Flanders
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the Art

Monitoring programme on strict forest reserves in Flanders (Belgium): Methods and operational protocols – Update 2024 with revised protocol for lying deadwood

With an overview of the intensive monitoring sites

Kris Vandekerkhove, Peter Van de Kerckhove, Anja Leyman, Luc De Keersmaeker, Arno Thomaes, Margot Vanhellemont, Els Lommelen, Marc Esprit, Stefaan Goessens

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Authors:
Kris Vandekerkhove, Peter Van de Kerckhove, Anja Leyman, Luc De Keersmaeker, Arno Thomaes, Margot Vanhellemont, Els Lommelen, Marc Esprit, Stefaan Goessens
Research Institute for Nature and Forest (INBO)

Reviewers:
Kristine Vander Mijnsbrugge

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Location:
Herman Teirlinckgebouw
INBO Brussel
Havenlaan 88 bus 73, 1000 Brussels, Belgium
vlaanderen.be/inbo

e-mail:
kris.vandekerkhove@inbo.be

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MONITORING PROGRAMME ON STRICT FOREST RESERVES IN FLANDERS (BELGIUM): METHODS AND OPERATIONAL PROTOCOLS

UPDATE 2024 WITH REVISED PROTOCOL FOR LYING DEADWOOD.

With an overview of the intensive monitoring sites

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Summary

This report provides a detailed description of the measurements that are performed and the field protocols that are applied in the research programme on monitoring of unmanaged forests (strict forest reserves) in Flanders (Belgium).

This monitoring programme was originally conceptualised in 1997-1999 to fulfil the obligations and commitments on the scientific goals for forest reserves, as they were set by law in the Flemish Forest Decree (1993), the Executive Order of the Flemish Government on Forest Reserves (1995) and the Ministerial Decisions upon designation of new reserves and their management plans. Some of the sites are also part of LTER-Belgium (Cools et al. 2016).

Concepts on forest reserves and methods of forest reserves ecological monitoring are based on and in line with long-running programmes in most other European countries (Vandekerkhove 1998, Parviainen et al. 2000).

Measurement protocols and data processing were set from the beginning of the programme and were first published in detail by De Keersmaeker et al. (2005). Since that time, technology and tools have developed, and some minor changes to the method were applied. The original report (Vandekerkhove et al. 2021) describes in detail the applied tools, methods and SOPs (Standard Operating Procedures).

Since the first edition in 2021, important changes have been made to the protocol regarding the measurement of lying deadwood. This second, revised edition contains the updated INBO protocol for strict forest reserves describing the current protocol for lying deadwood, combining Line Intersect sampling of smaller fragments, and Full Area assessment for the larger logs.

The report describes in detail the consecutive steps of preparation, execution and data handling for field measurements in strict forest reserves (see table of contents).

In a final chapter of the report, every site in the network of intensively monitored sites is described: basic information (location in Belgium, climatic conditions, soil type, altitude), specific monitoring set-up (any divergence from the standard set-up, e.g. different plot size of circular plots or core area), and the years of sampling. This overview has been updated to 2024.

This report should allow potential users of the data to investigate whether the acquired data meet their requirements or level of detail, in order to include them in their studies. The overview of monitored sites can also be useful for researchers looking for suitable research sites for which detailed and extensive data on dendrometrics and vegetation are already available.

Since the first edition in 2021, efforts have been made to make our datasets available online on Zenodo. Site level data are freely accessible via 10.5281/zenodo.8017673 and link to the plot-level datasets that are available upon request. All online datasets are regularly updated. We invite interested researchers and potential users of the data to check the available Open Data or to contact the authors for further interdisciplinary and international cooperation.

Samenvatting

Dit rapport geeft een gedetailleerde beschrijving van de metingen die worden uitgevoerd en de veldprotocollen die worden toegepast in het onderzoeksprogramma voor monitoring van onbeheerde bossen (vroeger 'integrale bosreservaten') in Vlaanderen (België).

Dit monitoringprogramma werd in 1997-1999 geconceptualiseerd om te voldoen aan de verplichtingen en verbintenissen rond de wetenschappelijke doelstellingen voor bosreservaten, zoals deze bij wet waren vastgelegd in het Vlaams Bosdecreet (1993), het uitvoeringsbesluit van de Vlaamse Regering inzake bosreservaten (1995) en de Ministeriële Besluiten betreffende de aanwijzing van nieuwe reservaten en de beheerplannen. Sommige sites maken ook deel uit van LTER-België (Cools et al. 2016).

Concepten over bosreservaten en methoden voor ecologische monitoring van bosreservaten zijn gebaseerd op, en in lijn met, langlopende programma's in de meeste andere Europese landen (Vandekerkhove 1998, Parviainen et al. 2000).

Meetprotocollen en dataverwerking waren al vanaf het begin van het programma vastgelegd en voor het eerst in detail beschreven in De Keersmaeker et al. (2005). Sinds die tijd zijn er nieuwe technologieën in gebruik genomen en zijn er enkele kleine wijzigingen in de methode aangebracht. Het oorspronkelijke rapport (Vandekerkhove et al. 2021) beschrijft in detail de toegepaste tools, methoden en SOP's (Standard Operating Procedures).

Sinds de eerste editie in 2021 zijn er belangrijke wijzigingen aangebracht in het protocol met betrekking tot het meten van liggend dood hout. Deze tweede, herziene editie bevat het bijgewerkte INBO-protocol en geeft aan hoe het liggend dood hout sinds winter 2022-2023 wordt opgemeten. Daarbij worden kleinere fragmenten ingemeten via Line Intersect-sampling, en grotere fragmenten nog steeds via volopname.

Het rapport beschrijft in detail de opeenvolgende stappen van voorbereiding, uitvoering en gegevensverwerking voor veldmetingen in strikte bosreservaten (zie inhoudsopgave).

In het laatste hoofdstuk van het rapport beschrijven we elke specifieke site die is opgenomen in het netwerk van intensief gemonitorde sites, met basisinformatie over de locatie in België, de klimatologische context, het bodemtype, de hoogteligging en de specifieke monitoringopzet. Ook verduidelijken we of de locatie specifieke afwijkingen vertoont van de standaardopzet (bijvoorbeeld afwijkende grootte van cirkelvormige proefvlakken of kernvlaktes). Het bevat ook de jaren van bemonstering voor elke locatie. Ook dit overzicht is geactualiseerd tot zomer 2024.

Dit rapport moet potentiële gebruikers van de gegevens in staat stellen om na te gaan of de verkregen gegevens aan hun eisen of detailniveau voldoen, zodat ze in hun onderzoek kunnen worden meegenomen. Het overzicht van gemonitorde locaties kan ook nuttig zijn voor onderzoekers die op zoek zijn naar geschikte locaties waar nu al gedetailleerde en uitgebreide gegevens over dendrometrie en vegetatie beschikbaar zijn. Sinds de eerste editie in 2021 zijn er ook inspanningen geleverd om onze datasets online beschikbaar te maken op Zenodo. Gegevens op siteniveau zijn vrij toegankelijk via DOI 10.5281/zenodo.8017673. Daar zijn ook links voorzien naar de gegevens op plotniveau, die op aanvraag beschikbaar zijn. Alle online datasets worden regelmatig bijgewerkt. Wij nodigen geïnteresseerde onderzoekers en potentiële gebruikers van de data uit om de beschikbare Open Data te controleren of contact op te nemen met de auteurs voor verdere interdisciplinaire en internationale samenwerking.

Recommendations for management and/or policy

This report provides detailed information on the measurement protocols applied in the monitoring programme on strict forest reserves in Flanders. It is an updated version of the protocol from 2021, incorporating changes in methodology for the measurement of lying deadwood.

It is recommended that such a reference document is produced and regularly updated for all standardised monitoring programmes and measurement campaigns that are performed at INBO and other research institutions. It should accompany all datasets that are provided as open data.

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Table of contents

 https://doi.org/10.21436/inbor114075052

1 INTRODUCTION

Since the year 2000, a standardised monitoring programme for unmanaged forest reserves has been deployed in a set of reserves in Flanders, Belgium.

This monitoring programme was originally conceptualised in 1997-1999 to fulfil the legal obligations and commitments on the scientific goals for forest reserves, as they were determined by the Flemish Forest Decree (1993), the Executive Order of the Flemish Government on Forest Reserves (1995) and the Ministerial Decisions upon designation of new reserves and their management plans.

Concepts on forest reserves and methods of forest reserves ecological monitoring are based on, and in line with, long-running programmes in most other European countries (Parviainen et al. 2000, Vandekerkhove 1998).

Measurement protocols and data handling were developed and determined already from the beginning of the programme, and were first published in detail by De Keersmaeker et al. (2005) (in Dutch, with English summary and captions). Since that time, technology and tools have developed, and some changes to the method have been applied. This report describes in detail the applied tools, methods, and SOPs (Standard Operating Procedures). It is an update of the original report (Vandekerkhove et al. 2021) and contains the newly applied protocol for lying deadwood, in use since winter 2022-2023.

The current report describes in detail the consecutive steps of preparation, execution and data handling for field measurements in strict forest reserves. The following topics are covered :

- Selection of sites for monitoring
- Overview of the standard measurement scheme
- Preparatory phase: implementation of the field measurement scheme to the site (desktop)
- Set-up in the field of the measurement scheme
    - Grid of circular nested plots
    - Core area
- Field protocol for measurements in circular plots
    - Soil samples
    - Dendrometric measurements
        - Standing trees (living/dead)
        - Lying deadwood
        - Rejuvenation (seedlings, saplings and young trees < 5 cm diameter at breast height)
    - Vegetation relevés
    - Georeferenced oriented photographs
    - Fish-eye photographs

- Field protocol for measurements in core areas
    - Soil samples
    - Dendrometric measurements
        - Standing trees (living/dead)
        - Lying deadwood
        - Rejuvenation (seedlings, saplings and young trees < 5 cm diameter at breast height)
    - Vegetation relevés
    - Georeferenced oriented photographs
    - Fish-eye photographs

- Field protocol for additional measurements
    - Full survey of 'Particular elements' (Biotope Mapping): very large trees (VLT) and coarse dead wood (CDW)
    - Vegetation 'facies' mapping
- Data handling, calculations and open data
    - Data control
    - Calculations of tree and fragment volumes
    - Calculation of derived measures (e.g., stem density, basal area, living stock,...)
    - R scripts for data handling on Github (package *forrescalc*) and open data available on Zenodo

In the final chapter of the report, every specific site that is included in the network of intensively monitored sites is described giving some basic information on location in Belgium, climatic conditions, soil type, altitude and the specific monitoring set-up. It is also clarified whether the site has specific divergences from the standard set-up (e.g. different plot size of circular plots or core area).

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2 SELECTION OF SITES FOR MONITORING

For the selection of sites that should be eligible for monitoring of natural dynamics, a set of basic criteria are applied. They are based on international recommendations (e.g. EU-COST-E4 and Projektgruppe Naturwaldreservate, compiled in Vandekerkhove 1998).

By 'monitoring network' is meant: the set of unmanaged forests in which the intensive monitoring method is applied. This is a selection from the full set of strict forest reserves in Flanders.

For this purpose, these reserves have to meet international criteria. This means:

- The continuity of non-intervention is guaranteed through legal status or management plans;
- the network must be representative of the forest types present in Flanders;
- the area of the selected forests must be sufficiently large: they must meet the criterion of Minimum Structure Area (MSA). This minimal area varies between 15 and 50 ha, depending on the vegetation type.

Vandekerkhove (1998) and De Keersmaeker et al. (2005) elaborated on these criteria:

- In Flanders, about 25 different climax forest communities can be distinguished at vegetation association level. A representative network should encompass examples of these communities resulting in at least 20 reserves. Five forest types are too fragmented, or are embedded in other types.

- For all these communities, the sites that most closely refer to ‘natural’ forests are selected. This means sites that are most complete or characteristic with regard to species composition, show a wide age distribution, and/or longest time since last intervention.

- In order to be representative, this network must also take into account the phytogeographical differences (e.g. *Quercion* forests both in the Atlantic district and in the Subatlantic district of the Campine region)

- If the monitored network of strict reserves is limited to 'semi-natural' forests, its function as a reference is strongly limited since the forests in Flanders are often highly anthropogenic. After all, more than 60% of the Flemish forest area consists of poplar and conifer stands. Therefore, it is necessary to complement the network with these anthropogenic forest types, adding up to the network.

- For a set of Atlantic forest types (*Endymio-Carpinetum, Carici remotae-Fraxinetum, Alnion*), Flanders has a role to play at international level. These types are therefore deliberately overrepresented in the network.

The current network covers a total of about 20 sites. This means that the network is still not complete. More sites are added if possible. This depends on the available manpower, but also on the availability of suitable sites. In some forests that are predestined to be included in the network, some preliminary management interventions are still being performed (e.g. removal of invasive exotic tree species). Once these interventions are concluded, these sites are eligible to be added. An overview of the sites currently included in the network is given below.

Fig. 1. Map of Belgium showing an overview of the network of sites with intensive monitoring

Table 1. Overview of the monitored sites (with CA = core area, CP = circular plots) and approximate year of survey. For details per site: see chapter 11.

Site no.	Site code	Site name	Forest type	Survey years
1	SON-CA	- Sonian Zwaenepoel Core Area	Atlantic beech	1986, 2000, 2010, 2020
	SON-KP	- Kersselaerspleyn CP	Atlantic beech	2000, 2010, 2020
	SON-EX	- 2nd Extension + Harras CP	Atlantic beech	2010, 2020
	SON-HR	- Harras CA	Oak hornbeam	2009, 2019
2	WDL-SR	Wijnendalebos	Atlantic oak-beech	2002, 2012, 2022
3	MDW-EB	Meerdaal - Everzwijnbad	Subatl. oak-hornbeam	2002, 2012, 2022
4	WHH-SR	Withoefse heide	Quercion/Pine	2003, 2012, 2022
5	HNC-SR	Hannecartbos	Coast. dune forest	1991, 2001, 2011, 2021
6	WLB-CA WLB-TR	Walenbos	Alluvial Alder Swamp	1991, 2001, 2011, 2021
7	RDB-FQ RDB-AP	Rodebos	Subatl. beech Alluvial	1991, 2001, 2011, 2021
8	HRN-SR	De Heirnisse	Base-rich alder forest	2003, 2013, 2023
9	HLB-JH	Hallerbos – Jansheideberg	Atlantic beech	2004, 2014, 2024
10	CHB-QB CHB-AL	Coolhembos	Quercion Alnion	2004, 2014, 2024
11	BTR-SR	Bos Terrijst	Atlantic beech	2005, 2015
12	MDW-PM	Meerdaal - Pruikenmakers	Subatl. oak-hornbeam	2006, 2016
13	LDK-SR	Liedekerkebos	Atl. oak-beech	1985, 1996, 2006, 2016
14	SVD-QB SVD-AL	Sevendonk	Quercion Alnion	2007, 2017
15	MZB-SR	Muizenbos	Alluvial forest	2008, 2018
16	BEM	Bos t'Ename	Atlantic beech and alluvial	2015
17	KLB	Kluisbos	Atlantic beech	2019
18	KMT-SR	Kolmontbos	Subatlantic oak-hornbeam	2020
19	PDB-BW	Peerdsbos – 'Boswachter' CA	Atl. oak-beech	2017
20	MDW-DH	Meerdaal - De Heide (CwS)	Subatlantic oak-hornbeam	2016

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3 STANDARD MEASUREMENT PROTOCOL

3.1 BACKGROUND

The standard methodology for the monitoring of strict forest reserves in Flanders was developed based on experience and methods in neighbouring countries (Kätzler 1984, Bücking 1989, Peterken & Backmeroff 1988, Koop 1989, Albrecht 1990, Althoff et al. 1993, Projektgruppe Naturwaldreservate 1993, Mountford et al. 1999) the guidelines of the European COST-action E4 (Hochbichler et al. 2000) and some own preliminary studies (Van Den Meersschaut & Lust 1997a,b, Van Den Meersschaut et al. 2000). From these some global requirements and conclusions were drawn:

A decent monitoring of a reserve should involve at least the basic dendrometric measurements (species, diameter at breast height (DBH), height of upper canopy, regeneration), combined with vegetation relevés. Analysis and typology of the soil should also be done, at least once at the beginning of the monitoring.

Two sampling methods are commonly used in Europe for the monitoring of strict reserves:

- systematic grids of sample plots (often circular plots)

- larger full-survey plots with fixed or variable size (often called 'core area')

In the 1950s to 1980s, also strip transects were sometimes used (e.g. Leibundgut 1982, Mayer 1976, Korpel' 1995). They have a good demonstrative value, but have shown drawbacks considering repositioning (positional error), data analysis and extrapolation.

Both sample plot grids and core areas have their advantages and opportunities. A standardised grid of sampling plots will produce reliable data on the variability and development of the whole reserve, while the core area will provide more detailed (spatially explicit) information on the ecological processes that trigger the spontaneous development and the interactions between tree layer, soil and ground vegetation. It is therefore advisable to apply a combined sampling, with both sample plots and core areas.

The sample plots are preferably circular plots (less edge effects and uncertainty on the relocation), with a minimum size of 500 m². Within a sample plot, subplots can be established for measurements on regeneration and herb layer vegetation. Core areas should at least have a surface of 0.5 ha, square or rectangular, with a minimum width of two times the tree height (60-80 m).

In order to produce reliable data for the whole reserve (accuracy levels of 5 to 10 %) on basal area, species composition and stem number using sampling plots, a sample size of at least 15-20 % of the total area is needed (Van Den Meersschaut et al. 2000).

Measurements should be repeated at least every 10 years. This interval is long enough to detect changes and not too long to miss out on some developments (Hochbichler et al. 2000).

3.2 OVERALL SET-UP

Based on the requirements and recommendations in 3.1, a standard methodology was developed, combining a grid of permanent sample plots with a core area (Fig. 2).

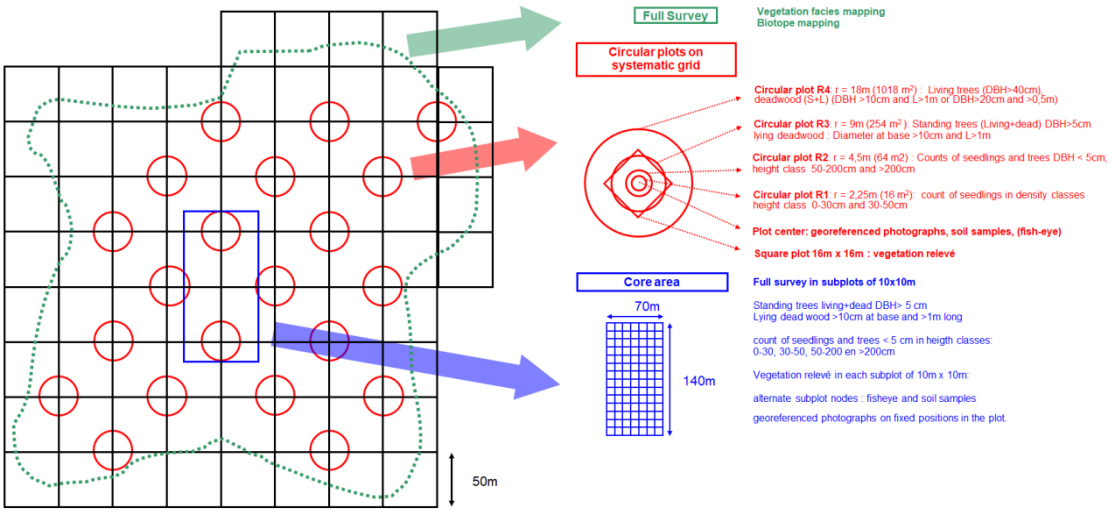

Fig. 2. Visualisation of the monitoring layout, combining a core area with grid-based circular plots. Since 2022, an adapted method is applied for the sampling of lying deadwood (not shown in the figure)

The grid system consists of circular nested plots, with the largest radius 18 m (= 1018 m²), set out on the alternatingly selected nodes of a 50 m x 50 m grid. The total area covered by the 18 m radius plots amounts to 15- 20% of the area of the forest reserve.

The grid is standard oriented North-South, however if a useful and permanent reference line in the field is available (e.g. a straight road or path), then the basic orientation of the grid is aligned with this field reference.

In these sample plots basic measurements are performed on woody vegetation (position, species, diameter at breast height (DBH) , height of selected trees, regeneration) and the herbaceous layer. The plot design and the methodology of the measurements are similar to the Flemish Forest Inventory (except for additional detailed measurements of lying deadwood), thus allowing immediate comparison. At the first sampling survey in the sample plots, the dendrometric and vegetation measurements are combined with soil samples.

Oriented digital photographs are taken from the centre point of the plot. These repeated snapshots do not deliver quantitative data, but can be very illustrative for changes over time. At the first survey, also fish-eye images were made to quantify canopy cover.

The core area is located in the most representative part of the reserve and is aimed to perform more intensive and spatially explicit measurements. The standard dimensions of the core area are 70 m x 140 m, which is in accordance with the Dutch methodology (Koop 1989). All trees are identified and their position and size are measured; vegetation and regeneration are mapped in detail in 10 m x 10 m subplots; soil and light conditions are analysed.

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All plot and tree measurements are performed and stored electronically using FieldMap technology, and regularly transferred to a central geodatabase ('mother database'), of which new versions are regularly backed up.

The methodology is flexible and can be adjusted to local conditions as long as it meets the minimal requirements. In the forest reserve of Sonian Forest for example, the radius of the largest circular plot was expanded to 30 m, as tree dimensions and distances are extraordinarily high in this site. Size extension was necessary in order to comply with the basic principles of Kramer & Akça (1982), Richter & Grossmann (1959) or Spurr (1952) pointing out that an individual plot should at least contain respectively 25 to 30, 12 to 14 or 20 to 30 trees. By simultaneously widening the grid in Sonian Forest to 100 x 100 m, the sample size of 20% could be respected. Also the core area at this site is considerably larger than required, covering 10.75 ha instead of 1 ha. This large-scale full survey is based on the fact that detailed dendrometric information was available for this area from 1986 and 1991, providing opportunities for interesting detailed comparisons.

In other sites, full grid surveys were not possible due to inaccessibility of the site (e.g. swamp forests such as Coolhem forest). In that case, only one or two core areas were set up. These core areas can be standard size or smaller, again due to inaccessibility, homogeneity or border effects (e.g. 50 m x 100 m).

In sites with high density of medium-sized lying deadwood fragments, it was decided in 2023 to introduce a new sampling protocol, combining Line Intersect Sampling (LIS) for the fragments of 10-30 cm diameter and Full Area Sampling (FAS) for larger logs.

The systematic grid of circular plots is mainly to be considered as a classic systematic sampling, allowing for a global overview on the diversity of the site and the development and diversification of the area as a whole: what is the distribution of tree species, stem number, basal area, vegetation types and species; and how do they develop over time? However, as these plots are permanent, they can also be considered as individual, be it small, permanent plots, allowing precise analysis of changes at plot and individual tree level (e.g. diameter increments). For spatial analysis, they are less useful, as the size of the plot is too limited.

The need for more detailed analysis on spatial patterns in trees and soil condition and interactions between tree layer, regeneration and ground vegetation is covered by measurements in the core area.

Fig. 3. Site Jansheideberg in the forest of Hallerbos: an example of Atlantic lowland beech forest (Endymio-Fagetum) with typical spring aspect of bluebells (*Hyacinthoides non-scriptus*)

Fig. 4. Monumental decaying beech tree in strict forest reserve Joseph Zwaenepoel (Sonian Forest)

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4 PREPARATORY PHASE

4.1 SITE BACKGROUND INFORMATION

When a site is selected for monitoring, and before the sampling set-up is decided in the field, a thorough analysis of the land-use and management history of the site is made. Also, an overview of existing knowledge and research at the site is compiled.

Part of this data consists of maps (historical maps, vegetation maps, forest mapping, management plans, ortho-photographs...), which - if necessary - are digitised and georeferenced so that they can be combined in a GIS environment.

The most important findings and a detailed reconstruction of the forest management can be integrated in a monitoring report (e.g. Vandekerkhove et al. 2012), or compiled in a separate scientific report (so-called 'basisrapport') (e.g. Baeté et al. 2002, 2003a,b,c, 2004a,b,c, 2006a, b, c, 2007, Smets et al. 2005).

