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Management of Coppices in Central Dinnarides in the European Concept of Coppice Management – A Case Study of Lika

Martina Đodan[1,*], Darko Smerdel[2], Valeriu Norocel-Nicolescu[3], Sanja Perić[4]

(1) Croatian Forest Research Institute, Division for Silviculture, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia; **(2)** Croatian Forests Ltd., Directorate Zagreb, Ulica kneza Branimira 1, HR-10000 Zagreb, Croatia **(3)** Transylvania University of Brasov, Faculty of Silviculture and Forest Engineering, Șirul Beethoven 1, RO-500432 Brasov, Romania; **(4)** Croatian Forest Research Institute, Common Affairs Service, Cvjetno naselje 41, HR-10450 Jastrebarsko, Croatia

*** Correspondence:** e-mail: martinat@sumins.hr

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ABSTRACT

Coppices are traditional silvicultural form which is defined and regarded in quite diverse ways throughout its long history. This is the oldest way of forest management known to man, so this form is broadly spread throughout the Europe and the world. It encompasses different tree species and site conditions. This resulted in numerous and diverse approaches to coppice management, which are not only the result of site conditions and biology of tree species, but also of geo-political placement and complex historical and socio-economic circumstances. This is the situation present at Lika region, which is a quite interesting case study for analysis of coppice management. Moreover, it could be regarded as the example of specific coppice management case study for the Southeast Europe, distinctly differing from coppice management in Central Europe. Research provides insight into shaping of complex issues of coppice management in Lika region under specific bio-geographical, ecological, historical, and socio-economic circumstances. This is compared with examples of coppice management from European surrounding, so neglected coppices from Lika region are placed in the concept of contemporary coppice management regarded from recent scientific and expert perception. For example, research excluded coppices in Lika region as the ones with the longest rotations out of all European countries, low intensities of silvicultural efforts and conversion of European beech coppice which could be significantly optimized.

Keywords: silvicultural activities; coppice area; tree species composition; socio-economic and ecological limitations

INTRODUCTION

Coppices or stump forests are defined in many ways throughout history and countries (Glavač 1962, Cestar and Hren 1968, Evans 1992, Fuller and Warren 1993, Čavlović 1994, Barčić et al. 2021). The term is used to describe a forest that can be regenerated via adventive shoots after cutting (Nicolescu 2018, Unrau et al. 2018). In Croatia coppices are defined as low forests, created from stumps and root collars (NN 97/18, 101/18, 31/20 and 99/21). Coppicing as a management system is one of the oldest known to man, and while many coppices are neglected and degraded, over thirty million hectares of coppices can be found around Europe (Unrau et al. 2018).

This vast European area under coppices, characterized by geographical and ecological varieties, as well as historical circumstances resulted in a variety of different coppices and management approaches. This is the reason they are considered one of the most complex issues in European forestry. Thus, these influences in the long history of this management system required the classification of coppices, the main types being simple coppice and coppice with standards. Among the variety of different management approaches it is important to recognize which management goals and approaches are the most beneficial for a specific area in terms of potential benefits (e.g. socio-economic, ecological, historical, cultural). Furthermore, management goals and approaches significantly influence the selection of silvicultural activities and the use of resources. A few decades ago the interest in coppices declined significantly throughout Europe (Müllerová et al. 2015, Slach et al. 2021), which resulted in two directions: coppice conservation/

management or coppice conversion. Considering the low area of coppice forests in Western and Central European countries, it is evident that those countries decided upon coppice conversion (Unrau et al. 2018). In Croatia, similarly to other Southeast European countries like North Macedonia and Serbia, only a smaller area of coppices underwent active conversion. Many were left without clear management goals, resulting in a lack of efficient silvicultural guidelines. Mostly, coppices are managed passively, in the conversion process by ageing (Unrau et al. 2018, Trajkov et al. 2019, Markov et al. 2022, Đodan et al. 2022). Finally, this results in a decrease in production, financial gain, and biological, social, and environmental benefits. These are crucial for the areas with a significant share of coppices, which are mostly underdeveloped and poor.

Lika is a historic and geographic area situated in the Central Dinnaric region. It is a subregion of Gorski Kotar, a larger mountainous region of Croatia. It is geographically and economically separated by high karst area (MARC 2016), which represents the bridge between the Adriatic region and inland of Croatia. The vast majority of Lika is situated atop limestone and dolomite, porous rocks, which resulted in a variety of karst formations and karst plains. It spreads from ca. 500 m to 1,757 m above sea level. Its geographical placement resulted in unique historical and socio-economic circumstances, diverse ecologic features, significant areas under coppices and complex management issues. In Croatia, coppice forests cover 14.5% of the total forest area, while a large share of coppices are found in Lika (29%) (MARC 2016). Coppices in Lika are shaped by specific and complex societal, historical, and economic factors and geomorphological limitations, which have led to their neglect and decline (Štimac 2010). Management complexity of Lika coppices could further arise from forthcoming climate changes (Grätz and Brnada 2015, Climate change adaptation strategy for Croatia 2020). Despite the complexity of coppice management (CM) in Lika, only a few studies are available (Štimac 2010, Đodan et al. 2022, 2024), with no comprehensive overview of management practice or comparison to European management trends and current scientific knowledge.

