Subject review

Trends and Perspectives in Coppice Harvesting

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Abstract

Coppice management is applied to many species, in many countries and in many ways, so that several harvesting techniques have been developed depending on specific local conditions. However, all techniques designed for handling coppice stands must be suitable for coping with small stem size and stump crowding, and often with steep and generally difficult terrain. Traditional harvesting systems are labor intensive because they usually include motor-manual felling and processing into one-meter lengths at the stump site, and manual loading of the short logs onto pack animals or tractors. Thus, in industrialized countries, these systems are no longer viable and they are being replaced with mechanized cut-to-length and whole-tree harvesting, depending on site conditions. Mechanization dramatically improves worker safety, and compensates for the reduced availability of rural labor, with their propensity to perform heavy and low-paying jobs. Much progress has already been made, with the massive introduction of modern harvesters, forwarders and tower yarders in coppice harvesting operations. The presence of multiple stems on the same stump offers a serious challenge to the introduction of mechanized felling to coppice harvesting operations, because stump crowding hinders felling head movements. However, new machines have been designed that can handle coppice stumps. Further research should address the relationship between stump damage and regeneration vigor, in order to define new standards for cut quality. Silvicultural practice may need adapting to the new harvesting technology and to the products required by the modern bio-economy.

Keywords: felling, extraction, productivity, logging, mechanization, biomass, management

1. Introduction

Coppicing is a traditional silvicultural system whereby stand regeneration after cut is obtained from the re-sprouting of cut stumps, rather than from the establishment of new trees from seed. As a consequence, this system is only suited to those species that can sprout new shoots from their stumps after cutting. Such capacity is typical of some hardwood species, if the interval between cuts does not exceed 50–60 years. To keep the re-sprouting ability, frequent cutting is needed and the application of coppice management requires relatively short rotations.

Coppice management is extremely efficient, because it offers the benefits of simplified care, prompt regeneration and short waiting time. On the other hand, coppice management has some important limitations, and especially the exclusion of softwood species and the relatively small size of assortments produced, which is the obvious consequence of the short rotations characterizing coppice management.

For these reasons, wood from coppice forests is likely used as energy and as industrial wood, typically firewood and pulpwood, although coppice forests are also a main source of posts, tool handles and fencing materials (Buckley 1992). Historically, coppice forests are associated with rural communities and represent the ideal complement to conventional agricultural systems. Coppice woodland was widespread all over Europe until recent times, when industrialization transformed both the economy and the landscape of many regions (Coppini and Hermanin 2007). In the post-war years, traditional coppice systems have suffered from the competition of oil and plastic, which have resulted in a decreasing interest towards the active management of traditional coppice stands (Hédl et al. 2010). Therefore, large areas of coppice forests are not managed any longer.

However, in the last years new applications of the coppice concept have been developed, specifically designed for industrial use and/or for a changing agriculture. For the sake of clarity, the authors of this paper have decided to distinguish among three broad types of coppice stands, as follows (Table 1).

Table 1 Main types of coppice stands

Coppice definition	Conventional	SRF	SRC
Species type	*Quercus* sp. *Fagus sylvatica* L. *Ostrya carpinifolia* L. *Etc.*	*Populus* sp. *Eucalyptus* sp. *Acacia* sp.	*Salix* sp. *Populus* sp. *Eucalyptus* sp.
Rotation years	15–40	5–15	2–5
Product type	Firewood	Pulpwood	Chips
Economy domain	Industrial and small-scale forestry	Industrial forestry	Industrial agriculture
Harvest technology	Forest	Forest	Agricultural

Conventional coppice. This is established with indigenous hardwood species (oaks, chestnut, beech, hornbeam etc.) and occasionally exotic ones (Robinia). It is harvested on 15–40 years rotations for a large variety of products, and it is managed within the framework of a rural economy according to local traditional practice. It is generally harvested with forestry equipment, small-scale or industrial.

