Prevention of Soil Erosion and Rockfall by Coppice and High Forest – A Review

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Introduction

An important regulating ecosystem service of forests is their ability to protect against natural hazards such as soil erosion and rockfall, particularly on steep slopes. The ability to provide this service strongly depends on the forest structure and condition (e.g. Dorren et al. 2007, Imaizumi et al. 2008, Fuhr et al. 2015, Moos et al. 2017). With coppice, however, the question remains whether clear-cutting might actually exacerbate slope erosion, and if, in their abandoned or converted state, coppice stools could eventually become unstable and prone to collapse. In such a case, the risk of rockfall may be enhanced (Radtke et al. 2014).

At higher altitudes in the European mountain regions of Switzerland, Austria, Slovenia, Italy, Cyprus and Spain, coniferous forest species such as Norway spruce (*Picea abies)*, silver fir (*Abies alba*) and European larch (*Larix decidua*) predominate in protection forests, while broad-leaved species with innate coppicing ability are more prevalent at lower altitudes. These include European beech (*Fagus sylvatica*), oak (*Quercus* spp.), chestnut (*Castanea sativa*), lime (*Tilia* spp.), maple (*Acer* spp.), ash (*Fraxinus* spp.), hazel (*Corylus avellana*), whitebeam and wild service tree (*Sorbus* spp.), hornbeam (*Carpinus betulus* L.), hop hornbeam (*Ostrya carpinifolia*), and black locust (*Robinia pseudoacacia*) (Jancke et al. 2013). Beech in particular may reach as far as the upper timberline (1600-2000m asl) in the Alps, as in southern Switzerland (Ceschi 2014), or in Slovenia (Perret et al. 2015).

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Tree cover increases rainfall interception and transpires away soil moisture, thereby reducing runoff, so that a continuous or semi-continuous canopy may give good slope protection. Standing and lying trees can slow down, deviate, or stop falling rocks, and thus reduce their propagation and intensity (Perret et al. 2004, Dorren et al. 2007). By adopting appropriate forms of silviculture and eco-engineering, these forests can permanently reduce the risks to human life and property, although in extreme cases the trees may have to be supplemented or replaced by civil engineering and bioengineering solutions (Dorren et al. 2005, Dorren et al. 2007). From one point of view the high stem densities in coppice form strong physical barriers and extensive rooting networks (Gerber and Elsener 1998) and can re-grow rapidly after cutting, when parts of the root system may remain alive. On the other hand, abandoned coppices on slopes can develop a large aerial biomass relative to their root system (Conedera et al. 2010), which in time may cause stool instability and uprooting (Vogt et al. 2006). On more gentle farmland slopes in lowland regions, where the soil surface may be periodically exposed by arable cultivation, one alternative might be to grow short-rotation coppice stands of *Populus, Alnus* and *Robinia* to protect against soil erosion (Petzold et al. 2014).

The goal of this paper is to give an overview on the effect of coppice stands on risks induced by erosion, landslides and rockfall and to discuss management strategies aiming at high protection capacity of these forests.

1. The role of tree canopies

Trees intercept and transpire moisture, as well as increasing both water infiltration into the soil and the water storage capacity, thus delaying levels of soil saturation that could cause incipient slope stability (Forbes and Broadhead 2011). The level of this effect strongly depends on the type of vegetation (e.g. forest structure, species composition) and season (Anderson et al. 1976). While harvesting removes the coppice canopy, the probability of slope failure will depend upon the frequency of cutting, the amount of litter and brash left behind, and the presence of unharvested trees (Piussi and Puglisi 2012). Remaining tree roots tend to increase infiltration by increasing soil pore formation and forming networks that facilitate a faster drainage than if no channels were present (Vergani and Graf 2016). The recovering canopy of the transpiring crop may also reduce excessive soil moisture and, therefore, the risk of surface instability, although in cool, temperate regions where precipitation usually exceeds evapotranspiration, the advantages may be small. Nevertheless, soil loss resulting from forest harvesting can become an issue at slope gradients above 8-9° and it increases significantly above 20°, when major landslides and debris flows are likely to occur (Borrelli et al. 2016).