Furthermore, recent years brought a renewed interest in coppices throughout the Europe with the rise of political and expert awareness on their traditional, cultural, historical, biodiversity and other ecosystem services (Kamp 2022). Moreover, coppices are unique management systems, which in a simple and fast manner can provide firewood, charcoal, biomass (Mairota et al. 2016a, 2016b, Spinelli et al. 2021, Kamp 2022), a wide range of sustainable and environmentally friendly materials including construction material as well as small-diameter timber (Jarman and Kofman 2017). The production of such products is on the rise due to recent energy crises, as well as the increasing adoption of short rotation coppicing (SRC) as a viable source of biomass and fuel in some European countries (Desair et al. 2022, Zięty et al. 2022). Growing concerns about the effects of climate changes on forests put coppices in an interesting role since some studies suggest that shoots have higher resistance to drought, while coppices have higher stability in general (Larrieu et al. 2019, Šimková et al. 2023).

The lack of available studies, renewed interest and the complexity of CM made Lika best suited for analysis of CM in Croatia. Thus, the paper focuses on the state of Lika's coppices as well as the comparison of management issues and silvicultural interventions with the latest European trends. The final goal is to support forest practitioners in the improvement of technological processes in the region. The main goals of the paper are: (1) to give an overview of Lika's coppices and (2) to compare CM in Lika with European CM. Thus, this kind of research aims to cast a new light on Lika's coppices that could be further upscaled on CM in other areas in Croatia.

WHAT INFLUENCED COPPICE MANAGEMENT?

Historical Facts Influencing the Formation of Coppices

Coppices were one of the first forest management systems in Europe (Vandekerkhove 2016, Muigg et al. 2020). Evidence for coppicing goes as far as the Stone Age (Buckley 2020, Slach et al. 2021). Historically, humans were dependent on forest products as the forest provided them with shelter, food, fuel and building materials (Szabó 2010, Buckley 2020). There are also some historical documents about establishing coppices from Roman period (Čavlović 1994). Coppicing was the most widespread silvicultural practice in Europe and was used intensively all the way to the 19th century (Evans 1992). In Medieval times, large tracts of high forests were often cut down to obtain products from coppices, which effectively met the demands of that era. There is little data on the silvicultural activities (e.g. cutting intensity and methods of cutting) but we can conclude that these kinds of activities led to a clearing, degradation, and creation of coppices near the settlements (Čavlović 1994). Many forests were used intensely for coppicing, while only nobility and kings managed their forests in high forms for special purposes such as hunting (Becker and Unrau 2018). In the 17th and 18th centuries, coppices were also intensely used for the charcoal used in iron, glass, and leather industry (Buckley 2020).

With the first industrial revolution, demand for wood skyrocketed as it was the only available material (Evans 1992). This has led to intense forestry activities and was the reason for the development of organized forestry. The second industrial revolution, following the inventions of the internal combustion engine and electricity, led to the coppice abandonment. Fuelwood was substituted with gasoline and kerosene (Mairota et al. 2015). The dropping demand for fuelwood has led to the collapse of markets so only some forest owners continued the practice of coppicing (Peterken 1993). Some authors agree that many coppices were abandoned between the two World Wars (Peterken 1993, Mairota et al. 2015). In the latter half of the 19th century, with the decline of coppicing practices and a surge in demand for construction timber and paper production, forestry experienced a notable shift towards the cultivation of high forests. This has led to intense forest conversion to high forests especially in Central and Northwest Europe, while those coppices that were hardly accessible were neglected and finally abandoned (Kirby et al. 2017, Kamp 2022). On the contrary, some regions like the Mediterranean or Southeastern countries still have large areas of coppices that are equally important in their forest management (Unrau et al. 2018, Venanzi et al. 2019, Buckley 2020).

The history of CM in Croatia is not much different from the rest of Europe. There is evidence that coppicing was the predominant management system in Croatia in the past. Still, we do not know much about the technical and silvicultural activities that were used (Čavlović 1994). Lower quality forests were used by local people who could harvest the fruits, feed their cattle, and gather fuelwood. After the release of the first Forestry Laws in Croatia in 1769 (Anić et al. 2012) the gradual abandonment of coppices followed since already one million hectares of degraded forests (which included coppices) were converted to high forests (Rauš 1994). Coppices on good quality soils, with good connection by forest roads were mostly converted to high forests while the rest were abandoned or neglected. The management activities conducted in Croatia have undoubtedly left their mark on the coppices in Lika, contributing to the complex and diverse landscape that characterizes the region today.

Current Influences on Coppices and Management Outcomes

CM in South and Southeast European countries, including Croatia, has been influenced by societal changes and evolving forest needs (Spinneli et al. 2017). While more developed Central and West European countries have invested in coppice conversion, South and Southeast European countries have viewed coppices as a legacy of unsuccessful conversion, resulting in a high share of coppices in the total forest area, sometimes reaching up to 50% of the total forest cover (Buckley 2020). Additionally, the steep and rocky terrain in these regions often limits the production of coppices, making them ideal for soil protection against erosion (Barčić et al. 2020). However, a considerable number of coppices remained unmanaged due to other various reasons, including low financial interest, terrain limitations, steep slopes, questionable financial profitability, and poor relative road openness (Zlatanov and Lexer 2009, Štimac 2010, Bartlett et al. 2017, Đodan et al. 2022).