Short rotation forestry (SRF). Stands are established with exotic fast-growing species (eucalypt, acacia) and harvested on 5–15 years rotations for the production of industrial feedstock (generally pulpwood). SRF developed within the framework of a large-scale industrial economy and it is often geared to supply large industrial plants. SRF stands are often (but not exclusively) managed as coppice, and they occasionally undergo shoot reduction treatments (thinning). Stands are generally harvested with industrial forestry equipment, and occasionally with small-scale forestry equipment.

Short rotation coppice (SRC). Stands are established on ex-arable land with genetically-improved fast-growing species, indigenous (willow, poplar) or exotic (eucalypt, robinia). They are harvested on 2–5 years rotations for the production of industrial feedstock (generally energy biomass), and managed within the framework of small-scale or industrial agriculture. So far, SRC represents a niche sector and it is generally harvested with modified agricultural equipment.

This review focuses only on the harvesting of conventional coppice forests, because a comprehensive analysis of all three types could be too long for just one paper, and potentially confusing. Besides, the surface covered with SRF and SRC is still relatively small in Europe, especially if compared with that covered by conventional coppice. In fact, SRF covers about half million hectares concentrated in the Iberian Peninsula, where SRF eucalyptus plays a major economical role. On the other hand, SRC is unlikely to cover more than 25,000 hectares in Europe, and it does not have any significant impact on the European economy yet. In contrast, the importance of conventional coppice is vastly larger, and it dwarves those of both SRF and SRC. The total surface of conventional coppice in the EU and its neighbors is estimated to over 26 million hectares (Table 2), which is 50 times larger than the surface of SRF and 1000 times larger than that of SRC.

Table 2 Coppice forests in the EU and its neighbors

Country	Mi, ha
France	6.8
Turkey	5.7
Italy	3.3
Spain	3.0
Bulgaria	1.8
Greece	1.6
Serbia and Montenegro	1.4
Bosnia and Herzegovina	0.8
Republic of Macedonia	0.6
Croatia	0.5
Hungary	0.5
Albania	0.4
Romania	0.3
TOTAL	26.7

Note: the list includes only the Countries with at least 100,000 ha of coppice. Coppice is present in many other European countries than reported in the table (extracted from Nicolescu et al. 2015)

Conventional coppice forests represent a very large biomass resource, or a very serious landscape management problem if no productive use can be made of their potential, because abandoned coppice forests may degrade and become very susceptible to pests and forest fires. However, these immense reserves of woody biomass may represent the ideal solution to matching the large demand for biomass feedstock generated by a rapidly growing bio-economy (Matula et al. 2012). Biomass users need huge amounts of low-quality wood at short intervals, which is what coppice was designed to offer in the first place (Jansen and Kuiper 2004). While new short-rotation plantations are being established on ex-arable land, existing conventional coppice forests might be simply recruited into the new economy as an even larger source of raw material, thus being returned to active and profitable management when the demand for traditional coppice products is dwindling (Hédl et al. 2010).

The goal of this paper is to produce a general review of existing literature about the harvesting of conventional coppice stands, with the intent of:

⇒ building a general framework of available technologies and techniques

⇒ providing general productivity benchmarks that may serve as a base reference

⇒ describing current trends and future perspectives.

This paper does not have the ambition to include every single study appeared in the past, or to describe all possible techniques or to offer a comprehensive coverage of all aspects of coppice harvesting – and especially site impacts and human factors. However, the general picture drawn in this paper may represent a viable background for framing existing and new studies.

2. Silviculture and products

The traditional management of conventional coppice forests is quite simple, and it is based on clearcutting at the end of rotation. Standards are often released, with a density ranging between 50 and 100 trees per hectare, depending on the species. No other interventions are needed. If coppice management is no longer desirable, then the over-mature stand is thinned by removing approximately 40% of the standing volume. This intervention is expected to favor conversion into high forest, and it is followed by additional thinning treatments until the mature transitional forest is ready for regeneration felling.

