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A historical ecology of the Compiègne forest (N France)

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14.1. Introduction

The Compiègne forest (49°22' N; 2°54' E; 32–148 m altitude) is the third biggest state forest in the French lowlands. It is a subatlantic temperate oak-beech forest located at 70km north-east to Paris, which covers ca. 14,500 ha at the junction between the Aisne and the Oise rivers. The substrate is dominated by acidic sands and

limestones. It has long been considered as a very ancient woodland, which might have continuously existed since the beginning of the last post-glacial afforestation episode, *ca.* 10,000 years ago. This belief relies on the fact that (i) Historians of the 19th century erroneously interpreted Caesar's landscape description (*De Bello Gallico*) as a dense woodland at the time of the Romans conquest (1st century BC); (ii) following the Roman empire collapse (5th century AD), the forest became a royal hunting reserve until the French revolution in 1789; (iii) since the 18th century, the forest is a state forest managed for wood production and stag hunting. However, evidence is accumulating that the Compiègne forest may not be as ancient as previously thought, and has been patterned by thousands of years of human activities. Here we present a synthesis of recent research in historical ecology which has been conducted in this forest by the EDYSAN research group in Amiens (Jules Verne University of Picardie) to better understand the legacy of past human-forest interactions in the current forest ecosystem.

14.2. The ancient forest: an intensively managed agricultural landscape?

Landscape archaeology using aerial photographs developed in England and France from the 1950s onward (Dassié 1978). In northern France, it revealed a huge density of archaeological imprints (e.g., buried calcareous stones into silty topsoils) across agricultural landscapes, mostly of Gallo-Roman origin, indicating that the land was already intensively cultivated at that time (Agache 1978). In comparison, woodlands remained largely unexplored since the vegetation cover hides micro-reliefs, buried walls and other archaeological remains. Extensive archaeology using walking transects in the understories can help in finding visible topographic anomalies and artifacts, but may be limited by a dense ground vegetation or by management-induced disturbances.

In the case of large forests, such as the Compiègne forest, which were already present during the “forest minimum” (*ca.* 1850 in France; Bergès and Dupouey 2017) and have been continuously mapped over the last few centuries, it has been postulated that they likely exist since prehistoric times. This hypothesis was seemingly supported by ancient written sources. Pliny the Elder and Suetonius, for example, designed Gaul as *Gallia comata*, which means “hairy Gaul”, the Gaul prior to the Roman conquest (Clavel-Lévêque 1967). This was interpreted by historians of the 19th century as evidence for a land covered by forests (Maury 1848, 1850). However, the first archaeological explorations of the 19th century started to cast doubt on the ancient forest hypothesis, since a number of Gallo-Roman sites were discovered, such as *vici* (*i.e.*, urban areas), *villae* (*i.e.*, isolated farms), a sanctuary and several roads.

From 1997 to 2017, an intensive field survey was implemented, which revealed more than 300 Roman sites, mostly rural settlements, within the forest (Thuillier 2017). This field survey was complemented by a remote sensing survey using the LiDAR technology (Box 14.1). A first flight covering a small part of the forest was conducted in 2011 at 9 points per m²; a second one covered the entire forest in 2014 at a higher resolution (23 points per m²). A total of 5,710 anomalies were evidenced, including 1,457 one-off (*e.g.*, depressions, bomb holes), 3,797 linear (*e.g.*, banks, roads) and 456 zonal (*e.g.*, mounds, enclosures) anomalies (David 2016). All anomalies that cannot be identified with certainty were verified in the field. Some of them corresponded to prehistoric or protohistoric artifacts (*e.g.*, dolmen, cutting workshops, barred spurs), but the vast majority of them dated back the Gallo-Roman period (1st-4th century AC). Only a sandy area located towards the center-east of the forest was free from occupation sites (Figure 14.1).