Within the framework of the project "Issues of Coppice Management in Forest Administration Gospić", a SWOT analysis was conducted to assess the strengths, weaknesses, opportunities, and threats of coppices in the Lika region. The findings of this analysis highlighted a broad spectrum of challenges and risks that significantly impact forest management of the area. From the demanding and costly implementation of silvicultural practices to the challenge of accumulating capital for production, as well as the high expenses associated with construction of forest roads and the accessibility issues posed by land mines from the Croatian War of Independence. These factors collectively create a complex operational environment for forest management. Moreover, there is a pressing need to redefine forests with protective functions and navigate the intricate dynamics of coppice conversion, which necessitate lengthy processes and adaptive strategies.

Insufficient awareness regarding the application of new scientific discoveries and technological advancements, coupled with the shortage of high-quality forest planting material, further complicates the situation. CM is fraught with numerous risks, ranging from market and economic instability to labour shortages and expertise gaps, all compounded by shifts in habitat conditions due to climate change. Furthermore, there is a notable economic dependency on funding from the European Union, alongside the absence of adequate planning for forest reproductive material, especially nursery production. The lack of strategies to address the consequences of climate change and meet the rising demand for renewable energy sources further complicates the scenario. Additional challenges include inadequate mechanization and workforce training despite existing regulatory frameworks, soil erosion in steep terrain, and the imperative for continuous knowledge and skill updates to confront escalating biological and climate threats. In conclusion, the challenges and risks identified through the SWOT analysis of CM in the Lika region reflect of broader trends observed in CM across Europe (Buckley and Mills 2015, Salomón et al. 2018, Fernández-Manjarrés et al. 2021), especially in the mountainous and hilly areas (Müllerová et al. 2014, Miranda et al. 2022).

Nevertheless, in recent times CM systems have gained attention due to high growth potential and the benefits they offer for biodiversity and nature conservation (Suchomel et al. 2011, Vymazalová et al. 2021). Coppicing has been a standard practice for maintaining open areas in woodlands, contributing to the preservation of regional biodiversity, and providing essential habitats for various plant and animal species (Pullin and Knight 2001, Bergmeier et al. 2010). Coppices are also often recognized for their significant cultural value, as they are associated with traditional management practices and historical land use. Over time, the perception of coppices has shifted from being primarily valued for resource exploitation to being appreciated for their contribution to wildlife, recreation, amenity, and cultural heritage (Bartlett 2016). In many European countries, the conversion of coppices into high forests has endangered not only their natural values but also their cultural and historic significance (Buček et al. 2017). Ancient forests, often combined with ancient coppice stools and trees, are considered important cultural heritage, reflecting the values that society placed on these ecosystems in the past (Hermy and Verheyen 2007). Furthermore, coppicing and pollarding have been ancient practices across European wood pastures, representing cultural legacies (Plieninger et al. 2015). The growing economic crisis and the sudden rise in energy and assortment prices are anticipated to have a substantial impact on investments in coppice regeneration and the initiation of active CM in the years to come (Anić et al. 2007, Nicolescu et al. 2017, Kamp 2022). However, the economic challenges posed by the crisis and rising energy prices may hinder investments in coppice regeneration and active management (Calster et al. 2008). This is particularly significant given the historical decline of coppice forest management due to economic reasons, leading to the transformation of coppices (Mairota et al. 2015). Coppices are also important as they provide many different ecosystem functions (e.g. erosion control on steep and rocky terrain) (Cutini et al. 2015, Scarascia-Mugnozza et al. 2000, Barčić et al. 2020). The high stem density of coppice stands, their rapid growth, and the enduring root systems in the soil are valuable assets in terms of their protective function. This is especially relevant in the context of many coppices in mountain regions becoming uneconomic, leading to abandonment and aging of stumps (Đodan et al. 2022). The management of these forest stands poses a critical question for practitioners, requiring careful consideration of the ecological and protective functions of coppices (Vergani et al. 2017).

The re-establishment and improvement of traditional CM are not only economically beneficial but also contribute to rural re-settlement, employment, maintenance of cultural and historical practices, and reduction of fire risk, highlighting the multifaceted cultural and environmental values associated with coppices (Moreno 2015).

Area and Species Composition

Total coppice areas as well as species composition vary drastically between European countries depending on their management goals, silvicultural activities, and conversion policies. In Europe, there are currently around thirty million hectares of coppices, taking up to 15% of the total forest area (Unrau et al. 2018). In the Republic of Croatia, there are currently 358,803.98 hectares of coppices which take up to 14.5% of total forest area (MARC 2016). Out of that number 55% (198,026.29 ha) are state owned, while 45% (160,776.69 ha) are privately owned. Notably, the Lika region accounts for approximately 30% of the total coppice area in the country, covering a significant landmass of 77,140.9 hectares (MARC 2016). Thus, Lika has the highest proportion of coppice forests in Croatia (Figure 1).

In Europe, North Macedonia (57%) and Bosnia and Herzegovina (59%) are the leaders by the amount of coppices by area, followed by Serbia (54%), Greece (49%), Turkey (41%), Italy (39%), France (38%), Hungary (28%), and Portugal (27%) (Figure 2). Conversely, West, and North European countries show minimal to no presence of coppices which is a result of coppice abandonment in the 19th century and conversion of coppices to high forests (Müllerová et al. 2014).

