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"Coppice forests: past, present and future"
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500 years of coppice-with-standards management in Meerdaal Forest (Central Belgium)

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For centuries, coppice and coppice-with-standards were the main forest management systems in the northern and central parts of present Belgium. A high population density and a low forest cover in the whole region resulted in a high demand for wood, therefore strict regulations and management regimes were necessary to prevent overexploitation. We illustrate this with a well-documented case, that of Meerdaal Forest in Central Belgium, with reference to other sites in the region. Meerdaal Forest is a woodland 30 km east of Brussels. For centuries its high quality timber stands, especially oak, were managed as coppice-with-standards, with a gradually increasing share of standard trees. Using archive documents and ancient maps, we have reconstructed how this coppice-with-standard management has been developed and optimized over a period of about 500 years. Changes in cutting cycles and configurations were discerned, with a gradual increase of the importance of the standard layer over time. The analysis also showed how wood production could be successfully combined with other sources of income like grazing and pannage. We conclude that former managers of Meerdaal Forest, notwithstanding their lack of scholarship and reference works, developed a state-of-the-art sustainable and flexible management regime that allowed to provide high revenues during many centuries.

Keywords: Coppice-with-standards, Archive Documents, Ancient Maps, Long-term Forest Changes, Grazing, Pannage

Introduction

Since the Middle Ages, the northern and central region of present Belgium has been a densely populated and economically important area. Its countryside has been intensively used and altered by man over centuries. With a present-day forest cover of barely 12%, this area belongs to the least forested regions of Europe. This low forest cover is not a recent phenomenon. As early as 2100 BP, forest cover had already been gradually decreased to about 50% of the total land cover, followed by a slight recovery during the Early Middle Ages (4th-8th century – Tack et al. 1993, Verhulst 1995, Verheyen et al. 1999). Particularly during the Full Middle Ages (12th-13th century) a steep decline of woodland cover took place. Economic, demographic and organizational circumstances allowed for a large-scale transformation to farmland. Around 1250, less than 10% of woodland cover was left (Verhulst 1995, Tack & Hermy 1998). Afterwards, total forest cover remained at a similar figure, with a slight increase during the 18th century to about 12%, and declining to a minimum of about 9% halfway the 19th century, when fossil fuels made firewood a less indispensable source of energy. This stable overall figure conceals large deforestations, mainly for agriculture and infrastructure, that were outbalanced by new afforestations – primarily on former heathlands and alluvial meadows – targeted at the delivery of industrial wood products (Hermy et al. 2008, De Keersmaeker et al. 2015). As a result the actual forest cover is severely fragmented both in space and time. Only a small fraction (15 %) is considered to be ancient woodland, *i.e.*, continuously forested between the end of the 18th century and today (Hermy & Verheyen 2007, Hermy et al. 2008, De Keersmaeker et al. 2015).

Not only was the total forest cover very low during past centuries, but the remaining forests were also used very intensively in order to meet high demands for resources like firewood, utensils and construction wood (Tack et al. 1993, Tallier 2004, Vandekerkhove et al. 2009a, 2011). This history of low forest cover and continuous intensive use is comparable with other regions in the Northwest-European lowlands such as the Netherlands, NW-Germany, and Southern England (Buis 1985, Rackham 1986, Peterken 1993, Watts 2006, Schmidt et al. 2014).

The continuous high demand for wood products required strict regulation, control and proper management in order to pre-

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vent depletion of essential wood resources (Radkau 2011).

Until the 19th century, most forests were managed as coppice and, in larger estates of the nobility and monasteries on the more productive soils, as coppice with standards. High forest was exceptional at that time (Tack et al. 1993, Tack & Hermy 1998, Tallier 2004). This management was primarily based on craftsmanship and passed-on knowledge and traditions, in the absence of scientific literature and training. Books and training on silviculture only originated in the early 19th century, and were mainly focusing on the production of roundwood timber (Cotta 1817).

Scientifically trained foresters in the 19th and 20th century apparently had a rather low esteem of traditional forest management (Van Miegroet 1976). They associated traditional management forms with degradation and depletion, and also lack of timber quality (Brakensiek 2002, Radkau 2011). Their view was mainly based on a degraded status of many forests at the beginning of the 19th century, as described for Belgium in a document dating back to 1823 (Tallier 2004). Actually this kind of degradation was due to the disruption of traditional management over previous decades by large scale famine, political instability and war (Tack et al. 1993, Brakensiek 2002).

Recent insights, based on the study of archives and historic descriptions of specific woodlands in present Flanders (Tack et al. 1993, Verheyen et al. 1999, Baeté et al. 2009, Adriaenssens & Verheyen 2013) make clear that forest management from the 15th to the 18th century involved more craftsmanship and knowledge than often assumed, especially in coppice-with-standard forests. The area of our study, Meerdaal Forest, can be considered as one of such prime examples of coppice-with-standard management in the Low Countries. The high quality of its oak timber was renowned and already mentioned in 18th century documents (Goblet d'Alviella 1930).

The aim of this study was to reconstruct the management history of the coppice-with-standards oak stands for Meerdaal Forest, a well-documented example of this traditional forest management regime for Central Belgium, by combining the numerous historical sources that were at our disposal.

Material and methods

Meerdaal Forest is an ancient woodland site, located 30 km east of Brussels (Fig. 1). It covers approximately 1200 ha and still today mainly consists of old mixed oak stands (*Quercus robur* and *Q. petraea*), complemented by beech *(Fagus sylvatica)* and conifer stands. This woodland has played a prominent role in local history and economy, and was managed and owned for a period of over five centuries by the noble Houses of de Croÿ and Arenberg, who at the time belonged to the foremost influential aristocracy of the Low Countries (Roegiers et al. 2002).

Predominant soil types in Meerdaal Forest are Luvisols (in the south) and Podzoluvisols (in the north), which developed in Pleistocene aeolian deposits of loamy loess on top of tertiary sandy formations (Baeyens et al. 1957). The forest is located on a slightly undulating plateau, with an elevation between 55 and 105 m a.s.l. The prevailing sub-Atlantic climate of this region is characterized by a total annual precipitation of about 821 mm (uniformly distributed over the year) and minimum and maximum average monthly temperatures of 2.5 °C and 17.2 °C, respectively, with a yearly average temperature of 9.7 °C. Main vegetation types in Meerdaal Forest are *Stellario-Carpinetum* and *Milio-Fagetum* (*sensu* Noirfalise 1984) on Luvisols. On Podzoluvisols, the predominant vegetation type is *Fago-Quercetum* (*sensu* Noirfalise 1984).

We reconstructed the management history of the coppice-with-standards oak stands for this forest by the analysis and combination of different historical sources. We consulted archives of the House of Arenberg, partly conserved at the Library of the University of Leuven (AAH-KUL), at the National Archives of Belgium in Brussels (ARB-APA) and at the private archive of Arenberg in Enghien (ACA). These archives contain manuscripts and maps concerning management regulations, wood sale conditions, court cases and detailed accounts of annual revenues from the forest.

These archives all have a general inventory (De Fraine & De Fraine 1962, Brommer et al. 1984, De Moreau De Gerbehaye 1999, Mertens 1999, Vanrie 2005), but the content of the folders concerning forest management had never been analyzed before.