The final harvest of a mature coppice stand commonly yields between 90 and over 200 m^3 ha^{-1}, depending on species, age and site productivity. The harvest obtained from thinning (conversion) over-mature coppice is more variable and depends on how old is the stand, but it generally varies from 40 to 200 m^3 ha^{-1}. As a general rule, clear-cutting accrues profits, whereas thinning (conversion) generates losses (Motta et al. 2015). That is true for coppice as well as for high forest (Petty and Kärhä 2011). In the past decades, conversion was often subsidized with public grants, in an attempt to drive heavily anthropized ecosystems towards more natural forms, which was especially attractive at a time when energy wood was being phased out (Stajic et al. 2009). Today, a new appreciation of the cultural and ecological value of coppice stands has combined with the growing demand for wood biomass in causing a general reconsideration of the past emphasis on coppice conversion (Urbinati et al. 2015).

Coppice management implies short rotations, and that has a strong effect on product type. Stems are cut before they can get very large, and they are best suited for conversion into small-size assortments. Mean stem size varies most often between 0.05 and 0.25 m^3, and it is smallest for oak and largest for chestnut, regardless of treatment type (clearcut or thinning). In general, coppice harvesting yields very limited amounts of timber, which is obtained from the standards released in the previous harvest.

3. Traditional harvesting systems

In former times, manual work was dominant and it made sense to reduce cut stems to such a size that could be easily handled manually as early as possible, if that would not degrade assortment value. Firewood was cut into one-meter lengths at the stump site, before loading it on pack animals (Fig. 1) for extraction and transportation (Carette 2003, Lepper and Frere 1988). With minimum adjustments, animal extraction remained in use until a few years ago in countries such as Italy and France (Baldini and Spinelli 1989). Although there is no recent bibliography on the subject, anecdotal evidence points at its widespread current

Fig. 1 Extraction by pack-mules in a mixed oak coppice

use in the Balkans and Greece (Gallis 2004), with significant survivals in southern Italy as well (Civitarese et al. 2006). The only modern adaptations to this ancestral system are the introduction of chainsaws for felling and processing, and of trucks for transportation, so that animal work is limited to extraction (Piegai et al. 1980).

Small stem size, uncomfortable working position and the need for turning all stems into one-meter lengths combine to determine a very low productivity of motor-manual felling and processing, which is reported in the range between 0.3 (Piegai 2005) and 1.4 m^3 (Picchio et al. 2009) per scheduled machine hour (SMH) and operator. Manual bunching of one-meter logs contributes to such low productivity figures. Significant manual inputs are also required for leading the animals to the loading site, loading them with ca. 200 kg of firewood each, and unloading the product once back at the roadside landing (Spinelli et al. 2016a). The typical team comprises 2 operators and between 6 and 12 mules or horses. Extraction distances commonly vary from 200 to 800 m, depending on slope gradient and the direction of extraction: shorter distances can be sustained if extraction proceeds uphill, on steep slopes. The productivity of such team may range from 1.3 to 1.8 m^3 SMH^{-1}, depending on the number of animals and on work conditions (Baldini and Spinelli 1989).

The hourly cost of animals is relatively low, and it has been estimated to less than 8 € $hour^{-1}$, excluding the driver (Magagnotti and Spinelli 2011). However, if operators were paid the 25 € SMH^{-1} rate characterizing modern logging operations in industrialized European countries, this system would be too expensive to run. In that case, the cost would range between 18 and 80 € m^{-3} for motor-manual felling and processing, and between 70 and 100 € m^{-3} for extraction. Even the lowest cost combination (90 € m^{-3}) would be higher than the cost paid at the landing for quality firewood in the same countries, which is reported to be around 75 € m^{-3} (Spinelli et al. 2014). Obviously, this system is still competitive where labor cost is much lower than in industrialized economies, or where irregular underpaid labor is introduced, which is a growing phenomenon in many regions and represents the bane of law-abiding regular loggers (Pettenella and Secco 2004).

Once solved the problem of labor cost, mule logging offers several advantages, because it can be deployed in rough terrain and does not require opening new skid trails, which may incur additional cost and impact (Magagnotti and Spinelli 2011). More in general, animal logging allows a dramatic reduction of site impacts compared to other logging methods (Shresta et al. 2008, Spinelli et al. 2010a), especially when a dense residual stand is present, as is the case with coppice conversions. In fact, the anachronistic survival of animal logging in modern countries such as Italy is partly due to the subsidies released in the recent past for coppice conversion, which allowed bearing the cost of otherwise unsustainable work methods. However, the main threat to the survival of animal logging in industrialized countries is not financial viability, but the inconvenience of constant care. Animals must be attended to on a daily bases, and they cannot be parked in a barn and forgotten when the logging season is over.

