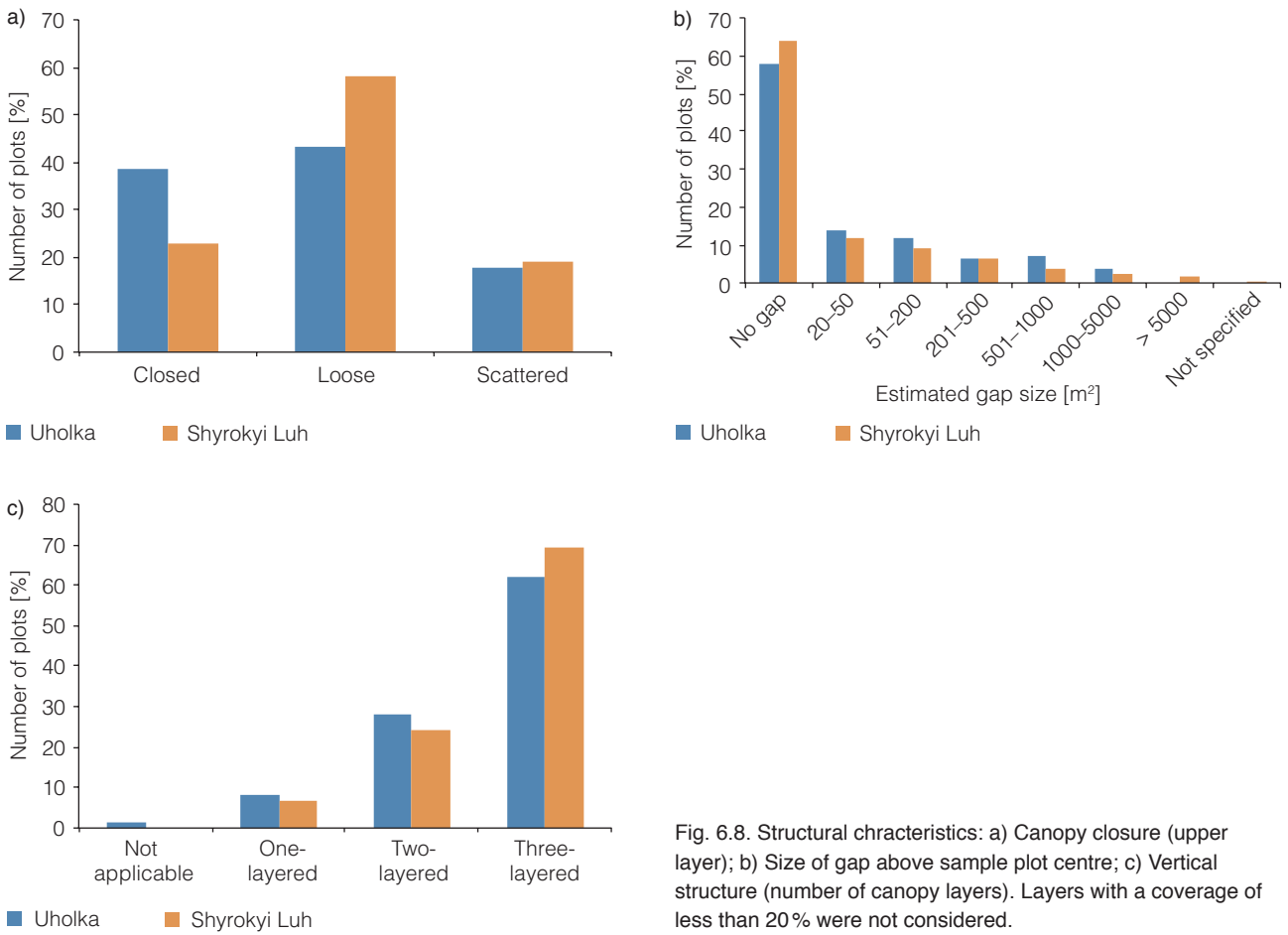


Fig. 6.8. Structural characteristics: a) Canopy closure (upper layer); b) Size of gap above sample plot centre; c) Vertical structure (number of canopy layers). Layers with a coverage of less than 20% were not considered.

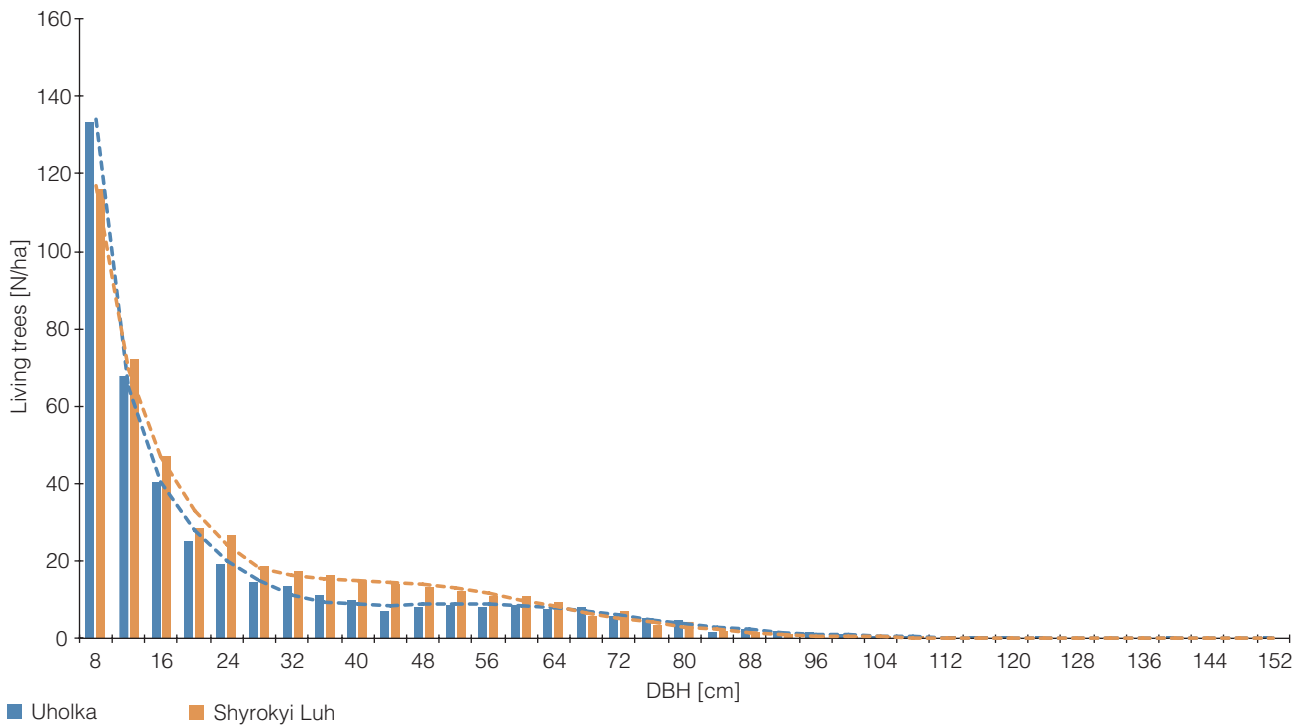


Fig. 6.9. Diameter distribution of living trees ≥ 6 cm DBH in the administrative units Uholka and Shyrokyi Luh. The numbers on the horizontal axis indicate the midpoints of the 4 cm DBH classes (e.g. 8 = 6.0–9.9 cm DBH class). The dashed lines show the distributions predicted by a three-parameter Weibull function.



Fig. 6.10. Even within small areas, the tree diameters range widely. Photo U.-B. Brändli.

clearly visible in the curve for Shyrokyi Luh. It seems to be a typical diameter distribution pattern for deciduous old-growth forests without severe (stand-replacing) disturbances (GOFF and WEST 1975; WESTPHAL *et al.* 2006; ALESSANDRINI *et al.* 2011).

Large and old trees

On average, 10 ± 1 trees per ha had a DBH of 80 cm or more (Fig. 6.11). Such giant trees were more frequent in Uholka (12 ± 1 per ha) than in Shyrokyi Luh (8 ± 1 per ha), possibly due to the better growth conditions at the lower altitudes. The largest tree measured was an elm with a DBH of 150 cm, a height of 43 m and a volume² of approx. 38 m³. The largest beech measured was 140 cm thick and had a volume of 28 m³. Both trees were found in the Uholka administrative unit. The largest tree encountered in Shyrokyi Luh, a beech, had a DBH of 115 cm and a volume of 21 m³. In both territories, trees of up to 50 m in height were found. The tallest tree measured was a 53 m beech.

A complementary study conducted in Uholka on 164 trees showed that beech in this area may reach an age of 450 to 500 years, although trees older than 150 years are prone to stem rot (TROTSIUK *et al.* 2012). Old trees, however, are not necessarily very large, and the largest trees are usually not the oldest ones. The oldest beech where the tree rings could be reliably counted was at least 464 years old and had a DBH of only 63 cm. The tree-ring analyses revealed that beech trees may survive long suppression periods of over 100 years. This explains why only a weak relationship between DBH and age was found, involving uncertainties of 100 to 200 years for a given DBH.

² Including branches ≥ 7 cm diameter.



