# 2 Silviculture

### Management matters.

What are the details of shoot production?

What silvicultural options are there for different types of coppice?

Between threat and opportunity – characterising two major invasive species.

How does this connect to the upcoming chapter on the operations of coppice forest management?

### Visit this chapter for:

Silvicultural guidelines for European coppice forests

Two potentially invasive tree species of coppice forests: *Ailanthus altissima* and *Robinia pseudoacacia*

Active management of traditional coppice forests: an interface between silviculture and operations

# Silvicultural Guidelines for European Coppice Forests

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## 1 INTRODUCTION

### 1.1 Coppice forests in Europe

*Coppice* is a forest regenerated from vegetative shoots that may originate from the stump and/or from the roots, depending on the species.

In contrast to forests originating from seed (the so-called *high forest*), the rotation period of coppice forests can be significantly shorter (approx. 5-30 years, depending on the type of coppice system). In 2000, about 16% of the productive forests in Europe were managed as coppice, covering a total area of about 23 million ha [53].

All European coppice forests consist of broadleaved tree species. Among them, eucalypts, a non-native species, is a bit of an outlier in terms of the environmental concerns discussed in this document. Even though eucalypts can be managed to be highly productive and cost-effective, they can have major detrimental effects to the environment such as soil depletion and fire risk.

Willows, poplars and black locust are treated as *short-rotation coppice* (SRC), which is usually regarded as part of agricultural-production systems.

### 1.2 Forms of coppice forests

There are different forms of coppice forests: simple coppice, coppice with standards, coppice selection, pollarding and short rotation coppice (Figure 1).

### 1.3 The biological and ecological process of vegetative regeneration

Re-sprouting is a natural adaptation of trees and shrubs that enables their survival after having been damaged. Coppicing is the operation of felling and vegetative regeneration of a forest. Coppice forests are thus usually a result of human activities (cutting). However, it is also possible for coppice to result from natural disturbances (e.g., wind throw, fire, animals,

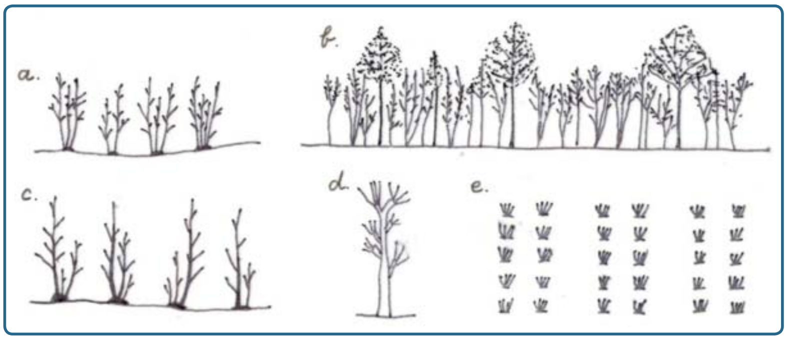

Figure 1. Different types of coppice forests: simple coppice (a), coppice with standards (b), coppice selection (c), pollarding (d), short rotation coppice (e) (drawn by J. Carvalho)

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storm, pathogens, etc.) and a few species can also sprout naturally (e.g., strawberry tree, Figure 2, as well as wild cherry, hazel).

The result of re-sprouting is the production of *coppice shoots* (coppice sprouts) that originate from coppice stools (stumps, Figure 3, and roots).

There are three forms of coppice shoots [25]:

**a. Stump shoots (sprouts):** originate from *dormant buds* buried in the bark. They have the same age as the tree on which they have been formed and can live in a dormant state for a long time, usually breaking the dormancy after major disturbance, e.g. cutting the tree.

**b. Stool shoots (sprouts):** grow from *adventitious buds*, which develop in the same season of the cut from callus tissue formed between the bark and the wood at the cut surface. They are not directly connected to the vascular system of the stump on which have been formed and are less frequent than the stump shoots.

**c. Root suckers:** originate from *adventitious buds* along the tree roots. Such shoots (Figure 4; following page) can occur:

- On standing trees, either after the soil has warmed due to exposure to sunlight or fire, or following the loss of apical dominance.
- Following the cutting of the above ground tree
- When shallow and/or thin tree roots are disturbed or wounded.

Figure 2. Natural sprouting in strawberry tree (Photo: J. Carvalho)

The stump shoots are more desirable than the stool shoots as they are more numerous, show a higher vigour, can develop independent roots sooner than the stool shoots, have a lower proportion of rot and are more intimately attached to the stump and so less prone to be separated from it. Consequently, the stump shoots should be favoured after cutting.

Compared to stump and stool shoots, root suckers do not show basal curvature, are less affected by disturbances (wind, snow) and rot and can separate fully and more quickly from the originating roots.

White poplar, aspen and black locust can produce large amounts of root suckers, a response that is encouraged when the original tree is cut or damaged.

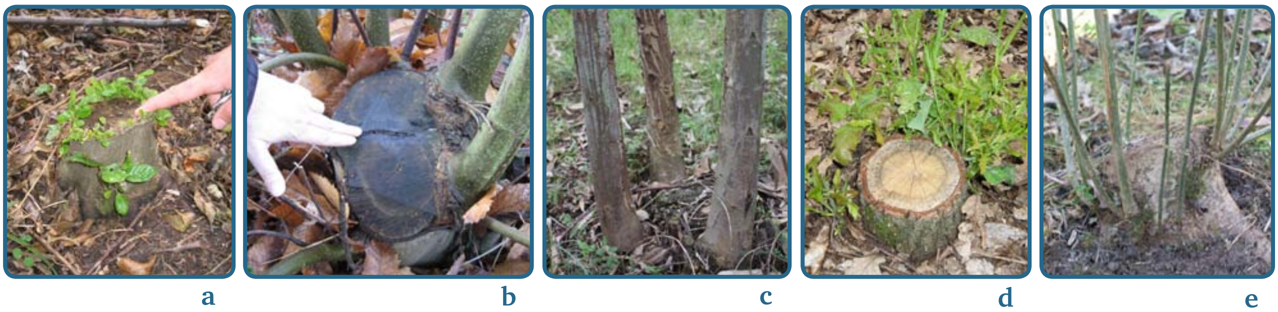

Figure 3. Stump and stool shoots on: hornbeam (a), sweet chestnut (b), eucalypt (c), sessile oak (d) and common ash (e) (Photos: V.N. Nicolescu and V. Bruckman)


a b

Figure 4. Root suckers of silver linden (a) and black locust (b) (Photos: V.N. Nicolescu and C. Hernea)

## Shoot production

The potential for shoot production mainly depends on the species, tree age, season of cutting and site conditions. In terms of the species, all native broadleaved tree species produce shoots and can be treated as coppice, albeit to different extents. European beech, for example, only re-sprouts at a young age (up to 20-25 years) and on richer soils; on more acidocline soils it re-sprouts poorly and so is considered unsuitable for coppice management on such sites. Other species, such as silver birch, also re-sprout best at lower ages and are therefore better suited for coppice systems with shorter rotations (<20 years).

The majority of broadleaved tree species, however, can produce shoots vigorously and abundantly up to an age of 40 years (e.g. Turkey oak, Holm oak, willows, poplars (not trembling), elms, black alder), while certain tree species can produce shoots for up to 100 years, or even indefinitely (e.g. pedunculate oak, sessile oak, Hungarian oak, sweet chestnut, linden, elms, and hornbeam), although the vitality of shoots decreases considerably at higher ages and stump diameter.

The production of shoots also depends on the *season of cutting*: the best time to cut for simple coppice is considered to be late winter - early spring, before the beginning of growing season. The only major exceptions to this optimal period are the oak tan-bark coppice, which is cut in May or early June, after the growing season has commenced, and alder, willow and poplar coppices on swampy sites, which are cut in winter or summer, when the ground is firm or dry enough.

*Light conditions* is another important factor for re-sprouting: the stumps should be in full light to produce shoots, as a shaded stump will coppice weakly and shoots will grow slowly. For light-demanding species (e.g. oaks, willows), this effect is more important than for more shade-tolerant species (i.e. linden, hornbeam, hazel), which still re-sprout well under the semi-open canopy of coppice with standards.

Coppicing also depends greatly on the *climate*: summer droughts and early or late frosts can reduce or even halt the production of shoots. A warmer climate fosters re-sprouting (in terms of the abundance and vigour of shoots), but this can result in the stump becoming exhausted more quickly.