This survey not only serves the interpretation of observed developments later on, but can also help to determine the selection of a particular configuration of the grid and especially the location of the core area. The core areas are selected in the most representative parts of the forest, preferably in stands with long forest continuity and diverse stand structure, or at sites where previous intensive research was performed.

The set-up and size of the sampling can be adapted if older monitoring grids are available. For instance in the sites of Liedekerkebos, Sonian Forest and Walenbos, sampling transects and plots formerly sampled in the 1980s (Van den Meersschaut et al. 1999, Van den Berge et al. 1990) and 1990s (Koop et al. 1992a,b,c) were continued and, where necessary, further elaborated to make sure that also older surveys could be integrated in the dataset.

4.2 PRESELECTION OF THE SAMPLING DESIGN

4.2.1 Selection of the sample grid

Based on the basic information compiled in 4.1 and the topography of the site, the grid system for the circular sample plots is selected. In a GIS, all relevant map data are compiled (borders, aerial photographs, stand maps from management plans, topographical maps). This is superimposed by a theoretical grid of 50 m x 50 m, which is standard North-South oriented. If a useful and permanent reference line in the field is available, such as a pattern of straight paths in a deviating direction, which can greatly simplify the site work or greatly reduce the number of edge effects, then the basic orientation of the grid will be aligned with this field reference.

The exact location of the grid is chosen based on all information collected. The aim is to achieve maximum integration of previous research and the topography and shape of the reserve.

On this theoretical grid, every alternating node is selected as a sample plot (thus resulting in a mesh width of 71 m). Gridpoints that are too close to the border of the reserve (< 30 m) or

where the plot hits a non-abolished road are excluded from the design. However, if this results in too few sample plots per site or stratum, plots can also be shifted for a few metres along one of the grid lines.

Depending on the selected starting node, two configurations are possible.. The alternative that gives the best results is chosen:

- Lowest number of abolished grid points (e.g. near the forest edge or on operational roads and tracks)
- For sites where different 'strata' occur (e.g. different forest types, management or management history), the option with the most representative stratified sample

The standard set-up consists of a grid with circular nested plots with the widest radius of 18 m (= 1018 m²) resulting in a total covered area between 15 and 20% of the total area.

In exceptional cases it is possible to deviate from the standard grid if this clearly represents an added value, for example if another grid from previous research is already present. In this situation, the size and location of the present grid was respected as was the case e.g. in Liedekerkebos and Withoefse heide (radius 20 m), in Sonian forest (radius 30 m, mesh width 100 m).

4.2.2 Selection of the core area

The **core area** has a standard surface area of 9800 m² or 0.98 ha, with standard dimensions of 70 m x 140 m. This was inspired and is in line with the Dutch Forest Reserves monitoring programme (Bijlsma & Clerckx 2019). If this size cannot be realised (for reasons of heterogeneity, edge effects or inaccessibility), a smaller plot of 50 m x 100 m is selected.

The position of the core area can be freely chosen, to best represent the site, but is preferably spatially linked to the grid (see Fig. 2). Usually the core area is positioned in a part of the reserve that is representative and homogeneous. In a few cases the core area is deliberately positioned on the boundary between contrasting stands (e.g. Jansheideberg, Muizenbos) or along a gradient (e.g. Rodebos). This is only the case if this choice is supported by a clear research hypothesis (e.g. tree species effects of ground vegetation, forest dynamics in stands with a contrasting management history).

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5 SET-UP IN THE FIELD

5.1 GRID OF CIRCULAR NESTED PLOTS

After the optimal sampling design is selected by a desktop analysis, the resulting layout is materialised in the field after a reality check.

A clearly identifiable point, e.g. an intersection of forest tracks, identifiable on maps and aerial photographs, is taken as the starting point for positioning of the grid. From this point, the grid points on the terrain are positioned and then permanently marked with Feno markers.

In the period 2000-2007, the positioning of the grid was done using a theodolite (electronic tachymeter or total station type Leica TC 805) and d-GPS (Trimble Pathfinder II). Since the implementation of FieldMap-technology, the grid is materialised using the integrated digital compass combined with a laser-rangefinder. The positional error using this configuration amounts to a maximum of 10-20 cm per reference point.

In some cases, minor adjustments to the grid are made. Circles that fall on paths are maintained if the path is not paved and no longer operational. Circles that fall on paved paths, which will be used permanently, can be shifted in the direction of either axis of the grid. Circles that intersect the reserve boundary or are partially located in the buffer zone (= 30 m wide outer border of the reserve, where safety fellings are allowed) will in principle be eliminated. If this results in the total sample covering less than 20% of the reserve, or an unbalance in the different 'strata' (if occurring) also a number of plots at these edges will be shifted inwards.

Fig. 5. A Feno marker is used to indicate the plot centre (photograph by Bruno De Vos)

5.2 CORE AREA

The position of the core area is chosen meticulously during a site visit, based on the preliminary literature and map study. The core area must be representative of the reserve and the forest type for which the reserve was selected. It is preferably chosen centrally in the reserve and is quite homogeneous (both vegetation type and tree composition). If possible, the core area should be selected at a location where interesting dynamics can be expected in the short term.

The core area is often directly linked to the grid: the points at 20 and 120 m on the central axis are grid points of the sampling plots. The core area is also permanently marked with Feno markers as follows: at the 4 corners and on the central axis after 20, 70 and 120 m, where points 20 and 120 m can already be part of the grid of sample circles.

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6 SOIL SAMPLING

The soil survey is performed during winter at the first survey campaign. Samples are taken at fixed positions in the circular sample plots and in the core area.

In the sample plots, the thickness of the litter layer is measured with a ruler and the mineral topsoil is sampled at fixed depth (0-10 cm) using a 3 cm diameter auger, taking five subsamples within each plot, close to the centre of the plot. These subsamples are aggregated to one soil sample, dried to constant weight at 40°C.

In the core area, detailed data on the micro-variability of soil conditions is aimed at. Therefore, 85 fixed points are sampled. At least three subsamples are taken with an auger, in the immediate vicinity of the selected grid-point (< 1 m away), alternately located on the 10 m x 10 m grid of the core area. One row outside the core area is also sampled, to allow for interpolation (Fig. 6).

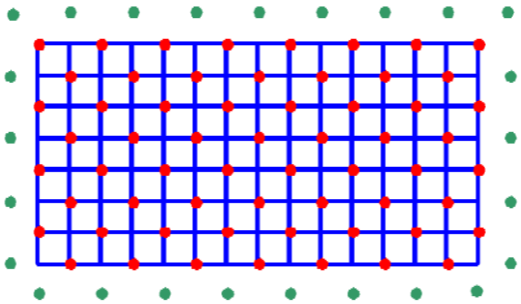

Fig. 6. Grid points in the core area at which 60 fish-eye photographs are taken and mineral soil (0-10 cm) is sampled (red dots). Soil is additionally sampled on 28 grid points outside the core area (green dots).

Sample preparation

Soil samples are stored in a sealed plastic bag and stored at 4°C. The samples are weighed and dried for 7 days at 40°C in a ventilated oven. The dried soil samples are weighed again and ground into particles with a diameter of less than 2 mm. This is done by means of a soil crusher Cross Beater Mill SK100 (Eijkelkamp).

The moisture content is determined at 40°C and at 105°C. The analyses are done on the samples dried at 40°C and the results are corrected with a factor that takes into account the difference in moisture content at 40° and 105°.

Sample analysis

Samples are analysed on moisture content (weighing fresh and after drying), texture (Sand, Loam, Clay fraction), Carbon content (loss of ignition), pH-$CaCl_2$, CEC (Ca, K, Na, Mg, Al, H), Kjelldal-N and plant-available P using the Standardised Operation Procedures also applied in ICP-Forests, and described by Cools & Devos (2016).

7 FIELD PROTOCOL FOR MEASUREMENTS IN CIRCULAR PLOTS

7.1 DENDROMETRIC MEASUREMENTS

7.1.1 WHAT is measured ?

The circular sample plots for dendrometric measurements are a set of circular nested plots with different sizes depending on the dimensions of the woody elements, i.e. the diameter at breast height (DBH, at 130 cm height). Details on HOW all elements are measured are given below in chapter 7.1.2.

7.1.1.1 **Sample circle A4 = radius 18 m (1018 m²)**

Living trees
Threshold: DBH of 40 cm and more

- Position of all living trees

- Position of all coppice stools with shoots that meet the DBH threshold

- Species identification of all positioned individuals

- DBH of all positioned trees and shoots

- Height measurement on a selection of trees and shoots of coppice stools (see below)

- IUFRO vitality classes (Leibundgut 1956) (see below)

Dead trees
Threshold: Standing dead trees, shoots and snags with DBH > 10 cm and height > 1.3 m; lying deadwood segments with largest diameter > 10 cm and length > 1 m or largest diameter > 20 cm and length > 50 cm

- Snags (= broken at stem or primary branch level): position, DBH, height, species and decay stage (see 7.1.2.2)

- Coppice stools and multi-stemmed trees with dead shoots/stems that meet the threshold: position and species of the stool; DBH and decay stage of every dead shoot. Height is derived from height curves (see 7.1.2.4).

- Standing dead trees (complete tree): DBH, annotation of crown reduction class if present (see below), decay stage (see 7.1.2.2). Height derived from height curves (see 7.1.2.1).

- Lying deadwood (segmented in individual sections: stem section, branch limbs, even if still connected), each segment that meets threshold: position base + top, diameter at both ends, species (if possible), decay stage (see 7.1.2.2)

Update: since winter 2022-2023, in reserves with high density of small to mid-sized lying deadwood, the Full Area Sampling (FAS) as described here is limited to segments with a threshold diameter of 30 cm. Smaller objects(branches, stems) of 10-30 cm diameter are sampled using Line Intersect. For details: see chapter 7.1.2.2.

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For the trunk base of lying dead trees, the type of origin - uprooting (pit+mound) or breakage - is registered. Dead branches in living trees are not registered (only dead stems and shoots in coppice stools or other multi-stemmed trees). Tree stumps of harvested trees are also normally not registered (only in explicit cases when also managed stands are included in the monitoring).

7.1.1.2 **Sample circle A3 = radius 9 m (254 m²)**

Living trees
Threshold: DBH of 5 cm and more

Measurements identical to circle A4, but lower DBH threshold of 5 cm:

- Position of all living trees with DBH between 5 and 40 cm

- Position of all coppice stools with shoots with a DBH between 5 and 40 cm

- Species of all positioned individuals

- DBH of all trees and shoots with measured position

- Height for a selection of trees and shoots of coppice stools

- IUFRO vitality classes of each positioned tree or shoot;

Dead trees
Threshold: Standing dead trees, shoots and snags with DBH > 5 cm and height > 1.3 m

Measurements for standing deadwood identical to circle A4, but with lower DBH threshold of 5 cm; no additional measurement of lying deadwood in A3

- Snags: position, DBH, height, species, decay stage (see 7.1.2.2)

- Standing dead trees and dead shoots/stems of coppice stools or multistemmed trees: position, DBH, crown reduction, species, decay stage (see 7.1.2.2). Height is derived from height curves (see 7.1.2.1).

- Lying deadwood: no additional measurements to the ones in the full A4-circle. This means:

Lying deadwood segments : position and Diameter (base+top), species, decay stage

Update: from winter 2022-2023, the Full Area Sampling (FAS) as described here is limited to fragments with a threshold base diameter of 30 cm. Smaller fragments (branches, stems) of 10-30 cm base diameter are sampled with Line Intersect. For details: see chapter 7.1.2.2.

7.1.1.3 **Sample circle A2 = radius 4.5 m (63.6 m²)**

Threshold: living trees with DBH < 5 cm and height > 50 cm

- count of individuals per species in 2 height classes: 50 - 200 cm, > 200 cm

- Game impact (registered since 2014): number of trees per species impacted by browsing or by fraying (roe deer)

Observations are made in the summer half year, during the vegetation survey (see further).

7.1.1.4 **Sample circle A1 = radius 2.25 m (16 m²)**

Threshold: seedlings, living trees smaller than 50 cm in height

- Count by species in 2 height classes:< 30 cm, 30 - 50 cm

- Count in frequency classes: 1, 2 - 5, 6 - 10, 11 - 20, 21 - 40, 41 - 60, 61 - 100, >100, >1000
- Game impact (registered since 2014): number of young trees per species impacted by browsing or fraying (roe deer). For large numbers, percentages of impacted trees are noted.

7.1.2 HOW: details and protocols for measurement

7.1.2.1 **Standing single trees (living/dead)**

Measuring the position of trees was originally performed with a theodolite (Leica TC805) to measure distance and azimuth of the tree from the plot centre. Since 2007, these measurements are done using Laser Technology Instruments (LTI) in combination with FieldMap software (IFER). The measurement device combines FieldMap software, a field computer and measurement hardware: Laser Forest Pro - LTI (distance, vertical angle) and Mapstar digital compass – LTI (azimuth, horizontal angles) (Fig. 7).

Fig. 7. FieldMap measurement configuration showing telescopic sight, Laser Forest Pro (below) and Mapstar digital compass (vertical box-shaped device on the left).

First, the team navigates towards the selected reference position (plot center) for measurement, using the navigation tool of FieldMap. Then all tree positions are measured in relative or local coordinates to the circle plot center. The device is positioned on the center point, or a selected position that has been measured relative to the plot centre (mirror at the center point, device distance and angle to the mirror measured).

Next, the mirror is placed in front of the selected tree: a position is measured and the tree is registered (ID code).

The **species** of the tree is determined. Most species are identified up to species level. As measurements are performed in winter time, not all identifications are possible. In some cases, a tree is revisited during the summer campaign (vegetation and regeneration) for decisive identification. Willows (*Salix*) are subdivided in two groups: round-leaved willows (type *Salix caprea)* and lancet-leaved willows (type *Salix alba*).

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The **diameter at breast height** (**DBH** = at 1.30 m above ground level) is measured using a measuring tape or a calliper. For calliper measurements, two perpendicular measurements are done, pointing in the direction and transversal to the direction of the plot center, and the average value is registered. For exceptional situations, measurements follow the guidelines as shown in Fig. 8.

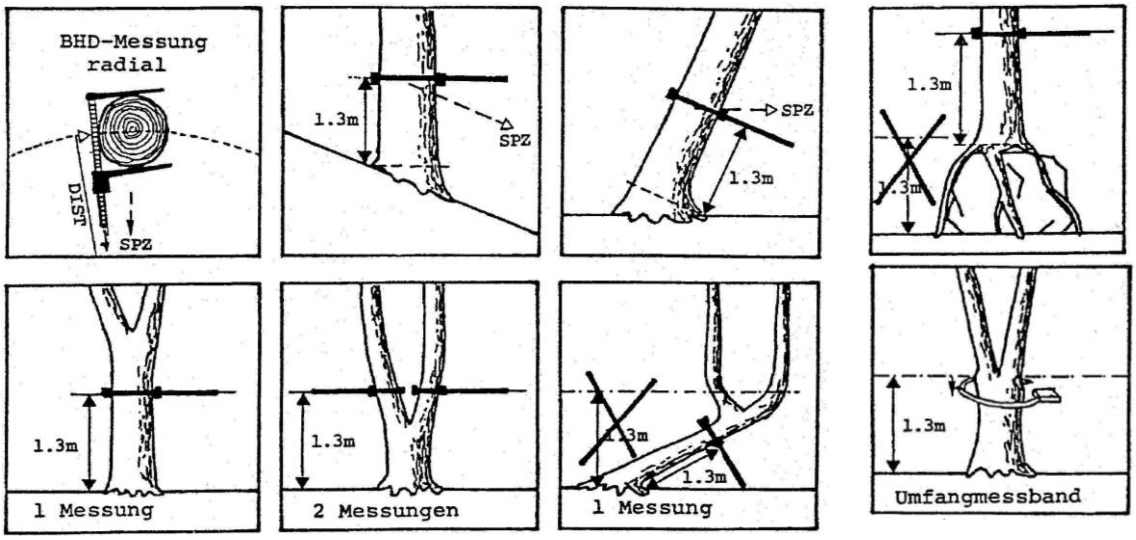

Fig. 8. Guidelines for measuring the DBH, also in peculiar situations (figure from Kärcher & Förster 1994, Keller 2005)

After registration of the diameter, the position of the tree is automatically corrected by the software to represent the middle of the stem. If the center of the stem is located beyond the radius of the respective sample circle, a warning is given ("Tree is outside the plot, Accept anyway?"), so the tree can be removed from the plot.

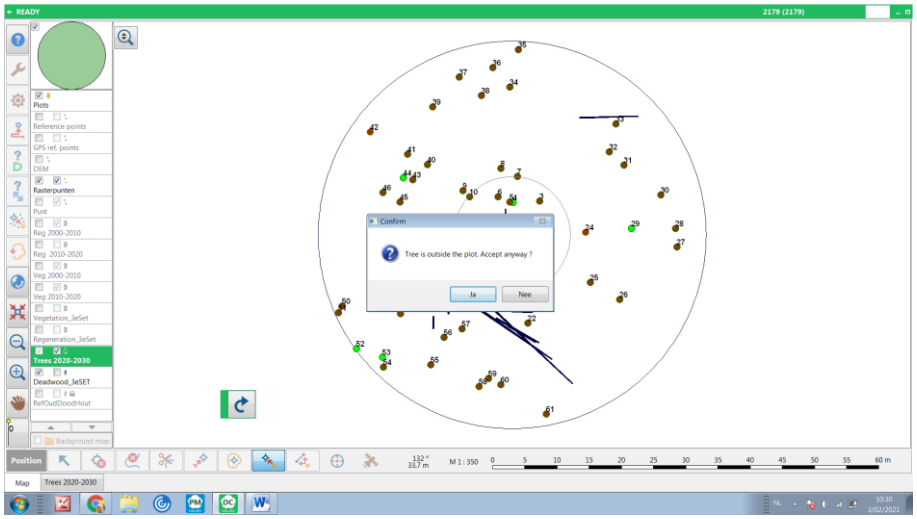

Fig 9. Warning shown on the field computer indicating that a measured tree is outside of the plot

Height measurements are performed on a selection of trees. Originally a vertex (type Haglöf DME 201) was used. Now, height measurements are usually performed with the Laser Forest Pro (LTI), heights are directly added into the FieldMap database. The choice between instruments to measure height is based on the presence of very tall trees (35 - 50 m) in the plots, for these trees the distance range of the instrument has to be large enough.

For practical reasons, the height measurements should preferably be carried out in the winter half year when deciduous trees are in off-leaf status.

Not all tree heights are measured. A selection of trees is made for every species over the different DBH classes. Usually the following DBH classes (cm) are used:

5 - 10
10 - 20
30 - 40
40 - 50
50 - 70
70 – 90
90 – 110
>110

At least 10 tree heights are measured per diameter class and per tree species, for the whole reserve (or specific subareas if distinct site conditions occur within the reserve). Trees are selected based on good visibility of the top. Crooked, tilted or bent trees are excluded from the selection, as they are not representative for the large majority of trees. When selecting trees for height measurements in the sample circles, attention is also paid to the distribution of the individuals per tree species or per tree species group, over the whole of the reserve area. Dead intact trees are generally not selected for height measurements.

Based on these measurements, tree heights are generated for all trees, using diameter-height curves that are calculated based on the DBH and height measurements of the selected trees in the Field-Map Inventory Analyst tool. In further calculation of the tree volumes, these calculated heights (CalcHeights) and measured DBH values are applied in tariff formulas (see below).

Heights (and volumes) of dead standing trees with an intact crown are generated, like for the living trees, from the diameter-height curve that was calculated. Volumes are calculated as for living trees. **Height of snags** (dead trees broken at trunk or primary limb level), however, is always registered. Their volumes are calculated using DBH, stem length and tree taper equations incorporated in the FieldMap software. **For living and dead standing trees with partial crowns** (part of the crown broken out), tree volumes are calculated as for intact trees, but corrected for the lost crown volume. The share of missing crown is estimated and registered in a specific field (CrownVolumeReduction), for later correction of calculated crown wood volumes. Used classes are: 25 , 50, 75 and 100% (based on resp. 10-40% , 40-60%, 60-90% or > 90% of the original crown volume missing).

For dead standing trees, also the **decay stage** of the tree is registered (for details on decay classes, see below at ‘lying deadwood’).

Furthermore, the 3x3 **IUFRO vitality classes** (Leibundgut 1956) are annotated for every living tree and shoot:

 https://doi.org/10.21436/inbor114075052

Height class:
B (Bovenetage = Upper canopy) : tree height > 2/3 canopy height
M (Middenetage = Mid canopy): tree height = 1/3 to 2/3 canopy height
O (Onderetage = Lower canopy): tree height = <1/3 of canopy height

Vitality class:
KR (Krachtig ontwikkelde bomen): vigorous tree
N (Normaal ontwikkelde bomen): normal vitality
KW (Kwijnende bomen): languishing tree

Near Future Growth Potential (Hall et al. 1978):
V (Voorgroeiende bomen): predominant tree
M (Meegroeiende bomen): co-dominant tree
A (Achterblijvende bomen): suppressed tree

7.1.2.2 **Lying deadwood: Full Area Sampling**

Lying deadwood is registered and measured as deadwood segments. Complete trees or tree crowns, even if still in one piece, are subdivided in cylindrical or truncated cone segments.

Until the 2021-2022 *inventories, each segment with a length of 1 m and diameter of 10 cm and more at the largest end (or 50 cm long and > 20 cm diameter), was fully registered.* ***From 2022-2023 onwards****, the threshold diameter was set at 30 cm, and smaller segments are registered through Line Intersect Sampling (see 7.1.2.3).*

For all segments meeting the size threshold, the following measurements are performed. The **position and diameter at both ends** are measured (Dbase, Dtop). If the fragment crosses the border of the plot, still both positions and diameters are measured: the FieldMap-software includes a tool that automatically cuts off the part outside of the sample plot when calculating volumes (see below). For the stem segment of uprooted trees, the base diameter is measured at approximately 1.30 m from the treebase (to avoid the root buttress bias), and the status (uprooted vs. broken) is registered.

For each segment, tree species is identified (as far as possible). If the segment is too far decayed for species determination, genus is noted, or broadleaved/coniferous.

In order to get a picture of the distribution of the deadwood over the different decomposition classes, a **decay stage** is assigned to all measured deadwood segments (Table 2). These decay stages are based on the classification developed in the Nat-Man project (Christensen and Vesterdal 2003), and described in De Keersmaeker et al. (2005) and Dhiedt et al. (2019). The assignment is based on visual characteristics (presence of bark, etc.) and on the softness of the wood (Table 2). To this end, the depth to which a knife can penetrate the wood is assessed. Each measured deadwood segment is assigned to one representative stage of decomposition. If one segment (e.g. the stem) has a very large variation of decomposition stages over its full length or when a part is still alive, the element is subdivided in separate segments with diameter and position measurements at both ‘ends’, so the volume can be assigned to one specific decay stage.

Table 2. Description of the 6 decay stages of deadwood

Decay Class	Stage Description
1+	Clearly dead this year (e.g. fallen during a summer storm): there are still dried leaves or tree buds on the tree
1	Dead for a maximum of 2-3 years: all branches, even the smallest ones, are still present; the bark is intact and the wood is hard
2	Superficially decayed: bark is loose (begins to peel off); wood may not be penetrated with a knife blade for more than 1 cm.
3	Moderately decayed: bark largely peeled off; wood can be penetrated with a knife blade over several cm (especially sapwood: heartwood -if present- is still predominantly hard)
4	Largely decayed: bark has gone, the whole trunk is decayed and soft; only lying deadwood, standing trees have fallen over; cross-section oval
5	Remains in the litter layer: you can still see where a tree was (diverging vegetation; slight elevation in the terrain), some fragments and mold remaining

7.1.2.3 **Lying deadwood: combined Line Intersect and Full Area Sampling**

Context

Over the years, the amounts of lying deadwood have increased significantly in the strict reserves and the sample plots. This makes the full-area sampling of deadwood very time consuming and often hardly feasible, e.g. when several tree crowns fall into a plot.

We therefore examined other sampling methods that combine reduced workload with minimal loss of information and plot level precision.

A solution for the workload is to increase the threshold diameter of registered deadwood segments. However, a large share of the deadwood volume is found in the lower dimensions: in our reserves, the fraction 10 - 30 cm diameter represents on average more than 1/3 of the volume of all lying deadwood (Thomaes et al. 2024).