2. Root reinforcement

Shallow landslides occuring on slopes carry earth, mud, clay and other debris; they are generally less than 2m deep (Rickli and Graf 2009, Sidle and Bogaard 2016) and are often triggered by heavy rainfall or earthquakes. Tree rooting forms a fibrous reinforcement, increasing the soil shear strength: in general, the coarse roots (>10 mm diameter) act as anchors or soil nails, while fine to medium roots (0.01-10 mm diameter) tend to reinforce and 'pin' together the soil profile (Stokes et al. 2009). We can distinguish basal root reinforcement along a potential slip surface, lateral root reinforcement at the margins of the landslides, and stiffening effects of soil under tension and compression (Mao et al. 2012, Schwarz et al. 2015, Cohen and Schwarz 2017). These effects are mainly influenced by root density, root tensile strength and depth of rooting. The glue-like exudates of root mycorrhizae provide additional soil strength by contributing to the formation of soil aggregates (Bronick and Lal 2005). In an investigation of a steep slope revegetated 25 years earlier by hydroseeding and supplementary planting of grey alder (*Alnus incana*) and purple osier willow (*Salix purpurea*), Burri et al. (2009) showed that soil aggregate stability approached that of a nearby mature ('climax') beech forest on a similar incline. In coppices, a window of susceptibility to erosion begins when roots start to decay after cutting, and persists until new woody vegetation and root growth is achieved.

Slopes also appear to influence root morphology, with the larger roots orientated uphill and assisting soil anchorage, as observed in downy oak (*Quercus pubescens*) and manna ash (*Fraxinus ornus*) by Chiatante et al. (2003). Di Iorio et al. (2005) found the same tendency in maiden (uncoppiced) trees of downy oak, growing on slopes ranging from 14 - 34°, where the first-order laterals tended to cluster asymmetrically, in an upslope direction, and to form resistant I-beam cross-sections. This adaptive root architecture emphasizes the resistance of these up-slope roots to pullout, counteracting the turning moment that tall, upright tree stems of abandoned coppice stools are constantly subject to. A study of managed and abandoned chestnut coppices in northern Italy, situated on slopes of 13 - 35°, showed denser but shallower rooting in the 0 - 50 cm soil profile of a currently managed stand compared with overaged stands (Bassanelli et al. 2013). This may have been influenced by the renewal of the root systems after each coppicing event, although there was less soil depth than in the abandoned coppice sites. The study showed that root tensile strength was not affected by abandonment, but simulation modelling suggested that slopes of >35° were intrinsically unstable and likely to lead to shallow landslides, particularly those with high levels of soil moisture saturation. These authors concluded that maintaining a regular coppice cycle was essential to prevent shallow landslides occurring on steep slopes. On the other hand, Dazio et al. (2018) suggested that aging chestnut coppice stands in southern Switzerland tended to provide progressively more root reinforcement, owing to an increasing proportion and absolute number of coarse roots.

The roots of different tree species appear to react differently to coppicing. In birch (*Betula* spp.) coppice, Bédéneau and Pagès (1984) found that medium to coarse (>5 mm diameter) roots were the same age as the stool, suggesting that the old root system remained intact, whereas in chestnut the roots were freshly regenerated (Dazio et al. 2018). The latter also seems to hold true for beech (Amorini et al. 1990, Bagnara and Salbitano 1998) and maple (Lees 1981) but not for some *Eucalyptus* species, which tended to keep their original root systems after cutting (Riedacker,1973, Wildy and Pate 2002). It seems likely that the drastic reduction of carbohydrate resources resulting from stem loss forces the plant to direct its energies into shoot production, with root development (especially that of coarse roots) lagging behind. This is exacerbated when short rotations are applied; in a hybrid poplar plantation, for example, coppicing caused the plants to use carbohydrates stored in the roots for the new stem growth, potentially inhibiting rooting (Lee 1978, Bédéneau and Auclair 1989).

The amount of rooting, and particularly the development of structural coarse roots, has particular implications for coppice. In maiden trees and in old coppice, there is some evidence that the ratio of coarse to fine roots increases over time, whereas younger coppice tends to be more dependent on fine rooting (Montagnoli et al. 2012, Di Iorio et al. 2013). Laboratory and field pullout tests (Giadrossich et al. 2013, Vergani et al. 2016) have been used to estimate the tensile force of root bundles, which also clearly demonstrate a power law relationship between root diameter and tensile force. Root reinforcement can be estimated using a number of different models, most recently by the Root Bundle Model (RBM) (Schwarz et al. 2013), which uses a Weibull survival function to account for mechanical variability and the relative contributions of different combinations of coarse and fine roots. Simulations show that coarse roots are disproportionally influential in effecting root reinforcement - the maximum tensile force of a single root of 50 mm diameter being the equivalent of more than 500, 1 mm diameter roots (Vergani et al. 2017).