Re-sprouting is also more abundant and can be longer (up to 300 years or even more) on rich soils with a good water supply than on poorer and drier soils. The same phenomenon occurs on warm, sunny and drier slopes, which are more favourable for re-sprouting than the colder, shaded and more humid ones.

Sprouting is also affected by wind, snow and browsing, which induce the detachment of stool shoots and compromise the vegetative reproduction of trees. Periods of continued high browsing pressure (by deer or livestock) may lead to depletion and eventual death of the stools.

### Sucker production

On one hand, suckering depends on the *species*: the most important sucker producers are poplars (trembling/aspen, white, black and hybrid), black locust, grey alder, linden, field elm, field maple, wild cherry, wild service tree, Pyrenean oak, and holm oak. Root suckering rarely occurs in oaks (pedunculate, sessile, pubescent), European beech, hornbeam, common ash, and Norway maple. On the other hand, sucker production also depends on *soil conditions*: more suckers occur on sites with lighter (sandy) and mobilized soils than on heavy and compact ones.

The distance to which certain tree species produce suckers can be up to 10 m (black locust, wild cherry, white poplar, wild service tree, etc.) or even longer (35 m in aspen), thus allowing the trees' expansion to surrounding openings.

## 1.4 Socio-economic values of coppice forests

For centuries, coppice forests served as a sustainable source of *raw materials* for the local communities [11] (Figure 5). A steep decrease in demand for firewood due to the widespread use of fossil fuels led to a strong decrease in coppice forests over the past two centuries, especially in many Central- and Western European countries. However, over the last two decades there has been a renewed and growing interest in coppicing in Europe due to the increasing demand for energy production from renewable resources, as desired by EU policy. This development was mainly triggered by climate change mitigation policies in the wake of Kyoto Protocol [55]. In addition, an increase in the price of firewood over the past few years has also stimulated a recent interest in coppicing as a forest management alternative [32].

Coppice forests may provide the following:

**Rural livelihoods**: regular income, sustainable employment and resources

**Bio-economy**: renewable, sustainable and environmentally friendly biomaterials & fuels

**Protection function**: prevents soil erosion, rock fall, landslide & avalanche

**Sharing economy**: community use & recreation

**Provision**: timber & non-timber forest products

**Enrichment**: biodiversity & cultural landscapes

Figure 5. Timber forest products from coppice: sweet chestnut in England (a) and Italy (b), black locust in France (c) and oak in Austria (d) (Photos: V.N. Nicolescu, J. Carvalho and E. Hochbichler)

Traditionally, coppice forests were managed to provide wood material, with the main product having been firewood. Further common products were charcoal, basketry, sticks, fencing, mining timber, poles, pulpwood, and small-sized timber.

Recently, studies have shown that biomass can be economically harvested from traditional coppice forest systems using modern machines [47]. This makes coppice forests an interesting alternative source for obtaining woody biomass, for instance for energy or biochar production [37].

*Short-rotation coppice* (SRC, Figure 6) is another possible way of producing biomass for energy. Harvesting of SRC should be fully mechanized.

Non-wood products such as truffles and fungi, tanbark, wild forest fruits and honey from domesticated bees can also be obtained from coppice forests. Furthermore, in certain cases, coppice can be beneficial for the development of hunting game. The periodic felling creates opportunities for the development of ground vegetation, which provides food for herbivores.

Coppice forests are often described as “hotspots of biodiversity” [51]. The mix of young open and older closed-canopy stages promotes the diversity of fauna and flora (e.g. [11]). Habitat quality may be divergent, depending on current management practices.

Coppice with standards or over-matured (outgrown) coppice woodlands may, for instance, offer a large number of ecological niches as the stand structure tends to be heterogeneous and contain more deadwood [10]. The young open phases of the coppice cycle are beneficial to numerous light-demanding and thermophylous species. There is a significant interaction between coppice woodlands and the surrounding landscape in terms of habitat quality, as is shown in the case of bird communities [5]. Dense stands inhibit or limit the development of herbaceous ground vegetation and therefore decrease diversity of herb species after crown closure.

Coppice is an ancient form of forest management and so is part of Europe’s historical and cultural heritage. It proved to be a very effective way of producing raw material for traditional uses. In many European regions, large woodland areas were coppiced in the past, but in the last 100 years many coppices have either been converted into high-forest or are abandoned and overaged.

Figure 6. Short rotation coppice (Photos: V.N. Nicolescu)

# 2 COPPICE FORESTS AND THEIR SILVICULTURE

## 2.1 Simple coppice

Simple coppice is a forest management system in which trees are systematically and repetitively cut and regeneration is vegetative, by means of sprouting or suckering (often from the stump, alternatively from roots).

Simple coppice is applied especially on broadleaved tree species that can withstand repeated cutting, such as oaks, sweet chestnut, hornbeam, linden, eucalypts, ash, alders, black locust, poplars. European beech is less responsive to coppice [9] [21], so that the use of this tree species in simple coppices is less recommended. For birches, coppicing is possible if relatively short rotations (6-12 years) are applied. In these guidelines we are focusing on the most relevant tree species: oaks (Figure 7), beech, eucalypts, sweet chestnut, hornbeam, black locust, and silver birch.

The duration of rotations depends mainly on the species, re-sprouting ability, maximum productivity, targeted wood dimensions and local site conditions. Rotations are usually between 5 (willow osier) and 40 years (oak, hornbeam, beech), but can reach up to 60 years (alder). New shoots in this type of forest grow very fast at the beginning, as a result of their developed root system. Thus, the height and diameter increment culminates 20-30 years earlier than in forest originating from seeds, in accordance with local soil fertility and climate parameters (i.e. temperature, rainfall). The logged wood often has lower technical (industrial) wood quality, as it frequently includes knots, is curved in lower part of the trunk and may contain many technical defects.

As the majority of broadleaved species only re-sprout well until about 40 years after cutting, the rotation of stands treated as simple coppice generally ranges from 15 to 25 (30) years [24] [27]. Such stands produce small-diameter trees used for firewood, basket work, pea and bean sticks, hoops, hurdles, fascines, fencing, vine and hop poles, handles for tools and implements, pulpwood, etc. [34].

The rotation can be longer, usually up to around 35 years, if larger timber is desired. This is the case for oaks, sweet chestnut and black locust when the timber is produced for items such as wood barrels, flooring, mining timber, solid furniture [26] [42] [48] [49] [50].

There are many advantages of simple coppice:

- simple management
- low costs of natural regeneration
- low impact silvicultural interventions
- low vulnerability (wind throw, etc.)

However, many disadvantages also exist:

- unstable price of firewood
- high cutting/harvesting costs
- less market flexibility with lower product diversification potential

### Silvicultural management / operations

The intensity and techniques of silvicultural interventions depend on the production goals. Both natural regeneration (shoot origin) and planting trees (seed origin) can be used to establish simple coppice stands. When using natural regeneration, 5 to 10 trees per ha should be left after cutting as potential seed trees. In artificial regeneration 1 to 3-year-old seedlings are planted with density of 1,000-1,500 ha$^{-1}$ (eucalypts) or 4,000-5,000 ha$^{-1}$ (black locust). These species are cut two years after planting. In the case of other species, such as sweet chestnut, the plants are cut 7-8 years after establishment.

Figure 7. Holm oak simple coppice in Spain (Photo: P. Vericat)

Seedlings are also used to replace poorly sprouting or dying stumps. These operations can also be made by layering (chestnuts) and root suckering (black locust and lime). In managing eucalypts, fertilization is recommended after every harvest cut.

Between two coppice cuts, tending operations such as *cleaning-respacing* and *thinning* are sometimes required to improve productivity; they target the removal of unwanted species or individuals, improvement of the quality and quicker growth of final crop, and also produce small and medium-sized material that may increase financial return [34]. The number of these operations depends primarily on the rotation length, competition among shoots, and the wood market. For instance, in the black locust coppice stands of Hungary and Romania with rotations of 25-35 years, there are 1-2 cleaning-respacing and 1-2 thinning interventions [1] [42], compared to only 2 thinning in France [13]. In sweet chestnut coppices, the number of tending operations ranges from none in Britain [17] to 3 in Greece [8]. In eucalypt coppice there is only one thinning operation, 1 or 2 years after the cut.

Simple coppices reaching the rotation age are worked by the method of *annual coupes by area*, after deciding the rotation based on the size of material required. The total area treated as simple coppice is divided into annual coupes equal to the number of years in the rotation; each year, one coupe is coppiced. All material should be removed from the cutting area before flushing begins, so as to avoid damage to the fragile young shoots [16] [33] [46].