The tree species composition of European coppices is diverse and reflects the ecological and management history of these forest ecosystems. Tree species commonly subjected to coppicing include oaks (*Quercus* spp.), lime (*Tilia* spp.), ash (*Fraxinus* spp.), hornbeam (*Carpinus* spp.), European beech (*Fagus sylvatica* L.), hazelnut (*Corylus avellana* L.), sweet chestnut (*Castanea sativa*), poplars (*Populus* spp.) and willows (*Salix* spp.) (Unrau et al. 2018,

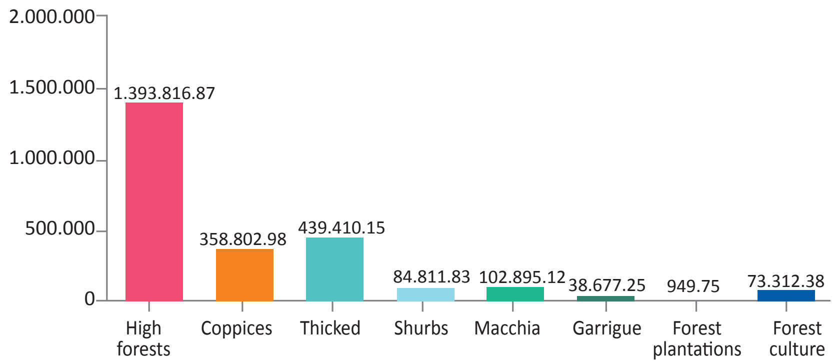

Figure 1. Forest area (in hectares) by silvicultural types in the Republic of Croatia.

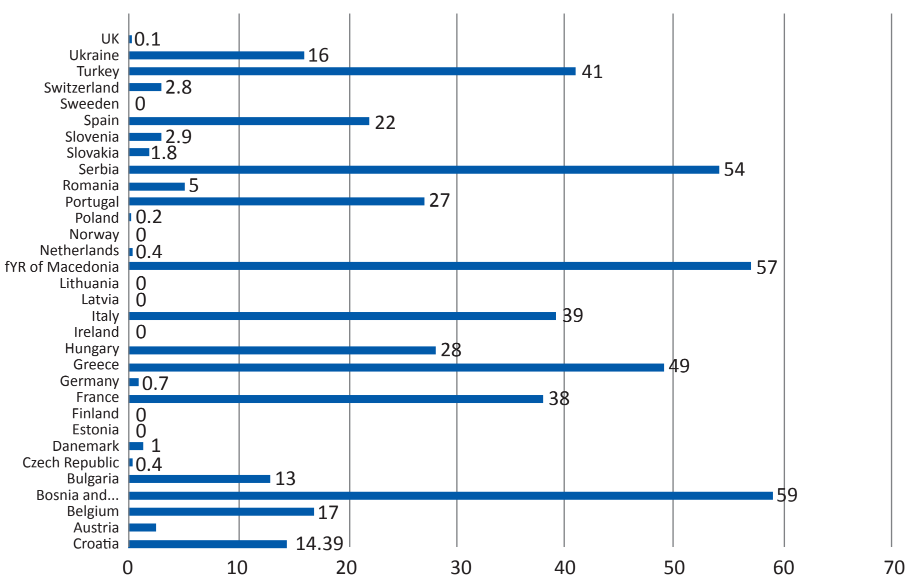

Figure 2. Share (%) of coppices in different European countries (Unrau et al. 2018).

Kadavý et al. 2019). Additionally, several non-native species have been introduced into European forests, with some becoming economically significant. One notable example is the black locust (*Robinia pseudoacacia* L.) which has various purposes in European forestry (Nicolescu et al. 2020), and the other one is eucalypt (*Eucalyptus* spp.) used in Spain and Portugal for bioenergy (Vega-Nieva 2015). Almost all these species are present in Croatian coppices since Croatia extends across Continental, Alpine and Mediterranean biogeographic regions (Figure 3). Thus, it has a remarkably high level of forest diversity (e.g. 11 out of 14 European forest types) (Matić 2012, Pilaš et al. 2014).

It is no surprise that *Fagus sylvatica* L. has the biggest share in coppices since it is the most widespread species in Croatia, with a share of 38.76% in high forests (CFMP). Additionally, *Fagus sylvatica* L. forms the dominant forest type over a large part of Western and Central Europe extending to the Mediterranean and higher altitudes (Sjölund and Jump 2015). European beech is commonly used in European coppices although it rarely reproduces vegetatively under natural conditions and is not recommended for this purpose (Packham et al. 2012, Đodan et al. 2022). Oaks are the most valuable tree species, thus significantly contributing to the high share in coppices (24.35%). *Carpinus betulus* L. (hornbeam) is a significant component of coppice forests in Europe with a wide ecological niche, thus it is commonly found in mixed deciduous stands. It is important to note that, unlike some countries in Europe, the use of *Salix* spp. and *Populus* spp. is not that common since short rotation coppices are not widespread in Croatia and their potential is yet to be discovered (Biljuš and Basarić-Sertić 2021).

The data acquired from Forest Administration Gospić (Lika, Figure 4) reveal E. beech as the prevalent tree species in the coppices of Lika, accounting for 61.83% of the growing stock. Following E. beech, the most abundant tree species are *Quercus petraea* (Matt.) Liebl. (6.32%), *Quercus cerris* L. (5.42%), *Carpinus betulus* L. (5.37%), and *Acer obtusatum* Waldst. et Kit. ex Willd. (4.37%). These findings highlight the dominance of hardwood species in the coppices of the Lika region (FA Gospić). We can see that the main tree species in Lika's coppices correspond with the tree species used in coppices in Croatia. Although E. beech has a high share in coppices in the Lika region, growing this tree species in coppices is not recommended, while oaks have better features for coppicing. Thus, the best practices of coppice conversion must be applied when E. beech coppices are concerned (Đodan et al. 2022).

