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 broad-leaved 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,

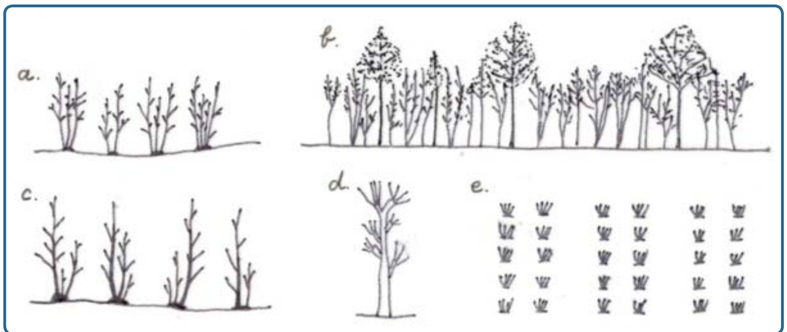

Figure 1. Different types of coppice forests: simple coppice (a), coppice with standards (b), coppice selection (c), pollarding (d), short rotation coppice (e) (drawn by J. Carvalho)

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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.

a b c d e

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

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].

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)

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

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

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.

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.

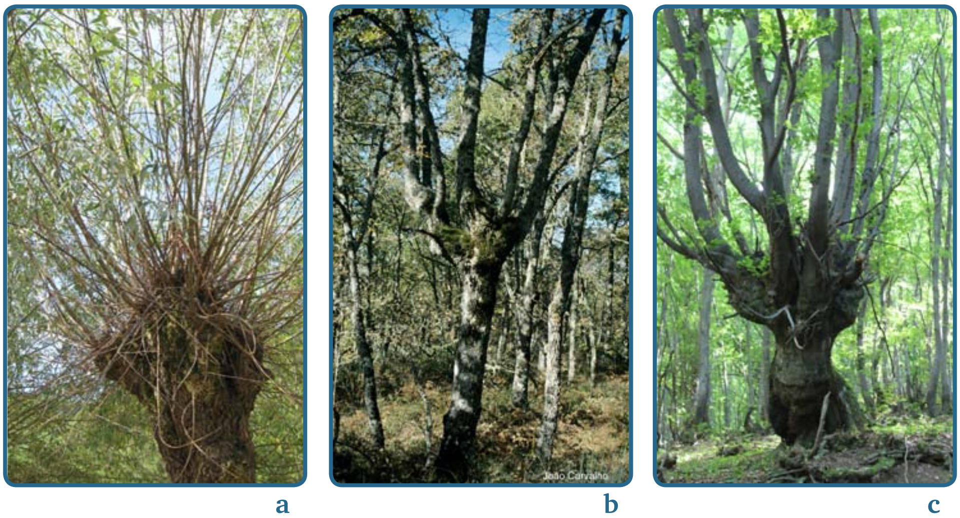

Figure 9. Repeatedly pollarded white willow (a), pedunculate oak (b) and European beech (c) (Photos: V.N. Nicolescu, J. Carvalho and O. Cardoso)

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) The largest trees are cut, the smaller are thinned	Rotation: 6-12 years Total cycle: 36 years Firewood, charcoal	1-2 shoots are kept per stump Current use is limited; Trend: convert to high forest	[15] [38]
Oak & hornbeam	Central & Western Europe (France, Belgium, Germany)	Even-aged coppice layer below: mainly hornbeam, hazel & field maple Uneven aged standards above: mainly oak (*Q. robur* & *Q. petraea*)	Rotation: 8-15 years (up to 30 years) for the coppice; 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] [7] [39] [43] [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]).

a b

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*

Common name	Scientific name
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*

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