4. Attempts at modernizing traditional harvesting systems

For a short while, chutes were the rage, and they were purchased in significant numbers especially by cooperatives and public administrations (Piegai 1985). While chutes could be easily stored for extended periods with no further care, log sliding turned out to require larger manual inputs than animal logging (Baldini 1987). Obviously, a cooperative or a public administration cannot offset labor cost by hiring irregular workers, and therefore chutes remained in some use as long as subsidies were available, disappearing with the end of public support.

All the above explains the search for a mechanical surrogate of the traditional mules, already started in the late 1980s (Baldini and Spinelli 1990). Over time, various micro-tractors have been designed and tested (Gallis 2004, Magagnotti et al. 2012) but none has ever obtained commercial success. Eventually, pack-mules have been replaced with the so called pack-tractor, i.e. a farm tractor equipped with front and rear bins capable of containing ca. 3 tonnes of one-meter logs (Piegai and Quilghini 1993). The bins are normally mounted on hydraulic lifts, so that they can be lowered to the ground for easier manual loading (Fabiano 2006). This solution is quite crude and it does stress the tractor frame, so that much anecdotal evidence is available about tractors splitting in half at the clutch flange. However, simple solutions often stick, and so it is for this artless method, which offers the benefits of minimum investment and specialization. The limits of the method are represented by extraction distance and terrain roughness. Small payload size prevents efficient use on distances longer than a few hundred meters, while the limited mobility of an encumbered farm tractor requires relatively easy terrain, or a good network of skid trails. Productivity is higher than reported for mule teams, and it varies from 2 to 4 m^3 SMH^{-1} with a crew of two (Piegai 2005, Verani and Sperandio 2003).

It is very important to remember that all these developments are the consequence of specific silvicultural trends, and especially the strong drive towards coppice conversion. The maneuverability constraints imposed by selection thinning have systematically favored such methods as mule extraction, sliding in chutes and pack-tractors. There would be no reason to use relatively small size boxes, if the circulation of a proper tractor-and-trailer unit was not hindered by a dense residual stand, without suitable openings for machine traffic. In fact, dedicated forwarding trailers are used in clearcuts, and offer better performance than boxes, even when manual loading is applied (Spinelli and Baldini 1992). Over 30 years of experience with suboptimal working method should motivate a general revision of the traditional relationships between silviculture and operation management, and lead to re-assessing the past emphasis on coppice conversion. Low operational efficiency is acceptable as long as grant money is available to cover unsustainable harvesting costs. When such grants are no longer on the table, then re-thinking the whole strategy is the only alternative to the end of active management, which would also configure as the end of coppice.

5. Mechanized cut-to-length harvesting

Mechanized cut-to-length (CTL) harvesting is based on the introduction of the classic harvester-forwarder combination (Kellogg et al. 1993). While representing a radical technological innovation, CTL harvesting is not a revolutionary system change, because it includes about the same task sequence observed for the traditional system, and namely: felling and processing at the stump site, and forwarding of short logs to the roadside over the forest floor. The main difference is that all tasks are performed by machines, so that »*no man is on the ground, no hand touches the wood*«. For this reason, the system must be adapted by increasing log length, because one-meter logs are too short for efficient mechanical handling. When CTL is introduced to coppice harvesting, log length is generally increased to 2 or even 3 m (Fig. 2).

Fig. 2 Mechanized cut-to-length harvesting in a chestnut coppice

The presence of multiple stems on the same stump offers a serious challenge to the mechanized felling of coppice, because stump crowding hinders head movements, and can be handled by very compact units only (Labelle et al. 2016). The ideal head for harvesting coppice is short (Zinkevičius et al. 2012), has two mobile knives only (Spinelli et al. 2002), and does not close its rollers in a triangular configuration (Moscatelli et al. 2010). That is the case of AFM 60, Kesla Foresteri RH20, SIFOR 350 or UTC CTL40 HW, just to mention some of the heads that have been successfully tested for hardwood harvesting (Martin et al. 1996, Spinelli et al. 2002, Suchomel et al. 2012). Regardless of machine choice, operator skills play a major role when applying CTL harvesting to coppice stands (McEwan et al. 2016).