After repeated coppicing, stools begin to rot and die (Figure 8) and show a gradual decline in yield, so that the potential of producing young and vital shoots decreases with increasing age and shoot diameter [23] [26] [35].

In order to maintain high productivity, the stools should be replaced after 2-3 coppice cycles in temperate regions [33] [52]. However, from a biodiversity conservation perspective it is recommended to preserve the old stools as they contain many microhabitats and rare epiphytes.

Figure 8. Old sessile oak trees treated as coppice with a high density of cavities and decaying wood; less productive than vigorous young stools but with high conservation value (Photos: V.N. Nicolescu)

## 2.2. Pollarding

Pollarding consists of cutting the tops of trees as to stimulate production of numerous straight shoots on the top of the cut stem (Figure 9). The shoots grow out of reach of browsing animals and flooding waters, which are the two main reasons for this type of management. Most typical pollards exist today along riversides and meadows. The most common species used are poplars, ash, willows, plane-trees, beech, chestnut, mulberry, oaks, linden, elms, black locust, maples, hornbeam and hazel.

Traditionally, some species were pollarded for both wood and fodder production, while beech and oak pollards were used to produce small-sized wood. With the shift in demand from small-sized wood and fodder to larger industrial wood (trunks), this type of pollarding has gradually been abandoned, especially with beech and oak. Furthermore, pollarded trees often show low trunk quality (hollow trunks and rot holes due to the regular cutting) and lower diameter growth. Many of the pollarded oak trees that may be found in the landscape (e.g. Britain, Turkey, Sweden) indeed have hollow trunks as a result of this kind of cutting.

Pollarding was and still is used for park alley and garden trees, along streets, roadsides, and hop gardens. In certain regions (e.g. Portugal), pollarded plane-trees are used to hold cables and vine plants. In areas with long pastoral traditions (Basque Regions of France and Spain) or with large-scale silvo-pastoral systems (Spain, Portugal), pollarding is done at heights of 2.5 to 3 (3.5) m, well out of the reach of cattle and sheep.

The most important forestry use of the pollarding system is to stabilize the banks of rivers, streams, and ditches, mainly with willows and poplars. In this case, pollarding is done at heights between (1) 2 and 3 m - *above the highest flooding levels over a long chronosequence* - to avoid any damage to the high stump caused by the flooding waters. In case of willow pollards, the cutting of shoots is carried out in the same way as simple coppice, especially during the winter. In time, after 2-3 cycles of cuts of 15-20 years, willow pollards begin to deteriorate (often becoming hollow) and the coppicing potential and vigour of shoots becoming increasingly reduced. Consequently, pollards are replaced with seedlings or so-called *rods*, which are (1 or) 2 m long and 3-5 cm thick, and that will be treated subsequently as pollards.

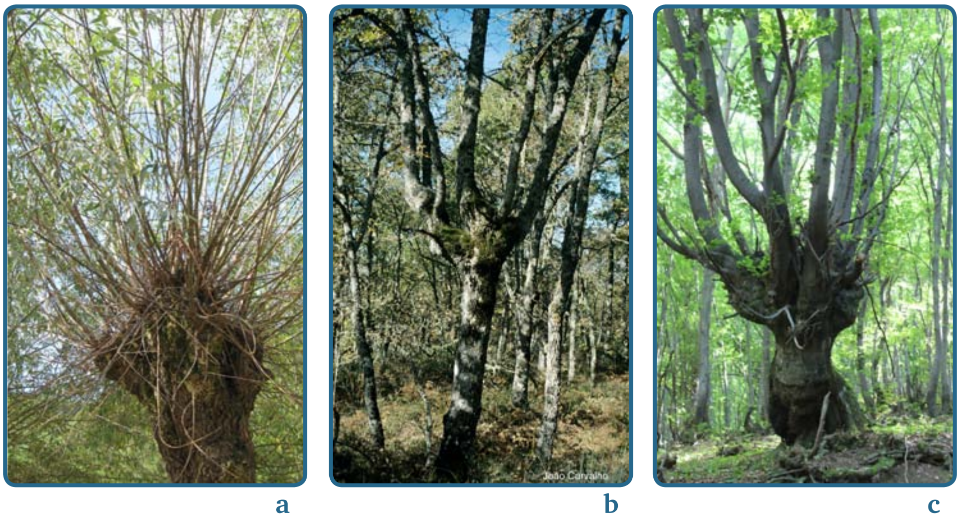

Figure 9. Repeatedly pollarded white willow (a), pedunculate oak (b) and European beech (c) (Photos: V.N. Nicolescu, J. Carvalho and O. Cardoso)

On the pollard tops, shoots are trimmed off periodically so that after this series of cuttings, the upper part of trunk looks like a reversed stump, sometimes called a ‘chair’ (Figure 10). After pollarding, many shoots may grow more or less vertically from the cut tree. These shoots may be subsequently thinned or left for self-thinning.

## 2.3 Coppice selection system

In a coppice selection system (CSS), a *target diameter* is fixed according to the size of aimed wood product, followed by an estimate of the age at which material of this size will be produced. This age determines the rotation, which is divided into a number of felling cycles (for instance: a rotation of 30 years includes three felling cycles of 10 years). The total area of forest under CSS is divided into annual coupes equal in number to the number of years in the felling cycle. Each year, coppice felling is carried out in one of the annual coupes [34]. Shoots of one to three (seldom four) ages coexist on the same stool, depending on the number of felling cycles in the rotation. Only shoots reaching the target diameter are cut, while the others are thinned.

The coppice selection system has historically been applied in certain parts of Europe, such as the Pyrenees, Apennines, Tessin Canton and the Balkan Peninsula, mainly in European beech and Holm oak forests (Figure 11).

In the case of European beech forests, the coppice selection system was commonly used in areas with poor soils and severe climatic conditions, where trees grow slowly. Under such

Figure 10. Pollarding of a narrow-leaved ash tree (Photo: J. Carvalho)

Figure 11. Coppice selection with European beech in Bosnia and Herzegovina (Photo: O. Cardoso)

conditions, the application of coppice selection system consisted of:

- Pyrenees: rotation of 30 years, with 2 felling cycles of 15 years or 3 of 10 years;
- Morvan Massif: rotation of 36 years, with 4 cycles of 9 years;
- Apennine Massif: rotation of 27-36 years, with 3 cycles of 9-12 years.

Two examples of coppice selection in European beech and Holm oak stands are depicted in Table 1.

Within the coppice selection stands, young shoots are better protected from frost, snow and grazing, due to the cover of older and largest shoots; apart from this, the soil remains permanently covered. Coppice selection is therefore interesting in the context of soil protection and habitat conservation. On the other hand, cutting at ground level is more difficult, it can damage smaller trees and the harvesting is more challenging and costly than clear-cutting.

When weighing these factors, this silvicultural system is considered to have more disadvantages than advantages, so that it has not been expanded outside the area where it was initially performed. Moreover, in cases of CSS with low productivity and vitality, these have been converted to high forests or selection forests, an example of which are the pure beech stands in Croatia.

## 2.4 Coppice with standards

Coppice with standards (CWS) is a silvicultural system in which selected stems are retained, i.e. *standards*, at each coppice harvest to form an uneven-aged overstorey that is removed selectively on a rotation consisting of a multiple of the coppice rotation [30].

Such stands are "the oldest form of irregular forest" [22], and comprise of two distinct elements [6] [16] [31] [33] (Figure 12):

**(a) A lower, even-aged storey** (*underwood*), originating from shoots and treated as coppice. This storey plays an *economic* role (produces small and medium-sized timber, used especially as firewood), as well as a *cultural* role (protects the soil and the trunks of standards in the upper storey).

Table 1. Two examples of coppice selection systems used in Europe

| Species | Region | Cutting technique | Rotation, felling cycle and products | Further information | Ref. |
|---|---|---|---|---|---|
| **European beech** | Italian Alps, Apennines, regions of Piemonte & Tuscany | Selection coppice (uneven-aged coppice)<br>The largest trees are cut, the smaller are thinned | Rotation: 6-12 years<br>Total cycle: 36 years<br>Firewood, charcoal | 1-2 shoots are kept per stump<br>Current use is limited;<br>Trend: convert to high forest | [15]<br>[38] |
| **Oak & hornbeam** | Central & Western Europe (France, Belgium, Germany) | Even-aged coppice layer below: mainly hornbeam, hazel & field maple<br>Uneven aged standards above: mainly oak (*Q. robur* & *Q. petraea*) | Rotation: 8-15 years (up to 30 years) for the coppice;<br>Selective felling of standard trees at every rotation (standard age = 2-6 rotations) | Prescribed stem numbers and shares of different age classes in the standards | [3]<br>[7]<br>[39]<br>[43]<br>[54] |

Figure 12. Coppice with standards in Austria (Photo: E. Hochbichler)

**(b) An upper, uneven-aged storey** (*overwood*) composed of taller but scattered trees (*standards*), originating from both shoots and seeds, distributed as uniformly as possible and treated as high forest. It is also has *economic* (produces a certain proportion of large timber) and *cultural* roles (provides seeds for natural regeneration) [14] [19] [40].