Fig. 6.11. Survey team posing in front of a giant beech. From left to right: Volodymyr Trotsiuk, Martina Hobi, Igor Cherniuk, Luca Mini and Jonas Stillhard. Photo M. Hobi.

6.4 Habitat structures

Deadwood and old trees provide the most important habitat features for thousands of wood-dwelling animals, fungi, mosses and lichen species (MÜLLER and BÜTLER 2010; BRÄNDLI and BERANOVA 2011; LASSAUCE *et al.* 2011) (Fig. 6.12). As many as one third of European forest species depend on deadwood for their survival (BOODY 2001; SIITONEN 2001). The uprooting of trees creates not only deadwood, but also a pit-and-mound microrelief with exposed root-plates, bare mineral soil and humus, which are also important microhabitats for many species (ULANOVA 2000; BOUGET and DUELLI 2004; LÖHMUS *et al.* 2010). The inventory data of the Uholka-Shyrokyi Luh primary beech forest may serve as a reference for such habitat elements when evaluating the ecological value of managed forests.

Deadwood, stumps and root-plates

The average number of dead standing trees was 30 ± 2 N per ha. 70% of them were broken (snags), and only 18% still had their complete crown including fine

branches (Table 6.5). In addition to the dead standing trees and snags, there were 3 ± 1 stumps (50–129 cm high) per ha. The average height of stem breakage of snags was 5.25 ± 0.01 m. The difference in the number of dead standing trees and snags between Uholka and Shyrokyi Luh is statistically not significant. In both administrative units, the ratio of living to dead trees and snags was the same (14:1).

The proportion of dead trees per diameter class was more-or-less equal for trees up to a DBH of 60 cm (6%), and twice as much for trees larger than 60 cm DBH (12%) (Table 6.6). The three DBH classes between 21 and 80 cm had all more-or-less the same number of dead standing trees (4–5 N/ha), which abruptly decreased to 1 N/ha in the DBH class 81–100 cm (Fig. 6.13). It seems that most of the beech trees reach their natural life span before they are 80 cm thick. As can be seen in Fig. 6.9, the number of living trees larger than 80 cm DBH also decreases abruptly.

The total volume of deadwood was 163 m³ per ha (Table 6.4), of which 84% was lying deadwood (Fig. 6.14). The ratio of standing to lying deadwood was the

same in both administrative units Uholka and Shyrokyi Luh. Fresh and hard deadwood contributed 37% to the total deadwood volume, and the proportion of more advanced decay stages was 17% to 27% per stage (Table 6.7). The decomposition rate depends mainly on the substrate specific variables tree species and size, and the environmental variables temperature and precipitation (HARMON *et al.* 1986; HERRMANN and PRESCOTT 2008; ZELL *et al.* 2009). In central Europe, dead beech trees take about 30 to 60 years to decompose completely (BÜTLER *et al.* 2005; CHRISTENSEN *et al.* 2005; LOMBARDI *et al.* 2008; MÜLLER-USING and BARTSCH 2009). The proportion of fresh and hard deadwood was higher in the standing deadwood than in the lying deadwood (Fig. 6.15). This may be because lying deadwood usually has soil contact and thus decays faster, while dead standing trees tend to break and fall when decay is more advanced. The volume of deadwood, particularly of fresh and still hard deadwood, was higher in Uholka than in Shyrokyi Luh (Table 6.7). This indicates that the mortality in Uholka has increased in the last few years due to endogenous (age) and/or exogenous factors, such as the storm of March 23/24, 2007 or the heavy wet snow fall of October 14, 2009 in the area. Even if the deadwood accumulation tends to be temporally and spatially clustered due to natural disturbances, the high average deadwood volume and its more-or-less even distribution across early and well-advanced decay classes (Table 6.7 and Fig. 6.15) indicate habitat continuity over the whole study area.

On average, 11 root-plates from fallen trees were found per ha in each of the two administrative units of the protected massif (Table 6.8 and Fig. 6.16). They were most frequent on hillsides with a slope of 21–40%. The pit-and-mound topography caused by the uprooting of trees may be still recognizable when the root-plates are already decomposed. The small mounds left by the decomposed root-plates indicate former natural disturbances, such as wind or landslides. 42 such mounds per ha were identified in the surveyed area. The similar densities of recent and former root-plates in Uholka and Shyrokyi Luh suggest the natural disturbance regimes in the two administrative units have been similar for a long time. Recent and decomposed root-plates (mounds) seem to be very rare on steep slopes, maybe due to erosion and gravity effects or different soil properties.



Fig. 6.12. Deadwood and old trees provide important habitats for many species. From top down: *Rosalia alpina*, *Bielzia coerulans*, *Lobaria pulmonaria*, *Hericium corraloides*. Photos: M. Brüllhardt, J. Bürgi, L. Mini.

Table 6.5. Number of dead standing trees, snags and stumps per ha (in total, 460 dead standing trees and snags and 49 stumps were assessed). Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

Category	Uholka [N/ha \pm SE]	Shyrokyi Luh [N/ha \pm SE]	Whole study area [N/ha \pm SE]
Complete trees with crowns including fine branches	5.1 \pm 1.3	5.2 \pm 1.0	5.2 \pm 0.8
Complete stems with remains of coarse branches	4.6 \pm 1.6	3.2 \pm 0.6	3.82 \pm 0.8
Snags	16.9 \pm 2.3	* 23.8 \pm 1.9	20.6 \pm 1.5
All dead standing trees and snags	26.6 \pm 3.8	32.2 \pm 2.6	29.6 \pm 2.2
Stumps	2.8 \pm 0.6	3.5 \pm 0.7	3.2 \pm 0.5

Table 6.6. Number of dead standing trees and snags according to DBH-class and in % of all standing trees (living and dead).

DBH-class	Whole study area	
	[N/ha \pm SE]	% of all trees
6–20 cm	16.4 \pm 2.0	6.0
21–40 cm	4.5 \pm 0.5	5.0
41–60 cm	3.2 \pm 0.4	5.8
61–80 cm	4.4 \pm 0.5	11.9
81–100 cm	1.0 \pm 0.3	12.4
101–120 cm	0.1 \pm 0.1	12.7
> 120 cm	0.0 \pm 0.0	0.0
All DBH classes	29.6 \pm 2.2	6.4

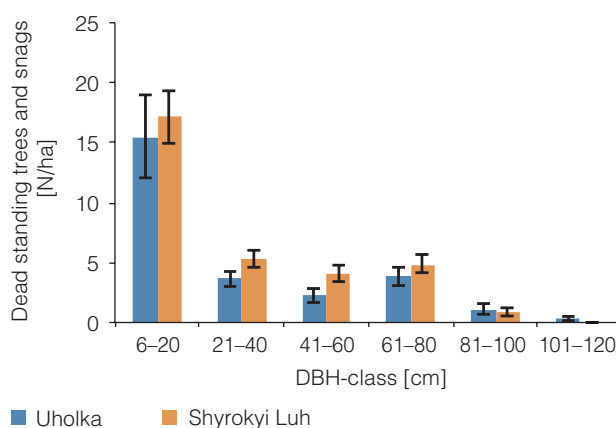


Fig. 6.13. Number of dead standing trees and snags according to DBH-class in the administrative units. Error bars = standard error.



Fig. 6.14. Lying deadwood covered with *Trichaptum bifforme*, a saprobic fungus commonly found on hardwood logs and snags. Photo M. Brüllhardt.

Table 6.7. Total deadwood volume (standing¹ and lying²) according to decay stage. Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001).

Decay stage	Uholka		Shyrokyi Luh	Whole study area	
	[m ³ /ha ± SE]		[m ³ /ha ± SE]	[m ³ /ha ± SE]	[%]
Fresh deadwood	22.2 ± 6.3	*	9.1 ± 2.2	15.1 ± 3.2	9.3
Hard deadwood	52.0 ± 7.2		37.6 ± 4.5	44.3 ± 4.1	27.2
Rotten wood	34.1 ± 5.7		29.8 ± 3.5	31.8 ± 3.2	19.8
Mouldering wood	42.9 ± 4.9		43.6 ± 5.6	43.2 ± 3.7	26.5
Mull wood	29.4 ± 4.1		25.5 ± 3.8	27.3 ± 2.8	16.7
Not specified	0.0 ± 0.0		1.5 ± 1.1	0.8 ± 0.6	0.6
Total deadwood	180.5 ± 12.9	*	147.1 ± 10.7	162.5 ± 8.4	100.0

¹ Standing dead trees and snags ≥ 6 cm DBH, ² Fallen trees and coarse woody debris ≥ 7 cm diameter.

