Comparison between crown thinning and girdling to enhance sporadic tree species in a coppice stand in Central Italy.

Journal:	*Annals of Silvicultural Research*
Manuscript ID	ASR-2022-0019.R1
Manuscript Type:	Research Paper
Date Submitted by the Author:	18-Oct-2022

Complete List of Authors:	Paoloni, Riccardo; Università degli Studi di Firenze Pacini, Alessandra ; Università degli Studi di Firenze Bidini, Claudio; CREA, Research Centre for Forestry and Wood Marchino, Luca; Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria, Centro Foreste e Legno Manetti, Mariachiara; CREA, Research Centre for Forestry and Wood Pelleri, Francesco; CREA, Research Centre for Forestry and Wood

Keywords:	Sporadic tree species, Girdling, Crown thinning

Comparison between crown thinning and girdling to enhance sporadic tree species in a coppice stand in Central Italy

Abstract

Sporadic valuable tree species and especially *Sorbus* species have gained importance in forest management as they increase tree biodiversity, ensure a higher resilience of the stand to climate change, and enhance valuable timber production. This paper reports the first results of a trial carried out in Central Italy in a Turkey oak coppice stand (aged 17 years) where three different silvicultural treatments (crown thinning, girdling and unthinned control) were applied to favour sporadic tree species. The monitoring was carried out for 5 years and showed the limits of girdling application as Mediterranean species like Turkey oak form easily scar cords and epicormic sprouting. Furthermore, the progressive reduction of canopy cover of the competitors resulted from girdling and the effect of the thinning and girdling on the growth of selected service trees (*Sorbus domestica* L.) were evaluated. The first results of this research have pointed out some difficulties in the girdling application and a higher effect of crown thinning in stimulating the growth of selected service trees.

Password: sporadic tree species, crown thinning, girdling, *Sorbus domestica*, *Quercus cerris*.

Introduction

During the last decades, minority tree species are increasing their relevance in forest management across Europe. The preservation of sporadic tree species is essential for many purposes, such as maintaining a high level of biodiversity, improving the touristic value of the landscape, increasing the feeding sources for wild animals, and enhancing valuable timber production (Spiecker 2006). The forests of Tuscany are very rich in sporadic tree species. Turkey Oak (*Quercus cerris* L.) and mixed broadleaved forests represent a category where sporadic tree species are more frequent. The western areas of Tuscany are characterized by a higher density of valuable broadleaved tree species, where the presence of different *Sorbus spp.* is particularly high (Mori et al. 2007, Damiani et al. 2011). In these areas, coppice stands, and coppice converted into high forests represent the most frequent management approaches. The frequency of minority tree species is higher in young coppices and tends to reduce in aged coppices or in those under conversion, due to the traditional management practices rather oriented to favour the main species as Turkey oak. This competitive fast-growing oak is well adapted to coppice system, and it can reduce the vitality of light-demanding minority tree species causing their progressive mortality or confining them in the lower layer. Recently an innovative approach of forest management (tree-oriented silviculture) has been applied in coppice stands (Sansone et al. 2012, Manetti et al. 2016), in coppices under conversion (Manetti et al. 2020) and in high forests (Pelleri et al. 2021) across the Italian territory. This approach expects the thinning practice to favour the free growth of a restricted number of early-selected crop trees by frequently felling their neighbouring competitors. Such procedure can be suitably applied in coppice stands to promote a restricted number of sporadic tree species, to reduce the competition of the main species permitting them to reach the dominant and codominant layers. In the young phase *(qualifying/first period of sizing)* the crop trees can be favoured by felling the direct competitors (localized crown thinning) or by reducing the vitality of the competitors by girdling (Wilhelm 2003, Schütz 2006). This second technique consists in removing a complete ring of bark and phloem from around the tree's stem, keeping intact the xylem and maintaining the flow of the raw lymph (from root to the crown) but interrupting the flow of elaborated lymph from the crown to the roots. This practice is easily operable during summer and has the advantage of avoiding the abrupt isolation of the crop trees reducing the risk of epicormic sprouting or wind throw. Within the time of 1-3 years, girdling causes a progressive weakening of the root system which leads to the death of the girdled trees (Roth et al. 2007, Moore 2013).