To establish a CWS stand, one first determines the age of the coppice rotation, then the following operations are carried out [39] [18] [19]:

1. Once the rotation age ***r*** (usually 20-25 years) has been reached, the coppice stand is clear cut as simple coppice, while reserving a certain number of a desired species in good form and increment as standards.

2. After another simple coppice rotation of 20-25 years, the great majority of standards of ***2r*** (40-50 years) are again reserved, extracting those that have deteriorated or are slow-growing. The majority of individuals are removed from the coppice storey, while a certain number of trees are reserved as second cohort of standards ***r***.

3. The same operation is repeated regularly for several coppice rotations of ***r*** years so the coupe about to be felled consist of coppice aged ***r*** years together with standards aged ***2r***, ***3r***, ***4r***... years, and a number of young prospective standards, aged ***r*** years.

**Standards** should originate from seed or, if not possible, from young and vigorous shoots, already individualized from the stool, or from root suckers. The trees reserved as standards should: originate from valuable and light-demanding species; have tall, large, balanced and open crowns; be wind-firm and; be scattered as regularly as possible [2] [6] [16] [33].

In CWS, standards are tall, but with shorter boles than high forest trees, and have wide and large crowns [19] [44] [50] – Figure 13). On the other hand, diameter increments are often considerably higher than in high forests.

The most recommended broadleaved standards are oaks, elms and ash. Other important species are sycamore, Norway maple, wild cherry, wild service tree, service tree, black walnut [6] [14] [33] [36]. European beech is not well-suited, mainly because of its tendency to sun scorch when isolated, in addition to its densely foliaged crowns, which casts a large shadow that negatively affects the growth of the coppice storey [6] [45] [52].

The number of standards in a CWS at a certain moment has evolved from a minimum of 16 young trees/ha (Flanders, 16th century [54]) or 30 trees/ha (Britain, 1543 [17]) to 40-50 trees/ha (France, Forest Law of 1827 [4]) or even 100 trees/ha (Germany [16]).

Figure 13. Oak standards in Austria (a) & France (b) (Photos: E. Hochbichler and J. Carvalho)

Nowadays, the proposed number of standards is 50-100 trees/ha for all age classes; the number of standards in each age class should be about half of the number in the age class immediately younger. For instance, in a stand with 100 standards/ha, there can be 50 standards in age class I (youngest), 30 in age class II, 13 in age class III, and 7 in age class IV (oldest) [26]. Hochbichler [28] [29] has developed stem number guidelines for different overwood cover percentages. The number of standards ranges between 82 and 163 trees/ha before cut in relation to an overwood canopy cover of 33% and 66% [target diameter of 60 cm; moderate sites; height of the overwood: 18-20 m; rotation: 30 years].

The rotations adopted for standards, "that should be reserved as long as they are healthy, vigorous, and growing sustainably" [36] reaches: silver birch from 40-60 years [28]; wild cherry (40) 50-70 years [19] [28] [36]; ash, elms, *Acer* sp. 75 (90)-100 years [19] [28] [36]; *Sorbus* sp. 50-70 years [19] [36] to 80-120 years [28]; oaks 100-130 years [17] [22] [28].

The **underwood** (coppice storey) in CWS consists of a mixture of species coppicing vigorously, able to withstand the shadow of standards (i.e. at least semi-shade tolerant species), and producing firewood [31] [45]. The most recommended species for underwood are hornbeam, field maple, European beech, linden, sweet chestnut, hazel [19] [27] [31] [45] [46] [52] [18]. The rotations of underwood used to be between 8 and 15 years, but are nowadays 20-30 years [7] [20] [28].

In CWS, the silvicultural operations to carry out depend on the stand storey:

(a) Underwood: release cutting, cleaning-respacing and 1-2 thinning(s); the latter operation if it is considered necessary to prepare the standards for their life after the cutting of coppice storey [40].

(b) Standards: Removal of epicormic branches along the stems (especially of pedunculate oak) that receive a surplus of light after the cutting of coppice storey [2] [9] [33]. These branches should be maximum 3 cm in diameter and the recommended season for cutting is before the beginning of a new growing season. Dead and dying branches, as well as those that are too long, should be also removed.

# 3 CONVERSION OF COPPICE FORESTS TO HIGH FORESTS

There are numerous reasons for coppice conversion, such as a change in management objectives or the targeted yield products (firewood vs. industrial wood), or concerns related to soil protection, conservation and landscape.

The most common conversions applied in European forests are (a) from simple coppice to either coppice with standards or high forests and (b) from coppice with standards to high forests.

There are currently two ways of achieving this aim: *direct* and *indirect* conversion. The former manages shoots of species already in the area, whereas the latter entails removing all species in the area and planting new species that are considered appropriate.

Some methods of *direct conversion* and *indirect conversion* are described in the following:

## 3.1 Direct conversion

In this case, the transition from simple coppice to high forest does not involve another silvicultural system. The method of direct conversion includes (i) *conversion by ageing* (conversion by full cessation of simple coppice cuttings), (ii) *mixed conversion* (conversion by partial cessation of simple coppice cuttings), and (iii) *conversion by replacement/restoration*.

**(i) Conversion by ageing** (conversion by full cessation of simple coppice cuttings): This is considered a *passive* procedure of conversion, where the simple coppice is no longer cut so that stands reach a maturity in which they are able to regenerate naturally by seed. During the waiting period, tending operations (e.g., cleaning, thinning) are applied depending on the stage of development. These interventions are halted after 60-80 years, after which silvicultural systems typical to high forests can be applied in order to regenerate the stands naturally by seed.

Conversion by ageing is applicable to healthy, vigorous and productive simple coppice stands, with full canopy cover, in which the target species are found in high proportion and the soil conditions are favourable to natural regeneration by seed. However, this method of conversion creates at least three problems:

- It takes many decades, depriving the forest owner from all income for quite a long period of time.
- The method is limited to the situation described above ("healthy, vigorous and productive simple coppice stands...").
- The method does not improve the age-class distribution of stands.

Due to the issues mentioned above, conversion by ageing has been abandoned since the 19th century in countries such as France, having been replaced by the so-called *method of selection*, or *intensive management of crop trees* (fr. *balivage intensif*), at least in vigorous stands that are rich in valuable broadleaved tree species. This is an *active* type of conversion and includes:

- Selection and paint marking of crop trees (originating from stump shoots or, preferably, from seeds). These should be vigorous, of good quality and as evenly spaced as possible.
- Initial application of high thinning in favour of crop trees. The subsequent thinnings are heavy and concentrated around the vigorous and valuable crop trees, in order to provide them with a "free-growth" state at crown level. This state will favour high wood production and the beginning of a rich seed production, supporting the conversion towards high forest at relatively young ages.

**(ii) Mixed conversion** (conversion by partial cessation of simple coppice cuttings): This is a *partially passive* method that targets the normalization of age-class structure of stands. In this respect, every 10 years a part of simple coppice stands are no longer exploited and are left to grow older in order to produce industrial wood, while the rest of the stands are treated as simple coppice. Proceeding in this fashion, the area of simple coppiced stands continuously decreases until they cease to exist, while the area covered with high forests increases and these stands form successive age classes.

**(iii) Conversion by replacement**: Is an *active* method that is usually used in degraded simple coppice stands that have a low proportion of valuable tree species, low canopy cover, low productivity, old stumps and low potential of natural regeneration by seed, compacted and fallow soils, etc.

The restoration of such coppice stands for their conversion to high forest can be done by:

- Clear-cutting, followed by planting, mostly of conifer tree species, such as pines or Norway spruce.
- Clear-cutting, followed by manual/mechanical seeding of species such as oaks.
- Use of high forest silvicultural systems, such as uniform shelterwood cutting (Figure 14).

Figure 14. Successive stages of conversion by using the uniform shelterwood system; holm oak stand in Croatia (Photos: T. Dubravac)

### 3.2 Indirect conversion

This method removes all current species and introduces new species to the area. It requires assessing each new species in order to ensure that it is appropriate for the local habitat.