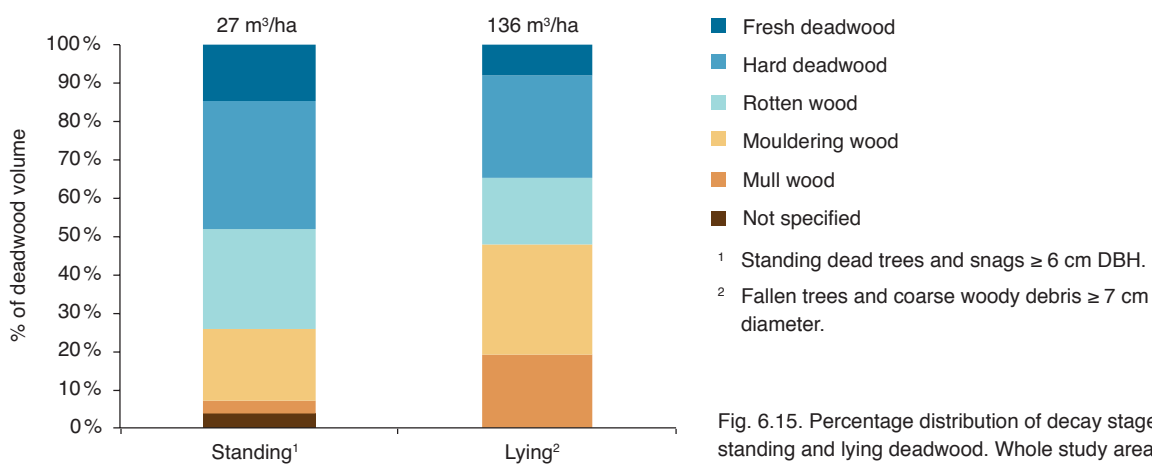


Fig. 6.15. Percentage distribution of decay stage in standing and lying deadwood. Whole study area.



Fig. 6.16. Small windthrow area with uprooted and broken trees. The pit-and-mound relief with exposed root-plates provides a variety of microhabitats. Photo M. Brüllhardt.

Table 6.8. Number of recent root-plates and mounds (decomposed former root-plates) according to slope. Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

	Slope [%]	Uholka [N/ha]	Shyrokyi Luh [N/ha]	Whole study area [N/ha]
Root-plates	≤ 20	2.0 \pm 1.3	35.0 \pm 35.0	7.5 \pm 5.8
	21– 40	14.0 \pm 3.7	12.0 \pm 3.2	13.2 \pm 2.5
	41– 60	3.3 \pm 1.3	4.7 \pm 1.3	4.0 \pm 0.9
	61– 80	4.2 \pm 1.8	6.4 \pm 1.2	5.6 \pm 1.0
	81–100	0.0 \pm 0.0	0.0 \pm 0.0	0.0 \pm 0.0
	All slopes	10.6 \pm 2.2	10.4 \pm 1.5	10.5 \pm 1.3
Mounds (former root-plates)	≤ 20	24.0 \pm 7.9	6.0 \pm 6.0	21.0 \pm 6.9
	21– 40	34.5 \pm 6.5	30.1 \pm 6.1	32.7 \pm 4.6
	41– 60	27.8 \pm 4.7	35.1 \pm 4.4	31.8 \pm 3.2
	61– 80	15.4 \pm 3.6	23.7 \pm 4.5	20.6 \pm 3.2
	81–100	–	5.0 \pm 3.3	4.0 \pm 2.7
	All slopes	41.5 \pm 5.2	41.8 \pm 4.2	41.7 \pm 3.3

Table 6.9. Number, proportion and mean DBH of living trees with microhabitats. Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

Type of microhabitat	Uholka	Shyrokyi Luh	Whole study area		Mean DBH [cm \pm SE]
	[N/ha \pm SE]	[N/ha \pm SE]	[N/ha \pm SE]	% of all trees	
Crown with deadwood	82.3 \pm 13.0	81.6 \pm 10.1	81.9 \pm 8.1	18.8	23.4 \pm 1.0
Broken crown	38.2 \pm 3.7	41.1 \pm 2.9	39.8 \pm 2.3	9.1	20.7 \pm 0.9
Broken stem	11.5 \pm 1.8	** 5.8 \pm 0.9	8.4 \pm 1.0	1.9	20.7 \pm 1.7
Polypores	1.3 \pm 0.4	* 3.0 \pm 0.6	2.2 \pm 0.4	0.5	63.8 \pm 6.2
Bark damage (bare wood core)	19.3 \pm 2.5	*** 33.0 \pm 2.7	26.7 \pm 1.9	6.1	40.8 \pm 1.6
Cracks in wood core	9.9 \pm 1.5	9.7 \pm 1.2	9.8 \pm 0.9	2.2	41.8 \pm 2.4
Hole	11.6 \pm 1.7	15.3 \pm 1.9	13.6 \pm 1.3	3.1	35.3 \pm 1.9
Cavity with mull wood	9.1 \pm 1.2	10.7 \pm 1.3	9.9 \pm 0.9	2.3	43.8 \pm 2.3
Hollow stem	2.8 \pm 0.8	4.6 \pm 0.8	3.8 \pm 0.6	0.9	56.7 \pm 4.2
Any type of microhabitat	142.6 \pm 12.1	156.5 \pm 9.6	150.1 \pm 7.6	34.5	26.5 \pm 0.8
Total number of trees assessed	414.5 \pm 19.4	452.5 \pm 15.2	435.0 \pm 12.2		24.8 \pm 0.5



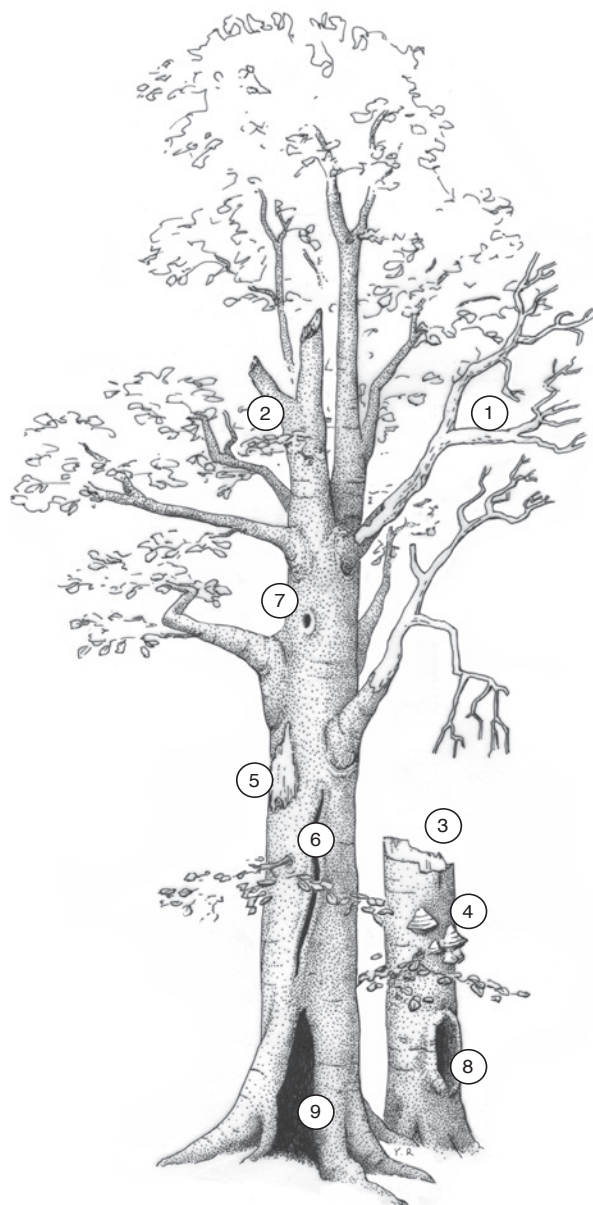
Fig. 6.18. Cavity with mull wood. Photo U.-B. Brändli.

Habitat trees

Habitat trees are living trees with special features, such as broken stems, cracks, holes or cavities, that provide microhabitats for specialised animals and plants (Fig. 6.17). In both units of the massif, 35% of all living trees featured at least one of the microhabitats listed in Table 6.9. Apart from bark damage and stem breakages, most of the microhabitats assessed were similarly frequent in Uholka and Shyrokyi Luh (Table 6.9). Bark damage was much more frequent in Shyrokyi Luh, whereas trees with broken stems were more numerous in Uholka. The latter might indicate a natural disturbance in recent decades with a core area in Uholka, e.g. the wet snow event of October 2009, which caused considerable damage at lower altitudes.

The most prevalent microhabitat type was deadwood in the crown of trees, followed by broken crowns and bark damage, whereas hollow stems or polypores (bracket fungi) are rare. Only one tree in a hundred had a hollow stem. Some of the microhabitats observed are independent of tree DBH: crown deadwood, broken crowns and broken stems. Trees with such microhabitats had a mean DBH of 21–23 cm, which was even a bit smaller than the average for the whole population (25 cm). Bark damage, cracks, holes and cavities with mull wood (Fig. 6.18) occurred more frequently in thicker trees (mean DBH 35–44 cm), and hollow stems even had a mean DBH of 57 cm and trees with polypores of 64 cm. While most types of microhabitats are related to tree age and occur mainly in old trees, microhabitats, such as broken crowns and stems and crown deadwood, may result from natural disturbances and can thus also be found in younger trees.

Polypores, holes, cavities with mull wood and hollow stem were assessed not only in living, but also in dead standing trees and snags (Table 6.10). Whereas polypores and holes were frequently found on dead trees and snags (on 31% and 23%, respectively), cavities with mull wood and hollow stems were quite rare (in 9% and 6%, respectively).