Box 14.1. *The LiDAR technology*

LiDAR has rapidly become a major tool in historical ecology. LiDAR (for Light detecting and ranging) is a technique for measuring distances using the properties of laser beams. The principle is to analyze the return time of a light beam between its emission source and an object. In forest, topographic LiDAR is mainly used. It is a LiDAR carried by an aircraft flying at low or medium altitude, measuring the topography over a relatively large area. It allows to assess the relative altitude of the ground and objects at a high precision (a few cm). The laser beam is reflected by the canopies, by tree trunks and branches, and by the ground. It is therefore possible to classify the cloud of points obtained by selecting the upper points, the intermediate points and the ground points, to develop a digital elevation model (DEM), a digital terrain model (DTM) and intermediate models. DTMs have archaeological or geomorphological applications. Elevation models and intermediate models rather have dendrometric applications, to assess standing timber volumes and the structure of forest stands. The higher the number of impacts reaching the ground (in points per m²), the higher the resolution of the resulting model. In Western Europe, the first archaeological applications of LiDAR were developed in the Rastatt forest, in Baden (Sittler and Hauger 2007). In France, the first archaeological survey was carried out in the forest of Haye, east to Nancy (Georges-Leroy et al. 2011). LiDAR is now used in a variety of applications and several European countries have developed programs to cover the entire national territory.

The results show that during the Gallo-Roman period, human activities were structured by an important Roman road, connecting two cities: Soissons (*Augusta Suessionum*), to the west, and Senlis (*Augustomagus*) to the south-west. The primary road crossed three secondary towns (*vici*), and several farms (*villae*) were scattered on both sides, the more distant ones being connected to the main road by secondary roads. The LiDAR also revealed that over almost the whole forest area, the land was divided into rectangular parcels, which were also consistently structured by the

ancient road network (Figure 14.2). They are very similar to those retrieved in other French forests, which have been shown to be the ancient agricultural lands, where plowing led to large geometric areas surrounded by banks possibly topped by a hedgerow (Georges-Leroy *et al.* 2011). In some parts of the forest, smaller parcels of more irregular shape sit on the top of these typical parcels of lands, probably of medieval origin (5th-15th century) (Buridant *et al.* 2020). This indicates that parts of the current forest were still cultivated in the Middle Ages.

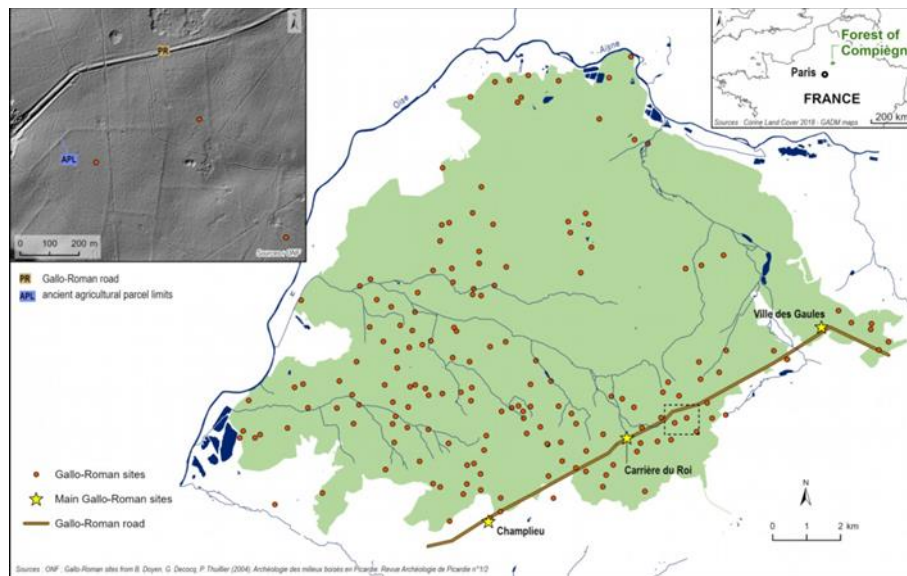


Figure 14.1. Former Gallo-Roman settlements in the current Compiègne forest. The top-right map shows the location of the forest in Northern France. The top-left image is a digital terrain model from the LiDAR which reveals the ancient parcels of agricultural land.