Trees that root relatively deeply, such as European ash (*Fraxinus excelsior*), *Quercus* spp., aspen (*Populus tremula*) and alder (*Alnus glutinosa*) give better soil anchorage, especially when species with different root forms are mixed together (Rayner and Nicoll 2012). With an increasing ratio of coarse to fine roots developing within a tree crop over time, we might expect that root reinforcement, and consequently soil stability, would also increase as coppices are converted, or gradually develop into high forests. In over-mature coppice crops, coarse roots will also extend outwards from the stool, stabilising a greater surface area than would be the case of recently cut coppice, which is more dependent on its finer roots (Dazio et al. 2018). On the other hand, by virtue of their very high stem densities, many coppices may reinforce the soil surface with their rooting as effectively as high forests. Breaking forces, taking into account root diameter, are also quite variable between species: for example, Vergani et al. (2012) found that beech roots were almost twice as resistant as larch (*Larix decidua*) and spruce. The order was beech (84N) >sycamore (65N) >hop-hornbeam (56N) >ash (47N) >larch (46N) >sweet chestnut (44N) >Norway spruce (40N).

When the shear zone lies below rooting depth, particularly on relatively impermeable clays liable to slope instability, the reinforcing effect of roots is expected to be negligible (van Beek et al. 2005). However, the hydrological regulation under a forest may have a positive influence on soil stability. When coppices on slopes are cut, a potential problem could arise if the rate of decay of the original root system is not compensated by the rapid regrowth of fine and coarse roots, or if the interval between harvesting and root regrowth is prolonged. New roots may not counterbalance the decay of the old root system in those species that tend to renew their roots after coppicing, lowering root reinforcement (Vergani et al. 2017). However, some coarse roots can take several years to decay and this may provide a sufficient interval of protection from the risk of shallow landslides. In felled beech stands in Northern Tuscany, Preti (2013) found that root tensile strength declined in a roughly linear fashion, at 11% per year for a total decay time of c. 9 years. This work also predicted that deforested slopes could be liable to shallow landslides within a decade of tree death, a period in which heavy rain- or snowfall events could easily occur. Silvicultural treatments could mitigate this risk, for example by extending the rotation period, as this might raise the level of root reinforcement and conserve soil resources (Rubio and Escudero 2003). Standard trees retained among the coppice could also provide pockets of permanent anchorage when the coppice is cut. Finally, uneven-aged or selective coppicing will maintain a permanent canopy and therefore reinforce rooting. In many situations, however, conversion of coppice to high forest can be extremely expensive and demanding compared to the default option of abandonment, or even coppicing on a short rotation (Vergani et al. 2017).

Uprooting of abandoned chestnut coppice (>50 years) was also investigated by Vogt et al. (2006) in the southern Swiss Alps on slopes of 20 - >30°. The uprooted stems were taller and larger, with the probability of overturning increasing on steeper slopes, particularly in hollows and gullies. To avoid large trees becoming unstable due to their increasing gravitational load, the authors recommended re-coppicing or thinning within the coming 30 years. Being more vulnerable to windthrow, the surface scars created by uprooting might form starting points for erosion. However, Conedera et al. (2010) did not consider this to be a long term issue, because any gaps were likely to be filled by forest regeneration in due course. Although surcharge resulting from the weight of overaged stools has also been suggested as a factor likely to cause shallow landslides and a reason for continued coppicing, this has been largely discounted (Stokes et al. 2008, Vergani et al. 2017).

3. The barrier effect

On very steep slopes exceeding 30° in the source (or release) area of rockfall, the protective effect of trees can actually be negative (Dorren et al. 2007) if, by swaying to and fro in the wind, they act as levers to loosen and tear open the soil profile (Frehner et al. 2005). On the other hand, apart from tree roots binding the soil surface together, they may intrude into rock fissures and also promote the decomposition of rocks by organic acids (Frehner et al. 2007).