Habitat trees with microhabitats

- 1 Crown with deadwood $\geq 10\%$ of crown volume
- 2 Broken crown (branches or bole) $\geq 10\%$ of crown volume
- 3 Broken stem
- 4 Polypores
- 5 Bark damage (bare wood core) $\geq 300 \text{ cm}^2$
- 6 Cracks in wood core $\geq 1 \text{ m}$ length
- 7 Hole in wood core with a diameter $\geq 3 \text{ cm}$ and a depth $\geq 5 \text{ cm}$
- 8 Cavity with mull wood at the stem base below 1.5 m in height
- 9 Hollow stem with a hollow diameter $\geq 50\%$ of tree diameter

Fig. 6.17. Definitions of the microhabitats surveyed on living trees. Drawing: Yvonne Rogenmoser.

Table 6.10. Number of dead standing trees and snags with microhabitats. Significant differences (t-test) between Uholka and Shyrokyi Luh are indicated with * (* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$).

Type of microhabitat	Uholka [N/ha \pm SE]		Shyrokyi Luh [N/ha \pm SE]	Whole perimeter [N/ha \pm SE]	% of all standing dead trees and snags
Polypores	6.9 \pm 1.2	**	11.3 \pm 1.1	9.3 \pm 0.8	31.4
Hole	5.1 \pm 0.9	*	8.0 \pm 1.1	6.7 \pm 0.7	22.6
Cavity with mull wood	2.1 \pm 0.5		3.0 \pm 0.7	2.6 \pm 0.4	8.8
Hollow stem	0.8 \pm 0.3	*	2.4 \pm 0.6	1.7 \pm 0.4	5.7
Total trees and snags assessed	26.6 \pm 3.8		32.2 \pm 2.6	29.6 \pm 2.2	

6.5 Conclusions

The inventory provides estimates of the main forest parameters with a precision of 5% (number of trees, basal area and volume of living trees) to 10% (volume of deadwood), at a confidence level of 95%. The estimates thus serve as good reference points for old-growth beech forests under similar conditions. The estimates are only precise enough for beech and, to a lesser extent, for sycamore. For other tree species and for rare occurrences, such as hollow stems, the estimates are not precise enough and the sample size should be enlarged.

Many of the features we found are typical characteristics of old-growth forests with gap dynamics, dominated by a small-scale disturbance regime (BAUHUS *et al.* 2009; WIRTH *et al.* 2009). They include a multi-layered forest structure with mainly small canopy gaps, a large tree diameter range (up to 150 cm dbh), the presence of up to 500-year-old beech trees, high growing stock (582 m³/ha), a high amount of standing and lying deadwood (163 m³/ha) of all decay classes, and a high density of habitat trees (150/ha; 35% of the living trees). The shape of the diameter distribution curve, the area-wide occurrence of regeneration of all species present in the overstorey and the absence of significant differences in the main forest parameters between the two administrative units of Uholka and Shyrokyi Luh indicate that the forest as a whole is in a steady state and likely to maintain its structure in the long run. The tree species composition and the forest structure observed both suggest that little timber apart from the occasional tree has ever been cut in the core zone. It seems, therefore, that the integrity and pristine character of the forest in Uholka and Shyrokyi Luh have been maintained. This fact, together with the vast size of the area, makes the forest of Uholka and Shyrokyi Luh one of the most valuable remnants of primeval forest in Europe. The traces of human presence (mainly in the buffer and transition zones, but in some places also in the core zone) show, however, the pressure exerted from the nearby settlements, on the one hand, and the “poloninas” (mountain pastures) on the other. The latter are not only used by the traditional shepherds, but also by commercial berry pickers. Tracks suitable for off-road trucks present a threat as they may also facilitate illegal activities like poaching and logging. The situation on the border of the reserve should be monitored continuously to identify any negative impacts early.

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7 Outlook

Brigitte Commarmot, Urs-Beat Brändli, Fedir Hamor, Vasyi Lavnyy

“This virgin beech forest may be eternal. It is a big, wild and natural forest I did not know we had in Ukraine. We used horse transport and lost our way at times, but no such huge primeval (beech) forest can be found anywhere else in Europe.”

Igor Cherniuk, student UNFU, Ukraine

In this publication, we presented the main results of the 2010 inventory in the Uholka-Shyrokyi Luh massif, Ukraine. Further analyses will include comparisons with other old-growth forests and managed forests, as well as structural analyses of the data we collected on various scales. In an ongoing PhD study, high-resolution stereo satellite images are being used to calculate a canopy surface model of the whole primeval beech forest of Uholka-Shyrokyi Luh. This model will be combined with point data from the terrestrial inventory to provide a basis for characterising the forest structure, identifying canopy gaps and analysing the large-scale disturbance regime.

The inventory was carried out and documented in such a way that it can be repeated, if desired. This allows the development of the forest to be monitored and any changes identified. Since the small-scale dynamics of old-growth forests may have considerable impact, the wooden poles marking the sample plot centres should be replaced after 5 to 10 years even if no second inventory is planned. Otherwise it could be difficult to relocate the exact position of the sample plot centres again even though their coordinates and the positions of all trees are known.

The sample plots may also be used for other (non-destructive) studies/inventories, which might benefit from comparison with the forest data collected. For example, a large-scale population study of the tree lungwort *Lobaria pulmonaria* has already been made, as has a floristic study of other lichens growing on trees (ongoing project of WSL and the M.G. Kholodny Institute of Botany of the National Academy of Sciences of Ukraine in Kyiv) on and around the sample plots.

We hope that this inventory has helped raise interest in this primeval forest and that it will provide a useful basis and impetus for further virgin forest research.



Appendix 1

Project organisation and division of tasks

Project management: Brigitte Commarmot, WSL

Coordination Ukraine: Vasyl Lavnyy, UNFU

Supervision: Peter Brang, WSL, Fedir Hamor, CBR

Scientific work:

Meinrad Abegg, WSL (data-base, data analyses)

Yuriy Berkela, CBR (GIS, maps)

Urs-Beat Brändli, WSL (inventory consulting, sampling method, field manuals, data analyses)

Brigitte Commarmot, WSL (sampling method, field manuals, field forms, data analyses)

Christian Ginzler, WSL (remote sensing, GIS, maps)

Martina Hobi, WSL (GIS, maps, tree-ring data, data analyses)

Edgar Kaufmann, WSL (volume tariffs)

Mykola Korol, UNFU (field manuals, data analyses)

Adrian Lanz, WSL (inventory design, statistical advice)

Raphaela Tinner (sampling method, field manual)

Translation:

Victoria Gubko, CBR (English/Ukrainian)

Mykola Korol, UNFU (German/Ukrainian)

Vasyl Lavnyy, UNFU (German/Ukrainian)

Preparation of logistics:

Vasyl Pokynchereda, CBR

Dmytro Sukharyuk, CBR

Victoria Gubko, CBR

Vasyl Rehus, CBR (forest manager, Uholka)

Valeriy Feyer, CBR (forest manager, Shyrokyi Luh)

Vasyl Lavnyy, UNFU

Instruments and equipment:

Brigitte Commarmot, WSL

Christoph Düggelein, WSL

Martina Hobi, WSL

Vasyl Lavnyy, UNFU

Safety measures:

Victoria Gubko, CBR

Martina Hobi, WSL

Ruedi Iseli, Hasspacher & Iseli Gmbh

Vasyl Lavnyy, UNFU

Vasyl Pokynchereda, UNFU

Field-work manager: Ruedi Iseli, Hasspacher & Iseli Gmbh

Field teams:

Martin Brüllhardt, student ETHZ

Janine Bürgi, student ZHAW

Lukas Glanzmann, student ETHZ

Andrea Grimmer, student ZHAW

Silas Hobi, student ETHZ

Oliver Leisibach, student ZHAW

Luca Mini, student ZHAW

Daniel Oertig, student HAFL

Matthias Ofner, student ZHAW

Jonas Stillhard, student ZHAW

Igor Cherniuk, student UNFU

Serhiy Gavryliuk, assistant professor UNFU

Andriy Khomiuk, student UNFU

Vasyl Kostyshyn, PhD student UNFU

Nataliia Rehus, junior researcher CBR

Volodymyr Trotsiuk, student UNFU

Group leaders:

Ruedi Iseli, Hasspacher & Iseli Gmbh

Mykola Korol, lecturer UNFU

Martina Hobi, PhD student WSL

Instruction of field teams:

Ruedi Iseli, Hasspacher & Iseli Gmbh

Mykola Korol, UNFU

Martina Hobi, WSL

Brigitte Commarmot, WSL

Raphaela Tinner, WSL

Meinrad Abegg, WSL

Data entry:

Vasyl Lutsyshyn, PhD student UNFU

Volodymyr Savchyn, PhD student UNFU

Administration, book-keeping:

Beate Hasspacher, Hasspacher & Iseli GmbH

Logistic support Uholka:

Vasyl Rehus (administrative support)

Vitaliy Motriya (administrative support)

Mykhaylo Rehus (administrative support)

Vasyl Krychfalushy (transport with horses)

Mykhaylo Tanchynez (transport with horses)

Ivan Dobrunyk (transport with truck)

Vasyl and Magdalyna Semyanovskiy (cooking)