Another option is to switch to Line Intersect Sampling (LIS), a method that is often used in deadwood volume assessments and can provide precise and unbiased figures on volumes, provided that the sampled intersect length and number of ‘hits’ is large enough to level out the randomness. Especially for rare elements such as large logs, which are important for the volume calculations but have a low chance to be hit by an intersect line, this can be a problem. LIS results from limited local transect lines are not suited as local estimator of the deadwood volume. This problem further increases if more detailed subclasses are aimed at (such as volume per species and/or decay class). Another drawback of LIS is that it does not register individual deadwood objects and therefore doesn’t allow for repeated sampling or identification of individual logs and log sections.

Full area sampling is therefore preferred when measuring rare and large-diameter lying deadwood and allows follow-up of individual deadwood objects while line intersect sampling seems more time efficient and advantageous for small-diameter lying deadwood, especially in forests where the small-diameter deadwood is more abundant. In such forests, line intersect sampling generates precise plot estimates of lying deadwood volume in case of sufficient hits.

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Consequently, we developed a combined protocol by using full area sampling to monitor all large-diameter lying deadwood and line intersect sampling to measure small-diameter lying deadwood objects. A detailed analysis was performed based on the existing datasets from all circular plots in strict reserves, looking at the bias, level of (local) precision and the retrieval rate for objects of different size and species using a 10 year resampling interval. The results of this analysis were published in Thomaes et al. (2024). The analysis resulted in a threshold diameter of 30 cm (at the larger end) for large-diameter lying deadwood segments (classic Full Area Sampling) and 10-30 cm diameter at the crossing of the transect line for small-diameter objects (Line Intersect Sampling).

In order to avoid including an object in both the full area and line intersect sampling monitoring, objects intersecting the transect line at a diameter below the threshold diameter but with a base diameter above the threshold should be either ignored in the field or corrected during data processing afterwards, based on the calculated diameter at the intersect line. For practical reasons, we decided to do a full LIS in the field, combined with FAS of all segments with base diameter above the threshold of 30 cm. Double counts are removed afterwards: the position of the large segments allows to discern deadwood segments that cross the intersect lines ('hits') and calculate their estimated diameter at the point of crossing, thus allowing to detect and remove the double counts.

New protocol

For lying deadwood segments with base diameter > 30 cm, the measurement protocol as described in 7.1.2.2 remains unchanged. Lying deadwood segments with base diameter between 10 and 30 cm are registered as described below.

In every circular sampling plot, a set of three intersect lines are installed in a fan-design (Fig. 10) facing North, 120° and 240° respectively. The lines start at 3 m from the center of the plot and run up to the border of the A4 plot. For the standard circular plots with 18 m radius, this means 3 x 15 m. For plots with divergent sizes, the lengths will be changed accordingly (Sonian forest plots with radius 30 m = 3 x 27 m).

Each log or branch crossing one of the lines is registered: diameter (measured perpendicular to the axis of the object), species and decay stage at the point of crossing. If an object crosses several lines, it is registered at every hit.

An object is considered to cross the line (or better: the imaginary 2-dimensional plane above the surface line) also when it does not make contact with the ground at that point. Hanging dead trees and snags with stem slopes of over 45 degrees deviation from zenith are counted as lying trees. If the angle is less than 45 degrees, the tree or snag is considered 'standing' (for measurements on standing dead trees, see 7.1.2.1).

The removal of double counts and the calculation of the resulting volumes, subdivided per species and decay class, are done at the office afterwards, using the formula of Van Wagner (1968):

$$V = (\pi^2/8L) \sum_{1}^{n} d_i^2$$

with V: Volume per area (m^3/m^2), L: Total transect length (m) and d_i: Diameter (m) of object i at the line intersection.

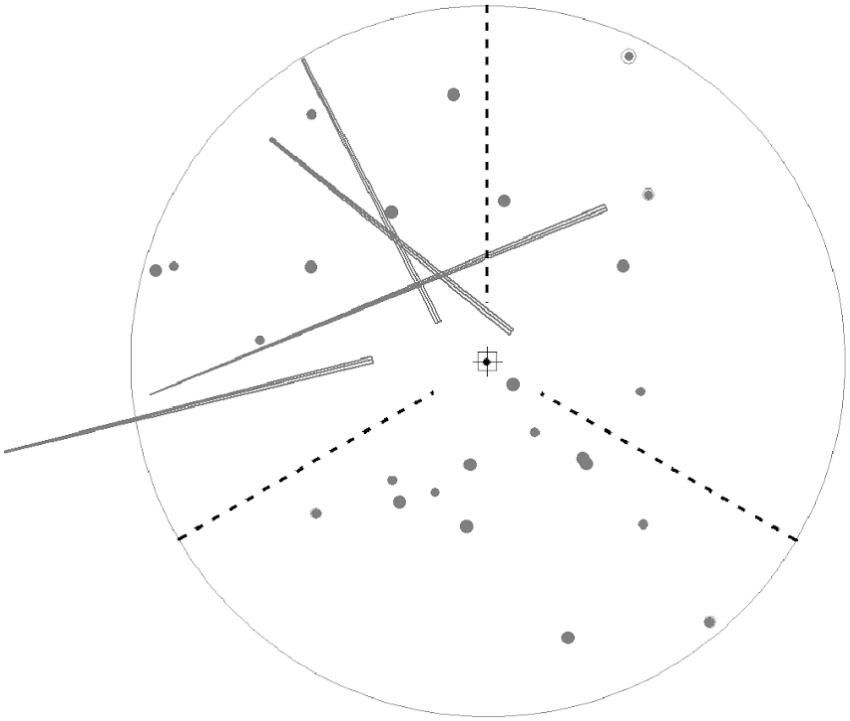

Fig. 10. Line Intersect Sampling design in the circular plots : 3 x 15 m lines in a fan design (North, 120° and 240°). Every dead lying or hanging object that crosses the line is registered. Correction for double counts with the Full Area Sampling of deadwood segments with base diameter > 30 cm is done at the office afterwards.

7.1.2.4 **Multi-stemmed trees and coppice stools**

The position of the center of the stool is measured by placing the mirror in the center of the stool itself. The stool receives a separate ID for living and dead shoots. All living and dead shoots that meet the size requirements are measured separately and linked to this position (separate 'shoot' layer). For all shoots, DBH and status (living/dead) are registered. For living shoots also IUFRO-classes are registered.

This allows for two alternative density calculations: based on the number of individuals, or based on the number of shoots (counting every shoot as a unit).

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For selected tree height measurements, shoots are treated similar to single trees: a selection of shoots in different DBH classes can be selected for height measurement. However, if single-stem trees are available for a specific species/DBH combination, these are preferred.

Volume calculations for coppice follow specific procedures (see 10.2.2.3).

7.1.2.5 Linking measurements of individual trees/shoots and deadwood segments in subsequent surveys

For standing trees/shoots:

In order to register and calculate changes for individual trees (e.g. DBH increment, mortality) between subsequent surveys, the datasets of subsequent surveys can be linked based on the position of a tree within the plot. For this purpose, the previous survey of standing trees is 'copied' (including tree ID) and 'updated' in the new dataset (new DBH, new status dead or alive, decay stage...). Linking the two surveys may reveal obvious errors, e.g. tree species changes. In this case, the identification is verified and the record is immediately corrected in the field, if needed, in the previous survey.

Sometimes, the link between two surveys results in uncertainties during the data control phase after field measurements. For instance: an ingrowing tree has surpassed the diameter threshold of circle A4 (40 cm DBH) in the new survey, but was not registered in the previous sampling. Was it below the 40 cm DBH threshold at that time, or was it forgotten? A dead tree in survey 1 is registered alive in survey 2: which of both surveys was wrong in the field? A large tree from survey 1 is no longer present in survey 2, but cannot be found, not even in the deadwood layer in the field. A simple registration in the field during the latest survey can clarify most of these uncertainties.

Since 2020, different possible 'transfers' between consecutive surveys are actively registered in the field during the survey campaign using standard typologies, allowing for more reliable data check and corrections of the dataset afterwards. These registrations are :

- New tree - new plot: plot not measured in previous survey
- New: new tree, omitted by mistake in previous survey
- New - ingrowth: first measurement, not measured in previous survey as DBH was below threshold value
- Living - living: living tree in survey 1 is still alive in the next survey
- Living - harvested: registered alive in first survey, harvested in second (stump visible)
- L - Ds: living tree in previous survey, now standing dead
- Ds - Ds: standing dead in both surveys
- Ds - living: 'lazarus' tree; the tree is still alive, the assessment in the first survey was wrong
- Ds - harvested: standing dead tree cut (stump)
- Undue: measured by mistake in previous survey (e.g. outside plot)
- L - deforested: living tree missing because plot was deforested between two surveys (remeasurement no longer possible, but old measurement still relevant)
- Ds - deforested: dead standing tree missing because plot was deforested between two surveys (remeasurement no longer possible, but old measurement still relevant)

Standing trees (dead or alive) that fall down between two surveys, transfer from the 'tree layer' to the separate 'lying deadwood layer' and are no longer registered in the tree layer.

For deadwood segments:
The deadwood segments are registered in a separate lying deadwood layer. As for the standing trees, the layer of the previous survey is loaded in the application, but not copied to the new layer. New deadwood measurements are performed in a new layer while the old deadwood fragments (lines) are displayed in the background. If a link is possible, the ID of the object is linked to the former measurement. Here again different situations may occur:

- Living - Lying deadwood (L - Dl): tree was windthrown between both surveys; ID link is made, if possible (for the stem section), with the ID of the living standing tree in the previous survey
- Ds - Dl: idem for lying stem of a tree that was dead standing in previous survey.
- Dl - Dl: lying segment is linked to its ID in the former survey; only done for the stem segment or primary limbs, not for individual branches (for obvious reasons)

7.1.2.6 **Rejuvenation (trees < 5 cm DBH)**

Since rejuvenation is most evident in leaf-on condition, this registration is carried out during the growing season. Rejuvenation here means all woody vegetation with a DBH < 5 cm.

In order to monitor the regeneration of the woody species, the rejuvenation is counted per height class.

In the sample circle A2 (radius of 4.5 m), all rejuvenation is exactly counted per species in the height classes 50 - 200 cm and > 200 cm.

In the sample circle A1 (radius of 2.25 m) all rejuvenation in the height classes 0 - 30 cm and 30 - 50 cm are attributed to frequency classes (1, 2 - 5, 6 - 10, 11 - 20, 21 - 40, 41 - 60, 61 - 100, >100, >1000). In case of very large numbers, which are uniformly distributed over the plot surface, only a section of the plot surface is checked and extrapolated to the entire surface.

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7.2 VEGETATION RELEVÉS

Vegetation relevés are made in square permanent plots of 16 m x 16 m (256 m²), centered on the grid point, with the corners in the four cardinal directions at 11.3 m from the central grid point.

One vegetation survey consists of two samplings: one in spring (April 1 - May 31) and a second visit in summer (June 15 - September 15) in order to register both spring and summer species at their optimal development. Both records are integrated to one result, taking into account the record with the highest cover (*cfr*. Mölder et al. 2014). In case no spring vegetation is present at the site, the first sampling is skipped.

All herbaceous species (vascular plants) and woody species (height < 200 cm) are identified, and their cover is estimated using the extended Londo scale (Londo 1984; Table 3). If required or preferred, the cover data can be transformed into percentage values using the midpoint value of the respective class.

Bryophytes are not identified, only their overall cover is registered (see below)

In 2015, a 'Browse index' was added for every registered species:

- No traces of browsing
- Traces of browsing (< 5% of individuals browsed)
- Significant traces of browsing (> 5% of individuals browsed).damage

Identification of vascular plants follows Lambinon et al. (1998). All species of the herb layer are identified up to species level. Exceptions are:

- *Rubus fruticosus*: identified as agglomerate (but *Rubus caesius* and *Rubus idaeus identified separately*)

- Young individuals of *Dryopteris dilatata* and *D. carthusiana* (if the distinction is unclear)

- Non-flowering *Epilobium* species, certain unidentifiable grasses and sedges,

- Seedlings of *Fraxinus excelsior* and *Acer* spp., or *Betula* and *Salix* spp., ... that cannot be distinguished.

As for the woody layer, the general rule applies that as much as possible is determined at species level, but not at the expense of reliability.

The **cover** of a herbaceous species or layer is defined as the horizontal projection of that species or layer within the borders of the plot. A species rooting outside the plot may thus have a cover within the plot, and its cover is registered.

Finally, also the total cover of the moss layer, herbaceous layer, shrub layer (2 - 8 m height) and tree layer (> 8 m height) is estimated (upper limit being the top height of typical shrubs such as hazel). For these layers, only the total percentage cover is estimated (i.e. no cover of individual species).

The moss layer cover always concerns the non-epixylic ('terrestrial') mosses of the plot area. Species on deadwood are therefore not included in the terrestrial moss layer, because deadwood is considered a specific substrate/layer.

Vascular plants growing on rootplates, on deadwood, epiphytes on living trees, submerged or floating on water, are also registered but explicitly assigned to a specific 'layer'. All plants not assigned to such a specific layer are considered to be terrestrial.

If applicable, the area covered by open water, by water plants and the % of bare soil due to disturbance by game is registered.

Table 3. The extended decimal scale of Londo (1984) applied in vegetation monitoring to estimate species cover

Cover (%)	**Annotation**
<1	.1
1-3	.2
3-5	.4
5-10	1-
10-15	1+
15-25	2
25-35	3
35-45	4
45-55	5
55-65	6
65-75	7
75-85	8
85-95	9
95-100	10

For species with cover < 1%, additional abundance classes are allocated (Table 4), based on the number of individuals (except for species that do not allow to distinguish individual plants, e.g *Rubus* spp*., Lamium galeobdolon, Holcus mollis*).

Table 4. Species abundance classes, applied for the class .1

Abundance	**Annotation**
1-3	r
3-20	p
20-100	a
>100	m

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7.3 FISHEYE PHOTOGRAPHS AND LIDAR SCANS

Hemispheric crown photography is a technique that is applied to quantify canopy cover and gap percentages. A digital camera (Nikon Coolpix 990) equipped with a fisheye converter lens (type FC-E8 with a viewing angle of 183° and a focal length adjustment of x 0.21) is mounted to a tripod, at an elevation of approximately 1 m above ground level in the center of the sample plot and a zenithal image is taken of the tree canopy (with the top of the horizontal image facing north).

The resulting image is processed using the software Hemiview 2.1, resulting in binary black-and-white images with calculation of visual sky percentages. Based on this result, a Leaf Area Index (LAI) can be calculated. This makes it possible to generate a 'light map' using kriging extrapolations and compare it with the stem positioning and vegetation. t must be said that this technique faces many challenges: pictures must be taken in leaf-on period, in full overcast conditions or early morning/evening before full sunrise or sunset. This makes the time window for acceptable conditions very narrow and difficult to practically organise. Moreover, the images do not always give satisfactory representations of the local conditions, as the presence of nearby stems or branches (close to the lens) have a disproportionate influence on the result. This is why fisheye surveys were only performed during the first survey period and not repeated during subsequent survey rounds.

Fig. 11. Result of fisheye photography: left = original image; right = binary image for visual sky to derive gap share and LAI

Newly available remote-sensing information, such as LiDAR scans, will provide more reliable opportunities to derive canopy gap patterns and subsequent shade casting and LAI estimates. An airborne LiDAR-scan for the full area of Flanders was flown in 2013 and is readily available for analysis (point cloud density approx. 12 points per m²). Today also UAV (drones) equipped with LiDAR scanners are available and provide new opportunities for detailed 3D scans (above and below upper canopy) of the forest canopy structure.

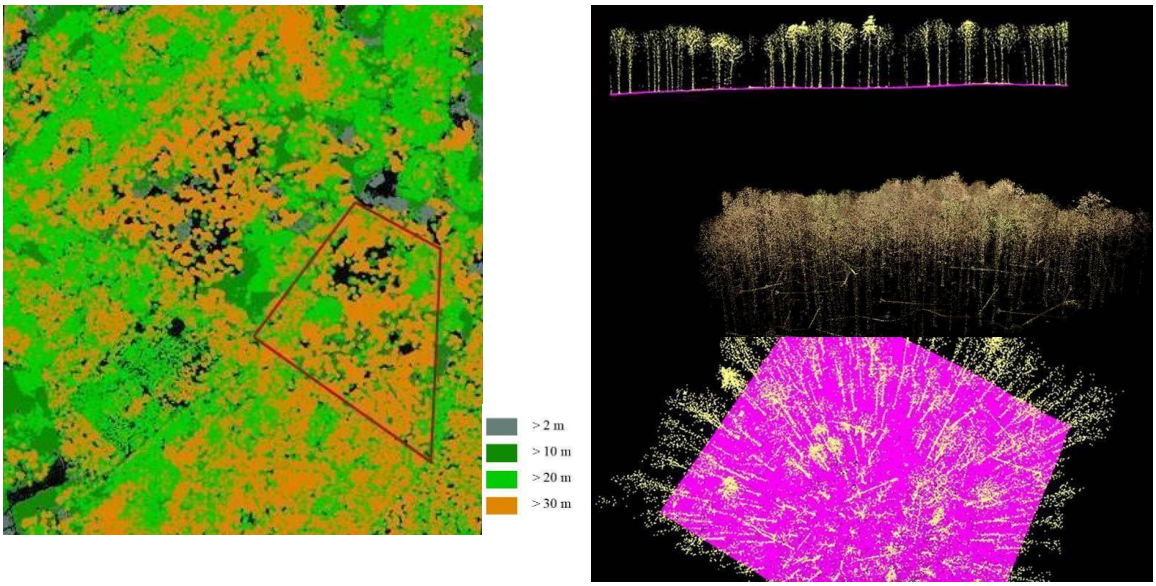

Fig. 12. Possibilities for canopy analysis based on LiDAR: some preliminary exercises. left : result based on a detailed scan at Sonian forest (red polygon : large core area); right: result based on the full-area (mid-resolution) LiDAR scan of Flanders (figure made by Erwin Meylemans of Flanders Heritage)

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7.4 REPEAT PHOTOGRAPHY

From the grid points, digital photographs are taken in one or more directions that give a characteristic forest image. These photographs do not serve further numeric and statistical analysis (but see: Hendrick & Copenheaver 2009, Hammond et al. 2020). They do provide illustrative images of changes over time in the vegetation, decay of wood, etc... as illustrated in Fig. 13 and 14. They are very useful in presentations of the results to a wider audience.

Plot code, angle and date are noted in the grid-point-layer of the FieldMap project. After downloading the digital photos, the photos are given an unambiguous file name that includes site name, year, plot code and angle of the photograph. The photos are collected in a central data directory for every site.

Fig. 13. Repeat photography illustrating the increase in cover of *Anemone nemorosa*, and the slow decay of oak stems, compared to small beech fragments (above: Bos Terrijst; mid: Pruikenmakers (Meerdaal Forest), below: Harras Core Area (Sonian Forest);left: first sampling event and right second sampling event, 10 years later.

Fig. 14. Decaying oak tree and spectacular decline of *Rubus fruticosus* in the reserve of Wijnendalebos between 2002 (upper) and 2012 (lower picture)

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8 FIELD PROTOCOL FOR MEASUREMENTS IN CORE AREAS

8.1 WHAT IS MEASURED?

The standard core area of 140 m by 70 m is subdivided into 98 square subplots of 10 m by 10 m (100 m^2), whereas small core areas (50 m x 100 m) consist of 50 subplots. The following dendrometric data are collected per 10 m x 10 m subplot:

Living trees

- Position of all trees with DBH of 5 cm and more

- Position of all coppice stools with shoots of DBH 5 cm and more

- Species determination of all positioned trees and stools

- DBH of all positioned trees and shoots > 5cm

- Height for a selection of trees (cfr. circular plots: 7.1.2.1)

- IUFRO vitality classes of each positioned tree or shoot

- Rejuvenation: count by species of trees with a DBH of less than 5 cm in four height classes:

  -Classes 50 - 200 cm and >200 cm: exact numbers

  - Classes 0 - 30 cm and 30 - 50 cm: frequency classes 1, 2 - 5, 6 - 10, 11 - 20, 21 - 40, 41 - 60, 61 - 100, >100, >1000

Standing deadwood

- Position of all trees and shoots with DBH of 5 cm and more and height > 1.30 m

- Species identification of all positioned trees and stools (as far as possible)

- DBH and decay stage (see 7.1.2.3) of all positioned trees and shoots > 5 cm

- Height of all snags (standing trees snapped at stem level)

Lying deadwood

Until the end of 2022, full area sampling of lying deadwood was performed as described below:

- Position of all lying deadwood segments with a diameter at the wide end of 10 cm or more and a minimum length of 1 m (or diameter of 20 cm or more and a minimum length of 0.5 m)

- Species identification (if possible) of all positioned segments

- Diameter (Dbasis and Dtop) of all deadwood segments with measured position

- Decay stage of all segments (see 7.1.2.3 for the description of the decay classes.

Tree stumps of formerly harvested trees are not registered in the standard protocol, but in some specific cases they are (e.g. to reconstruct the intensity of the most recent thinning before set aside).

Here again, we realised that with the increasing amount of lying deadwood in the plots, it became very time-consuming and practically impossible to continue this full sampling starting at a threshold diameter of 10 cm. Therefore, in line with the Circular Plot sampling, also for the Core Areas, a combined approach with Full Area Sampling of larger segments (threshold diameter 30 cm) and Line Intersect Sampling for the smaller diameters was introduced in the early spring of 2023, during the third assessment of the Core Area of the forest reserve De Heirnisse. A description of the design is given in 8.2.

Vegetation

Full vegetation relevé, including estimate of the tree, shrub, herb, and moss layer cover for every 100 m² subplot.

Repeat photography and fisheye photographs

On the central transect of the core area, photographs are taken at points 20.35, 70.35 and 120.35 on the central axis of the plot. Photographs are taken from those fixed points in a direction that gives a good representation of the site. The photographs are repeated from the same location and in the identical direction.

During the first survey campaign, also fisheye photographs were made on fixed nodes of the subplot grid (Fig. 6 in Chapter 6).

8.2 HOW: MEASUREMENT PROTOCOLS

Measurement procedures and protocols in the Core Area are largely identical to the Circular Plots. We refer to Chapter 7.1.2 for the details.

Dendrometric surveys of standing trees with DBH > 5 cm are done on the full area of the Core Area.

Vegetation relevés are made in every subplot of 10 m x 10 m.

For **lying deadwood**, all segments meeting the threshold diameter at the larger end (10 cm before 2023, since 2023 in some sites increased to 30 cm) are registered as described for the Circular Plots (see 7.1.2.3).

From 2023 onwards, in a number of selected sites with high density of mid-sized deadwood fragments (pointed out in Chapter 11), the smaller fragments (10-30 cm diameter) are registered using Line Intersect Sampling (details in 7.1.2.3). The sample design for the intersect lines is as shown in Fig. 15.

A total of six transect lines is set up, following the 10 m x 10 m subplot sections. In total two 140 m and four 70 m transect lines are installed (representing a total of 560 m). Lines are oriented perpendicular, and the same length is sampled in both directions, so no bias is created in case there is a dominant windthrow direction.

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The total sampled length per surface area is comparable to that in the circular plots. A total line length of 560 m will guarantee enough hits to level out the randomness effects of the Line Intersect Sampling, resulting in reliable unbiased estimates of deadwood amounts for the diameter classes 10 - 30 cm.