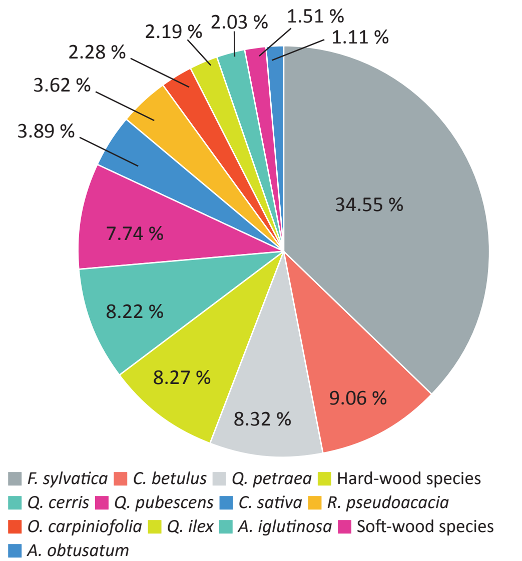

Figure 3. Tree species ratio in Croatian coppices according to the Croatian Forest Management Plan 2016 – 2025.

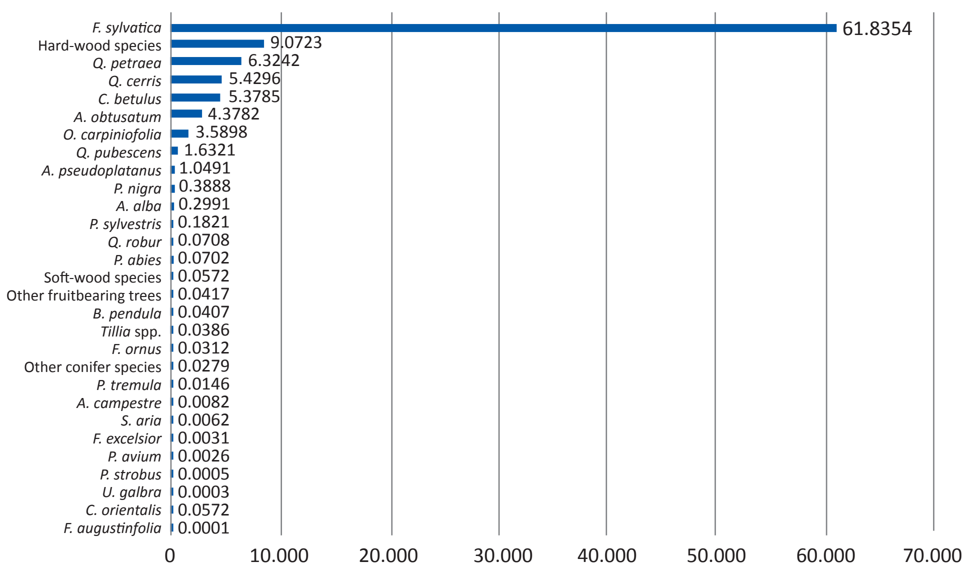

Figure 4. Share of tree species as % of growing stock in coppices of Lika region (Forest Administration Gospić).

COMPARISON OF COPPICE MANAGEMENT IN LIKA WITH EUROPEAN COUNTRIES

Management Goals

The management goals of coppices in Europe encompass a wide range of objectives, including biodiversity conservation, economic feasibility, soil and ecosystem health, climate change mitigation, and sustainable resource utilization (Müllerová et al. 2015). Additionally, coppices are important in addressing landscape protection, fire risk reduction, hydrological balance improvement, and sustaining rural livelihoods (Syampungani et al. 2016, Rodríguez-Calcerrada et al. 2021).

When dealing with CM no "one size fits all" approach can be applied since coppicing differs drastically between European countries. These differences emerge due to the long history of usage, goals of management and other political and socio-economic factors (Spinelli et al. 2017, Buckley 2020). In Mediterranean countries such as France or Italy coppicing is still a significant type of forest management as large areas (more than a quarter of forest area) are still managed as coppice forests (Hédl et al. 2017).

A common feature of most coppices in Croatia is the absence of any silvicultural activities throughout their development. Since they have developed spontaneously, this has led to the creation of a variety of diverse coppice types (Krejči and Dubravac 2004). At the same time, we can find high quality coppices, with high wood volume, good structure, and well-developed crown layer together with those of poorer quality, with lower wood volume and disrupted structure. Their origin is attributed to the unsuccessful regeneration of high forests, like those in the Lika region (Dubravac et al. 2018). The formation of coppices in Croatia has been influenced by intentional and unintentional processes, with historical and contemporary factors contributing to their establishment. Short regeneration period, absence of seed production and tending measures as well as the damages on new growth by grazing, are the most common reasons for the formation of coppice forests that are present today (Matić 2008). The management goal in Croatia varies depending on the site conditions and tree species composition. We can find coppice forests in the Mediterranean and Continental areas, with coppices in Lika falling under the latter. In cases of favourable ecological conditions and habitat potential, there is a great interest in coppice conversion (Čavlović 1994). Accordingly, coppices on rocky and steep terrain are important for soil protection (Barčić et al. 2020). Moreover, their conversion to high forest would not be cost-effective (Mairota et al. 2016b). The main activities in coppices of Lika region include the conversion of E. beech coppices (Đodan et al. 2024) or halting the negative influences in degraded coppices by preventing wildfires, browsing and uncontrolled cutting. By implementing these measures, we aim to improve forest structure, biodiversity and vitality of degraded forests (Štimac 2010). Furthermore, recent European policies offer new opportunities and perspectives for coppices in Croatia and in the region of Lika, in terms of nature conservation and enhancing biodiversity (Marchi et al. 2016, Weiss et al. 2021).