Tetyana Rehus (accommodation, cooking)

Mykhaylo Nemesh (transport, cooking)

Mariya and Vasyl Nemesh (cooking)

Tetyana Nemesh (cooking)

Logistic support Shyrokyi Luh:

Valeriy Feyer (administrative support)

Vasyl Mula (administrative support)

Ivan Tanchynez (transport with horses)

Andriy Dudla (transport with horses)

Ivan Moskal (transport with truck)

Petro Pokovba (transport)

Ivan and Olena Moksai (cooking)

Volodymyr and Marija Bohdan (cooking)

Ivan Oleksiy (cooking)

Vasyl Drahun (transport, cooking)

Appendix 2

Survey equipment (for each survey team)

Documents

1 Overview map on a scale of 1:20 000 (based on GIS data, with orthophotos from 2008 as background data) covering the whole study area

32 Sub-maps on a scale of 1:8000

2 Field manuals (German and Ukrainian)

Sets of forms on normal and waterproof paper (6 forms per plot in German and/or English; reference forms in Ukrainian)

3 Cards with codes for sample trees (German, Ukrainian and English)

2 Cards with codes for tree and shrub species

2 User's Manual with brief instructions for Vertex and Transponder, Criterion RD 1000, GPS Garmin etrex summit HC and GPS Trimble GeoXH/Juno SB (German and English)

2 Safety cards with emergency phone numbers

Rules of conduct in the field

Stationery

Writing material

Marking chalk

Lumber crayon with holder

1 Calculator HP 10s

Batteries for Vertex/Transponder and Garmin GPS

Equipment and tools

2 Backpacks

2 Cruiser vests

1 Pocket knife (Victorinox Forester)

1 Club hammer

1 First aid kit

2 Alarm whistles

2 Oak poles (4 x 4 x 40 cm; one with and one without marking) per sample plot

2 Mobile phones (personnel equipment)

Survey instruments and material

1 Clinometer SUUNTO (PM 5/400 PC)

1 Compass SUUNTO (KB 14/400 gon)

1 Compass Wyssen MERIDIAN MI-4007, 400 gon

1 Tripod for the Wyssen compass

1 Plumbline

1 Hypsometer Vertex IV (or Vertex III) (to measure distances and tree heights)

1 Transponder for Vertex

1 Criterion RD 1000 (only 1 instrument for 2 teams)

1 Monopod Gitzo GM1130MT (for Criterion)

1 GPS Garmin etrex SUMMIT HC

1 GPS Trimble GeoXH or Trimble JUNO SB with TerraSync Standard Edition Software

1 Calliper Haglöf MANTAX blue 80 cm

1 Diameter tape

1 Measuring tape (logger's tape with automatic rewind) 20 m (steel)

1 Measuring tape 50 m (fibreglass)

1 Digital camera, Sony Cyber-Shot DSC-WX1

1 Memory Stick, Pro Duo 4GB Sandisk

2 Plastic callipers for young trees (0 to 15 cm with 1 cm graduations)

2 Folding metre rules

2 Ranging poles (2 m)

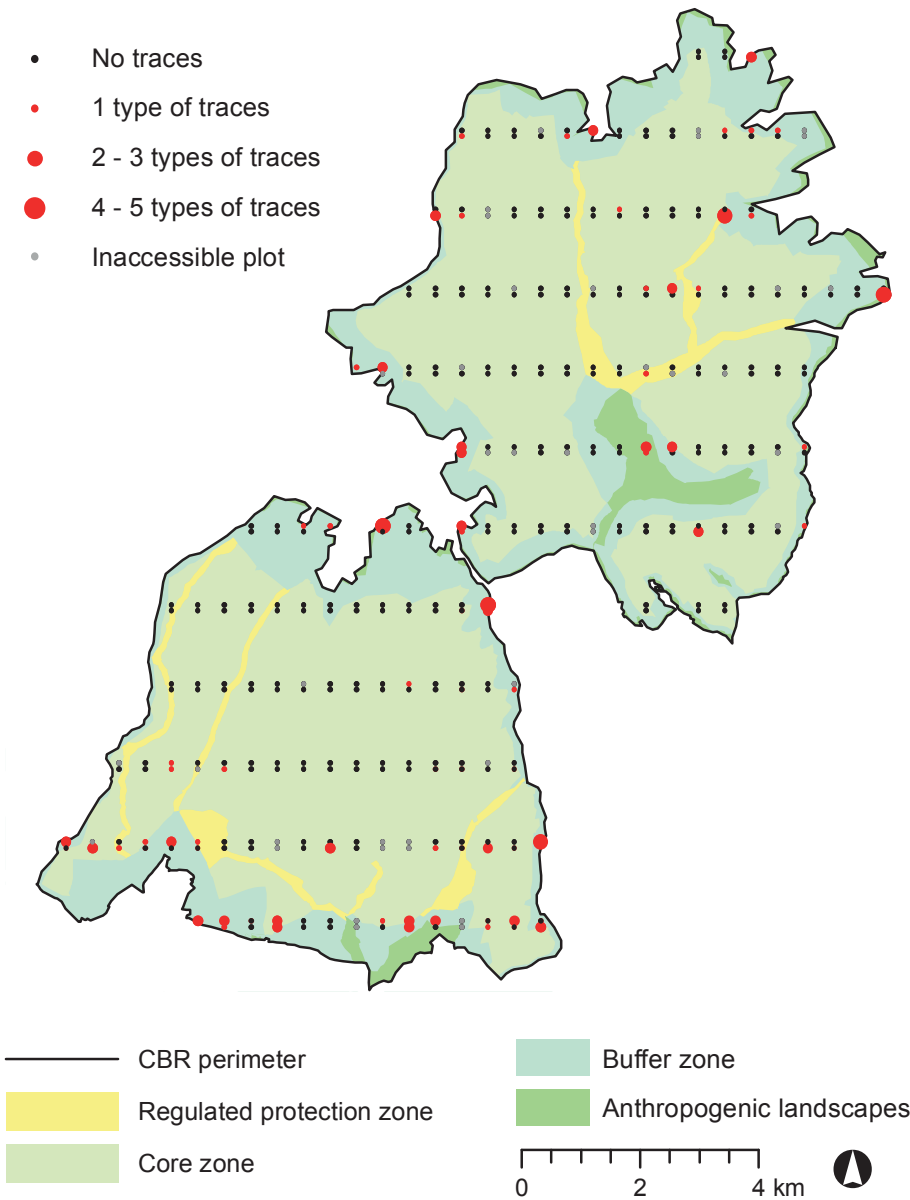
Appendix 3

Distribution of anthropogenic traces

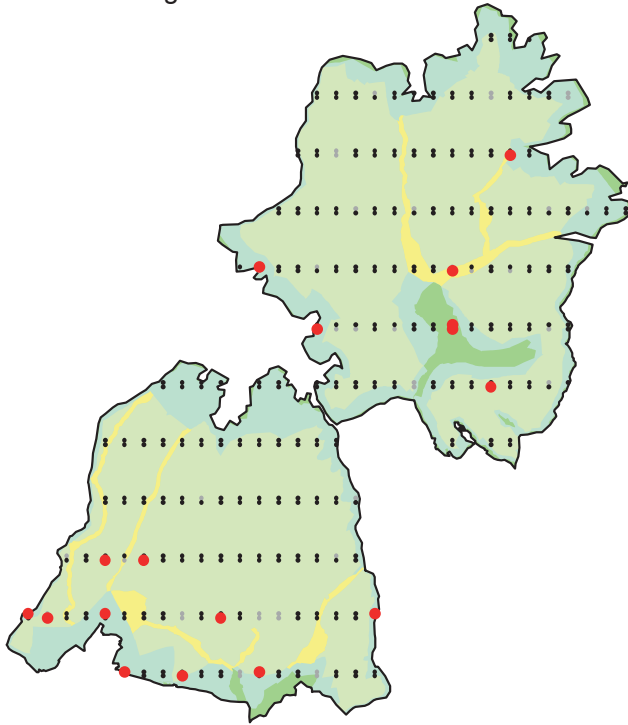
The map below shows the distribution of plots where anthropogenic traces (one or more types) were found. The number of different traces recorded may be used as an indicator of the degree of anthropogenic pressure and impact. For the distribution of the different types of anthropogenic traces, see the maps on the next double page.