An interesting feature of this “fossilized” agricultural landscape revealed by the LiDAR-derived digital elevation model is the presence of many closed circular depressions (CCD) that are systematically located along an inner edge of the rectangular parcels (Figure 14.3). They consist of 0.5-3m-deep depressions with a diameter ranging from 20 to 60m. A pedo-sedimentary analysis of cores taken outside, on the edge and at the center of 10 CCD was conducted to determine their origin. The shallowest CCD (sCCD) revealed a single-phase, non-stratified sediment infill. The filling material was clearly anthropogenic, consisting of a mixture of local soils, their limestone substrate and sometimes fragments of ceramics. At the top, soil horizon development occurred. In contrast, the deepest CCD (dCCD) showed no or little

infilling and the limestone substrate was encountered at <50 cm. Both CCD types had a bathtub shape with a flat bottom at the interface with the geological substrate, which is typical of an anthropogenic excavation. However, CCD could not be limestone quarries used to provide the building material -that are also present elsewhere in the landscape- since the hard limestone (e5b) was intact. The chemistry of the local substrate also excluded a karstic (sinkhole) or salt diapir dissolution origin (Delafosse 1948; Etienne et al. 2011). These CCD thus correspond to ancient pits, where limestone powder and calcareous marls and loess (e5b/c) were extracted. As we found no accumulation or overlying of these materials around CCD, we hypothesize that they were sprayed over agricultural lands to buffer the natural soil acidification under a humid temperate climate, thereby maintaining productivity. Liming was indeed a common practice for Gauls and Gallo-Roman, as mentioned by Latin agronomists (Varro, Pliny the Elder, Columella). The abundance of CCD (>100) in the Compiègne forest indicates that liming was a widespread practice during the Roman times. It not only creates an artificial topography and localized thick anthropogenic soils, but likely induced a general alkalisation of soils which durably impacted soil properties in former fields. Recent work suggests that liming effects on soil pH last several millennia (Brasseur et al. 2018), and hence can still impact vegetation and ecosystem functioning (Box 14.2).

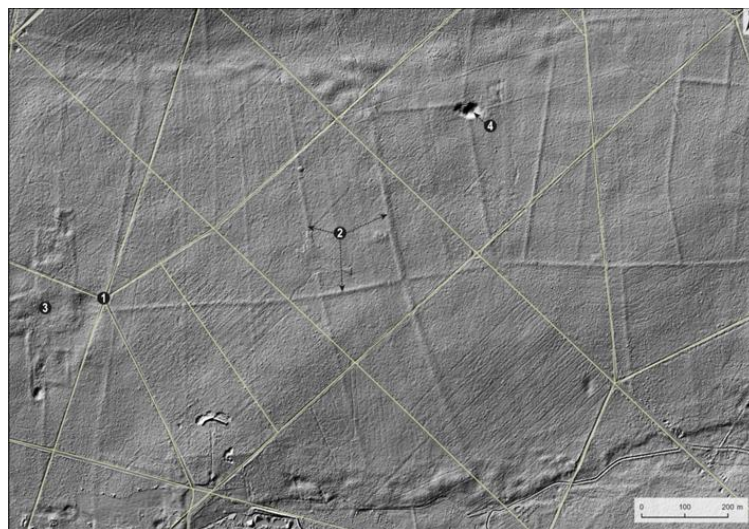


Figure 14.2. LiDAR image of part of the Compiègne forest. The current network of star-shaped roads (1) is inherited from the 16th-18th centuries (yellow lines). We can see under this network the rural territory organization from the Antiquity made up of large rectangular agricultural parcels (2), a residential area (3), and limestone extraction areas (4).

Box 14.2. *Impacts of Roman settlements on biodiversity and ecosystem functioning*

To test whether past Gallo-Roman settlement still affect the present characteristics of soils, vegetation and soil seed bank, we designed a comparative study (Plue *et al.* 2008). To each of twenty-four former isolated Gallo-Roman *villae* (*i.e.*, “sites”, where an inhabited building used to be settled) we paired an unoccupied site (*i.e.*, “controls”, free from any former human settlement but not from past human influence) at a distance of <200m, which shared the same topography, substrate and management history. A 800 m² quadrat was disposed in each site and control, into which all vascular plant species were recorded, and soil samples were taken for further soil chemical analyses and permanent seed bank assessment (25 cores per quadrats, 26cm-diameter, 20cm-depth after litter removal).