Similarities can be found with other European countries but nonetheless, each country has specific goals and strategies for managing coppices. For instance, in Italy, coppices play a key role in providing firewood as 70% of total wood production is used for firewood (Caserini et al. 2008). Coppices are managed in short rotations to meet the wood demand. Over time regulations have been issued to limit activities, degradation of coppices and to reduce negative impacts on ecosystems (e.g. water cycle, humus loss, nutrient removal) (Piussi and Alberti 2015). Management goals in Italy have been influenced by regional and governmental policies, directing forest practices towards coppice conversion (Montagnoli et al. 2012). This shift aims to mitigate the negative effects of frequent clear-cutting on soils, landscape, and biodiversity conservation. Adjourment of coppice exploitation has led to the production of "aged coppices", prompting alternative forms of traditional CM, such as coppice conversion (Riccioli et al. 2020). The conservation of coppices also plays a significant role in safeguarding biodiversity and promoting ecosystem services (Monaco et al. 2015).

Similar to Croatian and Italian, French coppices were predominantly used for fuel supply for domestic and industrial consumption (Ruch et al. 2018). Most coppices were abandoned after the Second World War and converted to coniferous species stands. In France, almost 30% of forests are regarded as protective forests, especially in alpine regions. In those areas, coppices composed of E. beech and *Quercus* spp. serve for protection against rockfalls (Dupré et al. 2017). Recently, the importance of coppices in the light of biodiversity conservation has been recognized here. Special attention is given to E. beech and oak stands, especially if they are older than 80 years. This type of stands provides important tree-related microhabitats for saproxylic and other organisms (Larrieu et al. 2019).

Coppice forests in Balkans play a key role in forest management as most countries have more than one-quarter of forests managed as coppices (Buckley 2020). A similarity of South-Eastern European countries with a high share of coppices is their inadequate past management. As a vivid example, Bulgaria, with 48% of total forest cover under coppices, has 74% of coppices under conversion (Markoff et al. 2018). The high number of coppices in the conversion process are a result of policies that date back to 1950s, which aimed to increase the productivity of Bulgarian forests (Markov et al. 2022). Currently, no plans for protection of coppices exist even though higher importance of coppices has already been given in some EU countries. Nevertheless, some Bulgarian coppices are included in Natura 2000 area (Stoeva et al. 2018).

Unlike Mediterranean and Balkan countries, western and central European countries have small coppice areas (Buckley 2020). This is a result of coppice decline in the 19th century and intensive conversion in favour of coniferous species. For example, coppice area in Germany declined drastically in the last one hundred years so currently coppices cover only 0.7% of total forest cover (Kamp 2022). One of the reasons for such a low coppice coverage is the definition of forests in German management plans: coppices older than 40 years are automatically categorised as high forests (Becker et al. 2018). Moreover, German national Forest Law mentions simple coppices and coppices with standards only in the context of conservational and recreational values.

Nowadays, conservation and cultural heritage are one of the main concerns for preserving and restoring this old silvicultural system in Germany (Vollmuth 2022, Kozdasová et al. 2022).

Silvicultural Activities

Silvicultural activities in coppices vary significantly across different European countries, reflecting diverse historical, ecological, and socio-economic contexts. European forestry differs the following coppice types: simple (low) coppice, coppice with standards, coppice selection system, pollarding, and short rotation coppice (Nicolescu et al. 2018). Nevertheless, many countries have their unique classifications.

In Croatia, the most common type of coppice is simple (low) coppice, where little silvicultural interventions have been made, followed by coppice with standards (ca 15%). Pollarding has only cultural value currently, while short rotation coppices are in the experimental phase using *Populus* spp. and *Salix* spp. (Dubravac et al. 2018). Croatian coppices are characterized by the absence of silvicultural activities and gradual degradation (Matić and Rauš 1986, Čavlović 1994, Krejči and Dubravac 2004). The sole management decision is if coppices will be managed as low forests or conversion will take place (Čavlović 1994). Inaccessible coppices on steep and rough terrain are not considered for conversion since it is a long-term process and may not always be economically sustainable (Cutini et al. 2015). However, when coppice with protective function is to be converted, natural regeneration under shelter should be used to preserve the soil as much as possible (Matić and Delač 2008). Coppices in favourable ecological conditions and with a considerable site potential are usually selected for conversion (Čavlović 1994). When coppice conversion is a management goal in Croatia, an appropriate conversion method has to be applied (Dubravac et al. 2018). The selection of conversion methods (direct or indirect), rotation length, site preparation, etc. highly depends on the structure (horizontal spatial distribution of seed trees), as well as the tree vitality, which can facilitate the process (Đodan et al. 2022). Silvicultural activities can influence conversion success, so those should be done in a timely manner. Since the development of coppices can be influenced solely by silvicultural measures, thinning represents a useful tool for preparing the coppice for conversion (Matić and Rauš 1986, Chianucci et al. 2016). Thinning is a crucial factor which is shaping coppice characteristics (Đodan et al. 2024), primarily their productivity (Matić 1990, Štimac 2010, Unrau 2018, Đodan et al. 2022). Furthermore, thinning could play a significant role in increasing stand resilience to climate stress (Marini et al. 2019, García-Pérez et al. 2021) particularly enhancing stand drought tolerance (Rodríguez-Calcerrada et al. 2011). In Lika region conversion "by ageing" is the predominant method used for converting coppices into high forests (Đodan et al. 2022). Additionally, coppice rotations in Lika are the longest in Europe (Ministry of Agriculture 2018), while the possibility of using natural regeneration is low. This further complicates the conversion process. To successfully convert E. beech coppices in the Lika region we recommend starting with thinning between 40 and 60 years of age, to prepare the coppice for conversion. By the age of sixty at the latest, regeneration and final cut should be performed (Đodan et al. 2022).