Furthermore, information on the management was compiled from published historical sources (Goblet d'Alviella 1930) and reports on silvicultural excursions by the Royal Belgian Forestry Association (Blondeau 1910, Bossu 1911a, 1911b, Brichet 1938, Geebelen 1959).

Based on all these sources, management regulations and regimes were reconstructed, as well as species composition and revenue shares for both the coppice and the standard fraction. The first compilations were made by Baeté et al. (2004, 2007, 2009) and Vandekerkhove et al. (2009b), and have been further replenished and explored in depth for this paper.

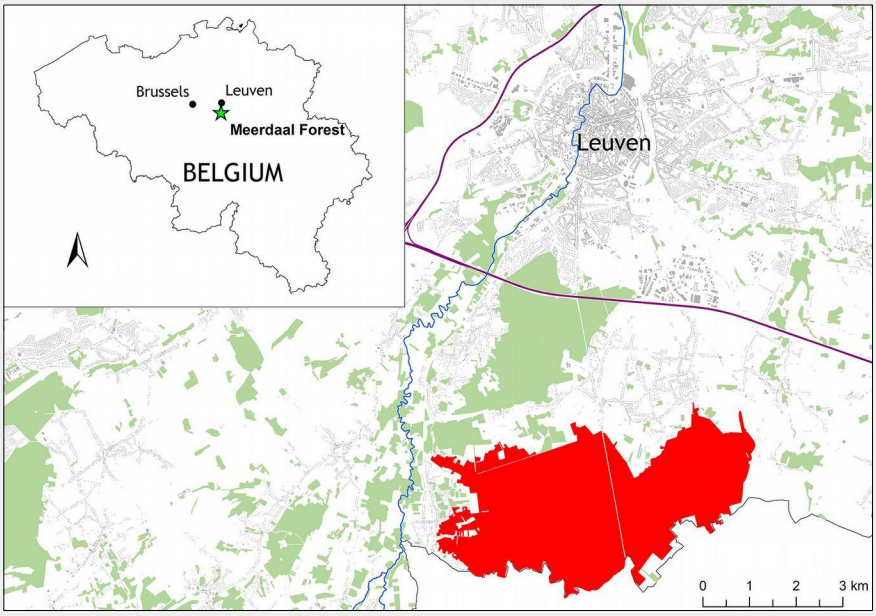

Fig. 1 - Location of Meerdaal Forest in Belgium, and outline of the current forest (red) on a large-scale map also showing other forests (green), the river Dyle (blue) highways (purple) and settlements (grey).

Results

Ownership history and user rights

The first known document referring to woodland in the area of the present Meerdaal Forest dates back to the end of the 12th century, when a "silva de Miradal" is mentioned in a charter of Pope Urbanus III.

During the 13th century, Meerdaal Forest was under supervision of the Duke of Brabant. During the 14th century it became temporarily subdivided between the House of Harcourt and the House of Gulik (Jülich), later Schoonvorst (Schönau). Through marriage in 1432, the part of the House of Harcourt came to Antoine de Croÿ. In 1442, he managed to buy the remaining part of the forest from the family of Schoonvorst and to reunite the ducal Meerdaal Forest (Charter, AAH-KUL).

The House of de Croÿ represented an important and influential dynasty and the Meerdaal Forest was an important part of

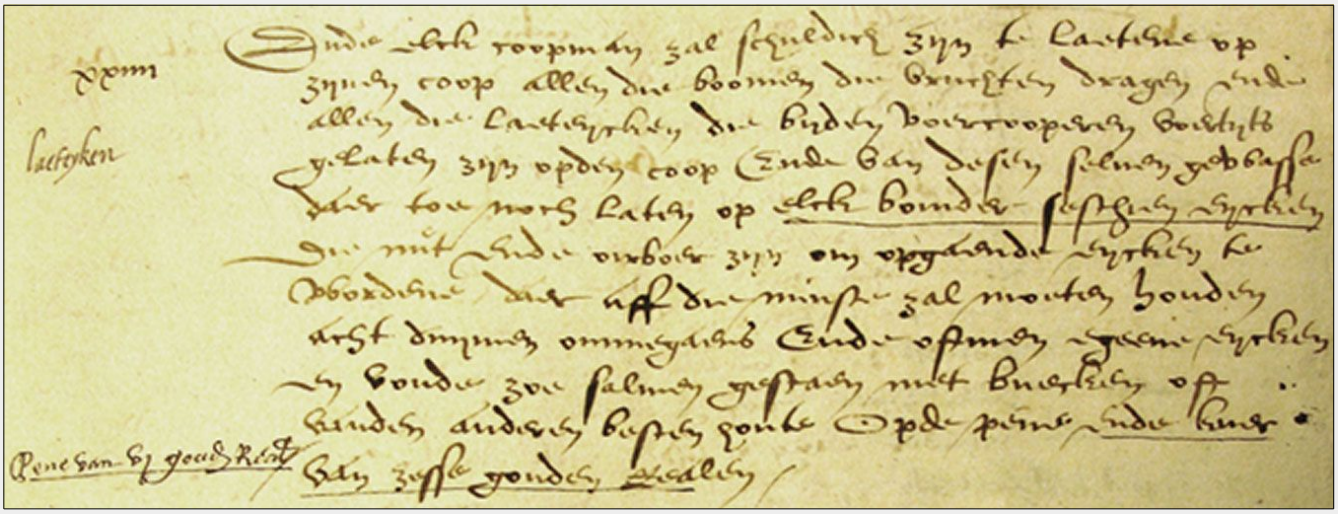

Fig. 2 - Excerpt from the sale conditions for the coppice wood, dated 1567 with the instructions on the conservation of standard trees. It reads "every buyer shall leave on his parcel all fruit-bearing trees, and all the 'leave-oaks' that were left on his parcel at previous sales, and above these on every ha 16 oaks that are decent to develop to standard oaks, with a size of at least 8 inches in girth [= 6.5 cm DBH], and if not enough oaks are available, he shall choose beeches or other species with valuable wood on pain of a fine of 6 golden reales' [if these conditions are not met] (AAH-KUL- folder BBM 682).

their domain, both as a source of income from wood and as an important hunting ground.

In 1615, the ownership passed on through marriage from de Croÿ to the House of Arenberg. This equally prominent noble family already owned several estates and large areas of land and continued to expand its territories in the Low Countries during the 18th and 19th century (Roegiers et al. 2002).

The forest of Meerdaal was declared a "Free Wood" (*Vrijwoud*) by the Duke of Burgundy in 1406, implying that all rights were assigned to the owner, even common user rights formerly granted to the local population (*e.g.*, the right to graze cattle, right to gather dead wood and specific game rights). It also entitled the owner to speak "higher justice", including capital punishments. As a consequence, the Dukes of de Croÿ and Arenberg gained more possibilities and freedom to organize forest management, to set up their own "Wood Court" (*Woudrecht*) and to generate additional revenues, *e.g.*, from grazing and pannage (see below – De Fraine 1963, Baeté et al. 2009).