The soil was persistently altered on the sites, resulting in elevated phosphorus levels and pH (dependent on initial soil conditions). The upper soil layers also contained scattered stone fragments, pieces of limestone and shards of roof tiles (*tegulae*). These altered soil features translated into significantly increased vegetation cover and seed bank density (1,500 seeds m⁻² vs. 333 seeds m⁻²), increased species richness in both vegetation (37.1 vs. 23.2) and soil seed bank (6 vs. 4), and increased compositional similarity among sites (Raup & Crick index: 0.53 vs. 0.76), as compared to unoccupied sites. In particular, the vegetation on Gallo-Roman sites had a significantly more competitive and ruderal but less stress-tolerant character than controls. Nitrogen-demanding and calciphilous species were strongly associated with sites, while acidiphilous species were significantly associated with controls. It is noteworthy that fruit trees (*e.g.*, apple tree, medlar tree) often appeared in the woody layers on the archaeological site or nearby. The local persistence of ruderal species below forest canopies is surprising. It is likely facilitated by forest management, which allows periodic light arrival at the forest floor, hence their recruitment from the soil seed bank and the replenishment of the latter.

These results revealed that 1,600 years after their reclamation and forest colonization, Gallo-Roman settlements still leaves a persistent trace on forest soil, vegetation and seed bank. By creating entirely different habitats with irreversibly (?) altered geochemical features, these archaeological sites form plant species-rich islands in an otherwise species-poor forest ocean, thereby contributing to biodiversity at the entire forest scale (Closset-Kopp and Decocq 2015). Furthermore, the Roman legacy in vegetation is not limited to former residences. Roman roads have likely served as important corridors for species, before and after their reclamation. For example, in the Compiègne forest, the archeophyte *Vinca minor* has been observed only on the former Roman road.

The area of the present-day forest of Compiègne was thus previously not a forest, but rather looked like an open agricultural land. Archaeological studies and pollen analyses suggest that the local deforestation started long before the Roman conquest (Perrière and Leroyer 2006). The first populations of farmers settled around 4500 BC

in the Oise and Aisne valleys, which border the current Compiègne forest at the west and north, respectively (Figure 14.1). At that time, the pollen diagrams are dominated by oak (*Quercus*) and hazelnut (*Corylus*), with lime (*Tilia*), elm (*Ulmus*) and alder (*Alnus*). This typical vegetation of the Atlantic period (5500-2300 BC) was probably an open-canopy forest. Beech (*Fagus sylvatica*) first appeared after 3000 BC and became common only after 1250 BC (Leroyer *et al.* 2017).