This practice is widely practiced in artificial forests. For example, shoots of valuable tree species, such as beech and oaks, that are lost due to damage, may have been replaced by low value species (such as hornbeam, cranberry, shrubs).

These undesired species must be removed from what were once oak and beech forests; subsequently, the soil is prepared and beech and oak seedlings are planted and tended.

This method can also be applied to coppice with standards (Figure 15). In this case, when cutting the coppice storey of 20-30 years, a high number of standards (500-600 trees per ha or even more) are left standing, while extracting the older standards of ***3r*** and ***4r*** ages if necessary. The conversion cutting begins 30 years after the selection of standards, when such trees are already 60 years of age (***2r***) and can produce seeds needed for natural regeneration.

Figure 15. Indirect conversion of a mixed broadleaved simple coppice to coppice with standards in Austria (Photo: E. Hochbichler)

# 4 RESTORATION OF COPPICE FORESTS

Restoration is particularly recommended in cases where vegetation cover has declined and can no longer be defined as forest. This can result from a variety of causes, such as inappropriate harvesting operations, poor silvicultural management, illegal logging, excessive grazing, or disturbances such as fires, wind throws, wind breaks, etc. In some regions, for example the Mediterranean, restoration can prevent further ecological site degradation, such as soil loss and the prevention of bare karst formation. It is important to remember that the formation of soil is particularly slow in such conditions (i.e. very slow organic matter turnover). It is this protective function that is the primary driver for this type of intervention; after a disturbance the interventions should be carried out quickly in order to stop the degradation process.

Degraded coppice forests have low soil fertility, poor soil structure, high risk of erosion and an insufficient number of seed trees. The prerequisite for a successful restoration is the removal of the predominant negative influence(s) that initiated the degradation (e.g., browsing, fires, etc.). This is a complex and expensive activity that is not possible when negative forces cannot be prevented effectively.

As with conversion, there are two types of restoration: *active* and *passive*. Planting (in groups or clusters) or sowing are the most commonly used methods in active restoration. Passive restoration allows for natural colonisation and successional processes to occur.

Proper species selection is essential in order to better suit degraded soil conditions and serve as a climate adaptation strategy. Appropriately selected tree species lower the possibility of degradation initiated by climate disturbances (e.g. fires, wind throw) occuring in the future. Climate change-induced disturbances, such as droughts, can directly affect the planting success during restoration, especially in the Mediterranean region.

Some specific cases of restoration of coppice forests are described below.

### 4.1 Aged / abandoned / neglected simple coppices

In aged/abandoned simple coppice forests (Figure 16) there is a need for a detailed survey of the sprouting ability of remaining stumps after cutting.

It is generally thought that the possibility to use remaining stumps for natural regeneration is rather low, although current research shows that some tree species (e.g., oaks, sweet chestnut) have a long-lasting sprouting ability, even as aged trees. It is recommended that the restoration of coppicing is done gradually, i.e. not cutting all shoots of the stool at once, but leaving a number of younger, vigorous shoots (sap suckers) that will enhance the re-sprouting. If re-sprouting is successful, all shoots can be cut again when reaching the rotation age [41]. If the sprouting (especially the production of stump shoots) is not satisfactory, additional planting and sowing should follow the cut.

Figure 16. Neglected simple coppice stand of *Quercus faginea* in Spain (Photo: M. Piqué-Nicolau)

### 4.2 Neglected pollard trees

Pollard trees that have been neglected due to social-economic changes are of high ecological and cultural value; they should be conserved and, if possible, restored. They can be an important seed source for natural regeneration. On the other hand, one result of neglect can be that the large crowns hinder the growth of younger regeneration after sowing/planting. In this case, shade-tolerant species should be used as a coppice layer, resulting in a specific type of coppice with standards, or a pollarded wood pasture [12] [41]. Such forests have a lower wood production potential but may be of high ecological and landscape value.

The restoration of neglected pollards can be done by cutting the shoots. A good idea would be to plant a new pollard next to the old one that will eventually replace it.

### 4.3 Abandoned coppice with standards

Another need for restoration arises in abandoned coppice with standards, which possess an unbalanced CWS structure due to the prolongation of the underwood's rotation age. The prescription of restoration activities depends on (i) the number of adequate, quality overwood trees per hectare, as well as (ii) the regeneration ability of (former) underwood trees. If there are enough high quality trees in the overwood (20-40 individuals/ha), the cut of the coppice should be combined with a selective cut in the overstory in order to provide enough light for re-sprouting. The harvesting of standards should be done carefully in order to minimise damage to the coppice stools. In case there is a lack of natural regeneration by seed, the high stump sprouting ability should be utilised, along with the planting or sowing of valuable tree species for the overwood.

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# ANNEX

List of common and scientific names of tree species used in the guidelines

| Common name | Scientific name |
|---|---|
| **Alder** | *Alnus* sp. |
| • Black | *A. glutinosa* |
| • Grey | *A. incana* |
| **Ash** | *Fraxinus* sp. |
| • Common | *F. excelsior* |
| • Narrow-leaved | *F. angustifolia* |
| **Beech** | *Fagus* sp. |
| • European | *F. sylvatica* |
| • Southern European | *F. moesica* |
| **Birch** | *Betula* sp. |
| • Silver | *B. pendula* |
| • Pubescent | *B. pubescens* |
| **Cherry** | |
| • Wild (sweet) | *Prunus avium* |
| **Chestnut** | |
| • Sweet | *Castanea sativa* |
| **Elm** | *Ulmus* sp. |
| • Field | *U. campestris* |
| **Eucalypt** | *Eucalyptus* sp. |
| **Hazel** | *Corylus avellana* |
| **Hornbeam** | *Carpinus* sp. |
| • European | *C. betulus* |
| • Oriental | *C. orientalis* |
| **Linden** | *Tilia* sp. |
| • Small-leaved | *T. cordata* |
| • Silver | *T. tomentosa* |
| **Locust** | *Robinia* sp. |
| • Black | *R. pseudoacacia* |
| **Strawberry tree** | *Arbutus unedo* |
| **Maple** | *Acer* sp. |
| • Norway | *A. platanoides* |
| • Field | *A. campestre* |
| • Sycamore | *A. pseudoplatanus* |
| **Mulberry** | *Morus* sp. |
| **Oak** | *Quercus* sp. |
| • Holm | *Q. ilex* |
| • Hungarian | *Q. frainetto* |
| • pedunculate | *Q. robur* |
| • pubescent | *Q. pubescens* |
| • Pyrenean | *Q. pyrenaica* |
| • Sessile | *Q. petraea* |
| • Turkey | *Q. cerris* |
| **Plane tree** | *Platanus* sp. |
| **Poplar** | *Populus* sp. |
| • black | *P. nigra* |
| • trembling, aspen | *P. tremula* |
| • hybrid | *P. x euramericana* |
| • white | *P. alba* |
| **Service tree** | *Sorbus* sp. |
| • wild | *S. torminalis* |
| • common | *S. domestica* |
| **Walnut** | |
| • black | *Juglans nigra* |
| **Willow** | *Salix* sp. |
| • osier, white | *S. alba* |

# Two Potentially Invasive Tree Species of Coppice Forests: *Ailanthus altissima* and *Robinia pseudoacacia*

Alexander Fehér and Gheorghe F. Borlea

## INTRODUCTION

Biological invasions lead to ecosystem degradation and threaten biodiversity and related ecosystem services. The two trees species that are most likely to invade coppice forests are *Ailanthus altissima* and *Robinia pseudoacacia*.

While *Robinia* is at times itself considered a species suitable for coppice management, *Ailanthus* is almost solely considered invasive in Europe. The latter is rarely cultivated, with only a few exceptions of Short Rotation Forestry management in Mediterranean countries (Bianco et al. 2014).

Despite the invasive nature of these two species, both also have certain uses and advantages. Along with providing a description of the general characteristics of *A. altissima* and *R. pseudoacacia*, this article will address some of these negative and positive aspects.