Meerdaal Forest remained under the Houses of de Croÿ and Arenberg until 1918, when the real estate of Arenberg was sequestered by the Belgian state, on the accusation of collaboration with the German enemy. In 1930 the forest was officially seized and became state forest (Baeté et al. 2004, 2007, ANB 2007).

Management regulations and sale conditions of the coppice-with-standard forestry system

Already in the 15th century, a Wood Court was installed for the Free Wood of Meerdaal, containing two "chambers", of which one dealt with trials on hunting and poaching, and the second specifically on wood theft and related offenses, illustrating the equal importance of both aspects of the forest (Baeté et al. 2009). An original register of 15th century court cases is mentioned in an early inventory of the Arenberg archive in Leuven (AAH-KUL), but could not be retrieved to date. From this earlier period, no documents referring to the forest management have yet been discovered.

The earliest detailed forestry-related documents retrieved in the archives date back to the second half of the 16th century (1552-1567 – AAH-KUL, folder BBM 682). It is a bundle of hand-written conditions and regulations concerning the sale of wood in the Meerdaal Forest (including fines and punishments for theft and fraud). They allow us to reconstruct in fair detail how the forest was managed, and show a very elaborate and sophisticated coppice-with-standards management regime.

Separate sale conditions were made for the sale of the coppice on the one hand and for the standards on the other. Both were sold to the highest bidder during separate sale auctions.

In autumn of the first year, the coppice wood was sold. The "coupe" of that year had been subdivided in advance into small parcels of coppice (with a customary size of 0.25 to 0.35 ha). Buyers were bound to follow strict regulations on when and how to cut the parcels they bought.

Fellings were to be done during the following winter, and concluded by the beginning of May. By the end of May, all coppiced wood had to be cross-cut and stacked between two standard trees in piles of maximum three feet high (=90 cm), and the twigs had to be bound together and piled up. All coppiced wood and twigs had to be removed from the forest by the end of March of the subsequent year (in later sale conditions shortened to the end of October of the second year, so within one year after the original sale). If not, all wood was confiscated and resold.

Moreover, there were strict guidelines on trees that had to be spared (Fig. 2). All standard trees from previous cuts and all fruit-bearing trees, being "apple trees" (probably crab apple, *Malus sylvestris*), "cherry trees" (presumably wild cherry *Prunus avium*), "pear trees" (most likely *Pyrus pyraster*) "and the like" had to be left untouched. Furthermore, buyers had to select and leave at least 16 new saplings of oaks per ha ("leave-oaks"), or "if insufficient oaks were present, other valuable trees like beech" to grow up to become new standard trees. "Leave-oaks" and the like had to measure "at least 8 inches in girth" (= 6.5 cm DBH). After the fellings, all this was checked by the forest guards, and fines were imposed if certain trees were unlawfully cut or when insufficient future standards had been selected.

In addition, all standard trees had to be pruned, and all brambles (*Rubus* spp.), broom (*Cytisus scoparius*) and "thorny shrubs" (probably *Rosa* spp., *Crataegus* spp., *Prunus spinosa*) and holly (*Ilex aquifolium*) had to be cut away. If the buyer failed to do so, the forest guards could hire someone else to do the job, and charge the double amount to the buyer. At the same time it was forbidden to graze their cattle or pigs, to mow or harvest weeds and bracken (*Pteridium aquilinum*), or to pick up any fruits like acorns, beech nuts, medlar fruits (*Mespilus germanica*), sweet chestnuts (*Castanea sativa*) and hazel nuts (*Corylus avellana*).

Immediately after the cut of the coppice, a selective cut in the standards was organized. In the beginning of the second year, the local forest guards marked the trees

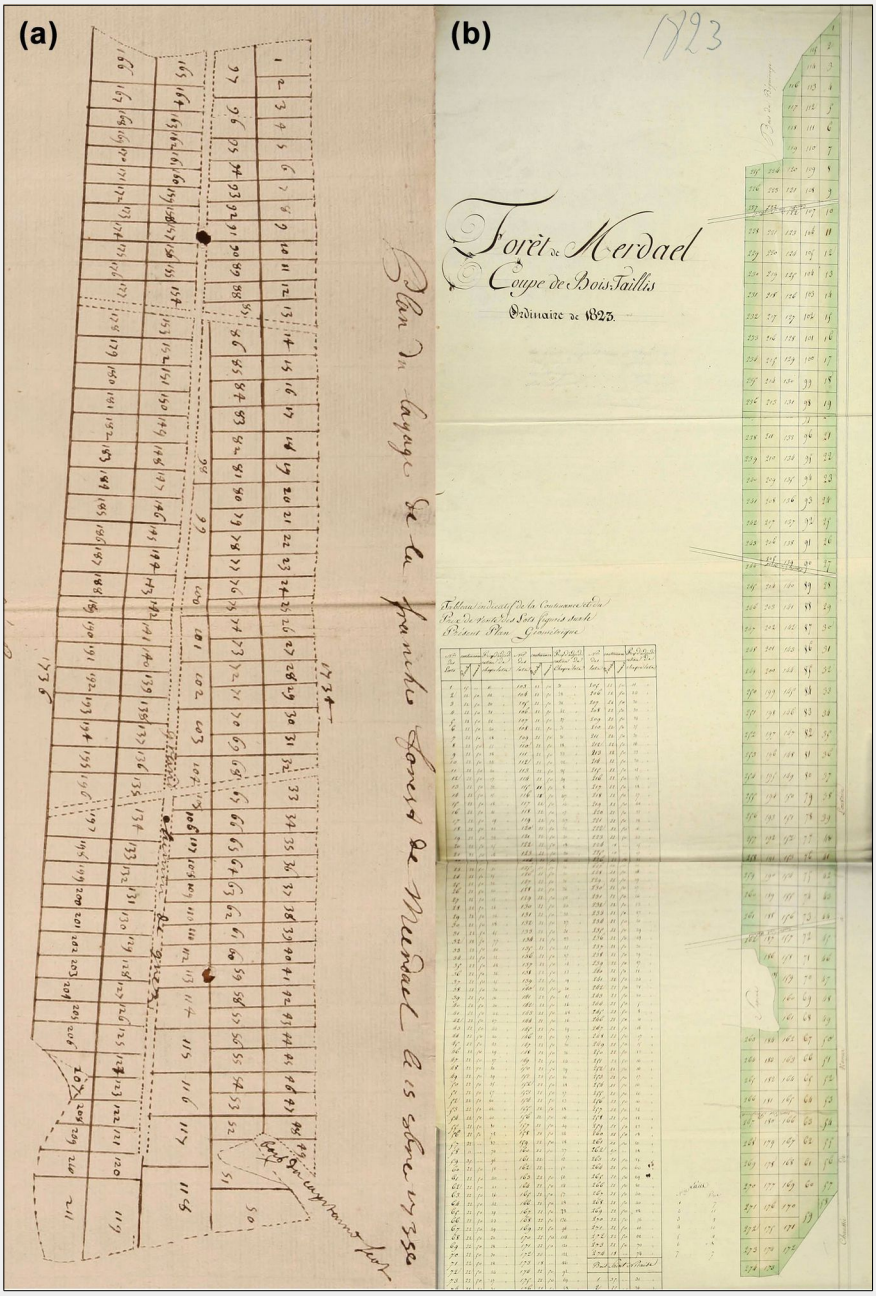

Fig. 3 - Examples of manuscript maps representing the cut and the parcels for the years 1735 (a - AAH-KUL - folder BBM 927) and 1823 (b - ARB-APA-folder KP509): lay-out and size of the parcels remain very similar over time.