The productivity of a modern harvester deployed in conventional coppice operations may vary from 2 (Forestry Commission 2011) to almost 10 (Spinelli et al. 2010c) m^3 SMH^{-1}, depending on stem size and operator proficiency. The productivity of the forwarder commonly ranges between 5 (Grulois et al. 1996) and 10 (Spinelli et al. 2014) m^3 SMH^{-1}, depending on machine model and extraction distance. Assuming an hourly rate of 120 € for the harvester and 80 € for the forwarder, the harvesting and extraction cost would vary from 20 to 50 € m^{-3}, which is within the price bracket of industrial wood users and much cheaper than the cost incurred for motor-manual work. Extraction can also be performed with forestry-fitted farm tractors, which allows reducing investment cost but results in lower payload and productivity (Spinelli et al. 2004).

Introduction of CTL harvesting is easier in the presence of industrial users, who can better support a sustained work flow. That is why CTL harvesting was first introduced to commercial coppice operations in central France, where the abundant chestnut resource was supplied to large particle board factories (Martin et al. 1996). It is only much later that the Italians (Spinelli et al. 2010b) and the Germans (Suchomel et al. 2011) followed suit.

6. Whole-tree harvesting and tree-length harvesting

Whole-tree harvesting (WTH) consists of felling trees and extracting them whole to the landing, where they are processed into commercial assortments (Stokes et al. 1989). WTH offers the advantage of simplified in-forest handling and is first documented in the US (Kammenga 1983). This basic scheme has proven to be so effective that it has remained virtually unchanged and appreciated until our days (Mitchell and Gallagher 2007). The main advantage of this system is to postpone processing to the landing, where it can be mechanized if terrain constraints make the stand inaccessible to harvesters (Adebayo et al. 2007). Even if no harvester is available, WTH moves motor-manual processing to a better worksite, where operation is more comfortable and productive (Spinelli et al. 2009).

As processing is moved to the landing, stump site work is simplified, which results in a relatively high productivity. Motor-manual directional felling may proceed at a pace between 1 (Bajić and Danilović 2004) and 4 (Spinelli and Magagnotti 2007) m^3 SMH^{-1} operator^{-1}. If the terrain is accessible to mechanical equipment, then feller-bunchers (Fig. 3) can be introduced and productivity will increase dramatically, reaching values between 4 (Spinelli et al. 2007) and over 8 (Schweier et al. 2015) m^3 SMH^{-1}. In fact, the main operational benefit of mechanized felling is not only the increased productivity, but rather the better presentation of felled trees, which are gathered in bunches and aligned towards the skidding tracks, so that extraction productivity receives a dramatic boost. Studies about the skidding of whole coppice trees report a wide range of productivity figures, which go from less than 3 m^3 SMH^{-1} for skidding with a forestry-fitted farm tractor (Cantiani and Spinelli 1996), to 5 (Currò and Verani 1984) or even 8 (Canga et al. 2014) m^3 SMH^{-1} when a dedicated skidder is used.

Fig. 3 Felling coppice with accumulating shears

Fig. 4 A light tower yarder routinely used in coppice operation

On steep terrain, cable yarding (Fig. 4) is the cost-effective alternative to building an extensive network of skidding trails, and results in a much lighter site impact compared to ground-based logging (Bolding et al. 2011, Spinelli et al. 2010). Productivity is somewhat lower than in ground-based operations, and varies from 3 (Currò and Verani 1986, Verani et al. 2008) to 7 (Spinelli et al. 2014) m^3 SMH^{-1}. However, the main difference is the crew size, which increases to 3 or occasionally 4 workers, whereas only 1 or 2 workers are required for a skidder. Furthermore, yarder set up and dismantle are time consuming, and they may add 20–25% to the actual extraction time (Spinelli et al. 2016b).