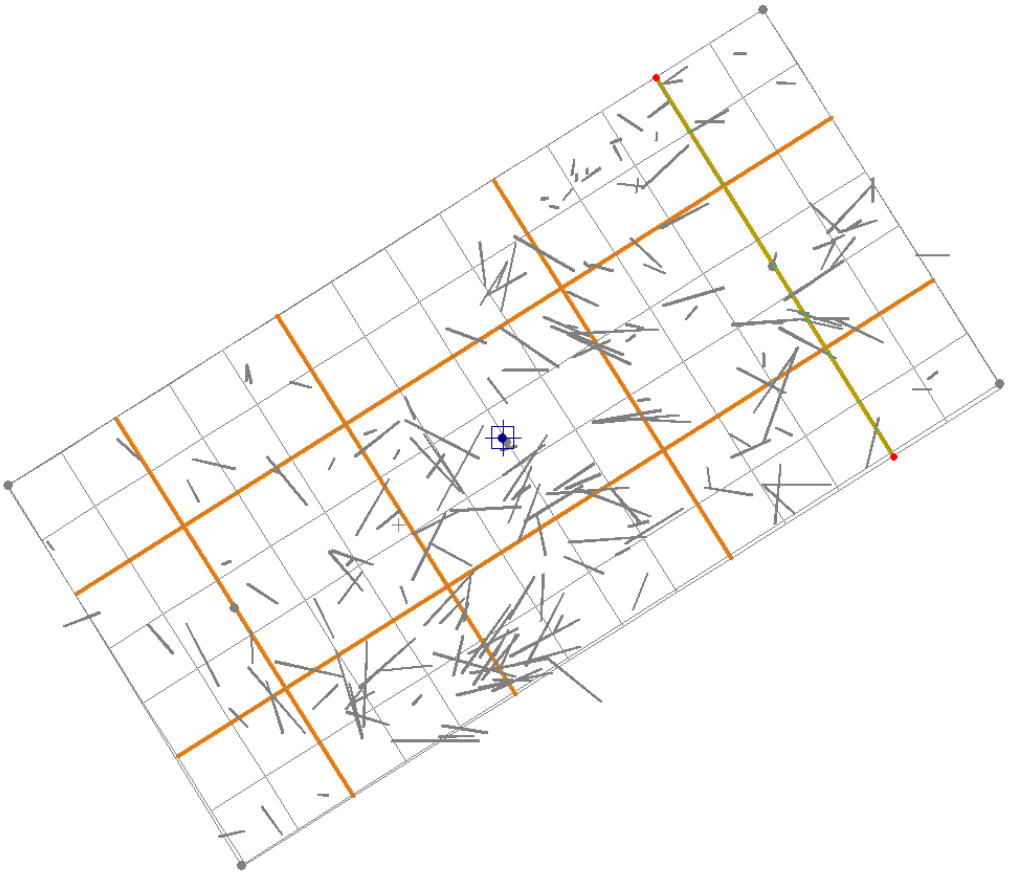

Fig. 15. Line Intersect design for a 70 m x 140 m core area – lying deadwood objects with base diameter 10 - 30 cm are registered using Line Intersect Sampling since the year 2023.

9 FIELD PROTOCOL FOR ADDITIONAL MEASUREMENTS

9.1 FULL SURVEY OF 'PARTICULAR ELEMENTS' (BIOTOPE MAPPING)

Some elements and structures are very rare and can be 'missed' using the standard sampling protocols, even if the sampling density is as high as in this monitoring programme (15-20% of the reserve area). This can involve specific topographic elements such as ponds, rivulets, rocky outcrops, anthropogenic structures (e.g. buildings) and growing/breeding sites of rare species. They mainly have an illustrative value, appealing to a wider public, but can also provide interesting topics for future investigation.

This survey is of particular interest for rare dendrometric elements: very large trees (VLT) and coarse dead wood. These elements can be very scarce in recently established reserves, and even in old reserves, the density of very large trees seldom surpasses 10 trees per ha (Vandekerkhove et al. 2018), resulting in density or volume estimations with very wide confidence intervals. The extrapolation of results from the standard sampling can thus result in strong over- or underestimations of the density and presence of these specific elements with very high ecological relevance. Therefore, a full survey is made of all very large trees and large-dimensioned deadwood elements:

VLT = Tree with DBH > 95 cm - For tree species that do not reach such dimensions, the DBH threshold can be lowered to 50 cm (*Betula, Alnus, Sorbus*) or 70 cm (*Carpinus, Acer*,...).

Large deadwood element = standing deadwood or lying deadwood object of 40 cm diameter or more (exceptionally lowered to 30 cm, e.g. in sites dominated by trees in DBH class 30 - 40 cm).

Position, species and diameter of these elements are registered; for deadwood also decay stage (similar to sampling plot registrations).

The methodology is described in detail by Govaere & Vandekerkhove (2005).

This mapping is done during the summer half-year, in the most productive period of the vegetation by systematically going through the entire forest reserve to be monitored, where all particular elements are mapped and registered with FieldMap technology. One team of two people can cover on average 3 - 10 ha in one day, depending on the density of elements and accessibility of the terrain.

9.2 DOMINANT VEGETATION TYPE MAPPING ('FACIES' MAPPING)

Based on the vegetation sampling plots, a set of 5 - 15 relevant 'vegetation facies' are derived, based on combinations of dominant species (e.g. *Pteridium* facies, *Rubus fruticosus* facies, *Anemone+Lamium* facies). These patches are then mapped over the full area of the reserve (Fig. 16). This characterization of the vegetation is the result of a "best professional judgement" and is based on the characteristic species. Some prior knowledge of the forest

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reserve (previous site visits and literature data) is indispensable to quickly develop an unambiguous typology. This mapping should be done in the period with the most productive plant growth. In forest reserves with spring flora, the area-wide mapping will take place in late spring.

A 'facies' mapping has been done once in most sites (during the first survey) and can be repeated at later times. In some cases, selected 'facies' can be re-mapped if considered relevant. For instance in the forest reserve of Bos Terrijst it was observed that dense vegetations of *Allium ursinum* significantly increased between two surveys; this specific facies was separately remapped during the second survey (Fig. 16 and 17).

Fig. 16. left : Example of a vegetation facies map for the reserve of Wijnendalebos - right: extension of the facies of *Allium ursinum* in Bos Terrijst between 2005 (dark green) and 2015 (light green = extension)

Fig. 17. Repeat photographs illustrating the significant extension of *Allium ursinum* in Bos Terrijst between 2005 and 2015

10 DATA CONTROL, DATA PROCESSING AND DATA STORAGE

10.1 DATA CONTROL

After completing the field measurements, a thorough data check is performed. An internal procedure stipulates the steps to be undertaken during data control. Part of the checks are performed in Access, part of the checks using R scripts. Over time all checks will be implemented in R.

Improbabilities (unrealistic dbh, height, dbh-height relationship) are detected, as well as missing values (dbh, decay stage for deadwood, height in case of snags), and trees outside the plot boundaries are removed. These are corrected based on the available data, or if necessary, the site is revisited and uncertainties are checked and corrected in the field.

For the surveys applying the Line Intersect - Full Area combined sampling for lying deadwood, double counts are removed from the Line Intersect data. For this purpose, diameters at the line crossing point are calculated for all larger logs and confronted with and removed from the Line Intersect dataset.

Once the data are thoroughly checked, they are ready for storage in the 'mother' database and consecutive data processing.

10.2 DATA PROCESSING

10.2.1 Overview

Part of the data processing is done in the data processing module of Fieldmap: FM Inventory Analist (www.fieldmap.cz). This is a very powerful and user-friendly software package, that allows us

- to build species-specific diameter-height curves
- to calculate the volume of lying deadwood segments inside the plot boundary

All other analyses are done using R scripts. To facilitate data processing in R, the package 'forrescalc' was developed (Lommelen & Leyman 2024). See https://inbo.github.io/forrescalc/ for further information on the package.

10.2.2 Volume calculations

10.2.2.1 **Intact standing trees**

The volume of standing trees with an intact crown, both dead and alive, is calculated based on two variables: (1) diameter at breast height and (2) total height of the tree.

Only for a selection of trees, tree height is measured in the field. These measurements are used to create **diameter-height curves** for every tree species. This is done for each site separately.

For each site, one of the two functions below is selected, whichever fits best.

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$$H = 1.3 + exp\ exp\left(P1 + \frac{P2}{DBH}\right) \qquad (exponential\ function)$$

Or

$$H = 1.3 + \frac{DBH^2}{(P1 + P2.DBH)^2} \qquad (N\ddot{a}slund\ function)$$

(with P1 and P2 = calculated parameters)

The best fitting diameter-height curve is constructed for each species and site (function and parameter estimates), using the measured tree heights per diameter class and species and the statistical tools provided in the FieldMap Inventory Analyst module (for details on the applied functions and spatial statistics, we refer to FieldMap Inventory Analyst technical background information).

Based on the species-specific diameter-height curves, a calculated tree height is generated for every tree (CalcHeight). Uncommon species, with insufficient tree height measurements to generate specific diameter-height curves, are allocated to the overall diameter-height curve of the site (all tree species combined).

The calculated height values, together with the DBH, are then used to calculate the individual tree volume using **tree volume tables with two entries** (DBH and height). Volume calculations include separate calculations for bole and for branch volumes up to a diameter of 7 cm (merchantable timber, over bark). Total volume is the sum of both results.

The applied volume tables are described by Dagnelie et al. (1985). For beech and oak trees, the tables by Quataert et al. (2011) are applied. For poplars, tables of Dik (1990), with diameter threshold of 10 cm are used, for Corsican pine the tables of Berben (1983). Species not listed in one of these tables are calculated with the formula for a species with a similar growth form ('group' in Table 5).

All calculations of volumes are performed using the formula and coefficients in Table 5. The applied formulas are identical to the ones applied in the Flemish Forest Inventory.

Table 5. Formula for the calculation of the bole volume (over bark), with coefficients for the most common tree species

Source	Species	Group	a	b	c	d	e	f	g	type
Quataert	*Quercus ro/pe*	1	0,1645	-0,005612	0,0000291	0	-0,00725	0,00025	0,0000023	1
Dagnelie	*Quercus rubra*	2	-0,02149	0,00095069	-0,0000043068	-0,000000070329	-0,00074299	0	0,0000037969	1
Quataert	*Fagus sylvatica*	3	-0,01115	0	-0,00000856	-0,00000004996	0	0,0000256	0,000003633	1
Dagnelie	*Betula* spp.	4	-0,011392	-0,0001001	0,00002829	-0,00000018695	-0,00059573	0	0,0000030811	1
Dik	*Populus* spp.	5	-4,608923	3,005989	-1,3209	1,605266	5,410272	0	0	2
Dagnelie	*Acer* spp.	6	0,010343	-0,0014341	0,000034521	-0,00000013053	0,00077115	0	0,0000030231	1
Dagnelie	*Fraxinus* exc.r	7	-0,039083	0,0019935	-0,000016148	-0,000000006419	-0,00098341	0	0,0000038373	1
Dagnelie	*Ulmus* spp.	8	-0,034716	0,0013586	-0,000013402	-0,00000005698	0,00016516	0	0,0000038818	1
Dagnelie	*Prunus avium*	9	-0,002311	-0,00037474	0,000015103	-0,000000025175	0,00033282	0	0,0000031943	1
Dagnelie	*Pinus sylvestris*	10	-0,039836	0,0015505	-0,0000061835	0,000000048022	0,000073997	0	0,0000029607	1
Dagnelie	*Picea abies*	11	-0,010929	0,0013945	-0,0000095965	-0,00000025164	-0,0027922	0	0,0000048985	1
Dagnelie	*Pseudotsuga*	12	-0,019911	0,00059559	0,000012901	-0,00000018587	0,00071591	0	0,0000039892	1
Dagnelie	*Larix* spp.	13	-0,03088	0,0014885	-0,0000049257	-0,00000012313	-0,0011638	0	0,0000041134	1
Berben	*Pinus nigra*	14	-0,002846	0	-0,00000022785	0	-0,00024768	0	0,0000039082	1

Type : Formula type 1: a + b * C130 + c *(C130 ^2)+ d *(C130 ^3) + e*H + f*H* C130 + g*H*(C130 ^2)
Formula type 2 (poplar, Dik): 1/1000 * (exp(1.10597 * log(Height) + 1.78865 * log(D) - 3.07192) - exp(-4.608923 * log(D) + 3.005989 * log(Height) - 1.3209 * log(Height)*log(Height)+ 1.605266 * log(D) * log(Height) + 5.410272))

Other tree species are allocated to one of these 'groups':

- *Carpinus, Quercus palustris*: group 1
- *Sorbus aucuparia, Juglans, Tilia* spp. : group 2
- *Castanea sativa* : group 3
- *Alnus* spp.*, Salix* spp. : group 4
- *Aesculus* spp.*, Cornus* spp.*, Crataegus, Rhamnus, Ilex, Malus, Mespilus, Prunus spinosa, Sambucus* : group 7

For trees (living and dead) with **significant loss of crown volume** (e.g. breakage of a primary branch) this is registered during field measurement, using 4 crown loss categories (for estimated respective crown volume reductions of 10-40% , 40-60%, 60-90% or more than 90%). A correction of the calculated crown volume is performed accordingly, based on this relative crown loss.

10.2.2.2 **Snags**

For snags (= tree that snapped at trunk level) both DBH and height are always measured. As the diameter at the snapping point cannot be measured, the volume of a snag is calculated as a cylinder based on DBH and measured height.

10.2.2.3 **Multi-stemmed trees and coppice stools**

For volume calculation, shoots are treated in the same way as individual trees.

Diameter at breast height is measured for each stem, and height is derived from the same species-specific diameter-height curves as constructed for the single stemmed trees. This allows the volume of each stem to be calculated using a two-entry tariff.

The stem volumes are then summed to determine the total volume of the coppice stool or multi-stemmed tree. If species-specific height models are unavailable for the site, a single-entry tariff is used instead.

10.2.2.4 **Lying deadwood**

With Full Area Sampling, lying deadwood is measured by subdividing every lying tree in single stem and branch segments (even if still connected). The volume of each segment that meets the threshold diameter is then calculated using the Smalian's formula for truncated cones. This formula states that the volume of a log can be closely estimated by multiplying the average of the surface areas of the two log ends by the log's length.

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$$Volume = \left(\frac{\pi.r^2 + \pi.R^2}{2}\right).L$$

where:

- L = length as calculated by the software, based on the position of base and top end
- R = diameter at the base
- r = diameter at the top

This formula is incorporated in the FieldMap software. Logs that cross the plot border are "cut off" (using incorporated GIS tools), and volume is then calculated by replacing total length and diameter with length and diameter at the intersection point.

For the stem segment of uprooted trees, the base diameter is measured at approx. 1.30 m from the tree base (to avoid the root buttress bias).

Until 2022, all lying deadwood objects were registered and calculated as described above. A new sampling protocol was introduced combining Full Area Sampling for the larger segments (threshold diameter of 30 cm at the larger end) and Line Intersect Sampling for the smaller segments, in 2022 in the Circular Plots and in 2023 in some of the Core Areas. (Specification for each site is given in Chapter 11).

For the larger fragments, calculations continue as described above.

For Line Intersect Sampling data, volumes are calculated for every registered hit and summated for all hits or for specific subgroups, using the formula of Van Wagner (1968):

$$V = (\pi^2/8L) \sum_{1}^{n} d_i^2$$

with V: Volume per area (m^3/m^2), L: Total transect length (m) and d_i: Diameter (m) of object i at the line intersection.

The calculated volume per hit is then assigned to the specific diameter, species and decay class.

The total volume per plot is the simple summation of the volume from the Full Area Sampling of the segments above the threshold of 30 cm diameter and the Line Intersect Sampling volumes for the smaller diameters.

10.2.3 Plot level results

Plot level results are calculated using the R package 'forrescalc' (Lommelen & Leyman 2024, https://inbo.github.io/forrescalc/).

These results include:

- dendrometric values of living trees:
  - tree number, basal area and volume per hectare
  - for all species combined, on species level and per diameter class (size class distribution)
- deadwood volume:
  - standing, lying and total deadwood volume per hectare
  - per decay stage, diameter class and species

- regeneration:
    - total number per hectare
    - number per height class and per species
- vegetation:
    - total cover per vegetation layer
    - number of species
    - cover per species
    - browsing index

These plot level results are the base for further analyses.

10.2.4 Further analyses

Plot level results allow for easy calculation of forest level results and comparison between subsequent periods. Analyses across all forest reserves, taking into account different strata (e.g., soil type, forest age, period not managed, main tree species), are also possible.

The package 'forrescalc' (Lommelen & Leyman 2024) contains some functions specifically created for this kind of analysis:

- The function *compare_periods* compares for each plot the differences between subsequent periods
- The function *create_statistics* allows to create statistics on the level of a single forest reserve or a specified stratum

Data on plot characteristics (soil type, elevation, vegetation type) are contained in separate tables stored in a local database, with regular backup on a web server.

10.3 DATA STORAGE

The raw data remains in the central geodatabase ('mother database') which is stored locally with regular backups on a web server.

Working versions of plot level results are stored in an open access git repository to facilitate collaboration between the researchers involved

The site level results are available as open access data on Zenodo (10.5281/zenodo.8017673) as are the metadata files containing background information about the site and the statistics and variables used.

Links to the validated plot level datasets are also available on Zenodo, and these data can be provided on request (dendrometry and regeneration: 10.5281/zenodo.7588680; vegetation: 10.5281/zenodo.7870740)

All online datasets are regularly updated. We invite interested researchers and potential users of the data to check the available Open Data or to contact the authors for further interdisciplinary and international cooperation.

11 DESCRIPTION OF THE SITES INCLUDED IN THE INTENSIVE MONITORING PROGRAMME

11.1 BOS TERRIJST

Basic information on the site :

Reserve short code: BTR-SR **Reserve number code: 11**

Surface area total reserve : 48.98 ha **Monitored area:** 38.40 ha

Coordinates **of the centroid (WGS84 decimal):** E 4.0843903135, N 50.7191175357

Altitude: 55 - 76 m ASL

MAT: 10.1 °C **MAP:** 804 mm

Soil types: Aca + Aba + Adp - Haplic Luvisols (Siltic)

Habitat types: 9130, 91E0

Vegetation types: *Endymio-Carpinetum, Endymio-Fagetum, Alno-Padion* - EEA: 6.6.2 & 6.11.2

Official reserve status: 1996

Unmanaged since: 2003

Last commercial harvest/planting intervention: 1981-1983

some tending and thinning in young stands of beech in 1980s and 1990s; limited introductory management upon installation of strict reserve: girdling and felling of a few *Quercus rubra*, Douglas fir and larch in 2000-2003

Specifications survey:

NONE – standard measurement protocol

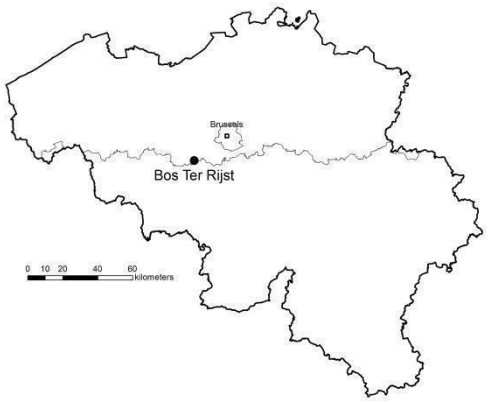
Number of Circular Plots: 50

Core Area: Yes (70 m x 140 m)

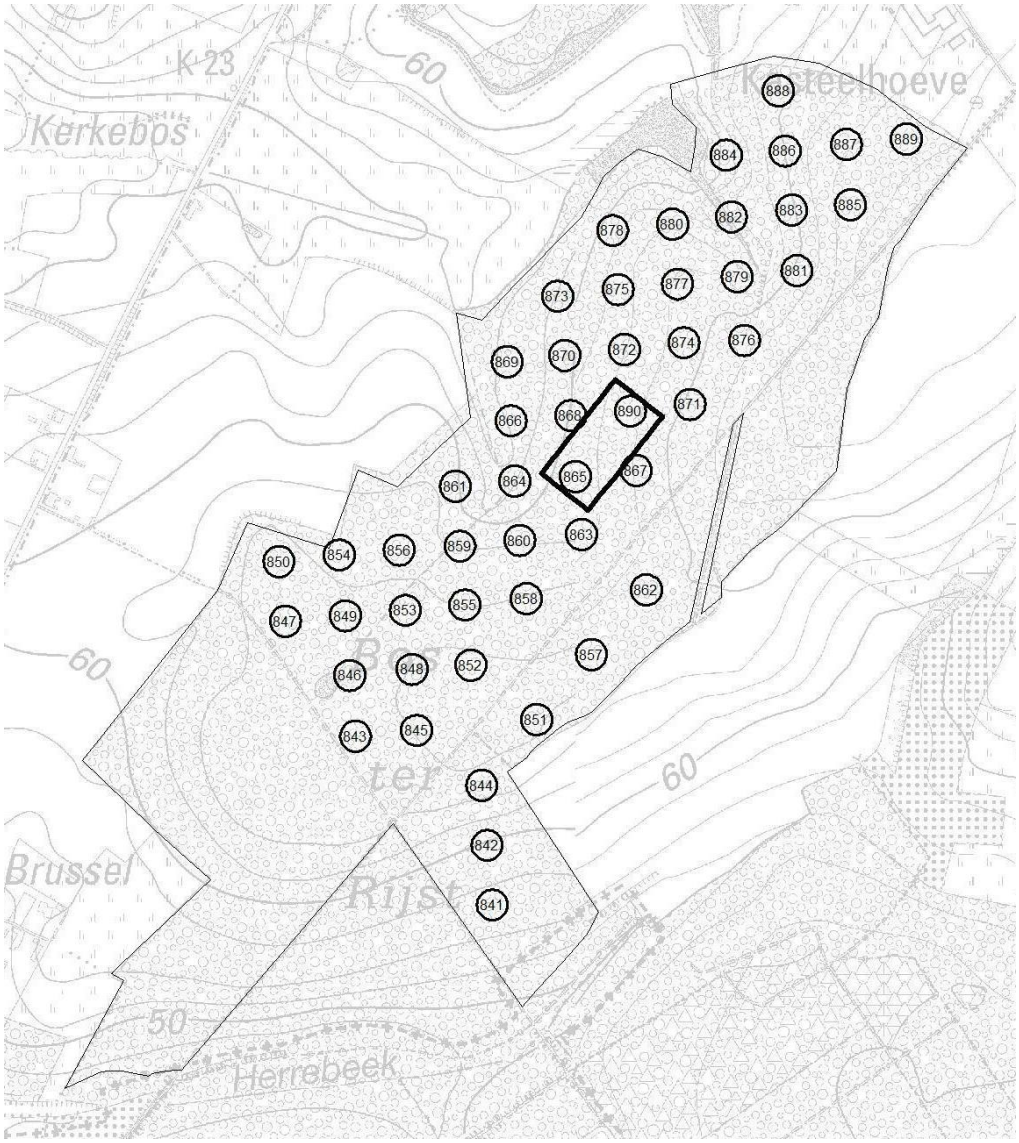
Survey years (up to 2024): 2004/2005 and 2014/15 - vegetation in 2005 and 2015

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area



 https://doi.org/10.21436/inbor114075052

11.2 DE HEIRNISSE

Basic information on the site:

Reserve short code: HRN-SR **Reserve number code: 8**

Surface area total reserve: 76.39 ha Monitored area: 42 ha

Coordinates of the centroid (WGS84 decimal): E 3.9986600846, N 51.1683458770

Altitude: 4 - 5 m ASL

MAT: 10.2 °C **MAP:** 763 mm

Soil types: Sep (+ Zdp and Ufp) - Eutric Gleyic Cambisols (Loamic) (+ Fluvic gleyic Phaeozems)

Habitat types: 91E0 (+9120)

Vegetation types: *Cirsio-Alnetum* - Base-rich variant of the *Filipendulo-Alnetum* with *Rubus caesius* and *Cirsium oleraceum* - EEA: 6.11.2; on sandy outcrop: *Violo-Quercetum* (atlantic *Fago-Quercetum*) - EEA: 6.6.2

Official reserve status: 1996

Unmanaged since: 2008

Last commercial harvest/planting intervention: 1991

Mowing of paths until 2002; in 2003 some 20 poplars were girdled; cut of invasive non-native species (*Quercus rubra* and *Prunus serotina*) in 2003-2004, with glyphosate treatment of the stumps; control and treatment of regrowth in 2008

Hydrology of the wider area (thus also the reserve) is regulated outside of the reserve.