that were to be felled with a "marking hammer", a small axe bearing a mark of the owner on the backside of the blade. This mark was imprinted on the trunk and the base of the tree. These trees were subsequently sold in a new auction, organized in May of that same year. Standard trees were sold in parcels of about 5 trees each. Similar strict regulations as in regard to the coppice had to be obeyed. All trees had to be felled by the beginning of the third year and checked by the local foresters to ensure that only marked trees were felled. For that purpose, all felling marks had to remain on the trees at all times. Again all trees had to be felled by the first of May of that third year, and removed by the end of May (or according to some regulations by St. John's Day, being 24th of June), with the fine of confiscation imposed on any buyer who was not able to comply.

Buyers were allowed to harvest the trees including their root bole. In that case the buyer had to cut the roots as close to the bole as possible, and had to refill the resulting pit.

Similar restrictions as in regard to the coppice applied for grazing of animals, the collection of hay or the picking of fruits.

These 16th century regulations remained active until the beginning of the 20th century, being only slightly amended over time, as demonstrated by the sale conditions and other regulative documents in the archives (AAH-KUL) from 1597, 1615, 1627, 1641, 1730 and 1785 and also from the management plan of 1913 (Antoine 1913).

Important amendments over time concerned the number of new standard trees ("leave-oaks") that were to be left by the buyers of the coppice. The regulation of 1597 increased this figure from 16 to 32 trees per ha. The instructions to the forest guards of 1615 further raised this figure to 40 trees per ha, which was consequently adopted in the sale conditions (*e.g.*, that of 1625 and 1641). Also, the responsibility for the selection of these trees was transferred from the buyer to the forest guards who had to select and mark the trees to be left. This was continued in the 18th century regulations but without imposing threshold densities: from 1730 onwards, the guards had to mark out all well-shaped young trees, originating from seed, which had to be spared. Selling regulations on coppice from that time even stated that buyers were required to leave all young trees originating from seed, even those that were not marked – thus forgotten – by the guards. Moreover, instructions to the forest guards of 1730 state that they should provide small nurseries in the forest, and transplant seedlings if there was insufficient natural regeneration of the required valuable tree species (primarily oak).

From 1785 onwards, the buyers of standard trees were obliged to plant a new tree when filling the pit originating from the felling of a standard. They even had to provide supporting stakes to make sure newly planted trees would not bend over.

Finally, documents and maps in the archives also contain information on rotation periods, and the spatial organization of the cuts. The first indication concerning rotation periods dates back to 1610. A document states that the forest is to be evenly subdivided in 20 "coupes" of which each year one is to be cut. The document however does not contain any spatial indication on the form and lay-out of these coupes.

The first maps giving details on the lay-out of the coupes date back to the beginning of the 18th century (1723-1790 – Fig. 3a). By that time, the rotation period in Meerdaal Forest had been reduced to 13 years. The forest was subdivided in North-South oriented strips of 250-400 m wide. Each year one strip was cut, followed by the westerly adjacent strip in the next year. In this way, the fellings shifted opposite to the dominant wind direction, preventing storm damage to the adjacent stands.

This lay-out was continued until the first half of the 20th century (Fig. 4), when the coppice-with-standard system was eventually abolished, with slight amendments to the width of the strips, and the rotation period. From 1800 to 1850 the rotation period was 14 years and from 1850 onwards it was again altered to 12 years (Fig. 3b).

These alterations and adaptations were partly done because the total area of cop-

Fig. 4 - Manuscript map representing the lay-out of the yearly cuts for the period 1835-1885 (ARB-APA-folder KP50).

pice-with-standards changed as some of the lesser productive stands were transformed into high forest of beech or Scots pine (*Pinus sylvestris*).

Information concerning the ultimate period of coppice-with-standards management in Meerdaal Forest is found in several documents (Blondeau 1910, Bossu 1911a, 1911b, Antoine 1913, Brichet 1938, Geebelen 1963). At the beginning of the 20th century, also after the confiscation of the forest by the Belgian state, the coppice-with-standards management was continued, retaining the 12 year cutting cycle. Brichet (1938) clearly stated that the cutting cycle is kept at 12 years, even though shorter rotations would be better for the standard layer, because the coppice still represented an important share of the output of the forest. After the Second World War, however, the market for coppice wood collapsed, and the last cut of the coppice was performed in the beginning of the 1950's (Geebelen 1963). Since then onwards, the remaining oak stands are managed as uneven aged high forest with group cuttings.

Reconstruction of the changes in structure and species composition over time

The archives not only contain sale conditions, but also detailed registers of revenues. By analyzing these registers, a reconstruction of the forest composition and overall structure, including the relative income share of the standard layer, can be reconstructed. Most of these registers still remain to be analyzed in detail, but a first sample already allowed to reconstitute developments in forest structure and composition over time.

The composition of Meerdaal Forest at the end of the 17th century could be derived from sale registers from 1692 (coppice) and 1693 (standards). In 1692, 221 parcels of coppice were sold. The following year, 197 parcels of standards were traded. The sale parcels of the standards contained detailed descriptions of the species composition of each parcel, allowing to reconstruct the species composition of that time, assuming the composition of spared and cut trees was similar. In total 1393 trees were sold, of which 1072 were oaks, 80 cherry trees, 65 crab apples, 7 beeches, 19 alders (*Alnus glutinosa*), 2 birches (*Betula* sp.), 5 ashes (*Fraxinus excelsior*), 2 lime (*Tilia* sp.), 11 hornbeams (*Carpinus betulus*) 4 alder buckthorn (*Frangula alnus*) and 125 unspecified trees. The document on coppice gives no specifications on its species composition.

At that time, the coppice fraction constituted 68% of the revenue, thus being the main source of income.

There are, however, clear indications that the importance and volume of standards in Meerdaal Forest gradually increased over time, as was already illustrated by the increased number of young trees that had to be spared on coppice sales.

Sale parcels of standard trees halfway the 18th century contained on average not 5-7, but over 10 trees. The sale of 1760 contained two times as many trees for a similar number of parcels compared to the year 1693.

By the beginning of the 19th century, the shares of coppice and standards in the annual revenue had entirely reversed. A map of the 1823 sale (ARB-APA, K&P, 509) mentions the overall income from that parcel. The coppice produced 11 700 Francs (31%), while the standards yielded over 26 000 Francs (69%). This share further increased in the following century. An overview of revenues for the period 1902-1913 (Antoine 1913) indicates that coppice represented less than 10% of the income. Inventory data in archives (AAC) and publications (Blondeau 1910, Bossu 1911a, 1911b) also contain information on the species composition at the time. The coppice layer was dominated (>70%) by hazel with some additional sweet chestnut, alder, hornbeam and lime. The standard layer still consisted mainly of oak (85% both in stem number and basal area), with ash, beech, maple (*Acer pseudoplatanus*) and grey pop-

lar (*Populus canescens*) as main additional species. The species that were important in the 17th century like crab apple and wild cherry represent less than 1% of the stem number, and even less in basal area and volume.