Due to these characteristics, management of E. beech in coppices is not recommended as this species does not form vegetative shoots easily, produces fewer and lower-quality shoots, has increased incidence of decay and heart rot, and lower yields (Nicolescu et al. 2018). In coppices of Lika region occurrence of weeds has not been observed, so despite the defective structure, habitat degradation does not usually occur. Conversion of coppices to climate-adapted species is recommended for most coppices in the region. However, careful assessment of the intended conversion area is needed, considering the shift in habitat conditions towards warmer and drier conditions, especially on exposed slopes and lower elevations (Đodan et al. 2022).

In Mediterranean countries, long and extensive use of coppices has led to the complex coppice typology. In France, simple coppice, coppice with standard, and short rotation coppice are recognized (Ruch et al. 2018). The predominantly used systems are simple coppice, covering 1.7 million hectares, and coppice with standards, found on 4.7 million hectares (11% and 30% of the French forests, respectively) (Lassauce et al. 2012). Similarly to other countries with a high share of coppices, most of the coppice with standards was converted after the 19th century but significant areas of coppices remain today. The silvicultural operations in coppices are mostly reduced to clear-cut and logging (Warnaffe et al. 2006). Coppices with standards are used for the production of industrial wood (including veneer) and firewood. For this purpose, the whole biomass of coppice is removed and only a low density of standards (up to one hundred trees per ha) is left (Larrieu et al. 2017). The density of standards is decreasing with coppice age, while the minimum number of standards is 40-50 trees per ha for French forests (Nicolescu et al. 2018). Coppice selection system (CSS) in France focuses on targeted diameter which is set as a management goal (Unrau et al. 2018). An age estimation is provided, which determines rotation and felling cycles. In this type of CM shoots of different ages and sizes can be found on the same stool, while only shoots that reach target diameter are cut (Coppini and Hemanin 2007). CSS has a long history in Europe, especially on low productive sites under poor soils and climatic conditions. French CSS was mainly used in (1) Pyrenees: 30 years rotation, with two felling cycles of 15 years or three felling cycles of 10 years and (2) Morvan Massif: rotation of 36 years, with four cycles of 9 years (Unrau et al. 2018).

Italy has one of the most complex coppice typologies in Europe: simple coppice, coppice with standards, compound coppice and coppice in conversion are the officially recognized ones (INFC 2007). Coppices are then divided into young, adult, old, coppices in regeneration phase and uneven-aged coppices (Mairota et al. 2018a). Coppice with standards is the most widespread CM system in Italy followed by simple (24%) and compound coppices (16%). The traditional oak management, especially for *Quercus cerris* L. is coppice with standards, in which 80-85% of total woody biomass is cut, while 70-120 standards per ha are released. For chestnut coppices, 85-90% of total woody biomass is cut and 30–100 standards per ha are released (Picchio 2018). E. beech coppices are managed by a traditional silvicultural system called selection coppice similarly to France. This old, neglected silvicultural system is again revitalized in Italy (Coppini and Hermanin 2007). Coppice conversion in Italy is a practice that has been used during the last few decades as a management goal in hilly and mountainous areas (Ciancio et al. 2006) to prevent negative offsets of erosion caused by the short rotation forestry (Ruch et al. 2018). In Italy, indirect, direct and conversion "by ageing" are used (Notarangelo et al. 2018). Similarly to Croatia, a positive long-term response of thinning in an E. beech coppice under conversion has been reported (Chianucci 2016). Average age of Italian coppices has increased in the last decades. More than 50% of coppices are over 30 years old. Currently, ca 151,000 ha (4%) of coppices undergo conversion (Notrangelo and La Marca 2021).

In Central European countries, where the conversion of forests has already been done extensively, silvicultural activities are focused on the restoration of abandoned coppice and their conservation (Kamp 2022). Simple coppice, coppice with standards, pollarding and short rotation coppice are recognised in Germany, although the area under coppices is low (<1 % of total forest area) (Becker et al. 2018). Coppices regenerate mostly vegetatively (from stump shoots and root suckers) and are harvested in small clearcuts (0.5-1 ha) using short rotations of 20-40 years (Borchard et al. 2016, Becker et al. 2018). Historically, after the cut, the soils were prepared for cultivation by burning and soil hoeing, which resulted in secondary succession (Van Der Werf 1991). The remnants of coppice with standards are highly appreciated for their biodiversity and cultural value (Vollmuth 2022). This is the reason for several attempts to restore old coppices in Europe (Kozdasová et al. 2022). Nice example is in the area of the Salzgitter Höhenzug mountains in Germany where an old coppice has been recoppiced since 1986 (Strubelt et al. 2019).