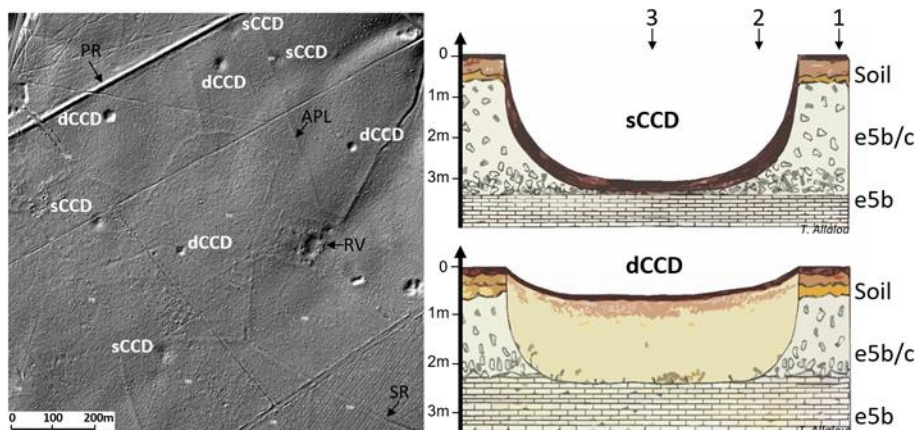


Figure 14.3. Left: LiDAR-derived digital elevation model revealing closed circular depressions filled (sCCD) or not (dCCD) by sediments. Other archeological features are visible: a Gallo-Roman villa (RV), Senlis-Soissons primary road (PR), a secondary road (SR), and agricultural parcel limit (APL). Right: Geological profile of a dCCD (top) and sCCD (bottom). e5b/c Eocene (upper Lutetian) powdery limestone, e5b Eocene (middle Lutetian) hard limestone. 1, 2 and 3 show core position for each of the CCD.

14.3. The Medieval forest: a woodland (re)birth or a savanna-like ecosystem?

Gallo-Roman settlements were quite suddenly abandoned towards the end of the 4th century AD, with archaeological evidence for destruction and fires as soon as the 3rd century AD (Frémont and Wamant 1975, 1976, Tuffreau-Libre 1977). A woodland is mentioned for the first time at the 6th century by Grégoire de Tours (*Histoire des Francs*), when he relates the death of the Merovingian king Clotaire I in 561, from a fever “while he was hunting in the forest of Cuise” (*dum in Cotia silva venationem exercet*). The forest of Cuise is presented as a hunting forest belonging to the royal domain. Since this first mention, historical texts confirm the continuous presence of a woodland in this area, which was later renamed Compiègne forest.

The forest colonization of abandoned fields occurred in the course of secondary succession, so that the early Medieval forest may have consisted in relatively dense oak-dominated woodlands. This hypothesis is supported by the low human population density in this area, following the Great Invasions; and the fact that the wood framework of local houses was built using tall trees with very narrow tree rings, suggesting they grew in packed populations, a typical characteristic of early-successional forest communities. The human pressure on the forest likely increased again with the demographic booming of the 12-13th centuries. Archaeological studies evidenced activities associated with the supply of wood, such as pottery workshops (starting at the 10-11th century), glass factories (12th century), and metalworking industries (14th century), all established into the forest. The number of glass factories increased at the 14th and 15th centuries, when several families of glass-makers immigrating from Eastern France established there. At this time, the bracken fern (*Pteridium aquilinum*) was likely abundant, since it was the only source of lye.

Dating of buried charcoals retrieved from kilns in topographic depressions in the center of the forest suggest that charcoal production was conducted at least from the 12-13th centuries till the years 1610-1670. However, no written source specifies the structure, extent and composition of the forest before the 16-17th centuries, so that it is challenging to reconstruct the Medieval forest. The latter likely has been patterned by two main drivers: user rights and hunting.

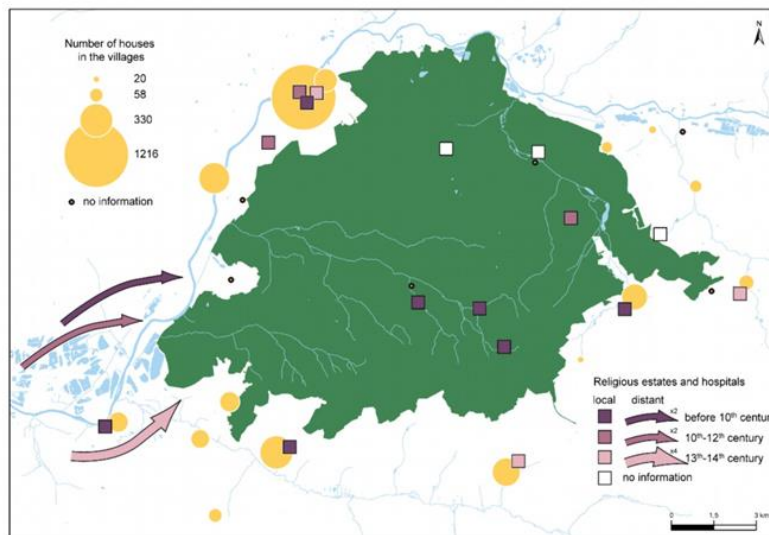
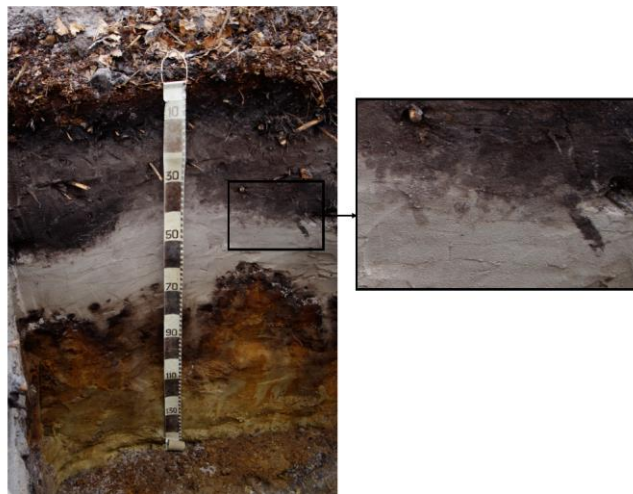