Once at the landing, whole trees are converted into conventional assortments (i.e. firewood, pulpwood, etc.), or thrown straight into a chipper. Whole-tree chipping offers the benefits of increased product recovery, simplified processing and higher productivity (Herrick 1982). Whole-tree chipping was tested early on in the Italian coppice stands (Baldini 1973), at about the same time as it appeared in the US (Koch 1973) and well before it was introduced to softwood thinning. Since then, whole-tree chipping has plaid a minor but steady role in coppice operations (Spinelli and Hartsough 2001), with the main purpose of supplying particle-board factories and some of the early chip-fuelled boilers. Today, a booming demand for biomass chips has created the conditions for a rapid expansion of whole-tree chipping, which has become very popular in many regions. The efficiency gains obtained with whole-tree chipping often lead to turning into chips those stems that could yield quality firewood, despite the higher price fetched by the latter assortment. An additional advantage of chip production is in the type of customer, because chips are generally delivered to industrial customers that absorb large quantities and offer better solvency, whereas firewood is sold to a large number of individual buyers, which complicates all administrative matters, including negotiation, billing and payment collection.

Despite its many advantages, WTH must be considered with some caution because of the risk for soil nutrient depletion (Helmisaari et al. 2011), which may result from removing nutrient-rich branch material (Lamers et al. 2013). Furthermore, taking branches to the landing may cause significant slash accumulation and disposal problems, if no market is available for them. In those cases, trees can be delimbed and topped before extraction, but not cut to length. That allows reducing inefficient stump-site work compared to traditional short wood harvesting, while increasing on-site biomass retention to mitigate possible adverse effects (Mika and Keeton 2013). This work system is known as tree-length harvesting (TLH) and is widely used to avoid the accumulation of residues at space-constrained landings (Westbrook et al. 2007). Substitution of TLH determines a large (>50%) increase of stump-site work compared to WTH, whereas landing work is only slightly reduced. Decreased work efficiency leads to a general increase of logging cost, which has been estimated at 10–15% over WTH (Putnam 1983, Spinelli et al. 2016b).

7. Cutting technology and coppice regeneration

One of the main obstacles when trying to introduce mechanized cutting to coppice operations is represented by the absolute need to prevent stump damage, in order to guarantee prompt regeneration. All cuts should be clean and as near to the ground as possible. Unfortunately, mechanical felling can seldom guarantee that these requirements are met, and therefore forest managers often forbid mechanized felling in their coppice forests and prefer incurring the higher cost of motor-manual felling.

Harvesting machines equipped with shears used in coppice forests are not a favored option because they do produce taller stumps than obtained with chainsaws or disc saws under the same conditions (Schweier et al. 2015, Spinelli et al. 2007). That depends on a number of factors, and especially on their working mechanism, which requires engulfing the stem within the full arc described by the closing blades. That might be difficult to achieve when too close to the ground and near the insertion of the stems on the stump. Therefore, operators tend to move the cutting point higher up, where the shear can wrap around the stem, thus leaving tall stumps (Fig. 5).

Fig. 5 Tall chestnut stumps after cutting with a harvester

Furthermore, shears may also cause significant stump damage (De Souza et al. 2016), which is generally explained by high compression stress (McNeel and Czerepinski 1987). Cracks and stump pull may be observed on a large proportion of the stumps cut with a shear, and their incidence varies between 20% (Spinelli et al. 2014b) and 70% (Schweier et al. 2015).

In contrast, disc saws may produce very low cuts if the operator is skilled, even lower than could be produced with a chainsaw (Han and Renzie 2005, Hall and Han 2006). Stump damage levels are also lower for disc saws than for shears (Schweier et al. 2015). The use of a disc saw generally results in improved cutting quality, which should relieve most concerns. The main obstacle to the introduction of disc saws is the excessively large size (and cost) of most machines currently available on the market. With few exceptions (Delasaux et al. 2009), commercial disc saw models weigh over 2 tonnes and are installed on expensive dedicated prime movers, or on very large excavators. On the other hand, chainsaw type felling heads are vulnerable to contact with soil and to frequent chain derail, the latter being generally caused by crowded stumps.