Number of different anthropogenic traces

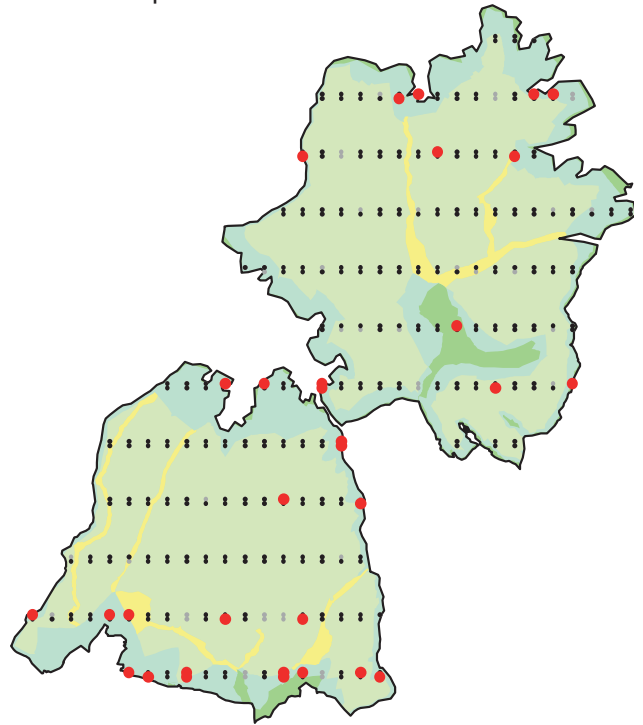
- No traces
- 1 type of traces
- 2 - 3 types of traces
- 4 - 5 types of traces
- Inaccessible plot



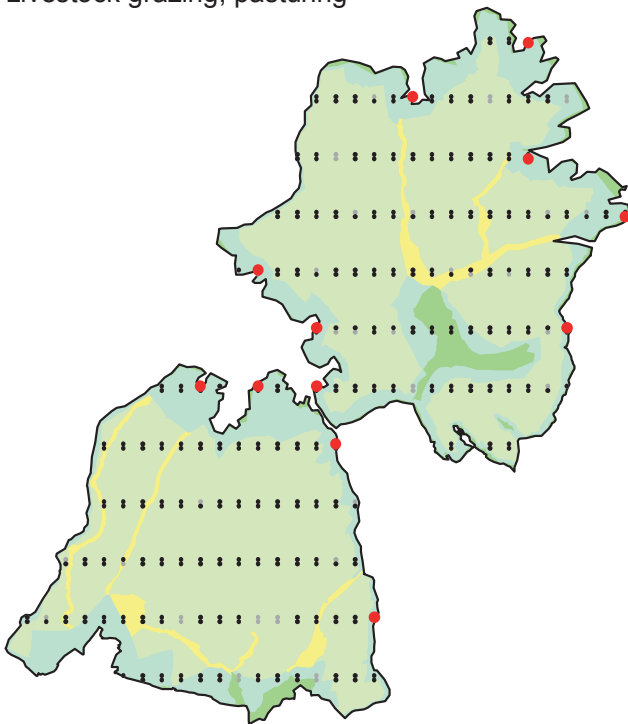
Timber cutting



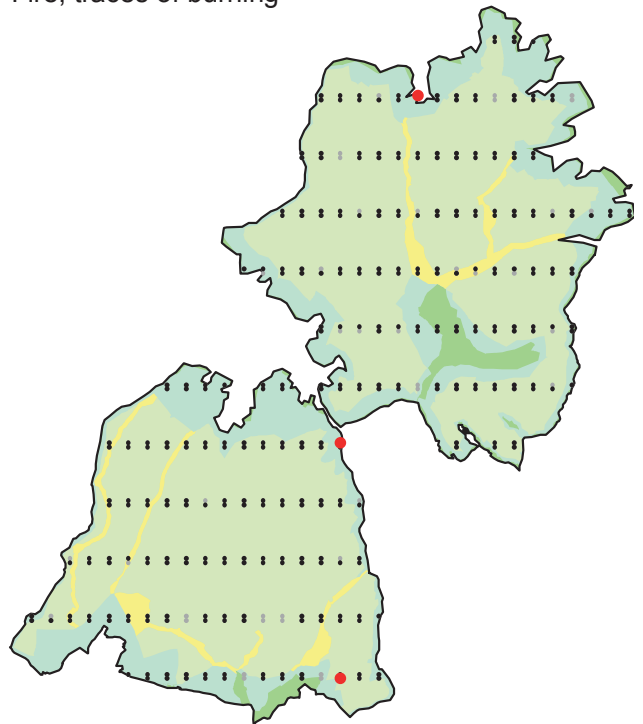
Roads and paths



Livestock grazing, pasturing



Fire, traces of burning

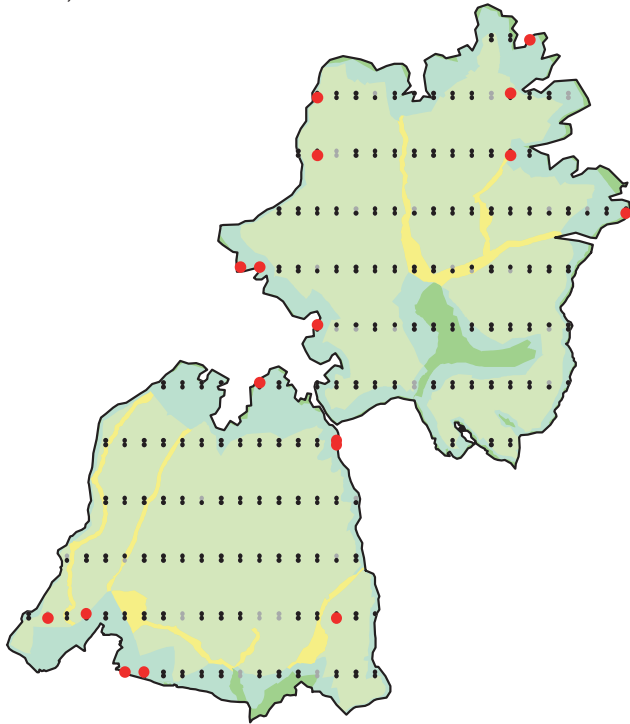


- Presence of traces
- Absence of traces
- Inaccessible plot

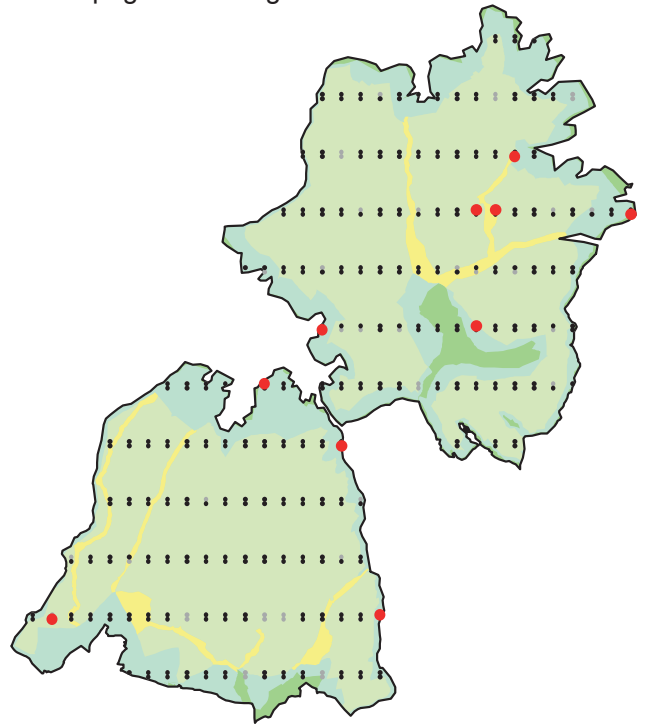
- CBR perimeter
- Regulated protection zone
- Core zone