Figure 14.4. State of play for user rights in the Compiègne forest in 1663.

Box 14.3. What do soil archives teach us?

Pedological pits were made in the center of the forest, close to a dune-like relief free from any archaeological artefact as revealed by the LiDAR imagery. The pits showed podzols covered a more or less thick layer of drift sands. The abundance of dung beetle galleries observed in one horizon of the profile (see figure below) suggests locally abundant animal waste associated with a pasture land use, and thus a rather open landscape. Consistently, the sand layer observed on the top of the paleosol may reflect intensive grazing-induced drift-sands on sandy soils.



Podzol profile in the drift-sands area (left panel). The soil is buried under ca. 35 cm of sand. The abundance of dung beetle galleries observed at contact between the dark organo-mineral horizon and the ash grey eluvial horizon just below (right panel) suggests local soil enrichment associated to a pasture land use.

To obtain a picture of past local species assemblages, we sampled soil charcoals in a podzol and two others soil types within currently mature forest stands (Feiss *et al.* 2017b). The radiocarbon dating returned no charcoals older than the 10-11th century. We found no relationship between the charcoal age and their vertical distribution, due to soil mixing associated with belowground biological activity. Soil charcoal assemblages thus hardly reflect temporal changes in forest stand composition. However, the fact that the oldest charcoals came from birch (*Betula*) supports the hypothesis that the 10-11th century forest was very open, with a substantial proportion of shade-intolerant tree species. Light-demanding, early-successional taxa, while missing from current tree communities, were almost systematically more abundant than shade-tolerant species across the three sites. This suggested that the forest canopy used to be much more open than today, consistent with a savannah-like landscape maintained by the intense human pressure and heavy grazing by wild and domestic animals (Feiss *et al.* 2017a).

Like many European forests in the Middle Ages, the Compiègne forest was not exclusively intended for wood production. Many uses were practiced by the local populations, such as picking up dead wood, cutting green wood, grazing by cattle and pigs. From the 13-14th centuries onward, these uses became user rights granted to local populations and institutions. These user rights were progressively restricted, especially by the forest reformation of 1663, to limit the overexploitation of the forest resources (Figure 14.4). Still, such rights were conceded to 16 communities of inhabitants, 25 ecclesiastical communities and one glass furnace. Some communities have their rights restricted to certain areas, while many others can take their herds throughout the entire forest. The authorized load often exceeded one animal per hectare, a density much greater than the carrying capacity of the forest. It is thus likely that the forest landscape at this time rather looked like a wooded pasture (*i.e.*, a temperate savannah; Rackham 1998) than a closed-canopy woodland, a hypothesis supported by soil charcoal analyses (Box 14.3).

At the same time (from the 17th century onward), with the progress in firearms, pheasant hunting became a fashion. Kings Louis XIV and Louis XV built seven pheasantries in the center of the forest. Pheasantries are closed, cultivated parks dedicated to the breeding of pheasants, which were then released in large open spaces (called “tirés”) into the forest, allowing them to take off. This practice was still ongoing at the 19th century, since Emperor Napoleon III was a lover of pheasant hunting and was often coming in the Compiègne forest for this purpose.