Both in the areas of transit (usually on >30° inclines) and deposition (<30° inclines), the protective effect of forests against falling rocks is basically due to the barrier effect of

Figure 1. Trees acting as barriers on a steep slope (Photo: Christian Suchomel)

standing and lying trees (Figure 1). Collisions with trees slow down or stop rocks, with sparse forests offering less protection than dense stands (Foetzki et al. 2004, Dorren et al. 2007). The main parameters influencing the degree of protection are: the forest density (number of stems ha^{-1}), the diameter distribution of the trees, the tree species' specific energy dissipative capacity, the length of the forested part of the slope, the block volume and the block's kinetic energy (Dorren et al. 2005, Moos et al. 2017). It is often suggested that only rocks <2 m^3 can be halted by single trees, but there are some examples from the Alps where rocks up to 20 m^3 have been halted (Dorren et al. 2007, Ernst 2017). Several studies have shown that the basal area, i.e. the total surface covered by tree stems in a given area, is a good indicator of the protective effect of forests against rockfall (Berger and Dorren 2007, Dupire et al. 2016, Moos et al. 2017). Not only large diameter trees (> 36 cm), but also small trees can stop larger blocks (> 1 m^3), provided that part of the kinetic energy has already been dissipated. Thus, coppices stands may offer sufficient protection against larger blocks when combined with larger trees on the upper part of a slope (Dorren et al. 2005).

A study by Dupire et al. (2016) used the rockfall algorithm Rockyfor3D (Dorren 2012) to generate simulations of the rockfall hazard in 3886 forest plots in the French Alps, based on sloping terrain of 20° or more. Using measures of the plot basal area and the mean tree diameter, they were able to calculate the minimum length of forest to needed to obtain a reduction of 99% in rockfall hazard. The study found that coppices dominated by deciduous *Fagus sylvatica* and *Quercus* spp. were the most effective stands in this respect, compared with pure coniferous stands of *Pinus* spp. and *Larix decidua*. Stands with high stem densities, high basal areas and greater biological and structural diversity were the most efficient, with the presence of a large number of trees being more important than lower densities of thicker trees.

Again using the RockyFor3D simulation model of rockfall (Dorren 2012), Fuhr et al. (2015) assessed the protection efficiency of pure and mixed uneven-aged stands dominated by beech, silver fir and Norway spruce along a maturity gradient. 'Young' stands with the highest stem densities gave the best protection against 1-2 m^3 rocks, but even the neglected 'sub-adult' and 'mature' stands had tree densities of >500 ha^{-1}. The 'mature' stands, containing some individuals up to 220-260 years old and a significant number of very large trees (>77.5cm DBH) still offered high levels of protection, particularly against the larger sizes of rocks. Recently logged plots were considered much less effective, as the low-cut stumps could act as springboards, rather than obstacles, for the falling rocks. Moreover, mature stands contained high volumes of deadwood, including snags, which increased the roughness of the forest floor and, after modifying the simulation model to consider this, the stopping distance of large rocks was reduced by 28%. Radtke et al. (2014) recommended a slight extension of the coppice cycle in broadleaved mixed stands dominated by *Ostrya carpinifolia* and *Fraxinus ornus*, arguing that 25-year coppice forests gave better protection than young coppice, while beyond 40 - 50 years of age many stools tend to lose stability or break apart.

4. Spatial arrangement of coppices

Coppice stems may be dense and clustered, with the multiple stems per stool in young stands tending to confer more protection than sparser, older stands with fewer stems per stool. A high stem density can reduce many risks (Ringenbach 2013), but in unmanaged stands the declining stem density, through natural self-thinning, decreases the probability of rock collisions. This could be balanced to some extent by the increasing diameter and mechanical resilience of older trees, unless they are more prone to rot, as well as by the build-up of high volumes of deadwood in unmanaged stands. Older stems have thicker, more absorbent and energy-disspating bark with which to resist rockfall and are more likely to arrest larger boulders with less stem damage. The higher stem densities associated with young stems may be effective against smaller (<0.25 m^3) rock sizes (Omura and Marumo 1988, Cattiau et al. 1995). Working in coppice stands of *Orno-Ostryetum* forest in northern Italy, Radtke et al. (2014) concluded that overaging did not adversely affect their protection function, at least for stands <60 years old, although the gaps between stools were generally larger. They also found that in theory, a random distribution of stems had a higher protective effect than clustered distributions because the gaps between coppice stools decreased the likelihood of tree impacts. In a test case on Apennine coppice, the average distance between tree/boulder contacts (ADC), a measure of the energy absorbed by a forest structure, needed to be adjusted upwards from a theoretical single-stem arrangement so as to account for the higher rates of energy dissipation by coppiced trees (Ciabocco et al. 2009). They suggested that management based on the now-obsolete coppice selection system, where some stems are retained on individual stools at each cutting, or coppices with large reserves or standards, could give good rockfall protection.