## *AILANTHUS ALTISSIMA*

### Species and Range

The *Ailanthus* genus (*Simaroubaceae* family) comprises tree species distributed in the Middle East and the Far East, but its only temperate zone representative is the tree of heaven or sky-tree (*Ailanthus altissima*). One of the other species, *Ailanthus confucii*, was native to Europe in the Tertiary (Eocene-Pliocene). *A. altissima* is native to Northern-Central China (in the Yangtze River regions), Northern Vietnam and North Korea. It was introduced to Europe and the United States in 1784, with its recent secondary range covering almost the whole of Europe, and it has spread to new areas of Asia, Africa, South America and Australia. The common names refer to the species' ability to grow up to 30 m high, as well as its outstanding fertility and competitive ability, especially on poor soils and in polluted air. The species can invade as seedlings or ramets derived from one or more individuals, forming concentric patches (clumps) in open grazing areas, forest gaps and clearcuts, including coppice (Knapp and Canham 2000, Call and Nilsen 2003). In some European countries (e.g. Greece), it is common in hedgerows surrounding arable lands and in adjacent wetlands, but quite rare in shrublands, grasslands and forests (!) (Fotiadis et al. 2011).

### Ecology

A single tree can produce more than 2 million seeds, some of which are persistent. It also has a powerful ability to sprout without damage; its suckering and clumping system is impressive, capable of extending to more than 100 m in diameter. *A. altissima* is less successful in heavily canopied forests (high forests), but coppicing, cultivation, browsing or any natural disturbance (e.g. frost, fire, stem or root damage) will stimulate its expansion and colonisation. Any vegetative propagules can set adventitious shoots and roots, and *A. altissima* has many seed dispersal mechanisms: wind (medium dispersal distance 120 m), water, birds, rodents and human agencies (people or machinery).

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The species can tolerate pollution and poor site conditions, being indifferent to soil fertility, and it can adapt to a broad range of natural and artificial soils, including barren rocky layers, sandy or clay loams, dry calcareous and shallow soils, artificial deposits of gravel, sand and other materials, saline soils (roots can be submerged in sea water), as well as acidic and alkaline soils. It can withstand conditions in most urban and industrial areas, but it is sensitive to ozone (Gravano et al. 2003).

It has a large ring-porous wood structure with which water is rapidly transferred from its roots to its leaves and, conversely, it can reduce transpiration on hot days by summer branch drop (Kowarik 1983, Harris 1983, Lepart et al. 1991). It effectively reduces water loss by stomatal closure and lowered root hydraulic conductance (Trifilo et al. 2004). Two-year-old seedlings develop coarse, lateral, unbranched and widely spreading roots up to 2 m long. *A. altissima* is classified as a shade-intolerant, early successional species (Knapp and Canham, 2000). Delayed hard frosts may cause injury to young plants and to the upper shoots of older plants; however, it can survive temperatures as low as -35 °C. The tree has allelopathic properties in bark extracts, leaves, and seeds etc. due to flavonoid substances such as acacetin, apagenin etc. (Udvardy 2008). The direct influence of secondary metabolites of *Ailanthus* on biodiversity in natural ecosystems has been questioned by Mihoc et al. (2015).

Figure 1. Canopied, uncut coppice forest (left), and *A. altissima* growing in a clearing (right), Bábsky Les, Slovakia (Photo: Fehér 2015)

The forest understoreys of *A. altissima* are usually species-poor and rather cosmopolitan in character; its root sucker density negatively correlates with floristic richness (e.g. in France: Motard et al. 2011).

No significant natural enemies are known for *A. altissima*, but mistletoe (*Viscum album*) can cause its death. A rare decline in *Ailanthus altissima* was reported from Styria (Austria), where both older (35 year-old) and young trees were infected with agricultural soil microfungi (*Verticillium* sp., *Phomopsis ailanthi, Nectria coccinea, Fusarium* sp. and *Verticillium* sp.), causing dieback of branches in the upper crown, with bark necroses extending down the stem (Maschek and Halmschlager 2018).

## Case Study

### Description

In our case study, the invasive behaviour of *A. altissima* was studied after making clearings in an aged oak-hornbeam coppice forest in Bábsky les (Slovakia) in 2015 and 2016. Each of the three sample plots measured 400 m$^2$:

A : clearing made in 2006,

B : clearing made in 2014, and

C : canopied coppice forest in process of aging at present – the uncut control (Fig. 1).

### Observations

The herb layer of the two studied clearings (A and B) was dominated by nitrophilous species, with *Sambucus ebulus* and *Galium aparine* together forming almost 100% cover.

After spontaneously invading, *A. altissima* outcompeted the native apophytic and synanthropic forest species through allelopathy and nitrogen accumulation, dramatically changing the species composition. In **area A**, the phytocoenological relevée had the highest abundance of the following species: *A. altissima, Sambucus ebulus, Galium aparine, Geum urbanum,* *Mercurialis perennis, Pulmonaria officinalis* and *Urtica dioica*. In **area B**, most abundant were *A. altissima, Quercus cerris, Carpinus betulus, Galium odoratum* and *M. perennis*, while in **area C** *Q. cerris* and *Acer campestre* were dominant. The behaviour of different species depended on the nature of the competition. In **area B**, *M. perennis* had a different seasonal optimum than *A. altissima*; *S. ebulus* (when simultaneously cut with *A. altissima*) re-grew more quickly than *A. altissima* but *G. aparine* and *Bromus benekenii* disappeared under dominant *A. altissima*. In **area A**, *Hedera helix* and *Clematis vitalba* spread, but *Melica uniflora* and *G. aparine* disappeared when *A. altissima* dominated (Fehér et al. 2017, unpubl.). Plant communities of clearings in the same forests were also studied by Pilková (2014), who related the species composition to different environmental conditions of water, nutrients, light, continentality, soil reaction and temperature (Fig. 2).

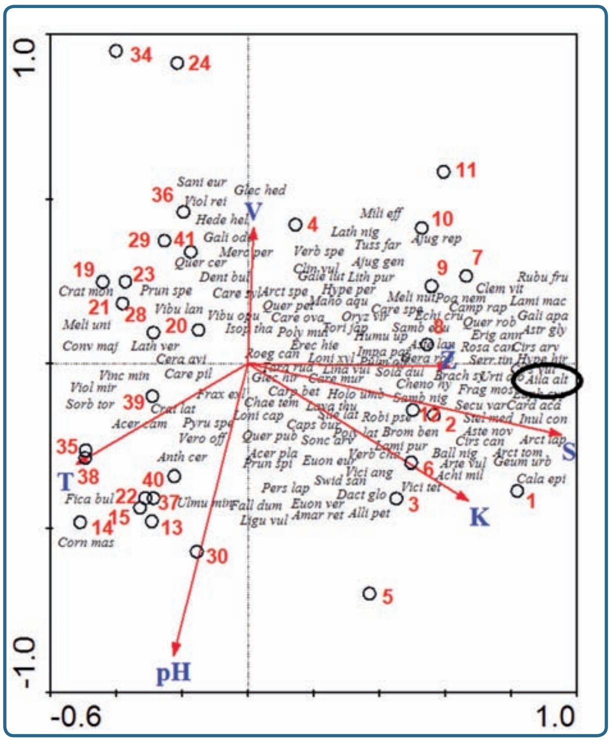

Figure 2. Occurrence of *Ailanthus altissima* is interrelated with nutrients and light (Pilková 2014, modified by Fehér). Ellenberg values: V - water, Ž - nutrients, S - light, K - continentality, pH - soil reaction, T - temperature

Management

To control *A. altissima* is quite problematic: for example, prescribed fire during the dormant season had a limited impact on its distribution (Rebbeck et al. 2017). Short-term mechanical and chemical treatment combinations did not reduce the number of resprouts over a five year period, although resprout biomass was reduced. Nevertheless, the long-term control of *A. altissima* resprouting was efficient, mainly as a result of reduced above-ground and below-ground growth; cutting alone, however, did not reduce it significantly. Some herbicides can be used to treat *A. altissima* but the required effect is poor (http://rvm.cas.psu.edu). The best control strategy is repeated and combined mechanical-chemical treatment.

## Conclusion

We can conclude that the presence of *Ailanthus altissima* in forests influences the species composition and structure of ecosystems, as well as the services provided by them. Sladonja et al. (2015) have carried out a detailed assessment of the disadvantages and advantages of the species: In terms of potential biological threat, *A. altissima* has a high invasive potential (fast growth and regeneration, allelopathy, high resistance to pollution and tolerates a wide range of environmental conditions), causes a decrease of biodiversity (i.e. replaces natural flora), is toxic and causes allergic reactions and dermatitis. On the other hand, it can provide certain ecosystem services, such as provisional services (pharmaceutical use, honey production, timber, paper, essential oils etc.), regulating services (erosion control, land reclamation etc.), cultural services (ornamental use, shade etc.) and supporting services (nutrient cycling, soil formation etc.). The extract from *A. altissima* is an antioxidant, antimicrobial and phytotoxic, having anticancer properties and is source of ailanthone (quassinoids), which has potential in treating malaria, HIV etc.