Basal area of the standard layer at that time varied from stand to stand between 14 and 18 m² per ha. By 1938, this basal area further increased to 21 m² per ha before, and 16 m² per ha after the fellings in the standards (Vandekerkhove et al. 2009b). The fact that there was still a vital coppice layer below, is explained by the dominance of hazel, a shade tolerant species, in this layer (Brichet 1938).

By that time, the average growing stock of the oak stands had gradually increased to reach values comparable to mixed uneven aged high forests. When the periodic cutting of the coppice was abolished (Geebelen 1963), the ultimate transition to high forest became a fact.

Other sources of income from the forest

Grazing and pannage – the practice of releasing domestic pigs in a forest, in order that they may feed on fallen acorns, beech mast, etc; Rackham 2003, Szabó 2013 – used to be important practices in many forests, and usually implied common rights to local inhabitants (Tack et al. 1993). As stated above, the status of Free Wood excluded all user rights in Meerdaal Forest, allowing the owner to obtain extra revenues from leasing these practices.

However, the owners of Meerdaal used this prerogative only to a limited extent, as they considered grazing and other former common rights to be detrimental to wood production.

In regard to pannage, the oldest documented regulations that could be retrieved for Meerdaal Forest date back to 1553. The right of pannage was awarded to the highest bidder. The animals were only allowed in the forest from autumn to the first of February. The conditions included that the animals should be herded at all times, and fenced in for the night. From 1785 onwards, only the collection of acorns by hand was still leased to the highest bidder, and only during mast years (Baeté et al. 2009, Vandekerkhove et al. 2009b).

Cattle grazing was not a source of direct income. According to a document from 1570 (AAH-KUL), it was only allowed as a specific user right to the monastery of Valduc, and also by the forest guards as an indirect source of income. All animals had to be herded, and no animals were allowed in coppice of less than five years old. At the beginning of the 18th century, the Arenbergs concluded that there was too much damage in the forest due to grazing and instructed that all formal and informal grazing rights were to be abolished (Baeté et al. 2009, Vandekerkhove et al. 2009b). Only the grazing organized by the guards was continued and strictly regulated: only the stands where the coppice was at least seven years old were entitled to be grazed with a maximum density of 10 animals per 100 ha. The main argument to organize this grazing was that it would allow for natural regeneration that would otherwise be suppressed by bramble (regulation of 1730). By 1785 however, also the cattle grazing was ultimately abolished over the whole forest.

Discussion

The study of archives to reconstruct historic forest management is often burdened by incompleteness of the information, and uncertainties in how far the information in the documents (like regulations) reflected the reality in the field. Nevertheless, they provide useful insights in the knowledge and practices over time (Szabó 2010).

The rich archives of the House of Arenberg allowed us to reconstruct in a detailed manner management practices and revenues from coppice-with-standard stands in Meerdaal Forest. The larger part of the extensive archives of Arenberg miraculously survived over time and still present a unique potential for further investigation, especially as they can be very informative and remain partially unexplored.

For this study, we could only analyze a fraction of these extensive and elaborate archives. The inventories allowed to make a selection of documents that provided good first insight in the management techniques. Many meters of archive however await further analysis and screening. By further elaborating on the account books, screening all available years from as early as 1690 until around 1900, and relating the mentioned income and currencies, it should be possible to reconstruct even more in detail the development of species composition and economic return, both in absolute and relative figures, from the forest over the centuries.

Still, the analyzed documents already allow us to reconstitute the forest management practices to a fair level of detail. Combined with other sources and in comparison with other coppice-with-standards from the Low Countries an even more complete picture could be composed.

Exactly for how long a coppice-with-standard management has been in use in Meerdaal Forest remains unclear, although at least since 1552, the date of the earliest studied documents on wood sale conditions in the archives. However, there are indications that this kind of management was already applied much earlier. Regulations in documents from the 1550's are indeed very detailed and elaborate, suggesting they relied on a longer tradition.

This is corroborated by wood sale conditions of the forest of Grotenhout that originally had the same owner: the Duke of Brabant. These sale conditions date back much earlier, the year 1432, and clearly describe a coppice-with-standards management. These conditions are strikingly similar to the earliest sale conditions from Meerdaal Forest. They include identical formulations for maintaining fruit-bearing trees and instructions to leave 16 young trees per hectare as future standards (Adriaenssens & Verheyen 2013). Therefore, it can be assumed that the earliest regulations from the 1550's are based on the same original documents as for Grotenhout, implying that a similar coppice-with-standard management was already in use in Meerdaal Forest at least from the beginning of the 15th century.

This management regime indeed perfectly combined the two main objectives of such ducal forests, being hunting and wood production. Coppice-with-standards management not only provided an important source of income from the sale of wood. It also resulted in temporarily open forest stands that were very suitable for hunting purposes. Especially during the first years after harvesting, the coppice with the retained standard trees provided an ideal "landscape setting" for the predominant hunting practice of that time: the par force hunting on red deer (*Cervus elaphus*) and wild boar (*Sus scrofa*). This type of hunting was applied until the 19th century, when it was gradually replaced by battues and stand hunting, also on smaller game like roedeer (*Capreolus capreolus*) and wildfowl (Baeté et al. 2009, Verbrugge 1996). The obligation for coppice buyers to cut away the brambles and thorny shrubs also applied to this context. This provided not only practical accessibility to foresters who had to mark out standards for the next year, but also to the par force hunting parties. Likewise, the instruction to leave all fruit-bearing trees was related to hunting as these fruits were an important food source for game, especially wild boar (Baeté et al. 2009).

The archives also reveal a well-organized, high performance silviculture by skilled forest managers resulting in a sustained high revenue for its owners.

Illustrative for their management skills is the number of young trees that were to be left on every cut. The original figure of 16 per ha halfway the 16th century was adjusted to 32 and finally 40 per ha at the beginning of the 17th century. This number of 40 standards per hectare in the smallest diameter class is perfectly in line with recommendations in 20th century reference handbooks on coppice-with-standard management for the Low Countries (Huffel 1926a, Poskin 1949). In other words, former managers of Meerdaal Forest already determined the required figures 300 years in advance, deprived of any reference work but relying on field observation and interpretation.

The analysis further shows an adaptive management where the consuming market is the main driving force. The traditional coppice-with-standard management, with the main focus on the coppice layer, as it was performed in Meerdaal Forest until the 17th century, was gradually transformed

under the influence of the Arenberg dynasty to a subtype with a strong dominance of quality standard trees.

Indeed, the original income proportion of standards (30%) and coppice (70%) that was in line with other coppice-with-standards forests in the Low Countries, even up to the 19th century (*e.g.*, Ename Forest and Wijnendale Forest – Tack et al. 1993), was gradually reversed to a 70% standards *versus* 30% coppice proportion during the 18th century. This 70/30 proportion was at that time also applied in other forests of Arenberg, like Hallerbos and Bois de Strihoux (Baeté et al. 2006a, 2006b).