Specifications survey:

NONE – standard measurement protocol

Number of Circular Plots: 68

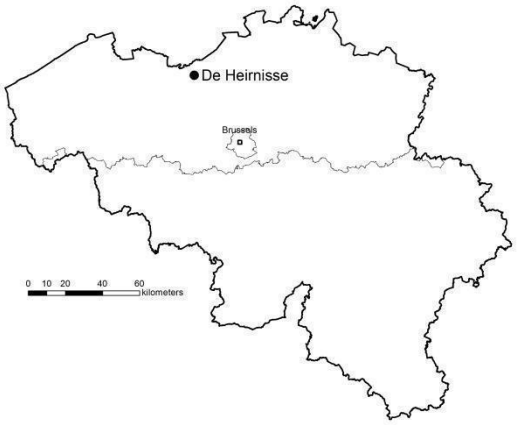
Core Area: Yes (70 m x 140 m)

Survey years (up to 2024): 2003/2004, 2013/14, 2023/2024*

* lying deadwood survey using Line Intersect and Full Area Sampling (in Circular Plots and Core Area)

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area

 https://doi.org/10.21436/inbor114075052

11.3 EVERZWIJNBAD (MEERDAALWOUD)

Basic information on the site:

Reserve short code: MDW-EB **Reserve number code: 3**

Surface area total reserve: 27.48 ha Monitored area: 27.48 ha

Coordinates **of the centroid (WGS84 decimal):** E 4.6791368202, N 50.7982678097

Altitude: 63 - 88 m ASL

MAT: 9.8 °C **MAP:** 820 mm

Soil types: Aba, Abc - Eutric Neocambic and Dystric Glossic Fragic Retisols (Siltic)

Habitat types: 9160

Vegetation types: Stellario-Carpinetum - EEA: 6.5.1

Official reserve status: 1995

Unmanaged since: 1995

Last commercial harvest/planting intervention: 1994 (commercial thinning)

Set-aside as a reserve in 1995; In 1999-2000 a few *Quercus rubra* still present in the reserve were girdled (3-4 trees); hunting until 1998.

Specifications survey:

NONE – standard measurement protocol

Number of Circular Plots: 48

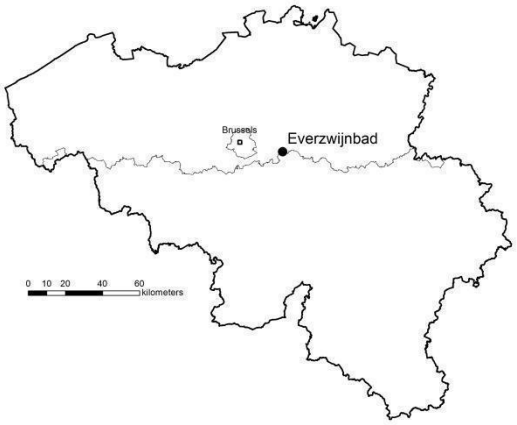
Core Area: Yes (70 m x 140 m)

Survey years (up to 2024): 2002/2003, 2012/13, 2023/2024* - vegetation in 2003, 2013, 2023

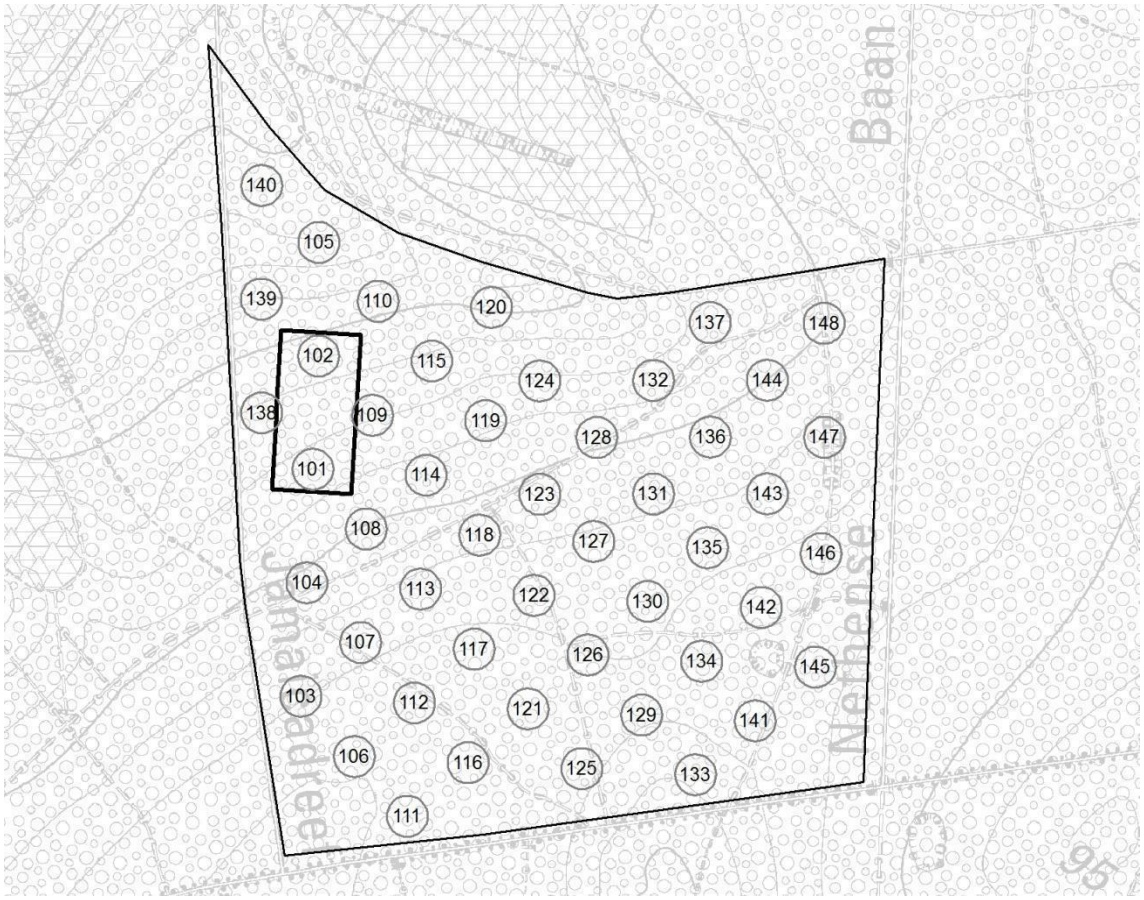
* lying deadwood survey in 2023 with Full Area Sampling (Circular Plots and Core Area)

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area



 https://doi.org/10.21436/inbor114075052

11.4 PRUIKENMAKERS (MEERDAALWOUD)

Basic information on the site:

Reserve short code: MDW-PM **Reserve number code: 12**

Surface area total reserve: 38.69 ha Monitored area: 38.69 ha

Coordinates of the centroid (WGS84 decimal): E 4.7152630115, N 50.7986339669

Altitude: 59 - 89 m ASL

MAT: 9.8 °C **MAP:** 820 mm

Soil types: Aba (Abc) - Eutric Neocambic (and Dystric Glossic Fragic) Retisols (Siltic)

Habitat types: 9160

Vegetation types: Stellario-Carpinetum/Primulo-Carpinetum - EEA: 6.5.1

Official reserve status: 1995

Unmanaged since: 2002

Last commercial harvest/planting intervention: 1993 (commercial thinning)

In 1998-2002 a few *Quercus rubra* still present in the reserve were girdled and *Prunus serotina* was cut all over the reserve (with glyphosate treatment of the stumps); last check for resprouting in 2006. Young trees surrounding suppressed crab apple trees were felled in 2000. All in all, these interventions were limited.

In 2000 two small stands of Corsican pine and Douglas fir were felled and removed; the adjoining stand of Scots pine was thinned as final introductory intervention. Also here, non-intervention was instituted since. Hunting until 1998 in the western half, until 2006 in the eastern half of the reserve.

Specifications survey:

NONE – standard measurement protocol

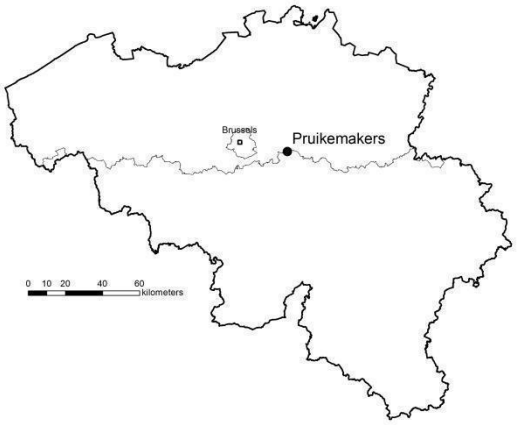
Number of Circular Plots: 66

Core Area: Yes (70 m x 140 m)

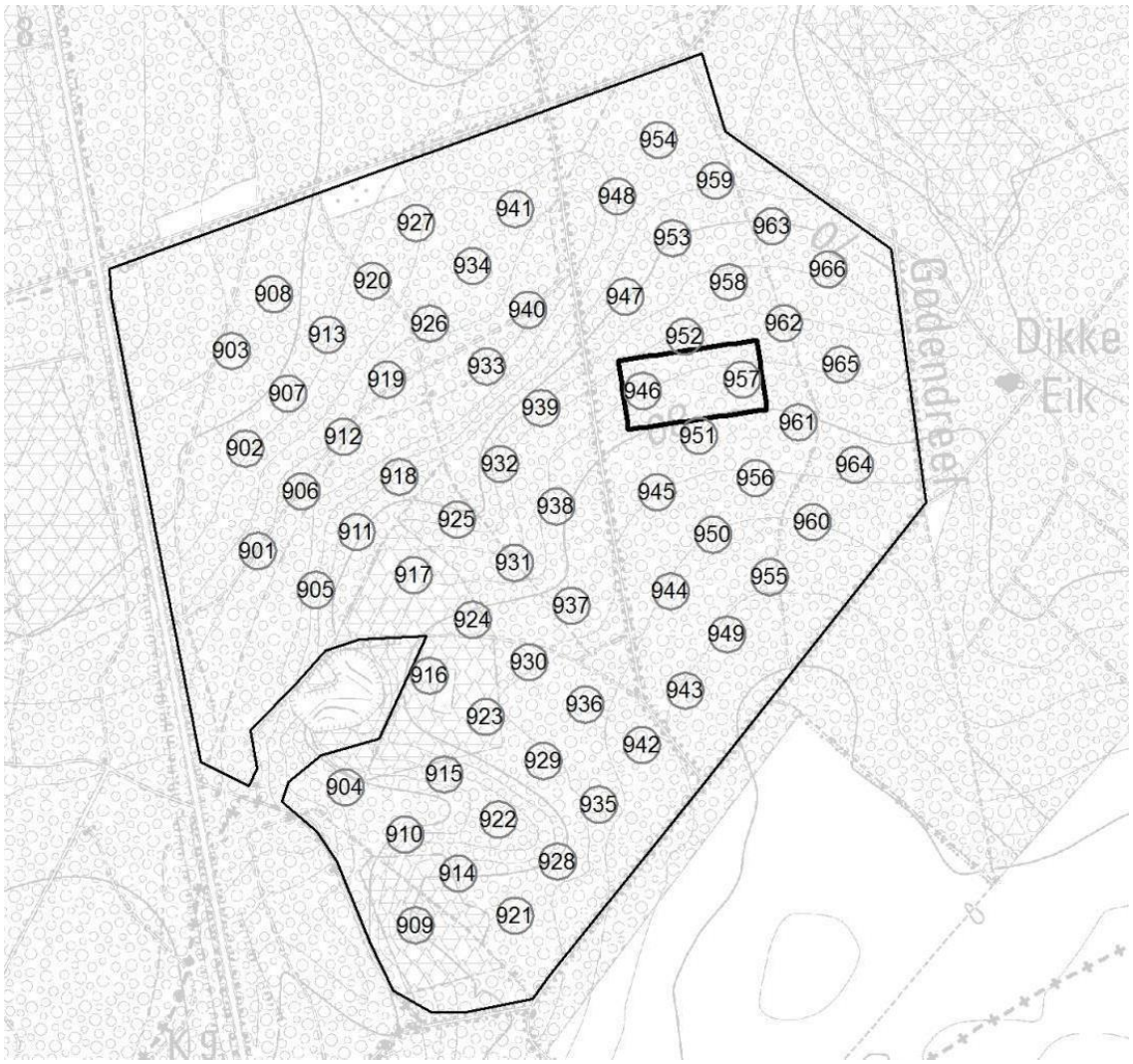
Survey years (up to 2024): 2005/2006 and 2015/16 - vegetation in 2006 and 2016

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area



https://doi.org/10.21436/inbor114075052

11.5 DE HEIDE (MEERDAALWOUD)

Basic information on the site:

Reserve short code: MDW-DH **Reserve number code: 20**

Surface area total reserve: 32.60 ha Monitored area: ca. 20 ha

Coordinates of the centroid (WGS84 decimal): E 4.7013401985, N 50;7971000671

Altitude: 64 - 79 m ASL

MAT: 9.9 °C **MAP:** 808 mm

Soil types: Abc - Dystric Glossic Fragic Retisols (Siltic)

Habitat types: 9160

Vegetation types: *Stellario-Carpinetum/Primulo-Carpinetum* - EEA: 6.5.1

Official reserve status: 1999

Unmanaged since: none - this is a managed site: coppice with standards restoration

Last commercial harvest/planting intervention:

This is an experimental site where coppice with standards management was reinstated. The area under study was subdivided in eight blocks, one to be felled every second year at the first cycle, one every 3 years from then onwards. Some delay in the realisation of the plans.

No planting of rejuvenation, but tending of oak seedlings possible.

First restoration fellings in 2001: coppice with standards cut in block 5 (Circular Plots 1433-1437), preparatory thinning in other plots; latest cut = block 3 (Circular Plots 1417-1426) in 2019.

Specifications survey:

Specific layout: stratified systematic plot layout with at least 5 sample plots per block; standard measurement protocol per plot

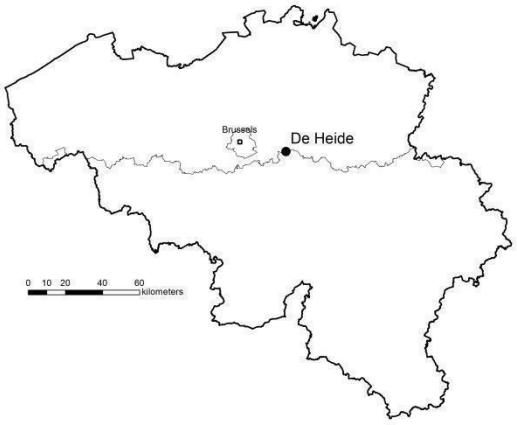
Number of Circular Plots: 52

Core Area: No

Survey years (up to 2024): 2016

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers)

 https://doi.org/10.21436/inbor114075052

11.6 JANSHEIDEBERG (HALLERBOS)

Basic information on the site:

Reserve short code: HLB-JH **Reserve number code: 9**

Surface area total reserve: 26.50 ha Monitored area: 22 ha

Coordinates of the centroid (WGS84 decimal): E 4.2772736527, N 50.7058140471

Altitude: 80 - 118 m ASL

MAT: 9.8 °C **MAP:** 837 mm

Soil types: Aba - Eutric Neocambic Retisols (Siltic)

Habitat types: 9130 Atlantic variant

Vegetation types: *Endymio-Carpinetum; Endymio-Fagetum* - EEA: 6.6.2 - Bohn: F5a

Official reserve status: 1996

Unmanaged since: 1994

Last commercial harvest/planting intervention: 1994

Mowing of paths until 2000; in 2001 a small stand of Corsican pine (at plot 821) was harvested and the cut area has been left unmanaged since then

Specifications survey:

NONE – standard measurement protocol

Number of Circular Plots: 33

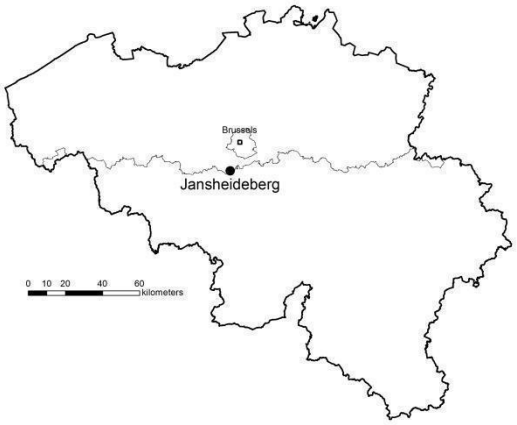
Core Area: Yes (70 m x 140 m) - non-homogeneous core area with northern half = mixed oak-hazel stand and southern half = monospecific beech stand

Survey years (up to 2024): 2004/2005, 2014/15, 2024*

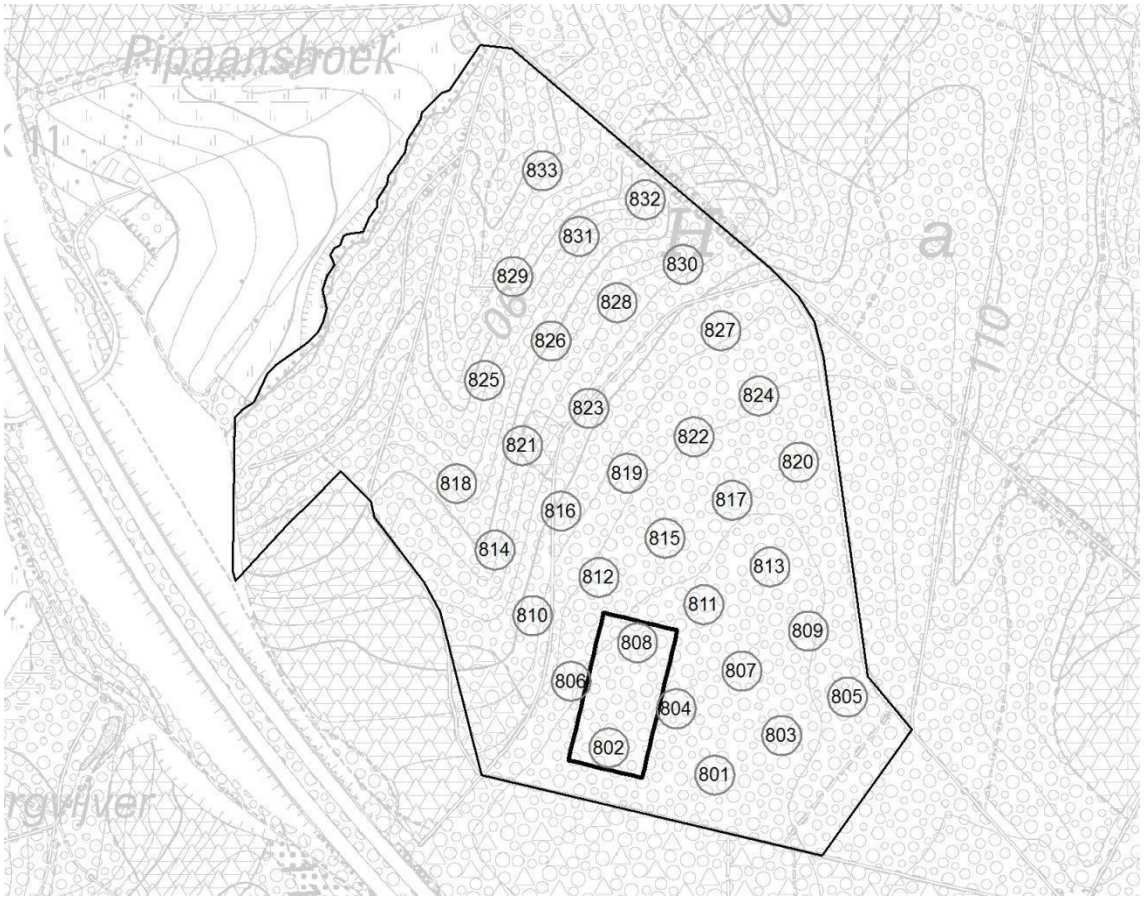
* lying deadwood survey 2024: Full Area Sampling (threshold base diameter 10 cm) in Core Area; Full Area Sampling (threshold base diameter 30 cm) and Line Intersect Sampling (diameter 10-30 cm) in Circular Plots

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area



 https://doi.org/10.21436/inbor114075052

11.7 WIJNENDALEBOS

Basic information on the site :

Reserve short code: WDL-SR **Reserve number code: 2**

Surface area: 91.60 ha, of which 65 ha strict reserve Monitored area: 64.15 ha

Coordinates of the centroid (WGS84 decimal): E 3.0408827382, N 51.0663101816

Altitude: 19 - 30 m ASL

MAT: 10.0 °C **MAP:** 705 mm

Soil types: Sdp - Eutric Stagnic Cambisols (Loamic, Abruptic), Zdh - Terric Anthrosols (Arenic, Spodi-relocatic)

Habitat types: 9120

Vegetation types: *Fago-Quercetum* - EEA: 6.6.2

Official reserve status: 1996

Unmanaged since: 2001

Last commercial harvest/planting intervention: 1984

1983-1984: commercially valuable coppice cut for the last time by a private owner right before the sale of the forest (standards were not cut), clearcut of a pine stand (stand 21) at the southern border of the reserve, with spontaneous regeneration of birch

1987-1993: removal of mainly windfall trees (in total about 250 trees), mowing of paths

2000-2001: introductory management in the strict reserve with clearcut of small Douglas fir stand in the north, harvest (ca. 500 trees in buffer zone) of intermixed larch trees, and girdling of larch trees (345 trees) and *Quercus rubra* trees (65 trees) in the rest of the strict reserve

Specifications survey:

NONE – standard measurement protocol

Number of Circular Plots: 123

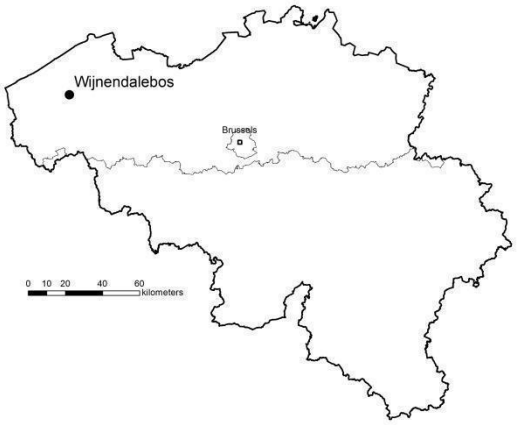
Core Area: Yes (70 m x 140 m) - homogeneous core area with oak, beech, chestnut, and sycamore

Survey years (up to 2024): 2002/2003+2004, 2012/13+2014, 2022/2023*

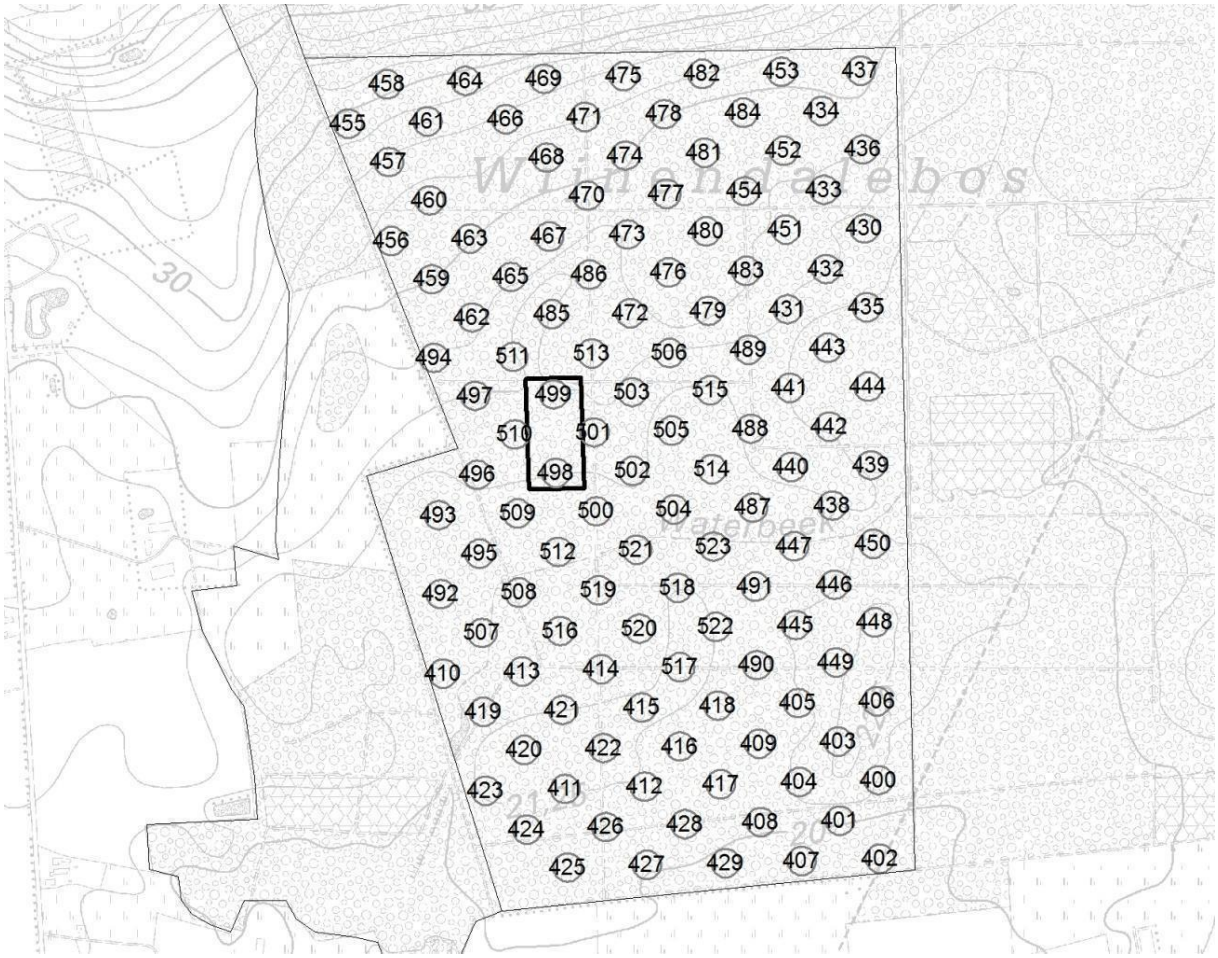
* Lying deadwood in 2023: Full Area Sampling (threshold base diameter 10 cm) in Core Area, Full Area Sampling (threshold base diameter 30 cm) and Line Intersect Sampling (diameter 10-30 cm) in Circular Plots

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and Core Area



 https://doi.org/10.21436/inbor114075052

11.8 MUIZENBOS

Basic information on the site:

Reserve short code: MZB-SR **Reserve number code: 15**

Surface area: 34.19 ha Monitored area: 34.19 ha

Coordinates of the centroid (WGS84 decimal): E 4.5682529447, N 51.1971862831

Altitude: 9 - 11 m ASL

MAT: 10.0 °C **MAP:** 781 mm

Soil types: w-Lep **-** Fluvic Gleyic Phaeozems (Loamic, Fluvic, Ruptic)

Habitat types: 91E0 - EEA: 6.5.9

Vegetation types: mostly *Alno-Padion,* some *Quercion* in the NE

Official reserve status: 1997

Unmanaged since: 1997

Last commercial harvest/planting intervention: 1997

In 1997 two last clearcuts of mature poplars were performed. One of the clearcut areas has been the object of a separate monitoring with 5 year interval (see below). Between 1997 and 1999 a limited number of trees of some invasive non-native species (*Rhododendron, Quercus rubra, Quercus palustris*) was girdled.