To conclude, shears represent the cheapest and most effective solution to mechanized felling in coppice stands, despite the lower cut quality (Chakroun et al. 2016). If shears are deployed, then motor-manual post-harvest stump trimming is a viable solution to excessive cutting height and felling-related stump damage, despite the additional cost and value loss derived from such practice (Martin et al. 1996).

In fact, there is very little scientific evidence about the effect of cut height and stump damage on stump mortality and re-sprouting vigor (Piskoric 1963, Roth and Hepting 1943). Increased stump mortality seems to be associated with the most severe damage type only (De Souza et al. 2016, Ducrey and Turrel 1992, Spinelli et al. 2017), which is relatively rare. None of the studies that have compared manual and mechanical cutting have found any significant differences in stump mortality or resprouting vigor (Crist et al. 1983, Ducrey and Turrel 1992, Giudici and Zingg 2005, Pyttel et al. 2013, Spinelli et al. 2016c). If at all, cutting with shears seems to prompt the emission of a larger number of shoots than when cutting with a saw (Cabanettes and Pagès 1986, Hytönen 1994, De Souza et al. 2016, Spinelli et al. 2017). In fact, resprouting vigor seems directly related to stump size, rather than to cut quality (Johnson 1975, Ducrey and Turrel 1992, McDonald and Powell 1983, Souza et al. 2016).

8. Conclusions: a new season for coppice

Coppice management is applied to many species, in many countries and in many ways, so that it may be difficult to describe a single example epitomizing the typical coppice forest and its management. And yet, all coppice stands present two common elements that have a strong impact on operational choices, namely: small stem size and stump crowding. Therefore, all the many solutions devised for coppice harvesting will reflect a variety of local conditions, but they will invariably contain some measures to cope with such common elements.

Small stem size affects the type of products that can be obtained from coppice stands, while limiting work productivity. At the same time, small stem size may favor mechanization and multi-tree handling, which are the main strategies to push down harvesting cost when low-wage labor is no longer available. In such event, stem crowding represents a major technical obstacle, because it hinders mechanized felling and may result in excessive cut height. New small-size disc saws are appearing, which may contribute to solving this problem.

If mechanization is the goal, then silviculture should be adapted to favor it whenever possible. All interventions should offer large enough removals (>80 m^3 ha^{-1}) and should allow machine access through the opening of roughly rectilinear paths, about 4 m wide. The systematic application of light selection thinning is a main obstacle to mechanization and it can make active management impossible, unless subsidies are released.

In fact, financial viability is not the main issue when decisions on coppice management strategies are taken. Manual work is associated with the highest accident risk and accident severity, and it accounts for most of the fatal accidents recorded in forest operations (Albizu et al. 2013). Previous studies have shown that the introduction of mechanized felling may reduce accident rates by a factor 4 (Bell 2002), and therefore replacing manual felling with mechanized felling is a strategic ethical requirement, not just a financial goal. Furthermore, mechanization is the only solution for the continued management of forest areas, in the face of a declining availability of qualified forest workers (Tsioras 2012).

Such crucial issues must be solved, if coppice management has to be rescued from its slow decline. In the absence of new public grants for cautious coppice management, the alternative is often no management at all. However, coppice is one of the few silvicultural models that depend on active management: there are no widespread natural ecosystems that are based on coppice regeneration. Thus, the end of management would be the end of coppice at all. That would be sadly ironic, since the moment is most favorable for a revival of coppice management. Coppice forests may be entering a new season, where they are reinstated to their important economical role because they are present, productive and efficient. However, coppice forest will enjoy the benefits of the modern bio-economy only if coppice management is modernized. For this reason, it is important to facilitate the transition of coppice management from a part-time rural activity to a modern industrial business. Mechanization is the obvious solution, because it compensates for the reduced availability of rural labor, with their propensity to perform heavy and low-paying jobs. For this reason, a compromise must be found between ideal practice and the operational limits of mechanization. Much progress has already been made, but the introduction of mechanized operations still encounters great resistance. That might be mitigated by a better knowledge about the effects of mechanized harvesting on coppice forests, which can only derive from dedicated research. Similarly, research may help developing new low-impact technology solutions, when these are needed.

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