Hence, the quality timber trees of the Arenbergs were widely renowned at that time. In this respect Goblet d'Alviella (1930) cites an anonymous document from 1789 in which the forests of the Arenbergs are highly esteemed for their "best quality of timber, well nursed and pruned, present in high numbers but without being disadvantageous to the coppice. They are preferred to the trees from the Sonian forest, as they have a much denser wood and are much more suited for carpentry".

This reputation surpassed the local market and attracted merchants from a wider area, resulting in a higher demand for construction wood, on which the forest management became attuned, with higher numbers of standard trees being spared.

A gradual increase in the number of standard trees was also found in other studies (Szabó 2010), although they may be related to completely different market mechanisms. In the case of Szabó (2010), the number of standards was risen notwithstanding the fact that the market was very local with a strong demand for firewood. In that case, the increase is related to the fact that the standard trees belonged to the owner, producing revenue for the lords, while the coppice was incorporated in the user-rights of the local population. Similar evolutions are therefore not always to be explained by the same economic arguments.

The documented reduction of the rotation period from 20 years to 12-14 years is quite remarkable. Szabó (2010) and Rackham (1975) found that the rotation period for the coppice in their study areas of Devin Wood and Hayley Wood was extended over the centuries and assumed that this was probably also the case in other European countries. Several other sources indeed subscribe this statement, be it less substantiated by concrete cases (Huffel 1926a, 1926b, Poskin 1934, 1949, Rubner 1960, Fuller & Warren 1993, Rackham 1995). In some regions, the increased rotation was imposed by law. Minimal rotations of 10 years were already installed as early as 1340; the forest code of Colbert from 1669 required rotations of 10 years and in specific cases even 25 years (Rubner 1960). Prolonged rotations may also be related to changes in use and required or preferred dimensions of the coppice (Rackham 1995) or related to a loss of productivity of the site due to depletion of nutrients (Fuller & Warren 1993).

In our particular case, however, the rotation period was clearly reduced, which appears in contradiction to the general trend mentioned above. However, the extension trend refers mainly to an earlier era: short rotations of 5-8 years are mainly related to the middle ages, and were already extended to 20-25 years by the 17th to 18th century (depending on the region – Huffel 1926a, Poskin 1949, Rubner 1960, Rackham 1975, 1995, Szabó 2010). The rotation of 20 years in 1610 in Meerdaal Forest can be considered in line or slightly ahead of this common trend. Several 20th century handbooks on silviculture (Huffel 1926a, Poskin 1949, Boudru 1989) however point out that a rotation of 20 years is often too long for coppice-with-standards forests on richer deep soils aiming at a high proportion of revenue from oak standards, as is the case for Meerdaal. There is not enough regeneration of oak in these long intervals that rarely coincide with mast years of oak, and the saplings are too long suppressed by the resprouting coppice producing ill-shaped and meager young trees. For the older standard layer, a more frequent intervention and selective harvest is also preferred. Finally, the coppice layer resprouts less vigorously with longer rotations in stands with relatively high growing stock in the standard layer, as was the case in Meerdaal Forest. On the other hand, rotations should be long enough so the coppice can grow high enough to suppress lower branches on standard trees. These 20th century handbooks propose rotation periods of 14-15 years to be ideal in these situations (Huffel 1926a, Poskin 1949, Boudru 1989). Again, the forest managers of Meerdaal Forest were several centuries ahead of these sources to come to this conclusion.

It also appears that this management regime was successful, as they could gradually increase the amount of standards, while at the same time, the average coppice parcels remained of the same size over the whole period, indicating that they continued to produce sufficient volumes of firewood, even on shorter rotations.

The 18th century forest managers of Arenberg apparently succeeded to increase production of construction wood aimed at a wider market, with a sustained delivery of sufficient amounts of coppice wood for the local market.

This again illustrates the exceptional skills of the local foresters of that time who, even in the absence of scientific training, scholarship and reference literature, developed an effective and productive management that provided in a sustained delivery of desired quantities and qualities of goods and services.

Conclusion

This case study based on archives concerning Meerdaal Forest illustrates that its former managers, notwithstanding a lack of scholarship and reference works, developed a state-of-the-art sustainable and flexible management regime that allowed to provide high revenues for many centuries.

It is made clear that long before modern science-based forestry, proper knowledge and craftsmanship in forest management was already present, tailored to local and regional market needs, providing high revenues to its owner and concurrently holding on to the principles of sustainability long before the word was invented.

List of abbreviations

The following abbreviations have been used throughout the paper:

- AAH-KUL: archive of the Arenberg family at the Library of the University of Leuven, Belgium.
- ACA: the private archive of the Arenberg family in Enghien, Belgium.
- ARB-APA: Arenberg archive at the National Archives of Belgium in Brussels, Belgium.
- ARB-APA, K&P : the section "Kaarten en Plannen" (maps and charts) of the Arenberg archive at the National Archives of Belgium in Brussels, Belgium.

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References

Adriaenssens S, Verheyen K (2013). Oude bossen van de Antwerpse Kempen [Ancient woodlands of the Antwerp Campine region]. Uitgeverij Davidsfonds, Leuven, Belgium. [in Dutch] [online] URL: http://hdl.handle.net/1854/LU-3229084

ANB (2007). Uitgebreid bosbeheerplan Meerdaalwoud - Heverleebos - Egenhovenbos [Extensive management plan Meerdaal Forest - Heverlee Forest - Egenhoven Forest]. Agentschap voor Natuur en Bos, houtvesterij Leuven, ANB, Brussels, Belgium. [in Dutch]

Antoine V (1913). Bois de Merdael et de Mollendael appartenant à Son Altesse Séréssime Monseigneur le Duc d'Arenberg [Forest of Meerdaal and Mollendael belonging to his excellency the Duke of Arenberg]. Handwritten management plan, fonds Lecart, ACA, Enghien, Belgium. [in Frech]

Baeté H, Christiaens B, De Keersmaeker L, Esprit M, Van de Kerckhove P, Vandekerkhove K, Walleyn R (2004). Monitoringprogramma Vlaamse Bosreservaten - Bosreservaat Everzwijnbad - Basisrapport [Monitoring program Flemish forest reserves - Forest reserve Everzwijnbad - background report]. Instituut voor Natuur en Bosonderzoek, Geraardsbergen, Belgium. [in Dutch]