Specifications survey:

NONE – standard measurement protocol

Number of Circular Plots: 46

Core Area: 70 m x 150 m, i..e., 70 m x 70 m in the ash stand (west), 70 m x 70 m in the poplar stand (east), and 10 m x 70 m on the former unimproved path in between

Survey years (up to 2024): 2007-2008 and 2017-2018

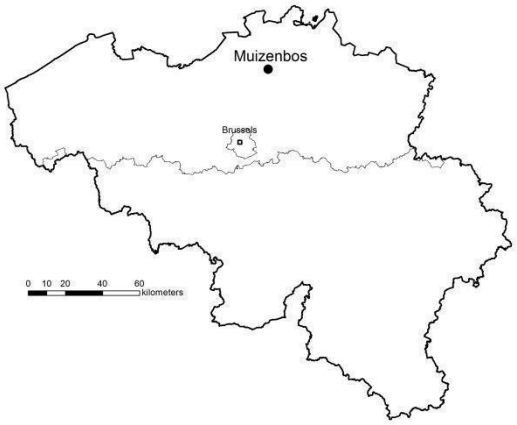
Additional surveys:

- **three** parallel transects (10 m x 100 m) on a managed path, in a strip of coppice with standards, and in unmanaged forest to study ground vegetation development (including *Colchicum autumnale, Dactylorhiza fuchsii, Valeriana dioica*): measured in 2002/3 and 2012/13

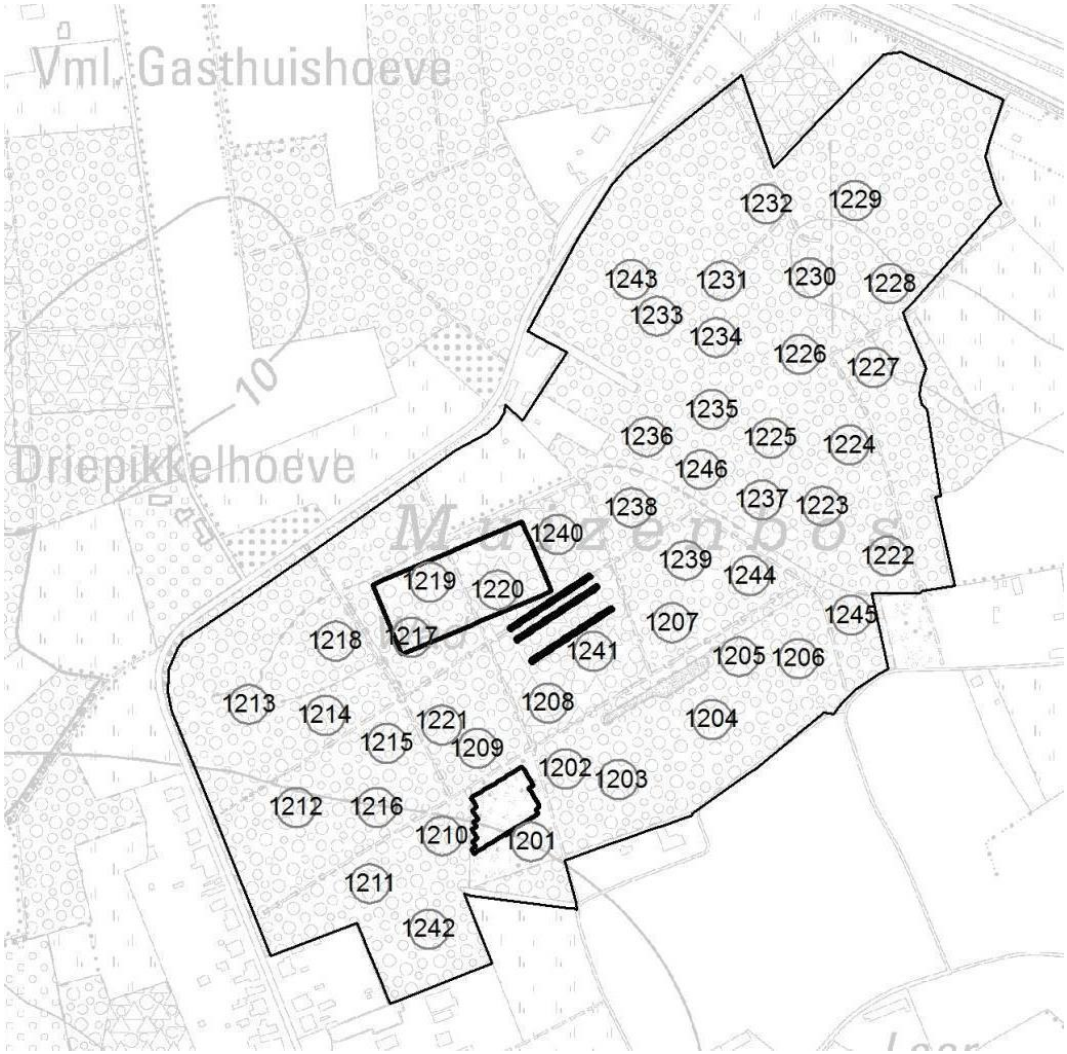
- full survey in a grid of 5 m x 5 m subplots on a former clearcut (total area ca. 0.25 ha) to study the development of tree and ground vegetation (vegetation cover) after clearcut: every 5 year remeasurement (1997, 2002, 2007, 2012, 2017, 2022), tree counts in 2007

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers), Core Area, vegetation transects and clearcut area



 https://doi.org/10.21436/inbor114075052

11.9 SEVENDONCK

Basic information on the site:

Reserve short code: SVD **Reserve number code:** 14

sub-ID : SVD-QB = Quercion / SVD-AL = Alnion

Surface area: 65 ha Monitored area: 51.40 ha

Coordinates of the centroid (WGS84 decimal): E 4.9370821182, N 51.2738039617

Altitude: 17-20 m ASL

MAT: 9.8 °C **MAP:** 797 mm

Soil types: Zep, Sep (Plaggic Arenic Anthrosols) for Quercion; V (Dystric Rheic Sapric Histosols) Sep/Pfp (fluvic gleyic umbrisols) for Alnion

Habitat types: 9190 and 91E0 -

Vegetation types: *Betulo-Quercetum* (31.43 ha) + *Carici elongatae - Alnetum* (19.95 ha) EEA : 6.4.1 and 6.11.2

Official reserve status: 1997

Unmanaged since: 1995

Last commercial harvest/planting intervention: 1994

In 1950-1975: very little management; some removal of dead wood for firewood (military area)

between 1975 and 1994: regular thinnings in the pine stands and selective thinnings to release oak trees until 1987, salvation harvest of wind-felled trees in 1991, last thinning in pines in 1994, last cutting of coppice in the swamp forest in 1986-1987

Specifications survey:

two smaller Core Areas, standard measurement protocol in Circular Plots and Core Area

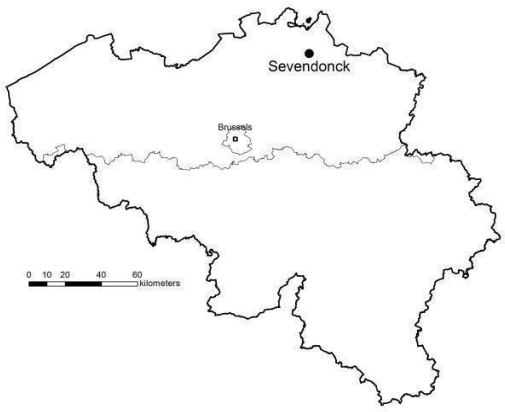
Number of Circular Plots: 78 of which 40 in Quercion, 38 in Alnion

Core Area: 2 smaller Core Areas of 50 m x 100 m, i.e., one in Quercion, one in Alnion

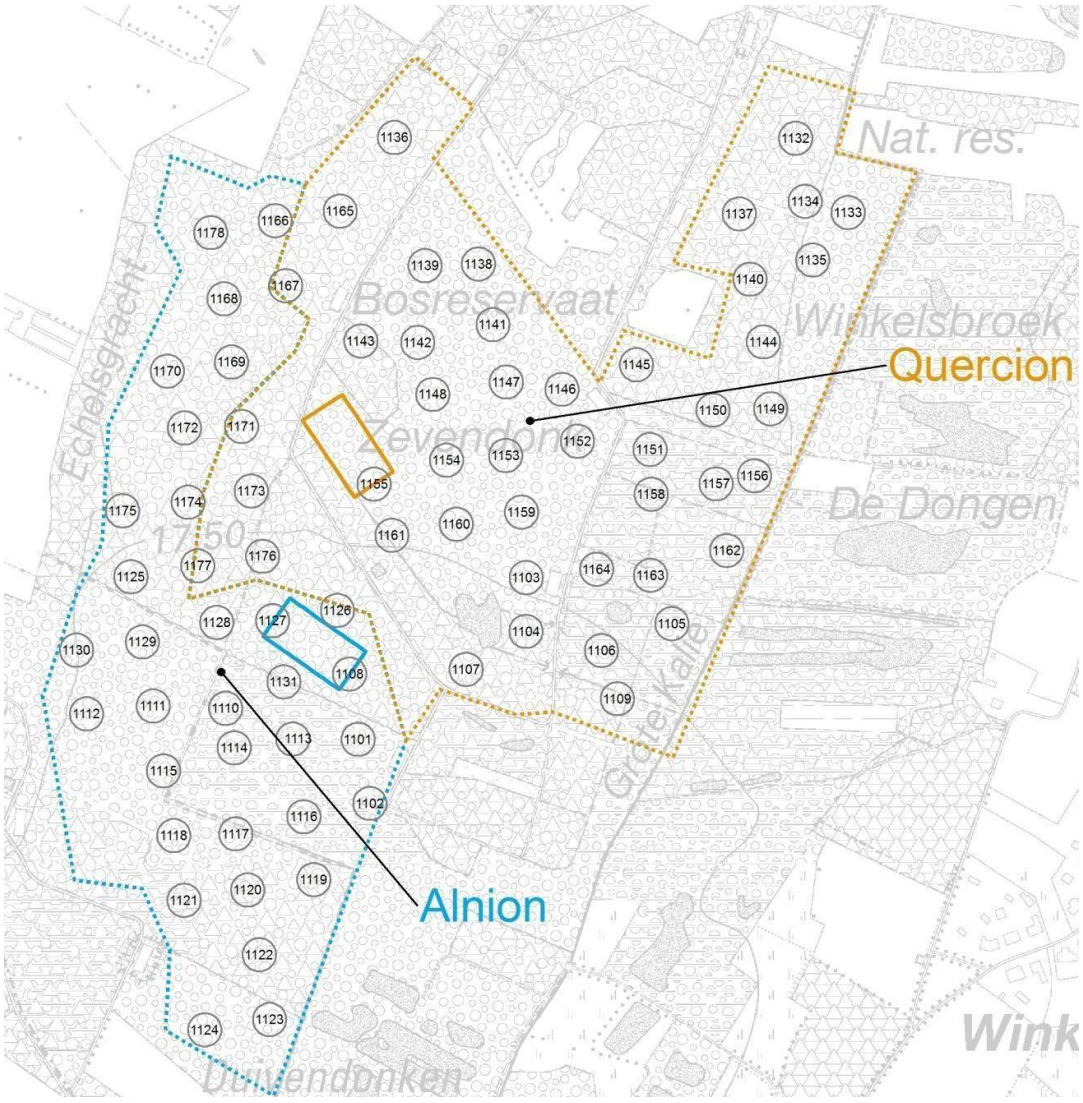
Survey years (up to 2024): 2006-2007 and 2016-2017

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers), two Core Areas, and indication of the extent of the two contrasting forest types in the area



 https://doi.org/10.21436/inbor114075052

11.10 KLUISBOS

Basic information on the site:

Reserve short code: KLB **Reserve number code: 17**

Sub-ID: KLB-FS (strict reserve - beech), KLB-PO (strict reserve - poplar), KLB-MC (managed-community forest), KLB-MS (managed – state forest)

Surface area: 50 ha reserve

Monitored area: 50 ha reserve, 60 ha managed forest

Coordinates of the centroid (WGS84 decimal): E 3.5030400753, N 50,7629013062

Altitude: 40-122 m ASL

MAT: 9.6 °C **MAP:** 775 mm

Soil types: LbB - Eutric Leptic Cambisols (Loamic), Lcc - Eutric Retisols (Loamic)

Habitat types: 9130 - Atlantic

Vegetation types: *Endymio-Fagetum*

Official reserve status: 2006

Unmanaged since: reserve: ca. 2000 (?)

Last commercial harvest/planting intervention:

in reserve: thinning in 1990s (?)

in managed forest: thinning in 2016-17

Specifications survey:

no Core Area, standard measurement protocol in Circular Plots

Number of Circular Plots:

reserve: 67 (11 in poplar stand, 56 in beech forest)

managed forest: 55 thinned, 6 unthinned

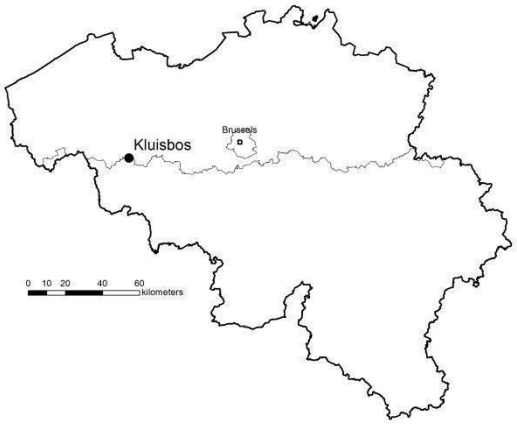
Core Area: No

Specific research topic for this site is the comparison of tree vitality and ground vegetation development between thinned and unmanaged beech stands.

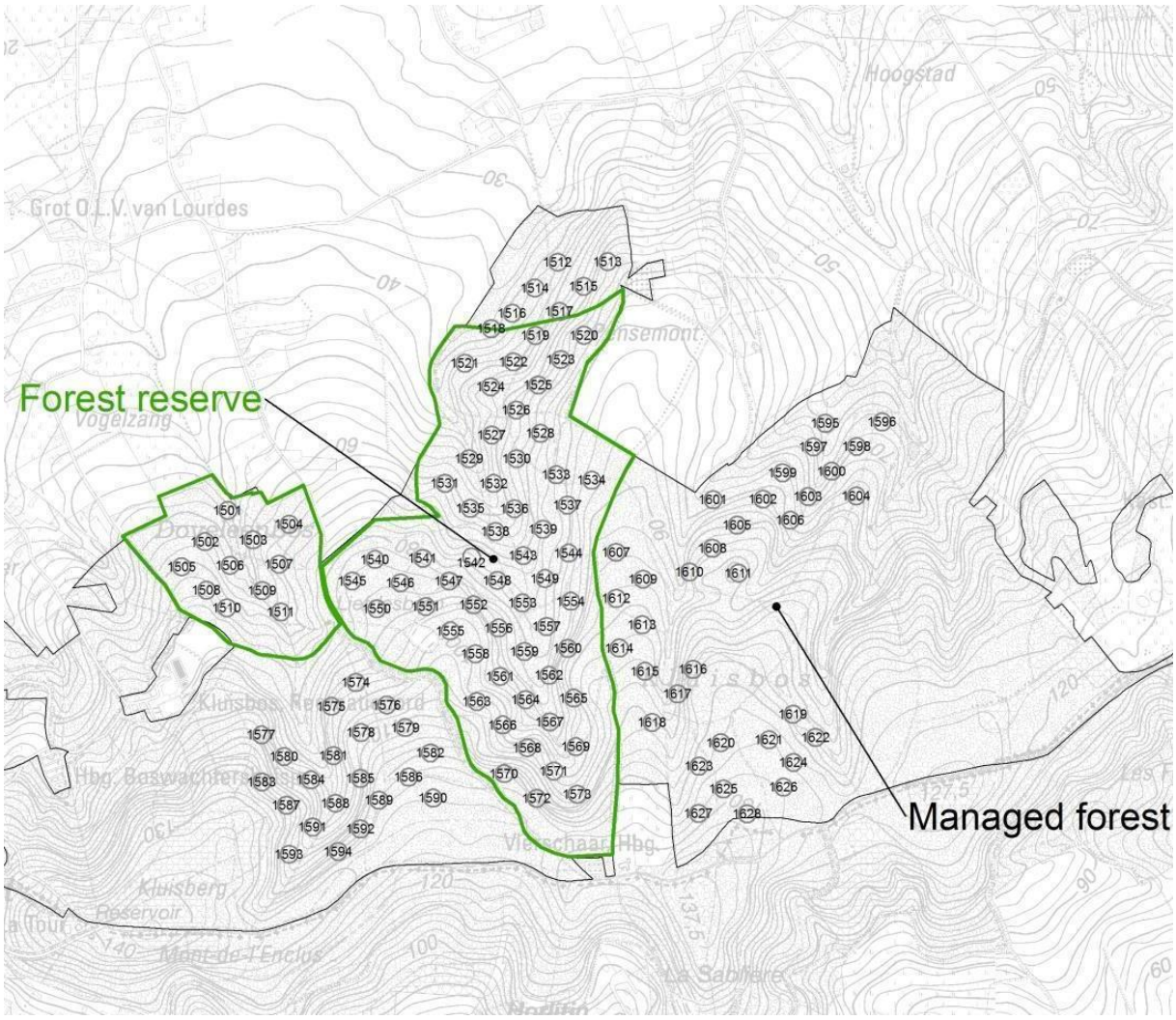
Survey years (up to 2024): 2017-18

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and indication of the forest reserve (= KLB-FS; with plots 1501-1508 -excl. 1507 in poplar forest =KLB-PO) and the plots in the managed forest. Left of the reserve is community forest (= KLB-MC); right = state forest (KLB-MS)



 https://doi.org/10.21436/inbor114075052

11.11 KOLMONTBOS

Basic information on the site:

Reserve short code: KMT-SR **Reserve number code: 18**

Surface area: 16.70 ha Monitored area: ca. 15 ha

Coordinates of the centroid (WGS84 decimal): E 5.4249100685, N 50.7990989685

Altitude: 67 - 104 m ASL

MAT: 9.7 °C **MAP:** 821 mm

Soil types: SAx/PAx (Eutric Cambisols (Loamic, Ruptic)) and UDx (Eutric Stagnic Cambisols)

Habitat types: 9160 and 9120 (+91E0 - Alno-Padion)

Vegetation types: *Stellario-Carpinetum* and *Fago-Quercetum (+ Alno-Padion)*- EEA: 6.5.1 and 6.6.2

Official reserve status: 1995

Unmanaged since: 1991

Last commercial harvest/planting intervention: no known harvests

No commercial harvest over at least the last 100 years, only removal of some dead trees and coppicing along the trails, mowing of trails.

Specifications survey:

no Core Area, standard measurement protocol in Circular Plots

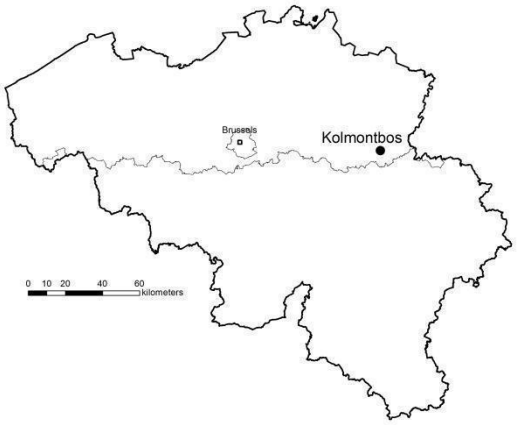
Number of Circular Plots: 32

Core Area: No

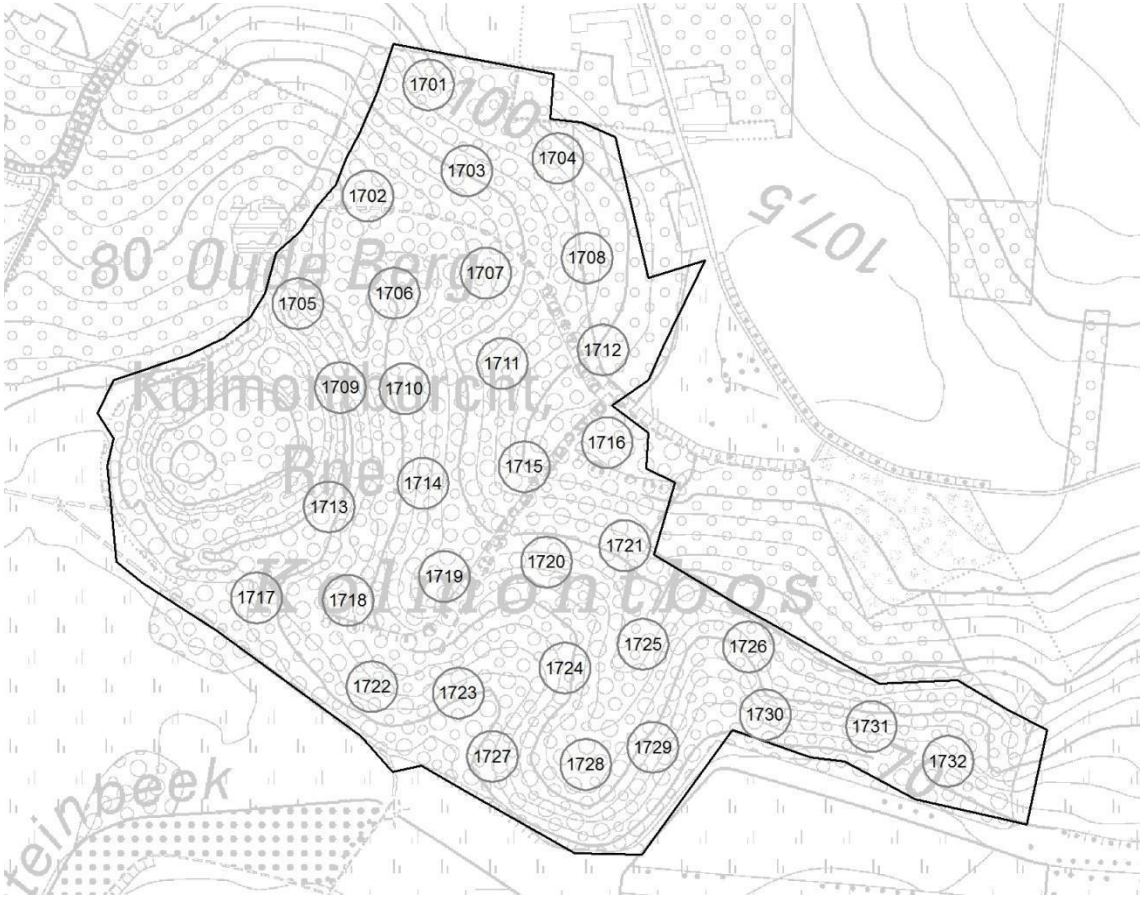
Survey years (up to 2024): 2019-2020

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers)



 https://doi.org/10.21436/inbor114075052

11.12 BOS T'ENAME

Basic information on the site:

Reserve short code: BEM **Reserve number code: 16**

Subplots : BEM-SR (= unmanaged, not grazed), BEM-MR (= managed, not grazed), BEM-SG (=unmanaged, grazed), BEM-MG (= managed, grazed)

Surface area: ca. 105 ha

Coordinates of the centroid (WGS84 decimal): E 3.6453900337, N 50.8558998108

Altitude: 13 - 70 m ASL

MAT: 10.0 °C **MAP:** 765 mm

Soil types: Ldc - Eutric Gleyic Retisols (Loamic), LDx and EDx - Eutric Stagnic Leptic Cambisols (Loamic, Ruptic), Lhp - Eutric Fluvic Oxygleyic Gleysols (Loamic, Fluvic)

Habitat types: 9130 Atlantic (+91E0 - Alno-Padion - EEA: 6.5.9)

Vegetation types: *Endymio-Fagetum (+ Alno-Padion)* - EEA: 6.6.2

Official reserve status: early 1990s + regular extensions

Unmanaged since: area unmanaged forest = unmanaged since 1990s

Last commercial harvest/planting intervention:

non-intervention zones: no commercial harvest since 1990s

areas coppice with standards: final cut of poplars with retention trees, re-instatement of coppice with standards with rotation period of 12-16 years

Part of the reserve is extensively grazed (year-round) with cattle.