## ROBINIA PSEUDOACACIA

### Species and Range

The second invasive plant, black locust (*Robinia pseudoacacia*), belongs to the family *Fabaceae*. Approximately 20 species of *Robinia* are known in North and Central America, the majority being shrubs. The *Robinia* genus was present in geohistorical Europe (Eocene-Miocene) (Keeler 1990). *R. pseudoacacia* is native to the Eastern part of North America where it has a patchy distribution, the most important being in the Appalachian Mountains (Cierjacks et al. 2013). It has become common in many parts of the world, including almost the whole of Europe (mainly Central and South-East), Asia, North and South Africa, South America, Australia and New Zealand. There are more than 3 million ha of plantations worldwide (Hanover et al. 1991). In Europe, other species of the genus are quite rare (e.g. *R. viscosa* and *R. hispida*).

### Ecology

*R. pseudoacacia* is a tree that can reach over 30 m in height and can live for well over 200 years. The root system is strong and produces suckers with root nodules that can fix nitrogen (at c. 30 kg of N year$^{-1}$ ha$^{-1}$) and it can adapt well to the local soil conditions. The species grows well on sand dunes and alkaline soils and tolerates drought, but cannot survive in anaerobic soils with stagnant water. Although young plants can tolerate shade, older trees require light.

Figure 4. *R. pseudoacacia* coppice a few years after the selection of stems, Romania (Photo: Fehér 2015)

Figure 3. *Robinia pseudoacacia* coppice stand, Slovakia (Photo: Fehér 2015)

Seeds remain on the tree for a long time (even until the following year) and a single individual can produce 15.000-17.000 seeds per year. Seed production increases exponentially with age; a 50-year-old stand can produce 1 billion seeds ha$^{-1}$ year$^{-1}$. The seeds are dispersed by wind and endozoochory. Germination is limited by a hard episperm, so that only a portion of the current year's seed may germinate annually; seeds in the soil seed bank can remain viable for over 40 years (Bartha et al. 2008). Abiotic factors, such as low temperature, can damage the seed perisperm and may limit seed germination. Young seedlings can grow up to 1 m tall in the first year; flowering occurs after five years. Vegetative propagation is sometimes dominant, arising either from the stem or root suckers. Its "rope-like roots" can be as long as 20 m. Due to this excellent vegetative propensity, coppicing is the most common form of management (Fig. 3 & 4).

Alliances

Stands of *R. pseudoacacia* are usually monodominant, but mixed forests are formed when they invade other forests (eg. oak forests, Fig. 5). The ground flora of *Robinia* forest is rich in nitrophilous plants, such as *Chelidonium majus, Ballota nigra* and *G. aparine*. Within the

Figure 5. Mixed aged oak-horbeam coppice forest invaded by *R. pseudoacacia*, Slovakia (Photo: Fehér 2010)

*Rhamno-Prunetea* class we can distinguish three alliances with *R. pseudoacacia*:

1. *Chelidonio majoris-Robinion pseudoacaciae* monodominant mesic groves with a well developed shrub layer and the associations *Chelidonio majoris-Robinietum pseudoacaciae* and *Poa nemoralis-Robinietum pseudoacaciae*;

2. *Balloto nigrae-Robinion pseudoacaciae* woodlands in dry, sandy habitats with grass-dominated herb layers and the association *Arrhenathero elatioris-Robinietum pseudoacaciae* and

3. *Euphorbio cyparissiae-Robinion pseudoacaciae* stands on dry shallow soils, with the association *Melico transsilvanicae-Robinietum pseudoacaciae* (Chytrý 2013).

## Distribution, Management & Use in Europe

In Europe, the best ecological conditions for *R. pseudoacacia* are in the Central-East, due to its continentality. Most production of black locust is in Hungary, where it covers 22-24 % of all forests (two-thirds of which are of coppice origin). About 50 years ago, Hungary had more black locust forests than all other European countries put together (Frank et al. 2017; "Hungary" report in Chapter 6 of this volume).

The new Hungarian forest act (Act 2009 XXXVII) allows for the coppicing of black locust. Different technologies are used, such as afforestation with deep loosening, trenching or deep ploughing, or semi-natural reforestation with root suckers and man-made reforestation using deep loosening or complete soil preparation (Frank et al. 2017). Rarely, the trees are also pollarded (e.g. Slovakia, Fig. 6). In Hungary, the tree is often defined as a national treasure or cultural heritage ("Hungaricum") and the majority of foresters and the local population disagree with the dominant European perception of an "invasive plant to be removed". The Hungarian understanding of the species is exemplified by the following statement: "The economic viability of biomass production by black locust has been debated many times ... but established in a multi-purpose, ecocycle-based agricultural system where its invasive character is carefully controlled and its usefulness is fully utilised (applying even clone selection for site-adaptation and best possible performance), both environmental sustainability and profitability should be guaranteed." (Némethy et al. 2017). In other Central and Eastern European countries (Slovakia, Romania etc.) new plantations are rarely established, but old plantations are maintained. A very productive variety with distinct features was described in Southern Romania. The profitability of black locust as short rotation coppice can be questionable (Stolarski et al. 2017) but it can be ecologically and environmentally attractive in previous mining and agricultural areas (Carl et al. 2017).

Figure 6. Pollarded *Robinia pseudoacacia* trees along a lane, Slovakia (Photo: Fehér 2010)

In the rest of Europe, *Robinia* is not planted, or only rarely, for example to limit soil erosion on sand dunes and hill slopes. The species is one of the most important melliferous trees (half of the Hungarian honey production originates from the black locust) and it produces excellent fuelwood, garden furniture and raw material for pulp. It can be important for soil improvement and N fixation, and for the phytoremediation of heavy metals and polycyclic aromatic hydrocarbons. Forests create shelter for wildlife, and parts of the plant can be eaten. The fresh flowers, for example, were traditionally consumed in Hungary, Slovakia and Romania, and sometimes still are today. The seeds are likely edible as well, although some authors label them as toxic since most parts of the tree contain toxalbumin and other toxins. Black locust also has medicinal properties (e.g. as an antispasmodic, emollient, diuretic and laxative). *R. pseudoacacia* is fast growing when young and resistant to harmful pests and diseases. It tolerates pollution well, but prevents natural succession processes and reduces local biodiversity. When it colonises an area, it changes the habitat radically through allelopathy, N fixation, altered water balance and shading, etc.) and it is almost impossible to control. The prescribed control strategy is a combination of mechanical and chemical treatments (for a minimum of 3 years), but new seedlings will emerge from the soil seed bank for many years afterwards.

## DISCUSSION

It is challenging to compare the invasive competition of *A. altissima* with *R. pseudoacacia*. Although *R. pseudoacacia* originally arrived earlier than *A. altissima*, the latter was able to spread at a faster rate over a period of 30 years (Radtke et al. 2013). During the coppice cycle of native species, both *Ailanthus* and *Robinia* can invade synchronously and successfully colonise fresh clear-cuts. Coppice management, consisting of repeated clear cuttings every 20-30 years, favours this spread. In the United States, Call (2002) observed that *A. altissima* and the native *R. pseudoacacia* were frequently found on disturbed sites and presented similar growth and reproductive characteristics, yet each had distinct functional roles, such as allelopathy and nitrogen fixation. *A. altissima* was the better competitor in mixed plantations; it consistently produced larger above- and below-ground relative yields. Locally, increased disturbances could lead to more opportunities for *A. altissima* to invade and negatively interact with *R. pseudoacacia*, besides replacing the native species.