- Buffer zone
 - Anthropogenic landscapes
- 0 2.5 5 km
-

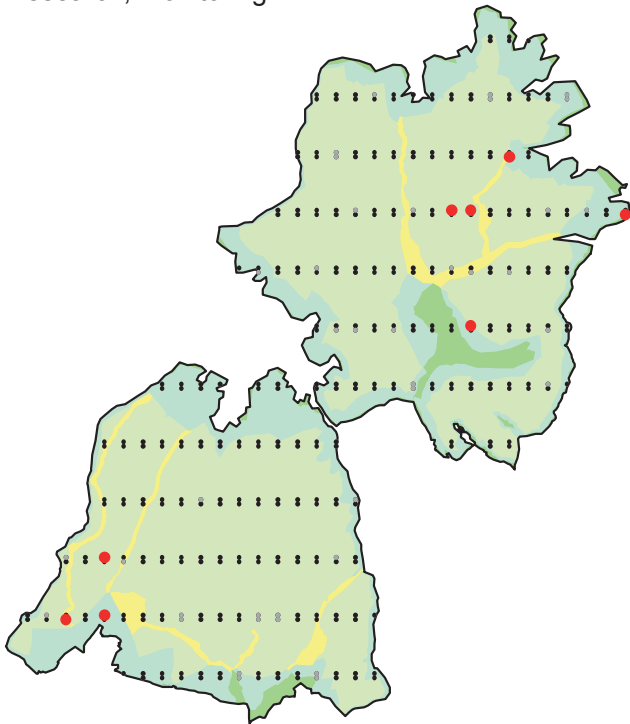
Litter, waste



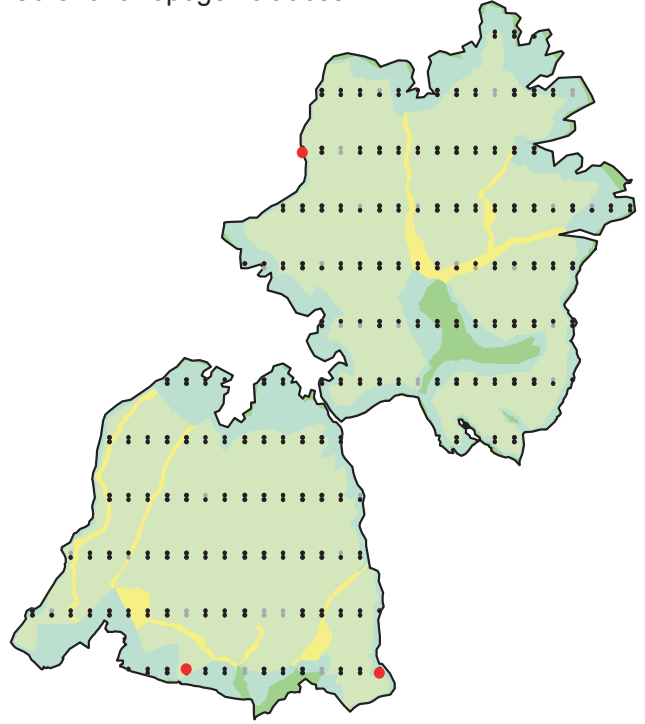
Anthropogenic damage to trees



Research, monitoring

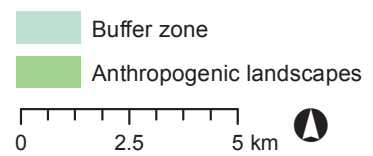


Other anthropogenic traces



- Presence of traces
- Absence of traces
- Inaccessible plot

- CBR perimeter
- Regulated protection zone
- Core zone



Appendix 4

List of tree species assessed

Number of living trees assessed per species during the sampling inventory 2010. RC (regeneration class) 1: 10–39 cm high; RC 2: 40–129 cm high; RC 3: \geq 130 cm high and $<$ 6 cm DBH.

Species	Trees \geq 6 cm dbh (500 m ² circle)	Regeneration (saplings)		
		RC 1 (5 m ² circle)	RC 2 (10 m ² circle)	RC 3 (20 m ² circle)
<i>Abies alba</i> Mill.	16	1	2	4
<i>Acer</i> sp.	1			
<i>Acer platanoides</i> L.	14	15	4	7
<i>Acer pseudoplatanus</i> L.	46	69	26	21
<i>Betula pendula</i> Roth	8			
<i>Carpinus betulus</i> L.	104	1	4	1
<i>Corylus avellana</i> L.	19	2	1	
<i>Fagus sylvatica</i> L.	6531	243	235	618
<i>Fraxinus excelsior</i> L.	7	2	1	
<i>Picea abies</i> Karst.	1			
<i>Prunus avium</i> L.			1	1
<i>Quercus petraea</i> Liebl.	1	2		
<i>Salix</i> sp.	1	1		
<i>Salix caprea</i> L.	9			
<i>Sambucus nigra</i> L.	8			
<i>Sorbus aucuparia</i> L.				1
<i>Ulmus glabra</i> Huds.	13	5	4	5
Total	6779	341	278	658

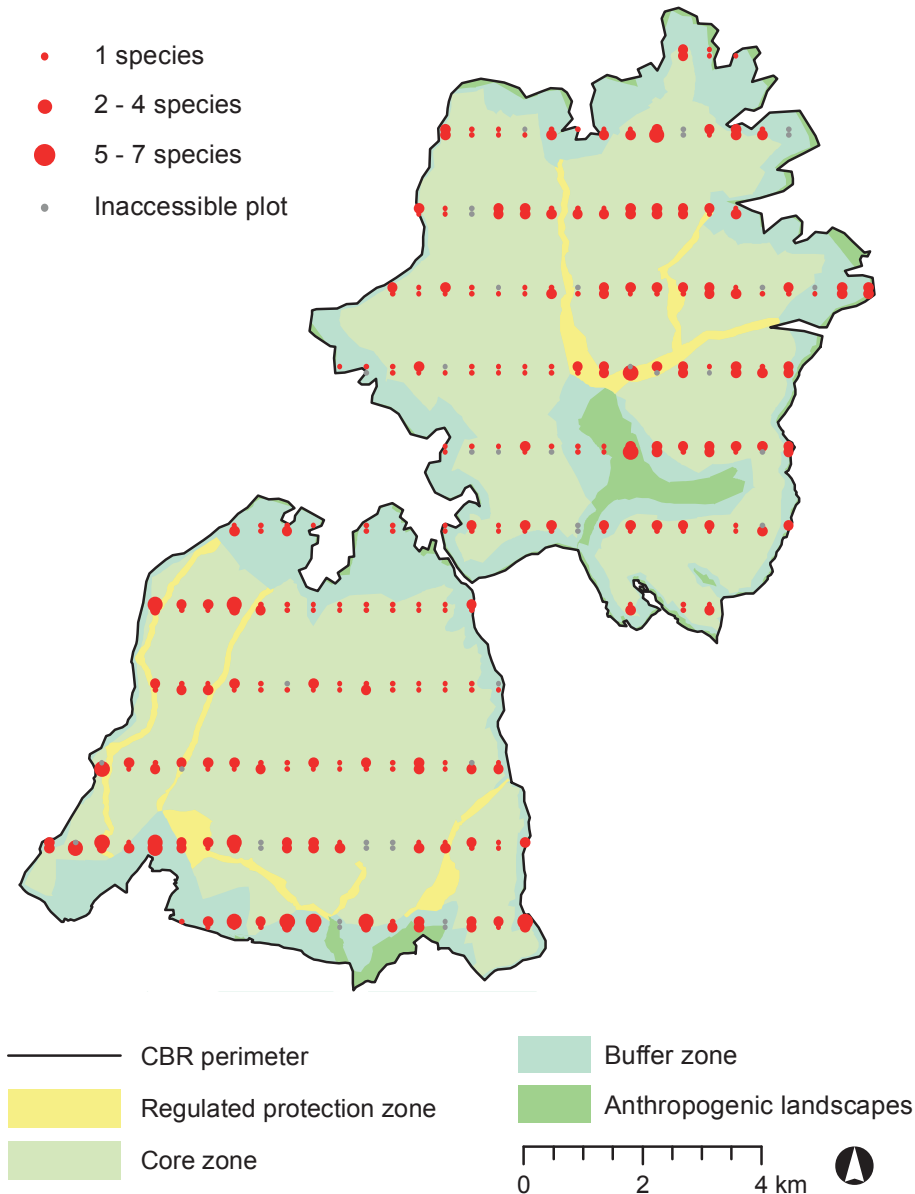
Appendix 5

Distribution of tree species

The maps on this and the following double page show the number of tree species per sample plot and the distribution of the main tree species found. "Presence" means that at least one living individual of the species was recorded on the plot, either in the population of trees ≥ 6 cm DBH or in the regeneration.

Number of tree species per plot

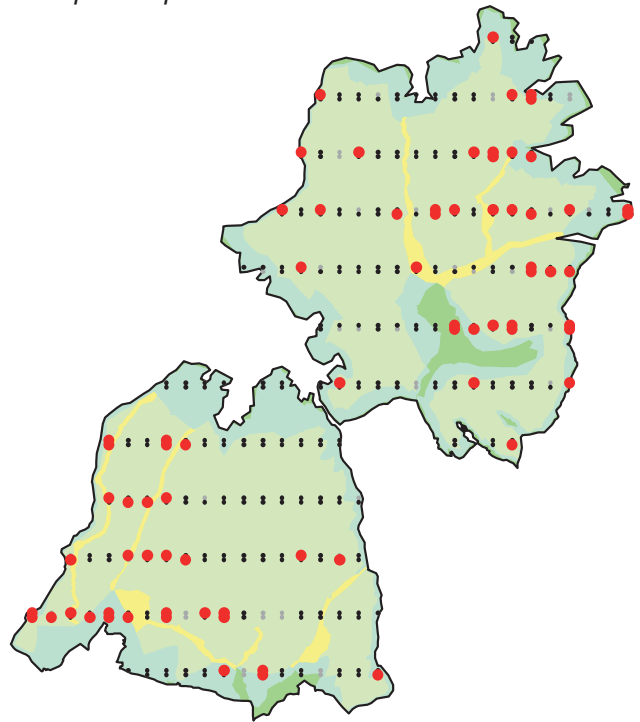
- 1 species
- 2 - 4 species
- 5 - 7 species
- Inaccessible plot