Specifications survey:

no Core Area, standard measurement protocol in Circular Plots

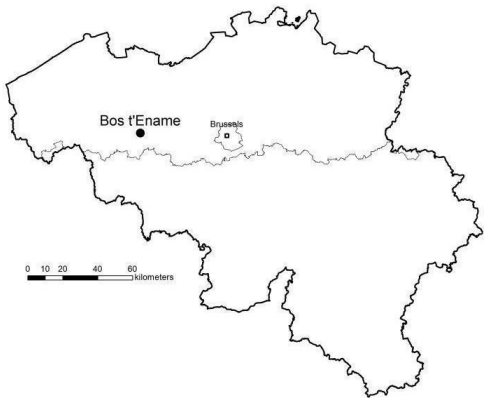
Number of circular plots: 73 plots spread over the different management types (for numbers per management type: see figure below)

Core Area: No

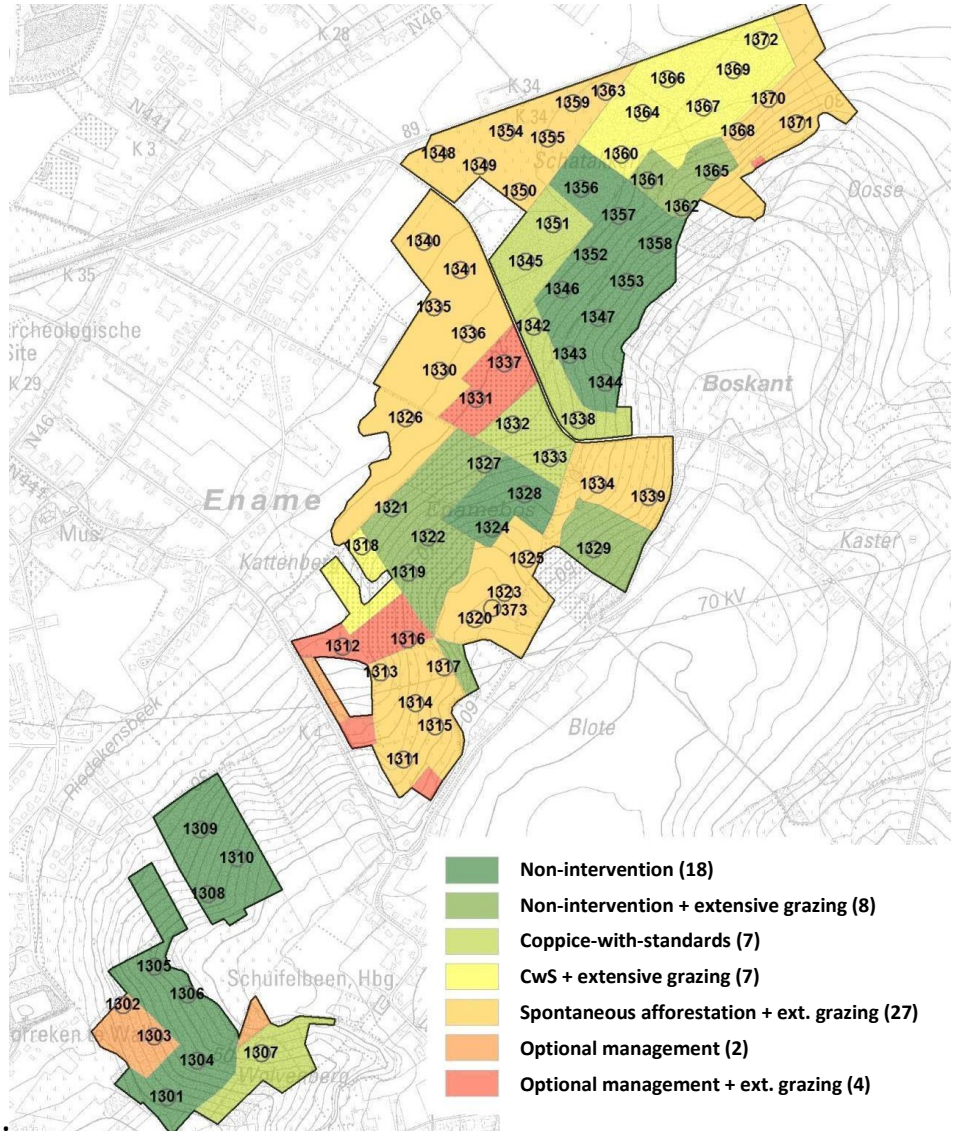
Survey years (up to 2024): 2014-2015 (vegetation: 2016)

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) in the different management categories



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 https://doi.org/10.21436/inbor114075052

11.13 LIEDEKERKEBOS

Basic information on the site:

Reserve short code: LDK-SR **Reserve number code: 13**

Surface area: ca. 21 ha

Coordinates of the centroid (WGS84 decimal): E 4.1143071489, N 50.8660778098

Altitude: 26 - 34 m ASL

MAT: 10.2 °C **MAP:** 785 mm

Soil types: Lda and Ada - Gleyic Luvisols (Loamic)

Habitat types: 9120 -+91E0 - Alno-Padion)

Vegetation types: *Fago-Quercetum* (+ *Alno-Padion*)*;* EEA: 6.6.2 and 6.5.9 respectively

Official reserve status: 2003

Unmanaged since: 1972

The area was used as transcontinental radio transmission station until 1972. Intensive coppicing of the forest stands and mowing of the lanes with the pylons was done to keep the vegetation low. No interventions in the forest stands since 1972. In 2006-2007, however, (immediately after the 2006 inventory) the intermixed *Prunus serotina* was removed (cut + glyphosate treatment of the stumps) as an introductory measure before the forest was officially set aside. Mowing of some of the lanes between the stands continued until 2003. A small patch (ca. 2000 m²) was cut, followed by sod cutting for experimental reasons, i.e., heath restoration, in 2005

Last commercial harvest/planting intervention: from 1930's to late 1960's: Intensive harvest of coppice to keep vegetation low for the transcontinental radio transmission function. Since that time mostly unmanaged (except for mowing of paths) - fully set aside in 2003.

Specifications survey:

Circular Plots: 30 plots with divergent plot size and DBH threshold because of earlier surveys - plot radius 15 m, living tree threshold DBH 5 cm and standing deadwood DBH 10 cm for the whole plot; regeneration and vegetation measured in 2006 and 2016 using standard method (circle A1 and A2; vegetation plot 16 m x 16 m).

Core Area: No

Additional strip-transect: 10 m x 340 m (34 subplots starting at south-west end) - surveyed in 1986, 1996, 2006 and 2016. Subplot measurements as in Core Area subplots.

Survey years (up to 2024):

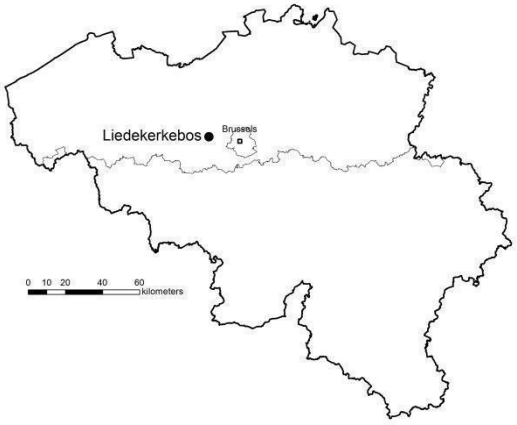
Dendrometrics Circular Plots: living trees in 1986,1996, 2006, 2016; deadwood in 2006, 2016

Dendrometrics transect: living trees in 1986,1996, 2006, 2016; deadwood 2006, 2016

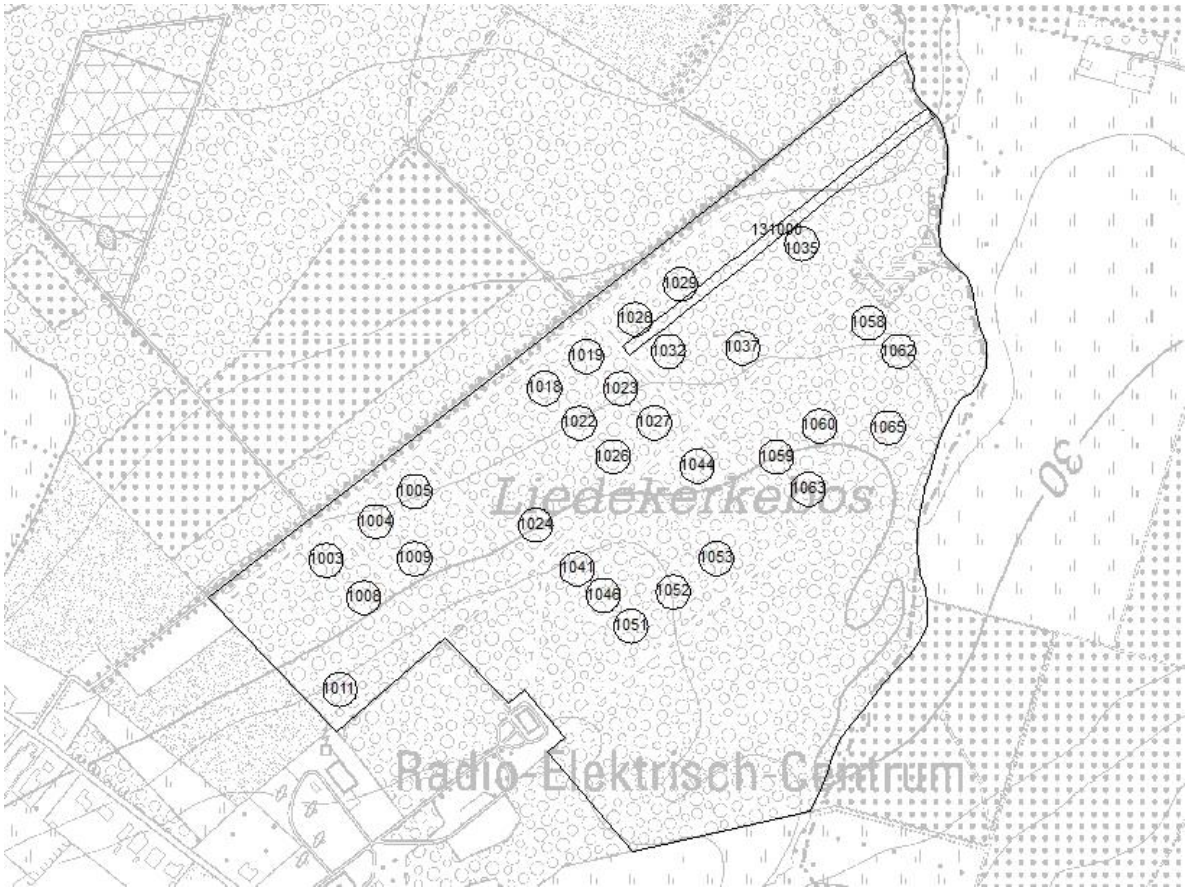
Vegetation Circular Plots and transect: 2006, 2016

Maps

Location within Belgium



Map of the site with grid of Circular Plots (plot numbers) and transect



https://doi.org/10.21436/inbor114075052

11.14 WITHOEFSE HEIDE

Basic information on the site:

Reserve short code: WHH-SR Reserve number code: 4

Surface area: ca. 18 ha

Coordinates of the Centroid (WGS84 decimal): E 4.4493598938, N 51.3708992004

Altitude: 24-26 m ASL

MAT: 9.9 °C **MAP:** 792 mm/y

Soil types : Zcgb and Zdgb : Albic and Gleyic Podzols (Arenic)

Habitat-types: Rbb Ppm (spontaneous Pine-birch forest)- EEA: 6.14.1 (+9190 EEA: 6.4.1)

Vegetation types: *Pinetum; Betulo-Quercetum*

Official reserve status : 1994 (Nature reserve) - non-official reserve status since 1984

Unmanaged since : 1943

Spontaneous afforestation after forest fire - no harvest interventions (some firewood collection in the 1960s and 1970s) - mowing of pathways until 1980s. Around 2000: removal and stump treatment of *Prunus serotina* (very limited in the reserve).

Last commercial harvest/planting intervention: none

Specifications for this survey:

Number of circular plots : 29 plots - divergent plot size and threshold due to earlier measurements (S. Vandewiele) - plot radius 20 m

Trees:

2002 : living tree threshold DBH 10 cm; deadwood S&L : DBH 10 cm for the whole plot;

2012 : living trees threshold DBH 10 cm; deadwood S&L : 10 cm

Regeneration : R=20m: count per species in 3 height classes : 0-50 cm, 50-130 cm and >130cm

Vegetation plot : standard plot 16x16m : 2003

Core Area : NONE - one transect 10x100m ('mycotransect') measured only in 2006 (10 subplots according to standard measurements in core area subplots)

Survey years (up to 2024):

First survey of dendrometrics (non-permanent plots): 1976.

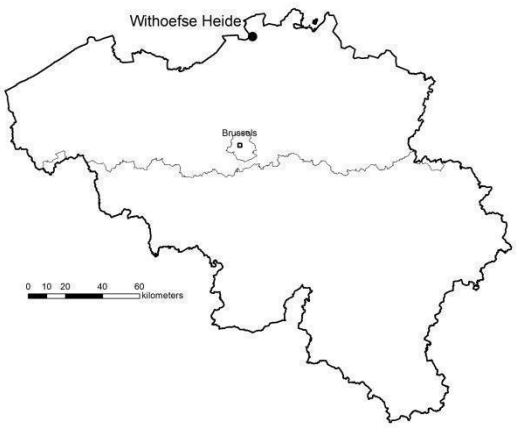
Dendrometrics circular plots : 2002; 2012, 2022

Dendrometrics transect : 2006

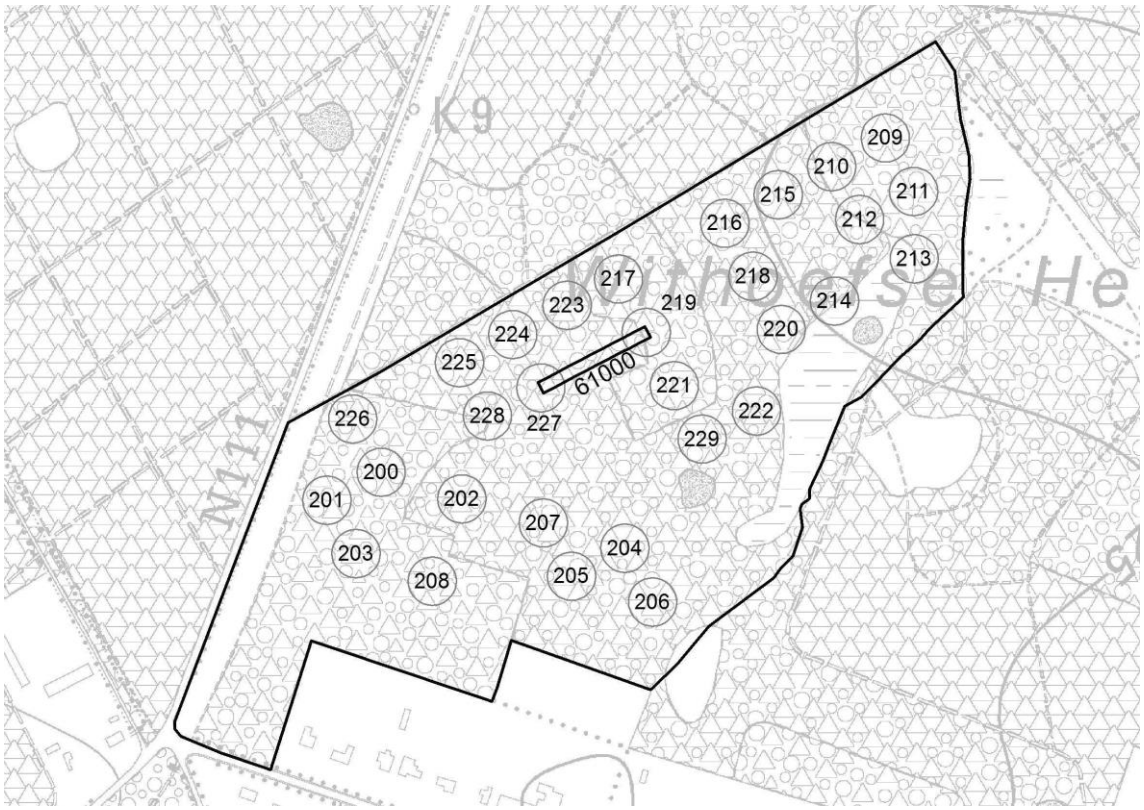
Vegetation : 2003 (not repeated in 2013)

Maps

Location within Belgium



Map of the Site with grid of circular plots (plot numbers) and transect



https://doi.org/10.21436/inbor114075052

11.15 COOLHEMBOS

Basic information on the site :

Reserve short code : CHB **Reserve number code : 10**

sub-ID: CHB-QB= Quercus / CHB-AL = Alnus

Surface area: ca. 78 ha, 50 ha unmanaged

Co-ordinates of the Centroid (WGS84-decimal): E: 4.314138 N:51.075599

Altitude : 2-5 m ASL

MAT : 9.8 °C **MAP:** 780 mm/y

Soil types : vLgp - Fluvic Reductigleyic Mollic Gleysols (Loamic, Thaptohistic)

Habitat-types: 91E0 - EEA: 6.14.1 (+9190 EEA: 6.4.1)

Vegetation types: *Carici elongatae – Alnetum* and *Lysimachio-Quercetum roboris*

Official reserve status : 1995

Unmanaged since : 1993

Coppice management; after WWII only coppicing for hunting purposes; after acquisition by the Flemish Government (1991), one commercial harvest of 94 poplar trees (and a little coppice) was performed.

Last commercial harvest/planting intervention: 1993

Specifications for this survey:

Number of circular plots : NONE

Core Area : two smaller core areas (50x100m) -

Western Core Area = typical mesotrophic swamp forest *(Carici elongatae Alnetum*)

Eastern Core Area = dryer form with oak, alder and *Osmunda regalis*

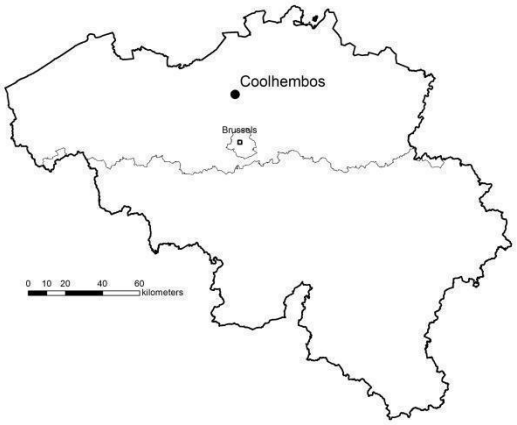
Survey years (up to 2024):

Dendrometrics : 2004/05, 2014/15, 2024/25

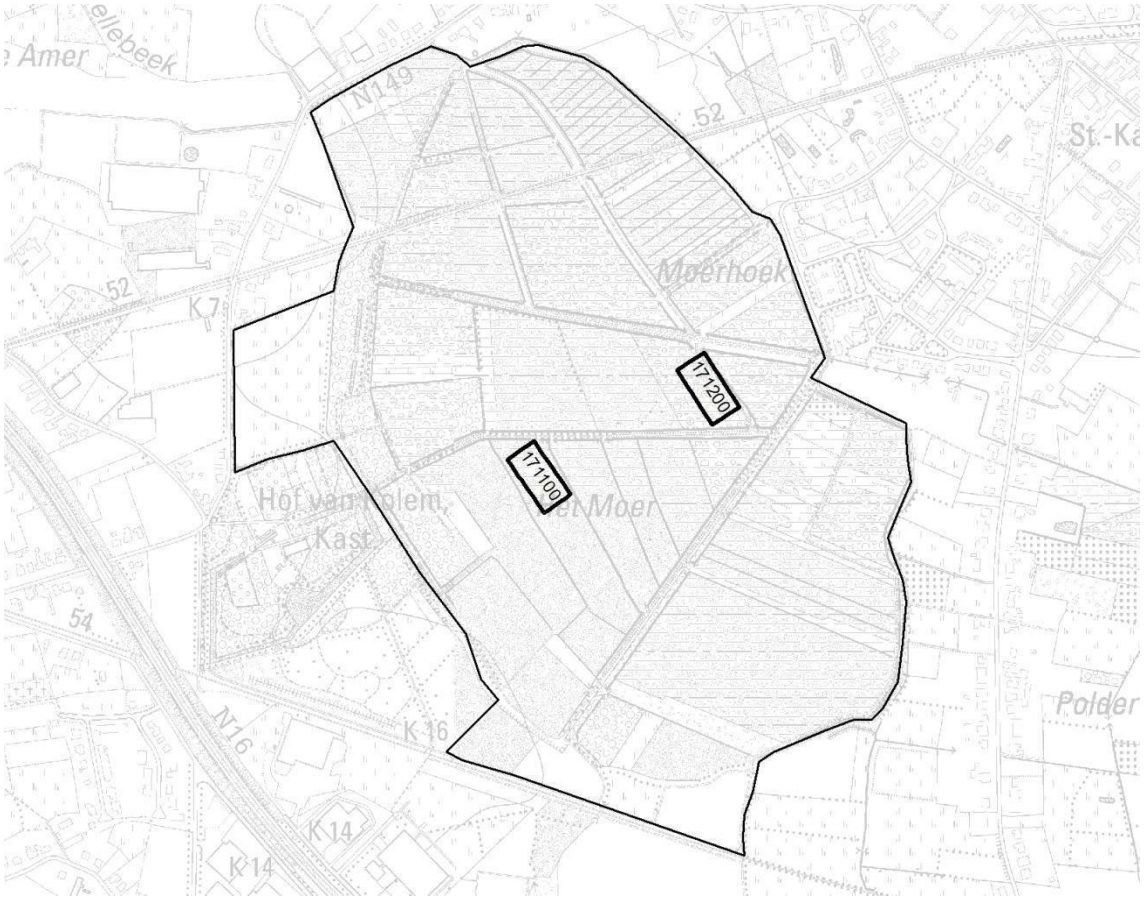
Vegetation : 2004, 2014

Maps

Location within Belgium



Map of the site with the two Core areas



https://doi.org/10.21436/inbor114075052

11.16 RODEBOS

Basic information on the site :

Reserve short code : RDB **Reserve number code : 7**

sub-ID RDB-FQ = Fago-Quercetum and RDB-AP =AlnoPadion

Surface area: full area ca. 90 ha, survey area = ca. 15 ha

Co-ordinates of the Centroid (WGS84-decimal): E: 4.314138 N:51.075599

Altitude : 50-70 m ASL

MAT : 10.0 °C **MAP:** 764 mm/y

Official reserve status : 1989

Unmanaged since : halfway 1980's

Specifications for this survey:

Number of circular plots : NONE

Core Areas : two sampling areas, originating from previous surveys by Koop et al (1991).