However, the Compiègne forest was also dedicated to the production of wood. At the 17th and 18th centuries, logs were floated to Paris via the Oise river, where there were used for construction and as fuel. Interestingly, the forest provided a lot of short, curved logs to royal shipyards on the Atlantic coast, as well as to a local shipyard, which built barges for inland water shipping. The abundance of short, curved logs suggests that the core of the forest, which was managed as a high forest for hunting, was surrounded by more intensively managed short-rotation, dense coppice-like woodlands.

14.4. The Contemporary forest (19th century onward): a closed-canopy multifunctional woodland

The today's forest landscape is mostly a legacy of recent periods of restoration and replanting, which started in the mid 18th century (Figure 14.5). From 1772 to 1792, deciduous trees, mainly pedunculate oaks, were planted by Pierre-Lucien Pannelier d'Annel and his son, Antoine-Lucien Pannelier. A second phase of reforestation occurred throughout the 19th century, over 6,610 ha (*i.e.*, 46% of the total forest area) (Buridant 2008). Following WWII, conifers, mainly Scots pine, were widely planted

over the less fertile areas. More than half of the forest is therefore composed of recent plantations (< 250 years old). It is likely that human disturbances associated with these plantations have facilitated the invasive spread of the American black cherry (*Prunus serotina*), which started towards the mid 19th century. The Compiègne forest is currently the most invaded in France, with ca. 80% of the forest area where the invader occurs, as isolated trees to monospecific stands, thereby significantly impacting the recipient ecosystem (Box 14.4).

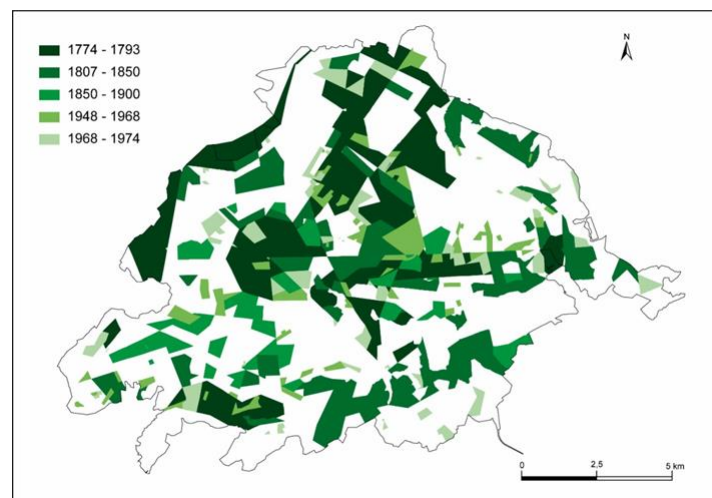


Figure 14.5. Tree plantation in the Compiègne forest from 1774 to 1974.

The current forest is mostly dedicated to timber production (oak, beech and Scots pine) and stag-hunting. As a public sub-urban forest, the forest also experienced an increasing pressure from local populations for their recreative activities. Two nature reserves have been created, one at the 19th century (Beaux Monts) and the other in the 1970s (Grands Monts). These reserves are useful tools to analyze the impact of the current forest management on vegetation (Box 14.5).

The first decades of the 21st century are marked by rapid changes in the forest vegetation in response to global changes (Box 14.5). These changes are event accelerating: most canopy tree species experienced severe dieback due to several non-independent factors: repeated drought episodes (beech), cockchafer (oak) and bark beetle (spruce) boom, chalararosis epidemics (ash), etc. As a result, light arrival at the forest floor increases with dramatic changes in the ground vegetation to come.