Radtke et al. (2014) also found that the protective effect against large rocks was still one-third greater in the overaged coppice stands than the equivalent site without significant tree cover immediately following coppicing, provided that a few standard trees remained.

Ciabocco et al. (2009) conducted a series of impact tests on fresh beech stems (3-10 cm DBH) using a reinforced 84 kg concrete pendulum bob, swung to impact with clamped, single coppice stems. As expected, this demonstrated that mechanical resistance increased with stem diameter and lessened with the height of impact. However, it was surmised that highly flexible young coppice stems, generally of smaller diameter than those in mature forests, could decelerate boulders effectively and that the clumping of stems on stools could act as additional small retention fences. Although probably limited in their ability to protect against rocks >1 m^3, simultaneous impacts against more than one stem on the same stool could effectively trap rocks between them (Figure 2). Nevertheless it was uncertain whether this multi-stemmed coppice structure produced a greater protective effect. Furthermore, the basal sweep of stems associated with slopes, resulting from growth stresses that form tension wood, could weaken them against impacts.

The history and spatial pattern of rockfall was investigated by Favillier et al. (2015) on sub-montane broadleaved forest on slopes of

Figure 2. Rock caught in a coppice stool (Photo: Christian Suchomel)

25 - 39° in the Vercors massif of the French Alps. An exhaustive analysis of wounds and bark scarring on the stems of individual trees and coppice stools revealed, as expected, a high incidence of impacts from rockfall near the top of the release zone, at frequencies of <20 years, as well as laterally in topographic depressions, which tended to funnel any rockfall. At 150 m downslope, the frequency of the damage interval fell to >40 years. Favillier et al. (2015) also demonstrated that the fast-growing downy oak, with its thicker bark, might be capable of absorbing more impact energy with less damage than an Italian maple (*Acer opalus*) of similar age. In a rockfall corridor in the French Alps, Stokes et al. (2005) showed that beech suffered less from stem breakage, wounding and uprooting than did the other species tested. Through winching experiments to break or uproot a tree, they found that beech was twice as resistant as silver fir and three times more than Norway spruce, which tended to uproot. In similar experiments, Dorren et al. (2005) ranked species in the following order of energy of dissipation: pedunculate oak (*Quercus robur*) >beech >sycamore >silver fir > larch/Norway spruce. There was a strong exponential relationship between stem DBH and the amount of energy dissipated from an impacting rock. Such differences could be attributed to the different xylem structure of the broadleaves, which can make them more resistant to splitting and deformation, and their greater number of roots that are anchored at a greater depth.

5. Silvicultural comparisons

In the southern Italian Apennines, Ferretti et al. (2014) developed a Synthetic Index of Protection (SIP) against soil erosion to compare the efficiency of different types of canopy of tree species, shrub and herbaceous layers, based on their respective interception values. Taking this (and slope angle) into account, they determined the most suitable silvicultural treatments providing a continuous canopy cover. Beech selection coppices, in which some stems were always retained on the stools, provided good protection, as did the conversion to an uneven-aged beech high forest structure, although both options were costly. With Turkey/downy oak forest cover, the alternatives were:

a) to continue coppicing,

b) to convert to high forest via a shelterwood system, or

c) to retain about 50 standards ha^{-1} along with the coppice (Ferretti et al. 2014).

The authors suggested making very small felling coupes, predicated on getting good natural regeneration, either from seedlings or coppice resprouting. Becker et al. (2013) argued that on steep slopes, small diameter coppice poles of low volume were both uneconomic and technically difficult to harvest. They suggested that on dry, steep slopes of up to 16.7°, slow-growing stands of oak could be grown on longer rotations (50-80 years) in order to produce a more profitable mass per unit ratio. High quality trees could be retained as standards (at densities of 20-30 ha^{-1}) to be harvested after two coppice rotations (100-160 years), while some poorer-quality trees could be left to die back naturally and become 'habitat trees'. Steeper slopes would require more expensive methods to be employed, such as cable harvesting.