Large Core Area '41000' (70x140m):

Soil type : A/L; Ada - Gleyic Luvisols (Siltic);

vegetation = 9120; Fago-Quercetum

Measurements : First measured by Koop in 1991; trees >5 cm DBH, deadwood, vegetation in central transect 2x100m

Measurement in 2001, 2011/12 and 2021/22 : full core-area according to standard measurements (dendrometrics and vegetation in 98 subplots 10x10m) (DBH threshold 5 cm)

Vegetation: 50 subplots 2x2m (1991), 10 subplots 2x10m and 10x10m (2001); 98 subplots 10x10m (2012, 2022)

Regeneration: only cover estimated in 1991 and 2001; standard survey core area in 2011.

Small Core Area '43000' (50x100m) :

Soil type : LDp - Eutric Gleyic Cambisols (Loamic, Colluvic)+ luvisols;

vegetation = gradient Alno-Padion (91E0 - EEA 6.14.1) to Fago-Quercetum (9120 - EEA: 6.6.2)

Originally only a transect of 10x100m, measured by Koop (1991) (DBH threshold 5 cm)

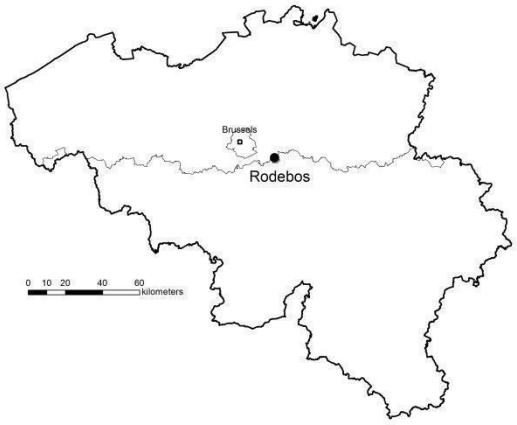
Re-measured in 2001 (10x100m).

For the resurvey in 2011 and 2021, it was decided to enlarge the transect to a 50x100m core area with 50 subplots (10x10m). Subplots surveyed as in a standard core area (dendrometry+ regeneration + vegetation).

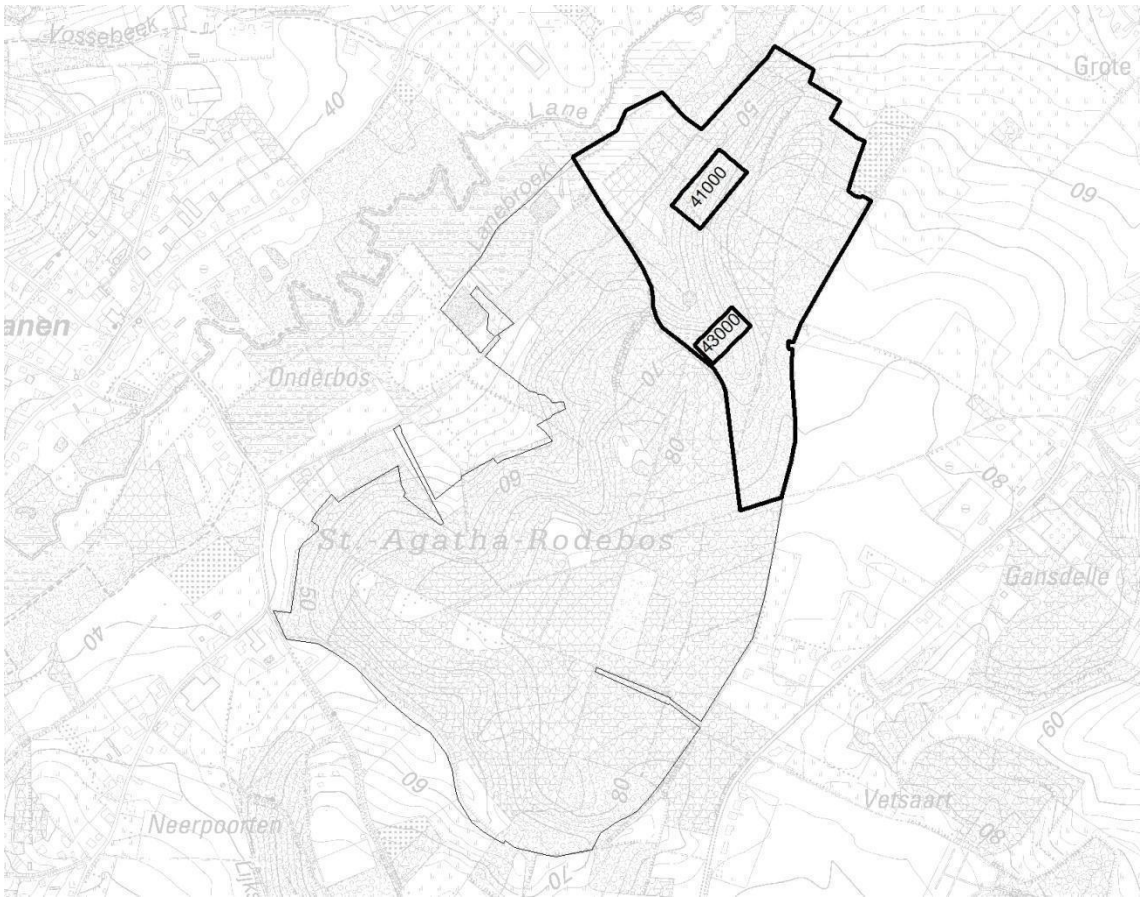
Vegetation: 50 subplots 2x2m (1991), 10 subplots 2x10m and 10x10m (2001); 50 subplots 10x10m (2012, 2022). Regeneration: only cover estimated in 1991 and 2001; standard survey core area subplots in 2011 and 2021.

Maps

Location within Belgium :



Map of the site with large and small Core area



https://doi.org/10.21436/inbor114075052

11.17 WALENBOS

Basic information on the site :

Reserve short code : WLB-SR Sub-ID CA =Core/TR = Transect **Reserve number code : 6**

Surface area: full area ca. 300 ha, surveyed area = 1 core and 1 transect

Co-ordinates of the Centroid of the core area (WGS84-decimal): E: 4.865944 **N**: 50.928474
Altitude : 25-30 m ASL

MAT : 10.0 °C **MAP:** 800 mm/y

Official reserve status : 1989

Unmanaged since : halfway 1980s

Specifications for this survey:

Number of circular plots : NONE

Core Areas :

Large Core Area '41000' (70x140m):

Soil type : V - Dystric Rheic Sapric Histosols

vegetation = 91E0 - mesotrophic swamp forest and Alno-Padion

Dendrometrics : First measured by Koop in 1991; trees >5 cm DBH, deadwood; re-measured in 2001 and 2011/12 : full core-area according to standard measurements (DBH threshold 5 cm)

Vegetation: 50 subplots 2x2m (1991), 10 subplots 2x10m and 10x10m (2001); 98 subplots 10x10m (2012)

Regeneration: only cover estimated in 1991 and 2001; standard survey core area in 2011.

Transect (10x100m) : 'Oligotrophic transect'

Soil type : Edb - Gleyic Umbrisols (Loamic)

vegetation = 91E0 - oligotrophic swamp forest

Transect of 10x100m, measured by Koop (1991) (DBH threshold 5 cm), remeasured in 2001 and 2011(10x100m). For the resurvey in 2011, it was checked if there was a possibility to enlarge the transect to a 50x100m core area with 50 subplots (10x10m), but due to limited accessibility and homogeneity, this was not possible. Subplots in 2011 surveyed as in a standard core area (dendrometry+ regeneration + vegetation).

Vegetation: 50 subplots 2x2m (1991), 10 subplots 2x10m and 10x10m (2001); 50 subplots 10x10m (2012)

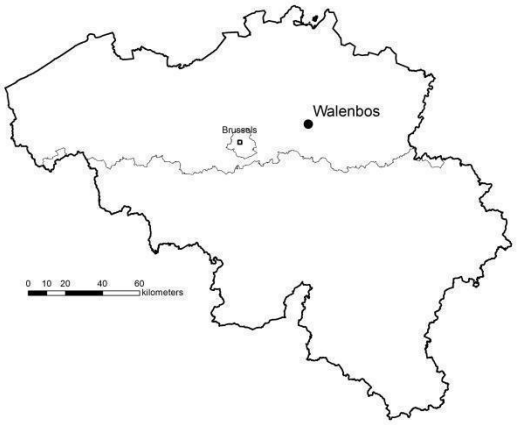
Regeneration: only cover estimated in 1991 and 2001; standard survey core area subplots in 2011.

Remark: In 1991 and 2001 an additional 'Mesotrophic transect' (10x100m) was monitored, located west of the Core Area. This transect was no longer measured in 2011-2012 and later.

//

Maps

Location within Belgium :



Map of the site with large Core area and transect

https://doi.org/10.21436/inbor114075052

11.18 HANNECARTBOS

Basic information on the site :

Reserve short code : HNC-SR **Reserve number code : 5**

Surface area: full area ca. 40 ha, surveyed area = 1 small core area of 50x100m

Co-ordinates of the Centroid of the core area (WGS84-decimal): E: 2.700425 N: 51.130789,

Altitude : 5-7 m ASL

MAT : 10.0 °C **MAP:** 600 mm/y

Official reserve status : 1989

Unmanaged since : halfway 1980's

Specifications for this survey:

Number of circular plots : NONE

Core Areas :

Small Core Area '31000' (50x100m):

Soil type : d.Db - Calcaric Planosols (Arenic, Ruptic)

vegetation = wet dune forest 2180 and 91E0 - mesotrophic swamp forest

Dendrometrics : First measured by Koop in 1991; trees >5 cm DBH, deadwood,

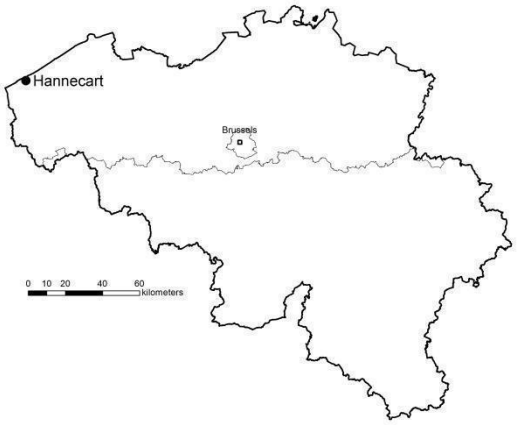
Re-measured in 2001 (10x100m). In 2011, this transect was enlarged to a core area of 50x100m; standard measurements for core-area subplots; remeasured in 2021.

Vegetation: 50 subplots 2x2m (1991), 10 subplots 2x10m and 10x10m (2001); 50 subplots 10x10m (2012, 2022)

Regeneration: only cover estimated in 1991 and 2001; standard survey core area in 2011 and 2021.

Maps

Location within Belgium :



Map of the site with Core area

https://doi.org/10.21436/inbor114075052

11.19 SONIAN FOREST : SFR JOSEPH ZWAENEPOEL (INCLUDING HARRAS AND KERSSELAERSPLEYN)

Basic information on the site :

Reserve short code : SON **Sub-id : CA/KP/EX/HR** **Reserve number code : 1**

Surface area: 230 ha

Co-ordinates of the Centroid (WGS84-decimal): E: 4,4137201309 N: 50,7569007874,

Altitude : 88-125 m ASL

MAT : 9.8 °C **MAP:** 840 mm/y

Soil type : Abc - Dystric Glossic Fragic Retisols (Siltic) (+ Acp - Eutric Cambisols (Siltic))

Official reserve status : 1995 - extension: 2010

Unmanaged since :

- SON-CA: 'core area' (ca 20 ha) unmanaged since 1983.
- SON-KP : area set aside in 1993 (80ha), to form together with the core area the official reserve 'Kersselaerspleyn' (100 ha)
- SON-HR : Reserve part 'Harras' (30ha) also mainly unmanaged since 1993, except small area with Coppice-with-standards restoration experiment (1995-2000), abandoned and since then unmanaged
- SON-EX: Extension area (2010) last intervention (thinning) in 2005-2008.

Previous management : originally managed as 'tire-et-aire' (= can be compared with Coppice with standards, but with rotation of 80-100 years - no coppice with resprouts but natural reforestation mainly with beech) until the beginning of 20th century. Since that time, until establishment of non-intervention: selective thinnings and group final fellings with replanting (until 1980's). Salvation harvest of wind-felled trees (mainly storms of 1991). Southern part of 'Kersselaerspleyn' was the last 'tire-et-aire' cut in 1908, replanted with mixed tree species.

Reserve consists of a mixture of overmature beech stands (200-250 year old), oak stands (Harras : ca. 200 year old) intermixed with younger stands after final harvest of the old beeches during 19th and first half of 20th century.

Specifications for this survey:

This is our 'master site' with a very wide range of measurements

Circular plots : 150 plots (64 in KP +86 in EX+HAR)

Circular plots are larger than standard plots, and use different threshold size (due to extraordinary size of the trees) - Base Grid = 100x100m

Circle A4 : (2000, 2010, 2020) : radius 30m (= 2827m²), threshold DBH = 30 cm
Circle A3 : (2010, 2020) : radius 12m (= 452.4m²), threshold DBH = 5 cm
Circle A1 and A2 (2010, 2020): radius 3m and 6m

Circle A1-A3 at first survey (2000; only Kersselaerspleyn): A1 = 2.25m, A2= 4.5m, A3 = 9m

Dendrometrics in CP :
- Kersselaerspleyn (excluding 'core area') : A1-A4 in 2000/01, 2010/11 and 2020/21
- Core Area : A1-A4 in 2010/11 and 2020/21; in 2000/01 only data on Circle A4 (threshold DBH=30 cm) generated by GIS from the core-area full survey
'extension' and 'Harras' : A1-A4 only in 2020/21.

Vegetation plots in these circles = standard 16x16m, similar recording periods as dendrometrics (spring and summer 2011 and 2021; in 2001 only summer vegetation recording). Additional: vernal flora in circular plots of 'Kersselaerspleyn' (incl. core area) may-2015.

Large Core Area : 10.75 ha

Dendrometrics : Full survey of all trees (L+D) with DBH>30cm in 1986-87; revisited in 1991 to record windthrown trees due to windstorms of february 1991 (Vivian & Wiebke). Volume calculations with tariffs (Van den Berge et al. 1990; 1992).

In 2000/01 : re-survey of full area, with DBH threshold of 30 cm, trees of 10-30 cm counted, not positioned; smaller trees not surveyed in full area but in subsamples (see regeneration).

2010 and 2020 : full survey of all trees (L+D) with DBH>5cm.

Regeneration: counted in standard height classes in subplots: 750 plots of 10x10m in 2001; selection of 140 subplots (every 5th row) of 10x10m in 2010/11 and 2020/21 (see transects on map)

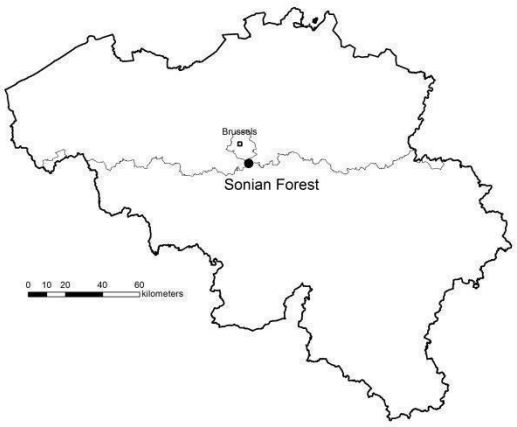
Vegetation : standard relevé on 10x10m subplots: 750 plots, only summer survey in 2001; 140 plots in 2011 and 2021 - spring and summer survey; additional survey in spring 2015 (vernal flora).

Standard Core Area 'Harras' : 70x140m

Standard measurement protocols of core-area subplots for dendrometrics, vegetation and regeneration in 2008/09 and 2018/19.

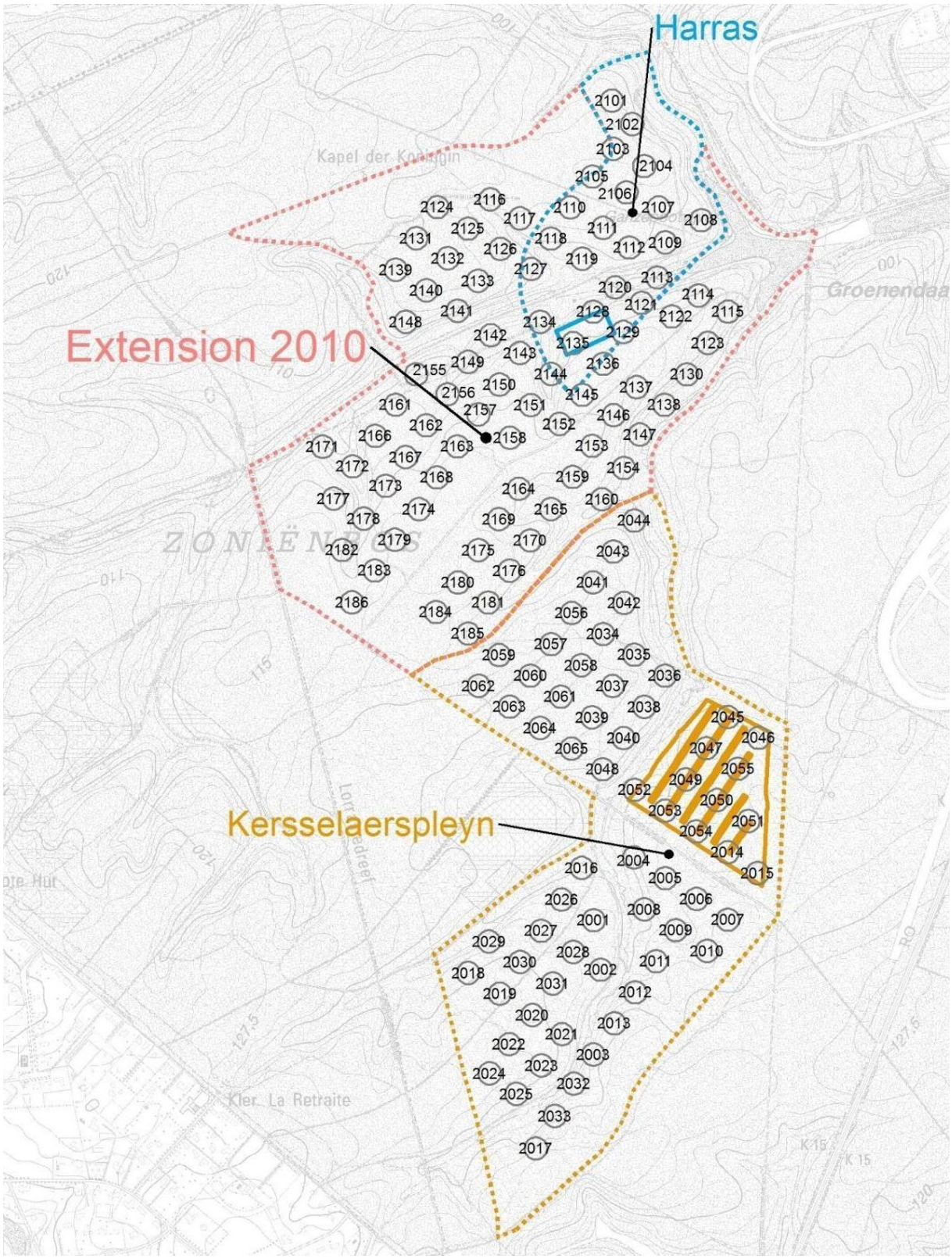
Additional standardised surveys of vascular plants, fungi, bryophytes and lichens on deadwood in 2001 and 2016-2021 on selected trees over the full extent of the reserve, but mainly in the core area.

Maps - Location within Belgium :



 https://doi.org/10.21436/inbor114075052

Map of the Site showing the different sub-areas, grid of circular plots (with plot numbers), large core area (trapezium shape) and Harras standard core area



11.20 *EXTRA* : PEERDSBOS- RESEARCH SITE 'BOSWACHTER'

Reserve short code : PBW **Reserve number code : -**

Basic information on the site : research plot of University of Antwerp (Evolutionary Ecology Group, Department of Biology)

Surface area: research plot full area ca. 10 ha

Co-ordinates of the Centroid of the core area (WGS84-decimal): E: 51.272681, N: 4.488357

Altitude : 8-9 m ASL

MAT : 10.0 °C **MAP:** 785 mm/y

Official reserve status : none

Unmanaged since : NA - no interventions over the last decade

Specifications for this survey:

Number of circular plots : NONE

Core Areas :

One large 'core-area' of approximately 10 ha

Soil type : Sep - Dystric Fluvic Gleyic Cambisols; - Calcaric Planosols (Arenic, Ruptic)

vegetation = acidophyllous oak-beech forest (9120)

Dendrometrics : tree positioning, species, DBH and tree code of all trees with DBH>20 cm (dominant tree layer -mainly oaks and beeches), in total 1558 trees in sept/oct 2017.

Tree DBH was already measured once before in 2010 and linked to tree ID-code (by Univ. Antwerp).

Budburst data were collected by Univ. Antwerp for all deciduous trees in 2010, and for a selection of trees in 2009 and 2017. In 2010, all trees were visited 5–6 times between 23 March and 19 May, with most frequent observations (three visits per tree) between 22 April and 6 May. One overall score was given per tree, on a scale from 0 to 6.

Breeding success of *Parus major* and *Parus caeruleus* in nest boxes attached to a selection of trees is performed yearly from 1997 to 2017. For this purpose, a constant set of 118 nestboxes were operational in the study plot, linked to a specific tree ID. A third of the boxes had small (26 mm) entrances (evenly spaced across the plot) allowing access to Blue Tits only.

More information: see

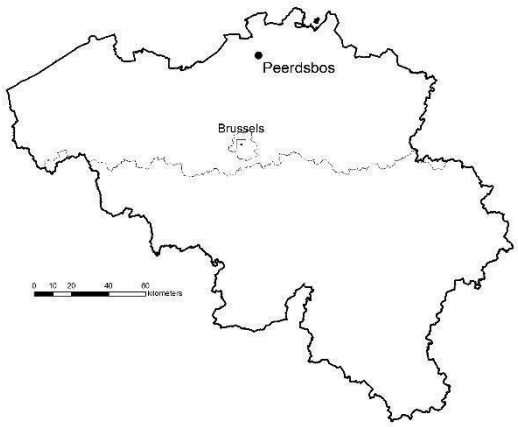
Adriaensen & Van de Kerckhove (2019) Fenologie in onze bossen, … over bomen en mezen. Bosreservatennieuws 16, 24-27.

Matthysen E., Adriaensen F., Vandekerkhove K. & Van de Kerckhove P. (2021) Great and blue tit laying dates vary with fine-scale variation in local tree composition but not tree budburst. Journal of Ornithology.

 https://doi.org/10.21436/inbor114075052

Maps

Location within Belgium



Location of the research plot 'Boswachter' (code 400000) within Peerdsbos

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Baeté, H., Christiaens, B., De Keersmaeker, L., Esprit, M., Van de Kerckhove, P., Vandekerkhove, K. & Walleyn, R., 2006b. Bosreservaat Bos Ter Rijst (Heikruis): basisrapport: situering, standplaats, historiek en onderzoek. Rapport INBO.R.2006.15, Instituut voor Natuur- en Bosonderzoek.

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