Baeté H, Christiaens B, De Keersmaeker L, Esprit M, Van de Kerckhove P, Vandekerkhove K, Wal-

leyn R (2006a). Bosreservaat Jansheideberg (Hallerbos); Basisrapport [Forest reserve Jansheideberg (Forest of Halle) - background report]. Instituut voor Natuur en Bosonderzoek, Geraardsbergen, Belgium. [in Dutch]
Baeté H, Christiaens B, De Keersmaeker L, Esprit M, Van de Kerckhove P, Vandekerkhove K, Walleyn R (2006b). Bosreservaat Bos Ter Rijst (Heikruis); Basisrapport [Forest reserve Bos Ter Rijst (Heikruis) - background report]. Instituut voor Natuur en Bosonderzoek, Geraardsbergen, Belgium. [in Dutch]
Baeté H, Christiaens B, De Keersmaeker L, Esprit M, Van de Kerckhove P, Vandekerkhove K en Walleyn R (2007). Bosreservaat Pruikenmakers (Meerdaalwoud) - Basisrapport [Forest reserve Pruikenmakers (Meerdaal Forest) - background report]. Instituut voor Natuur en Bosonderzoek, Geraardsbergen, Belgium. [in Dutch]
Baeté H, Van den Bremt P, Gaij M (2009). Heerlijk Vrijwoud [Seigniorial Free Wood]. In: "Miradal - Erfgoed in het Meerdaalwoud en het Heverleebos" [Miradal - Heritage in Meerdaal and Heverlee forest] (Baeté H, De Bie M, Hermy M, Van den Bremt P eds.), Davidsfonds, Leuven, Belgium, pp. 93-139. [in Dutch]
Baeyens L, Tavernier R, Scheys G (1957). De Belgische bodemkaart, kaartblad 102E (Hamme-Mille) [Belgian soil map, Sheet 103E (Hamme-Mille)]. IWONL, Brussels, Belgium. [in Dutch]
Bossu C (1911a). Excursion forestière en 1910. Première journée [Forestry excursion of 1910 - first day]. Bulletin de la Société Centrale Forestière de Belgique 18: 303-317. [in French]
Bossu C (1911b). Excursion forestière en 1910. Première journée (suite). Les bois de Meerdael et de Molendael [Forestry excursion of 1910 - first day (continued). The forests of Meerdael and Molendael]. Bulletin de la Société Centrale Forestière de Belgique 18: 369-378. [in French]
Blondeau L (1910). L'excursion forestière de juin 1910 [Forestry excursion of june 1910]. Bulletin de la Société Centrale Forestière de Belgique 17: 469-474. [in French]
Boudru M (1989). Forêt et sylviculture: traitement des forêts. [Forest and silviculture: treatment of forests]. Les Presses Agronomiques de Gembloux, Gembloux, Belgium. [in French]
Brakensiek S (2002). The management of common land in north-western Germany. In: "The management of common land in northwest Europe, c. 1500-1850" (De Moor M, Shaw-Taylor L, Warde P eds). Brepols Publishers, Turnhout, Belgium, pp. 225-245.
Brichet L (1938). Notice sur la Forêt de Meerdael [Communication on the Forest of Meerdael]. Bulletin de la Société Centrale Forestière de Belgique 45: 330-341. [in French]
Brommer P, Schleidgen W-R, Zimmer T (1984). Inventar des Herzoglichen Arenbergischen Archivs in Edingen/Enghien [Inventory of the Ducal Archives of Arenberg in Edingen/Enghien]. Veröffentlichungen der staatlichen Archive des Landes Nordrhein-Westfalen 16, Siegburg, Germany. [in German]
Buis J (1985). Historia forestis: Nederlandse bosgeschiedenis [Historia forestis: Dutch forest history]. Studia Historica XIV, HES, Utrecht, the Netherlands, pp. 1087. [in Dutch] [online] URL: http://library.wur.nl/WebQuery/wurpubs/80973
Cotta H (1817). Anweisung zum Waldbau [Instructions on Forestry]. Arnold, Dresden, Germany. [in German]
De Moreau De Gerbehaye C (1999). Inventaires des archives d'Arenberg, seigneuries - domaines: Aarschot, Bierbeek, Heverlee en Rotselaer [Inventory of the archives of Arenberg, nobility and domains of Aarschot, Bierbeek, Heverlee and Rotselaer]. Archives Générales du Royaume de Belgique ARA, Brussels, Belgium. [in French]
De Fraine M, De Fraine P (1962). Archief van het kasteel van Arenberg te Heverlee - Beknopte inventaris met register [Archives of the chateau of Arenberg in Heverlee - concise inventory with register]. Universitaire Boekhandel, Leuven, Belgium. [in Dutch]
De Fraine P (1963). Het woudgerecht van het vrijwoud van Meerdaal - Inleidende archiefstudie [the wood court in the free wood of Meerdaal - Introductory archival study]. Nauwelaerts, Leuven, Belgium. [in Dutch]
De Keersmaeker L, Onkelinx T, De Vos B, Rogiers N, Vandekerkhove K, Thomaes A, De Schrijver A, Hermy M, Verheyen K (2015). The analysis of spatio-temporal forest changes (1775-2000) in Flanders (northern Belgium) indicates habitat-specific levels of fragmentation and area loss. Landscape Ecology 30: 247-259. - doi: 10.1007/s10980-014-0119-7
Fuller RJ, Warren MS (1993). Coppiced woodlands: their management for wildlife (2nd edn). JNCC, Peterborough, UK, pp. 29. [online] URL: http://jncc.defra.gov.uk/pdf/pubs93_coppicedwoodlands.pdf
Geebelen M (1959). Excursion en forêt domaniale de Meerdael - Jeudi 27 aout 1959 [Excursion in the domanial forest of Meerdaal - Thursday august 27, 1959]. Bulletin de la Société Royale Forestière de Belgique 66: Novembre 1959. [in French]
Geebelen M (1963). Bedrijfsregeling Meerdaalwoud [Management regulation Meerdaal Forest]. Ministerie van Landbouw - Bestuur van Waters en Bossen - Inspectie Brussel - Houtvesterij Leuven, Brussels, Belgium. [in Dutch]
Goblet d'Alviella F (1930). Histoire des bois et forêts de Belgique: des origines à la fin du régime Autrichien; tome 4 [History of woods and forests in Belgium: from the origin to the end of the Austrian regime; part 4]. Lechevalier/Lamertin, Paris, France and Brussels, Belgium. [in French]
Hermy M, Verheyen K (2007). Legacies of the past in the present day forest biodiversity: a review of past land-use effects on forest plant species composition and diversity. Ecological Restoration 22: 361-371. - doi: 10.1007/s11284-007-0354-3
Hermy M, Van Der Veken S, Van Calster H, Plue J (2008). Forest ecosystem assessment, changes in biodiversity and climate change in a densely populated region (Flanders, Belgium). Plant Biosystems 142: 623-629. - doi: 10.1080/11263500802411023
Huffel G (1926a). Economie Forestière - tome troisième. [Forest economy - part 3] (2nd edn). Librairie Agricole de la Maison Rustique, Paris, France. [in French]
Huffel G (1926b). Les Méthodes de l'aménagement forestier en France; étude historique. [Forest management systems in France: historical study]. Imprimerie Berger-Levrault, Nancy-Paris-Strasbourg, France. [in French]
Mertens A (1999). Het Arenbergarchief in Edingen, structuurstudie en deelinventaris [The Arenbergarchive in Edingen, structure study and partial inventory]. Verhandeling gespecialiseerde Studies van Archivistiek en Hedendaags documentbeheer. Vrije Universiteit Brussel, Brussels, Belgium. [in Dutch]
Noirfalise A (1984). Forêts et stations forestières en Belgique [Forests and forest site types in Belgium]. Presses Agronomiques, Gembloux, Belgium, pp. 234. [in French] [online] URL: http://agris.fao.org/agris-search/search.do?recordID=US201300439625
Peterken GF (1993). Woodland conservation and management (2nd edn). Chapman and Hall, London, UK, pp. 374. [online] URL: http://books.google.com/books?id=8PYsZ5VWBCEC
Poskin (1934). La chêne pédonculé et le chêne rouvre - leur culture en Belgique [Pedunculate and sessile oak - their cultivation in Belgium]. Duculot, Gembloux, Belgium. [in French]
Poskin A (1949). Traité de sylviculture [Guide on silviculture]. Duculot, Gembloux, Belgium. [in French]
Rackham O (1975). Hayley wood: its history and ecology. Cambridgeshire and Isle of Ely Naturalists' Trust, Cambridge, UK, pp. 221. [online] URL: http://agris.fao.org/agris-search/search.do?recordID=US201300533095
Rackham O (1986). The history of the countryside. J.M. Dent, London, UK.
Rackham O (1995). Trees and woodland in the British landscape: the complete history of Britain's trees, woods and hedgerows. Weidenfeld & Nicolson, London, UK.
Rackham O (2003). Ancient woodland: its history, vegetation and uses in England (2nd edn). Castlepoint Press, Colvend, UK.
Radkau J (2011). Wood: a history. Polity Press, Cambridge, UK, pp. 399. [online] URL: http://books.google.com/books?id=2vBSvlaHOkkC
Roegiers J, Derez M, Nelissen M, Tytgat J-P, Verbrugge A (2002). Arenberg in de Lage Landen - Een hoogadellijk huis in Vlaanderen en Nederland [Arenberg in the Low Countries - a house of high nobility in Flanders and the Netherlands]. University Press, Leuven, Belgium. [in Dutch] [online] URL: http://lirias.kuleuven.be/handle/123456789/108255
Rubner H (1960). Die Hainbuche in Mittel- und West-Europa. Untersuchungen uber ihre ursprunglichen Standorte und ihre Forderung durch die Mittelwaldwirtschaft [The hornbeam in Central and Western Europe. Research on its original site and its promotion through coppice-with-standards]. Forschungen zur Deutschen Landeskunde 121. Selbstverlag der Bundesanstalt fur Landeskunde und Raumforschung, Bad Godesberg, Germany. [in German]
Schmidt M, Mölder A, Schönfelder E, Engel F, Schmiedel I, Culmsee H (2014). Determining ancient woodland indicator plants for practical use: a new approach developed in northwest Germany. Forest Ecology and Management 330: 228-239. - doi: 10.1016/j.foreco.2014.06.043
Szabó P (2010). Driving forces of stability and change in woodland structure: a case-study from the Czech lowlands. Forest Ecology and Management 259: 650-656. - doi: 10.1016/j.for