The relatively small stem sizes associated with coppice might be considered most appropriate in the deposition zone of slopes, at a point where the slope incline eases and most travelling rocks have been slowed by impacts on trees further up in the transit zone. Although regrowth of coppices after cutting is rapid, the same practice of restricting felling coupes to 40m in the fall line is commonly advocated (Dorren et al. 2015). Pure coppice stands are only recommended in areas with short transit area slopes of less than 75 m length (Frehner et al. 2005). Coupe sizes of 0.5 ha or more were less likely to give protection, since a weakened root reinforcement might allow loose rocks to reach their maximum velocity when travelling through the felling coupe. It was therefore recommended to keep clear cuts small and well-distributed throughout the whole protection area, with maximum widths of 20 m on steep slopes regularly prescribed. In the case of preventing shallow landslides, as opposed to rockfall, Vennetier et al. (2014) also recommended limiting clear cuts to <0.5 ha, certainly <1 ha, or adopting a selection silviculture to protect the soil, pointing out that the increased cutting intensity, as in coppicing for fuelwood, might exacerbate the risk of erosion.

Conclusions

After coppicing, stands regrow quickly and soon achieve stem densities of a critical diameter, which are able to withstand soil erosion and minor rockfalls, as well as recover quickly from stem wounding and breakages. As the stems of traditional, in-rotation coppices rarely exceed 15 - 20 cm DBH, their protection function tends to be limited for rocks greater than 1 m^3 (Jancke et al. 2009). With abandonment, and increasing stem size, there is always the risk of stools being uprooted on unstable steep slopes during high winds or due to soil oversaturation, although the same would equally apply to mature high forest crops. Overaged coppice stands will eventually self-thin, increasing their stool spacing, but Fuhr et al. (2015) showed that old stands were able to retain moderate stem densities, as well as some trees large enough to intercept large blocks of c. 5 m^3, while the high volumes of deadwood presented additional barriers.

By maintaining high stem densities, active coppicing does appear to provide an effective protection service against rockfall. As many former coppice forests develop into high forests, either through conversion or abandonment, they often retain the high stem densities that tend to reduce rockfall hazard (Dupire et al. 2016). Coppice harvests are also likely to be more economic in the deposition zone, below the steeper slopes, and may still be more cost-effective than converting the stand to a high forest structure. Coppicing also promotes strong lateral rooting reinforcement against soil shear, with many broadleaves tending to have deep roots. The 'retention fences' resulting from multiple stems on the same stool may be more effective in trapping rocks than discrete, single stems of equivalent diameter, especially if rocks impact more than one stem simultaneously, although this may be counterbalanced by the clumped stem distributions forming large gaps between stools.

Beech and several other broadleaves also have roots with a stronger tensile strength than those of conifers, their frequent competitors in mountain situations; for a given DBH their stems are also more able to dissipate rockfall energy. It is not clear, however, to what extent root reinforcement retains its effectiveness immediately after cutting, before canopy cover is re-established. Conversion or abandonment of coppices on very steep slopes does not necessarily impair their protection services. Most evidence points to high forests as being inherently more stable structures with respect to soil erosion, due to their greater amount of coarse rooting compared with coppice. Hence the abandonment of coppicing on vulnerable slopes may not adversely affect the ability to regulate shallow landslides, and may actually increase soil stabilisation, especially in the case of those tree species that need to renew their root system immediately after harvesting. However, in the special case of river banks and gullies, which are liable to debris flows during floods, managed coppice can avoid the overturning of large stems and their transport down swollen rivers (Rudolf-Miklau and Hübl 2010).

Since abandoned and over-mature coppices are even-aged, they will eventually break up synchronously. Under these circumstances, and particularly in the slow-growing conditions of mountain habitats, there may be insufficient naturally-seeded regeneration to take over the protection function of root reinforcement, especially if large gaps form. Thus, several authorities advocate only clearing small coupes at a time, or uneven-aged/group selection systems, which rely on small canopy openings that fill with natural regeneration. All of this assumes the presence of relatively few domestic or wild browsing animals, as the fresh shoots on a coppice stool and natural seedling regeneration are both equally vulnerable. If coppicing operations are to be continued on slopes, protection can be enhanced by keeping gap sizes to a minimum, retaining standards and ensuring natural regeneration.

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