Unlike to central and western European countries, coppices and coppice management differ significantly in South-East Europe. In Bulgaria, coppices in conversion (74%) and simple coppices are recognised (Nedyalkov et al. 1961). Simple coppices are practically abandoned so only short rotation coppices of black locust still fall under that category (Markoff et al. 2018). Low quality coppices were clear-cut and replaced with conifers, but that practice has been abandoned since 2006 due to the high expenses of stool suppression (Markoff et al. 2018). Now, the main path of coppice conversion in Bulgaria is "by ageing". Most of the Bulgarian coppices are over 60 years old (Zafirov and Kostov 2019). Total share of protected coppice forests is the highest in Bulgaria (40%), resulting from the shift to Natura 2000 status.

Another notable example of how CM is unique for each country is Romania. In Romanian forests, coppicing is forbidden, apart from native poplars, willows, and black locust stands, which can be managed as coppices (Nicolescu et al. 2018). On the other hand, in Scandinavian countries, such as Sweden, coppices have been used historically but now are abandoned and have a cultural value (Löf et al. 2018). Nowadays, only short rotation coppices of *Salix* spp. are present in Sweden.

Rotation of Coppices

Variations in coppice rotation across Europe reflect the historical, geographical, and socio-economic factors. Usually, coppices are managed in short rotations, so young trees (less than 30 years old) are cut down (Evans 1992). Coppice rotations are between 5 years (willows) and 40 years (oaks, hornbeam, E. beech). In some cases, up to 60 years (Nicolescu et al. 2018). The rotation depends on the management system and species. An interesting case can be observed in Croatia, where the rotation age is the highest in Europe. Rotation age in Croatia is imposed by legal acts. It is different for each species (Ministry of Agriculture 2018); for example, for E. beech and oaks (*Quercus pubescens* Willd., *Quercus ilex* L., *Quercus petraea* (Matt.) Liebl.) is 80 years, for hornbeam is 40 years and for *Robinia pseudoacacia* L., *Populus* spp., *Salix* spp., *Alnus* spp. is 30 years (Dubravac et al. 2018). Rotation age for E. beech (80 years) is the longest for that species in European coppices (Đodan et al. 2022). E. beech highly participates in Croatian coppices (35%), especially in Lika region (MARC 2016) so such a long rotation age complicates CM in Croatia (Đodan et al. 2022).

Rotation age of coppices in Mediterranean countries, where they are used extensively, are shorter. In France, coppice rotation age depends on the tree species as well as the main management goal. For French coppices, rotation age is 10–60 years for both coppices and coppices with standards (Nicolescu et al. 2018), although typical rotation age in French forests is about 30 ± 10 years (Larrieu 2016). Here, a coppices selection system is also used, but the rotation age depends on the region.

In Italy, rotation age depends on the management system and species. Rotation age of simple coppices, which are managed by clear-cutting is 8-10 years. Coppices with standards have a similar rotation age but involve the coexistence of stump shoots and trees from seeds. Uneven-aged coppices typically have a rotation of 6-8 years, while coppices in selection system are harvested based on targeted shoot size. Compound coppices involve the coexistence of high forests managed by a selection system and coppices managed by clear-cutting, with the age of high forests being 2, 3, or 4 times the rotation age of the coppice (Mairota et al. 2018b). E. beech coppices have longer rotation ages of 16-24 years (Mariotti et al. 2017).

In Central European countries like Germany, mainly *Quercus* spp., *Carpinus betulus* L., *Alnus* spp. and occasionally *F. sylvatica* L. are harvested in small clearcuts (0.5-1 ha) in short rotations of 20-40 years (Becker et al. 2018). In some cases, this is combined with standards, which have longer rotation ages up to 40 years (Vollumuth 2022).

In Austria SRC with a rotation age of 30 years are not classified as forests. For simple coppice 15-30 years rotation ages are used, for coppice with reserves 20-30 years for underwood and 40-60 years for reserves. In coppice with standards, the rotation ages are 20-30 years for coppice (underwood) and 100-120 years for standards (Kühmaier et al. 2018).

In Bulgaria simple coppice forests management has been practically abandoned. It was common in Bulgaria until 1950's with rotation ages of 15–30 years (Nedyalkov et al. 1961). Nowadays, only black locust (*Robinia pseudoacacia* L.) is used with a rotation age of 20 years (Ivailo et al. 2018).

In North Macedonia, another Balkan country with a high share of coppices, typical rotation ages varies from 10 to30, sometimes 40 years (Trajkov et al. 2019), although in some cases where different types of oak and European beech stands are present, coppice is managed on a rotation of 50 years (Trajkov and Nestorovski 2018).

CONCLUSIONS

Coppice management is highly complex, laying on the variety of distinct factors and circumstances. It differs significantly among European countries, while Croatian coppices displayed the state of coppices and CM of South-East European countries. Thus, consideration made for Croatian coppices in this study can be used for CM decisions in the Region. Significant changes in CM should be made for coppices in Lika region, and Croatia in general. European beech coppices should be converted in the age of 40–60 years. Conversion by ageing is not advisable for those coppices. The oldest coppices can be left for the purposes of the passive management due to their high biodiversity and ecosystem functions values. Moreover, we conclude that coppice management in Lika in general should be reconsidered and more emphasis should be given to the benefits that coppices provide. Also, considering growing value of coppices under climate and global changes, more research is needed into specific aspects of CM. The most significant ones are those related to wood quality and presence of wood root in relation to age in European beech coppices.

Author Contributions

MĐ developed the original idea, conceptualised the manuscript, conducted a review of the scientific literature, SP, DS and VNN reviewed the drafted manuscript, performed editing, and critically revised the work, DS provided national data, MĐ secured the research funding and wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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