eco.2009.11.026
Szabó P (2013). Rethinking pannage. Historical interactions between oak and swine. In: "Trees, Forested Landscapes and Grazing Animals: A European Perspective on Woodlands and Grazed Treescapes" (Rotherham I ed). Routledge, London, UK, pp. 51-61.
Tack G, Hermy M (1998). Historical ecology of woodlands in Flanders. In: "The ecological history of European forests" (Kirby K, Watkins C eds). CAB International, New York, USA, pp. 283-292. [online] URL: http://www.cabdirect.org/abstracts/19980613397.html
Tack G, Van den Bremt P, Hermy M (1993). Bossen van Vlaanderen - Een historische ecologie [Forests of Flanders - a historical ecology]. Davidsfonds, Leuven, Belgium, pp. 320. [in Dutch] [online] URL: http://lirias.kuleuven.be/handle/123456789/145498
Tallier P-A (2004). Forêts et propriétaires forestiers en Belgique de la fin du XVIIIe siècle à 1914. Histoire de l'évolution de la superficie forestière, des peuplements, des techniques sylvicoles et des débouchés offerts aux produits ligneux [Forests and forest owners in Belgium from the end of the 18th century until 1914. History of the evolution of the forest area, stands, forestry techniques and wood consuming market]. Royal Academy of Sciences, Brussels, Belgium. [in French] [online] URL: http://difusion.ulb.ac.be/vufind/Record/ULB-DIPOT:oai:dipot.ulb.ac.be:2013/106802/Details
Van Miegroet M (1976). Van bomen en bossen [About trees and forests]. (2 volumes). Story-Scientia, Antwerp - Leuven - Brussels - Ghent, Belgium. [in Dutch]
Vanrie A (2005). Archives du Palais d'Arenberg à Bruxelles: inventaire de la série des cartes, plans, tableaux et documents iconographiques [Archives of the Palace of Arenberg in Brussels: inventory of the series maps, charts, drawings and iconographic documents]. Algemeen Rijksarchief, Brussels, Belgium. [in French]
Vandekerkhove K, De Keersmaeker L, Menke N, Meyer P, Verschelde P (2009a). When nature takes over from man: dead wood accumulation in previously managed oak and beech woodlands in North-, West- and Central Europe. Forest Ecology and Management 258: 425-435. - doi: 10.1016/j.foreco.2009.01.055
Vandekerkhove K, De Keersmaeker L, Walleyn R, Köhler F, Crevecoeur L, Govaere L, Thomaes A, Verheyen K (2011). Reappearance of old growth elements in lowland woodlands in northern Belgium: do the associated species follow? Silva Fennica 45: 909-936. - doi: 10.14214/sf.78
Vandekerkhove K, Van der Aa B, Baeté H, Meuleman B (2009b). Bakermat van duurzaam bosbeheer. Pour le plus grand profit de son excellence [Cradle of sustainable forestry. To the best profit of his excellency]. In: "Miradal - Erfgoed in het Meerdaalwoud en het Heverleebos" [Miradal - Heritage in Meerdaal and Heverlee forest] (Baeté H, De Bie M, Hermy M, Van den Bremt P eds), Davidsfonds, Leuven, Belgium, pp. 139-171. [in Dutch]
Verbrugge M (1996). De jacht. [Hunting] In: "De blinde hertog, Louis Engelbert van Arenberg en zijn tijd, 1750-1820" [The blind duke, Louis Engelbert of Arenberg and his time, 1750-1820]. (Derez M, Nelissen M, Tytgat J-P, Verbrugge A eds). Gemeentekrediet, Brussels, Belgium, pp 133-134. [in Dutch]
Verheyen K, Bossuyt B, Hermy M, Tack G (1999). The land use history (1278-1990) of a mixed hardwood forest in western Belgium and its relationship with chemical soil characteristics. Journal of Biogeography 26: 115-1128. - doi: 10.1046/j.1365-2699.1999.00340.x
Verhulst A (1995). Landschap en landbouw in middeleeuws Vlaanderen [Landcape and agriculture in medieval Flanders]. Gemeentekrediet, Brussels, Belgium, pp. 191. [in Dutch] [online] URL: http://library.wur.nl/WebQuery/groenekennis/922363
Watts K (2006). British forest landscapes the legacy of woodland fragmentation. Quarterly Journal of Forestry 100: 273-279. [online] URL: http://www.cabdirect.org/abstracts/20063185462.html