We can conclude that both *A. altissima* and *R. pseudoacacia* are successful invaders that have become naturalised in many temperate regions. They are good competitors in relation to other trees and understory herbs in coppice forests, forest gaps and clear cuts (Tab. 1). They outcompete the local forest vegetation communities protected in NATURA 2000, and have a negative impact on biodiversity. NATURA 2000 habitats that are endangered by invasions of these species include 9170 *Galio-Carpinetum* oak-hornbeam forests, 91G0 Pannonic woods with *Quercus petraea* and *Carpinus betulus* and 91H0 Pannonian woods with *Quercus pubescens* etc. (Viceníková and Polák 2003). In other countries, the occurrence of either *A. altissima* or *R. pseudoacacia* is used as a criterion to assess the state of the NATURA 2000 habitat condition (Polák and Saxa, 2005). Nevertheless, in some European countries black locust is considered important both culturally and economically, and is well accepted and understood to be part of the cultural heritage. Such countries are interested in its future preservation (mainly in Hungary),

Table 1. Attributes of invasive behaviour in *Ailanthus altissima* and *Robinia pseudoacacia*

| **Attributes of invasive behaviour** | ***Ailanthus altissima*** | ***Robinia pseudoaccacia*** |
|---|---|---|
| early flowering maturity | 3-4 y | 5 y |
| flowers are easily pollinated by insects | yes | yes |
| no danger of late frosts | yes | yes |
| very prolific annual fruiting and sprouting | yes | yes |
| easy propagule dispersion by wind, water, animals, hazards | yes | yes |
| successful natural regeneration | yes | yes |
| rapid rooting and growth | yes | yes |
| successful vegetative propagation by adventitious buds | yes | yes |
| allelopathic substances inhibit growth of other seedlings and herbs | yes | yes |
| no important pests and parasites or predators | yes | yes |
| high tolerance of climatic conditions, pollution and infertile soils | yes | yes |
| seeds preserve their germination ability for a long time | yes | yes |
| nitrogen accumulation in the soil | yes | yes |
| expected life span | c. 150 y | c. 250 y |

but in others this is debated (eg. Romania, Slovakia). Coppice regimes should take into careful consideration the invasive potential of both species, especially in the continental climates of Central and Eastern Europe. A positive ecological utilisation of both species is also possible, such as the phytoremediation of soils contaminated by heavy metals (e.g. Cudic et al. 2016).

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# Active Management of Traditional Coppice Forests: An Interface Between Silviculture and Operations

João Carvalho, Natascia Magagnotti, Valeriu-Norocel Nicolescu,
Philippe Ruch, Raffaele Spinelli and Eduardo Tolosana

## Coppice and Coppice Silviculture

Coppice is a forest regenerated from vegetative shoots that originate from the stump and/or from the roots, depending on the species.

The potential of producing shoots depends on the species, tree age, season of cutting, site conditions and other factors. Most broadleaved tree species (e.g. oaks, sweet chestnut, linden, willows, poplars, hornbeam, elms, alders, black locust, eucalypts, etc.) produce shoots and can be treated as coppice.

There are different forms of coppice forests: simple coppice, coppice with standards, coppice selection and pollarding (examples in Fig. 1).

Coppice forests can provide many different products and services, such as wood and non-wood products, biodiversity, protection and heritage ecosystem services.

Approximately 16% of all productive forests in Europe are classified as coppice, covering a total area of ca. 23 million ha. These are mainly located in the far west, south and south-eastern parts of the continent. Over half of European coppice forests are situated in industrialized countries, such as France, Italy and Spain.

Since the renewal of coppice stands depends on active human intervention, abandonment is the greatest threat to the existence of coppice. The widespread abandonment that has occurred within the past century is a result of the social and economic transformation of European society, which has made traditional coppicing practices less profitable in many countries.

Converting coppice forest to high forest is an approach used to attempt to increase owner revenues and maintain active management. In some circumstances, this approach has been driven by subsidies or legal requirements. Such instruments do not, however, always achieve desirable results: Conversion requires suitable site, species and market conditions, and should not be generalized.

Under certain economic conditions there has been the opposite effect, where coppice has been degraded through overexploitation. The restoration of such coppice forests is possible and has been performed in some parts of Europe.

A new and interesting opportunity for expanding the active management of coppice stands is offered by the modern bio-economy, which is generating a large and sustained demand for biomass feedstock. Coppice management can supply this market with significant amounts of wood if the production can be achieved at competitive cost.

Coppice forests are acknowledged for providing important amenity, cultural and environmental services with the potential to generate greater revenues in the future.

Figure 1. Example of simple coppice (left) and pollarding (right) (Photo: V.N. Nicolescu)

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## Coppice Products and Operations

Many wood products can be obtained from coppice forests, such as firewood, biomass chips, fencing, assorted and industrial wood (pulp, panels, tannin etc.). Coppice also offers a variety of non-wood forest products, such as truffles, mushrooms and honey.

The market for these products can be local, regional and even international. Niche markets are also available for traditional small-scale products, such as baskets and crafts.

The industrial scale of some markets (pulpwood, panels, biomass etc.) offers great opportunities for reviving active coppice management. These specific markets require a high production capacity in order to supply large amounts of wood (Fig. 2).

Figure 2. Mechanized felling and bunching in a eucalypt coppice (Photo: E. Tolosana)

High production capacity is only achievable through the increased mechanization of harvest operations, which would also help to compensate for the effects of the high cost of labour and the labour shortages that are being experienced in most industrialized countries.

Technological progress has made possible the effective introduction of mechanized felling to coppice operations (Fig. 3), significantly increasing worker safety and productivity. Professional management of mechanized harvesting can prevent or minimize undesired effects, such as soil, stump and stand damage.

The productivity of motor-manual and mechanized harvesting improves with increasing tree size and harvest intensity. Productivity is also higher on flat lands and gentle slopes than on rough terrain. Long extraction distances have a negative impact on harvesting costs.

When harvesting is mechanized, the amount of wood removed must be large enough to offset the high fixed cost of transporting machines to the worksite.

Specific harvesting techniques and equipment (whole-tree harvesting, bundling, chipping, etc.) are required for the supply of feedstock to the biomass sector (Fig. 4).

Work safety has become a priority across Europe, and the accident rate and severity in mechanized felling is much lower compared with the motor-manual option.

Figure 3. Mechanized felling and processing (Photo: P. Ruch)

Figure 4. Coppice harvesting residues are chipped into renewable fuel (Photo: E. Tolosana)

## Considerations for Active Coppice Management

Active coppice management should be sustainable in all terms (economic, ecological, social), but also requires financial viability in the absence of subsidies or other financial aid. The total area of coppice forests in Europe is so large that subsidies can only be directed towards special cases.

Silvicultural prescriptions should be formulated in such a way that their practical implementation is easy and cost-effective.

The coppice silvicultural system and rotation should be chosen depending on the species and the requirements of the local, regional, national or international markets.

Abandoned, neglected or overexploited coppice forests are likely to degrade and may not fully (re-)cover their functions. Such degraded forests should be restored by using different techniques, which are seldom cost-effective and, thus, require subsidization.

Figure 5. Processor and yarder (Photo: R. Spinelli)

The financial viability of the commercial harvest of coppice in industrialized economies requires that a minimum amount of wood is removed and that a certain harvest intensity is applied. The combination of these two conditions determines the minimum harvest area. At the same time, there are maximum limits for harvest area that should not be exceeded, in order to preserve the ecological, protection and aesthetic functions of coppice forests.

Figure 6. Cable yarder extraction is the best solution when site conditions are not favourable to machine access (Photo: R. Spinelli)

Wherever labour costs are high, selective and low-intensity thinning incurs net operation losses. Mechanization can, however, increase the productivity, profitability and safety of coppice management operations. It can also compensate for the decreasing availability of rural labour in some regions. Mechanized harvesting requires specific work conditions and involves specific risks (Fig. 5 & 6).

Aside from the general conditions for successful operation, mechanization also requires sufficient annual utilization to depreciate the large capital outlay. If coppice rejuvenation is not impeded, then one may consider extending the cutting season beyond traditional practice. This is an important prerequisite when cutting is mechanized and the equipment can only be used in coppice forests.

Generally, the quality of cut in mechanized felling is poorer than that of motor-manual felling (Fig. 7). If poor cut quality compromises coppice re-sprouting and/or growth, then remedial action should be taken. On the other hand, if no adverse consequences are experienced on coppice re-sprouting and/or growth, then some tolerance for poor cut quality is advocated.

The unregulated access of machinery to the forest may result in damage to stumps, residual trees, advanced regeneration and soil. Therefore, preventive measures must be taken, especially when site conditions are unfavorable.

Whole-tree harvesting may negatively affect soil fertility, especially on poor sites and when leaves are also removed from the site. Therefore, whole-tree harvesting should be applied with caution, after a careful evaluation of site conditions and of potential undesired effects.

Figure 7. Motor-manual felling
(Photo: R. Spinelli)

## Concluding Statements

Coppice forests are an important renewable resource for Europe, with a large potential for providing products and services that have, thus far, only been used to a small extent.

The new awareness of the potential of coppice forests together with the existing and future markets for renewable biomass offer an ideal opportunity for reviving active coppice management.

Unlocking the full potential of coppice forests requires a strong connection between silviculture and forest operations.

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## “Coppice Forests in Europe”

**Coppice Forests in Europe**

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