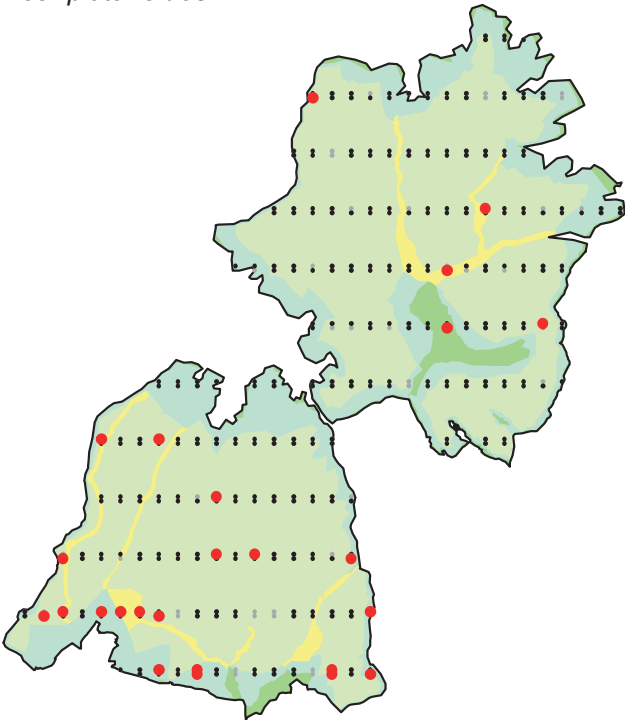
Fagus sylvatica



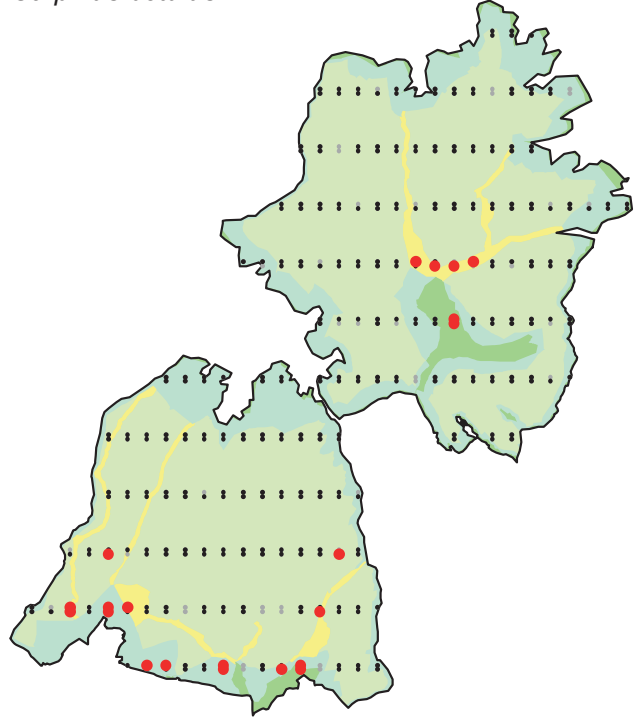
Acer pseudoplatanus



Acer platanoides



Carpinus betulus

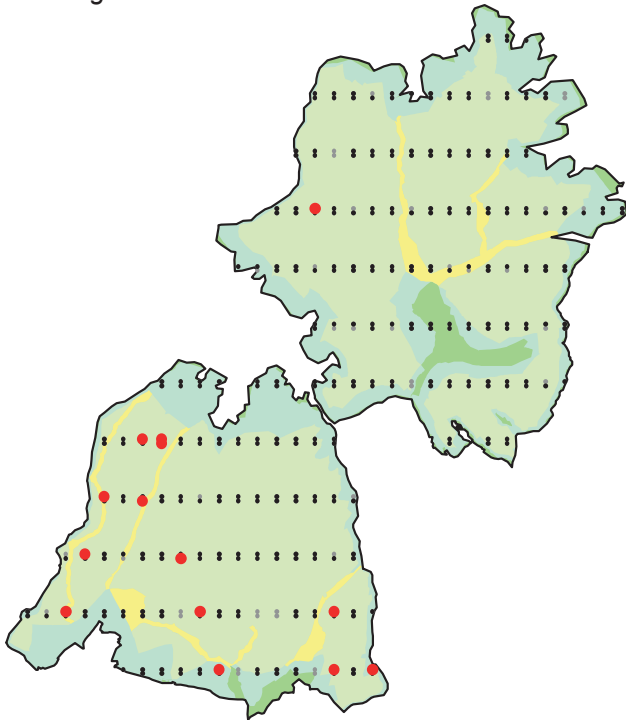


- Presence of species
- Absence of species
- Inaccessible plot

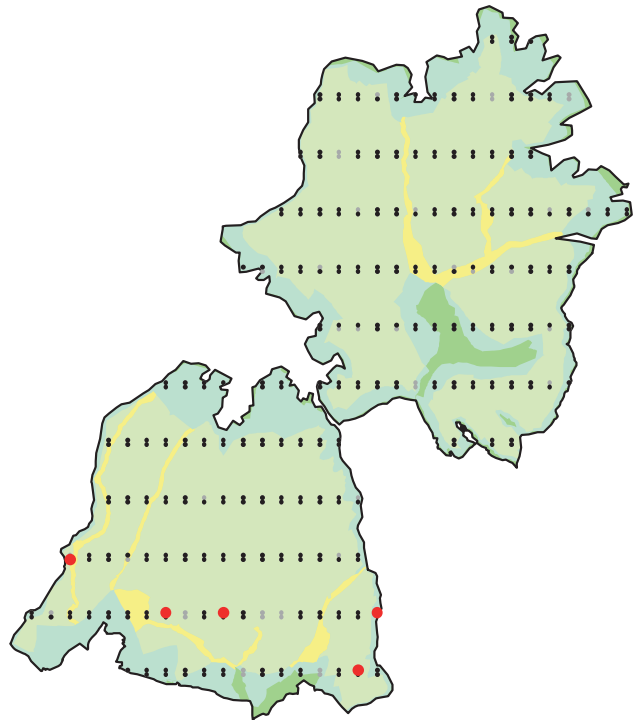
- CBR perimeter
- Regulated protection zone
- Core zone

- Buffer zone
 - Anthropogenic landscapes
- 0 2.5 5 km
-

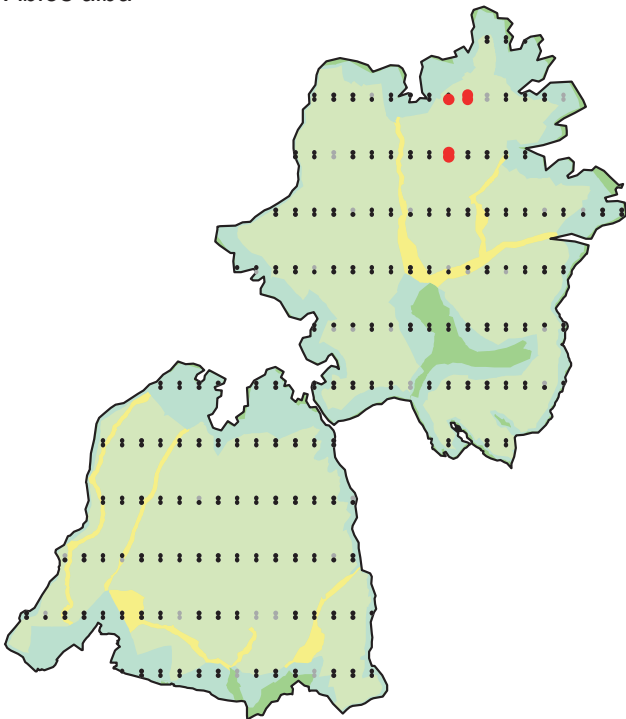
Ulmus glabra



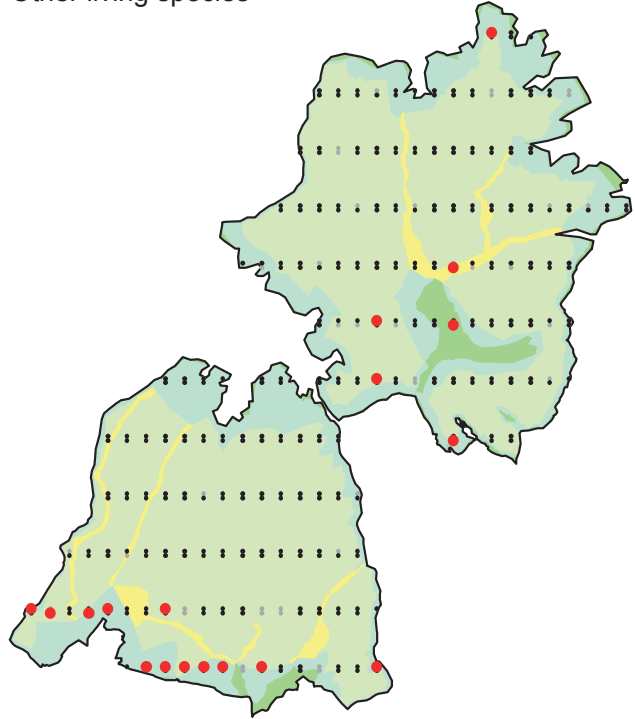
Fraxinus excelsior



Abies alba



Other living species



- Presence of species
- Absence of species
- Inaccessible plot

- CBR perimeter
- Regulated protection zone
- Core zone

- Buffer zone
 - Anthropogenic landscapes
- 0 2.5 5 km



In 2010, the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, the Ukrainian National Forestry University and the Carpathian Biosphere Reserve carried out an inventory of the Primeval Beech Forest of Uholka-Shyrokyj Luh in the Ukrainian Carpathians. This report describes the sampling design and the parameters assessed, the planning and organisation of the field work, and the management and analysis of the data collected. It presents findings about basic forest characteristics, such as species composition, tree densities, growing stock, volumes of standing and lying deadwood, forest structure, regeneration density and density of habitat trees, but also about the anthropogenic traces found within the survey perimeter of 10282 ha. This report should be particularly useful for people interested in reference values from primeval forests and researchers planning a similar inventory in remote areas.