Box 14.4. Impacts of *Prunus serotina* invasion on forest vegetation

Prunus serotina either escaped from the castle park or has been introduced directly in the Compiègne forest around 1850, but has been reported as an invader only in 1970. It has now spread in the entire forest. Many studies have been conducted to assess the impacts of the invasion, by comparing tree physiology, plant communities, soil properties, and disturbance history between *P. serotina*-invaded and uninvaded paired-stands. Overall, species assemblages in invaded and uninvaded stands were similar (Chabrierie *et al.* 2008). Habitat conditions and disturbances explained most of the variation in both plant diversity and *P. serotina* density, the last two factors being weakly associated. The herb layer of invaded stands exhibited significantly more specialist species and a lower trait diversity compared to uninvaded stands. Traits characterizing shade-tolerant, short-living ruderals and shade-avoiders (vernal geophytes) were significantly associated to invaded stands, while those associated to light-demanding graminoids characterized uninvaded stands. This indicates that *P. serotina* was becoming the new ecosystem engineer, first by inducing trait convergence and community specialization, thus promoting traits that enable species to capture resources in the new environment it was creating, and second by reducing the grain of local heterogeneities (Chabrierie *et al.* 2010). Compared to indigenous tree species, *P. serotina* exhibited higher foliar N, foliar P, and lower foliar C:N and N:P ratios (Aerts *et al.* 2017). *P. serotina* also affected foliar nutrient contents of co-occurring indigenous tree species leading to decreased foliar N and increased C:N ratio in beech, decreased foliar N:P ratio in hornbeam and beech, and increased foliar P in Scots pine in invaded vs. uninvaded stands. *P. serotina* thus changes nitrogen, phosphorus, and carbon cycles to its own advantage, hereby increasing carbon turnover via labile litter, affecting the relative nutrient contents in the overstory leaves, and potentially altering the photosynthetic capacity of the other broadleaved species.

Box 14.5. Vegetation changes at the Anthropocene

Recent vegetation changes have been recently documented using a resurvey study and a life-history trait-based approach (Closset-Kopp *et al.* 2019). This study highlighted decadal changes (1970–2015) in the ground vegetation and searched for the drivers behind these changes. A number of process-based hypotheses were tested using paired comparisons (old vs. new records) of community-weighted means and conditional inference classification trees for a number of traits across soil and management types. Compared to unmanaged stands (nature reserves), managed stands underwent the most pronounced vegetation changes, as a likely effect of modifications in forest harvesting practices since 1970. Consistent with general trends observed in European forests, species richness of vascular plants increased at both stand (α -diversity) and forest (γ -diversity) scales, due to the non-random, directional colonization by the same suite of species, causing compositional, functional and phylogenetic homogenization among habitats (*i.e.*, decreased β -diversity). Forest management, via the repeated passing of heavy forestry vehicles, emerged as the key driver of these changes. By altering canopy structure, it increased not

only light availability at the forest floor, but also the vulnerability of understories to climate warming and atmospheric deposits. Furthermore, increasingly heavy forestry vehicles that drive more frequently across forest stands likely generate microhabitats suitable for ferns, graminoids and N-demanding forbs and also act as dispersal agents.

14.5. Conclusion

All together, these results demonstrate that the Compiègne forest has established on an ancient cultivated plain and on neighboring plateaus, where many people used to live, work and trade for centuries. In this context, little place was left for woodlands during the Gallo-Roman period. The rural landscape rather looked like an intensively managed open field, maybe with a few small woodland patches restricted to the steepest slopes of surrounding hills and central sand dunes. The forest established progressively during the early Middle Ages, from the spontaneous afforestation of abandoned farmlands. Since the secondary succession was strongly constrained by human activities, wild and domestic herbivores, it is likely that the vegetation rapidly shifted from a dense early-successional woodland to an open wooded pasture, so that the late Medieval forest likely resembled more a temperate savannah than a closed-canopy woodland. Hunting activities have been a major driver of the forest landscape through medieval, modern and contemporary times, leading to the long-lasting maintenance of open habitats within a high forest. Canopy closure and the subsequent development of a shade-tolerant flora is probably a recent phenomenon, but which is currently challenged by global warming-associated environmental changes, since the forest canopy tends to re-open. Most importantly, we showed that past land use and historical human activities strongly shaped soil and vegetation features, thereby influencing today's ecosystem functioning. Current biodiversity patterns are thus a composite legacy of each of the historical periods experienced by the forest, which cannot be understood without a historical ecology perspective.

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