The girdling technique has been applied in different situations, both in trial and in forest practices for ecological and technical reasons such as:

(i) To increase the deadwood inside the forest creating new standing dead trees and snags to improve biodiversity (Mason et al. 2003, Mattioli et al. 2017)

(ii) To control the spreading of invasive alien species in natural forests (Mason et al. 2003, Hasstedt and Annighöfer 2020)

(iii) To reduce the cost in pre commercial crown thinning (Reque and Bravo 2007)

(iv) To reduce the risk of windthrow especially in dense stands subjected to heavy thinning (Peri et al. 2002)

(v) To favour the young crop trees reducing progressively the competition of the wolf trees (Wilhelm and Rieger 2017)

This study was carried out in a Mediterranean Turkey oak coppice stand (17 years-old) characterized by the presence of different sporadic tree species (mainly service trees *Sorbus domestica* L.). The main aim of the study was to evaluate the effectiveness and sustainability of girdling in reducing the vitality of the main competitors instead of felling them and the effect of two silvicultural treatments in stimulating the diameter growth of young sporadic valuable crop trees. Secondly, the purpose was to verify the functionality of two girdling tools, *cutting girdler* and *chainsaw girdler*.

The paper reports the first results of a comparison of three different silvicultural approaches applied to enhance sporadic tree species: localized crown thinning, girdling, and unmanaged control.

Methods

Study area

The study was carried out in Val di Merse Forest district (SI) and in the regional forest La Selva (coordinates: 43°14'24.5"N; 11°07'11.6"E). The area is located at an elevation from 370 to 480 m a.s.l. on silty marl with sandstone bedrock. The soil is "*typic haplustepts, fine-silty, carbonatic, mesic, shallow*" (unit RAD1-http://sit.lamma.rete.toscana.it/websuoli) slightly or moderately deep, well drained, with a silty texture, moderately alkaline and strong to moderately calcareous.

According to Anqua-Radicondoli meteorological station, the climate is Mediterranean with mean annual temperature of 14.5 C°, mean annual rainfall of 1,095 mm, rainy days 87 and with a dry period in July. The trial was performed in 2015, on an area of about 10 hectares with an average slope of 20% and with Est prevailing aspect. The trial was carried out in a Turkey oak coppice with standard (17 years-old) characterized by the presence of sporadic tree species. According to the forest types of Tuscany (Bernetti and Mondino 1998) the stand can be considered a sub-Mediterranean acidophilous Turkey oak forest with heather tree (*Erica spp.)* presence.

Stand characterization

The stand characteristics were evaluated by mean of 3 plots. In each plot, the stools and trees were measured inside a circular area with a radius of 10 m (314 m^2) using a DBH threshold ≥ 4 cm, while to estimate the standard trees density a radius of 20 m was used (1,256 m^2). The plots were located along the slope following an altitudinal gradient (top 460 m, medium 435 m, and low 395 m). Inside the smaller area the following parameters were recorded for each tree and shrub: DBH, species, origin (by seed or by stools) and height of an average sucker for each stool. Inside the bigger area DBH, height and species composition were measured for each standard tree.

Selection of sporadic crop trees and experimental trials

Inside the area of 10 hectares the best valuable sporadic tree species were selected, mapped, and marked according to the following criteria developed in the LIFE+PProSpot project (Mori and Pelleri 2014):

a) vigorous trees or suckers with the age of the stand, or young standard trees preserved in the previous coppicing

b) trees with stem quality suitable for valuable timber production.

c) minimum distance among trees 8-10 m

In particular circumstances, locally scarce or rare trees or trees suitable for seed production were selected.

For each selected tree the following dasometric parameters were measured: DBH, total height (H), crown insertion (Hins), H/D ratio, crown diameter (CD) by measuring 4 crown radius projections (N, E, S and W), and potential stem quality according to the 4 classes used for valuable broadleaved tree species (Nosenzo et al. 2012). In the whole, 126 sporadic trees belonging to the following species were selected: 3 field maples (*Acer campestris L.*), 6 narrow-leafed ashes (*Fraxinus angustifolia* Vahl.), 87 service trees (*Sorbus domestica* L.), 15 wild service trees (*Sorbus torminalis* L.), 3 elms (*Ulmus minor* Mill.) and 12 wild pears (*Pyrus pyraster* (L.) Burgsd).

The dasometric characteristics were measured in 2015 and in 2020.

Silvicultural treatments

In 2015, the following 3 silvicultural treatments were applied to preserve and favour the 126 selected sporadic trees:

a) crown thinning by felling all the competitors of the selected trees (T) (Fig. 1); this treatment was carried out in November.
b) girdling of all the competitors of the selected trees (G) (Fig. 2) two different girdling tools were used: *cutting girdler* (Cut-G) and *chainsaw girdler* (Chain-G) (Fig. 3); this treatment was carried out in June.
c) unmanaged control trees (C).

[Here the Fig. 1]

[Here the Fig. 2]

In order to obtain a homogeneous distribution in the whole study area, the 3 silvicultural treatments were assigned to the selected trees avoiding applying the same treatment on trees closer than 12-15 m between each other.

During the application of the two types of treatment (T and G), the same marking criteria of the competitors were applied (Paoloni 2016): all the competitors that dominated or compressed the crown of the selected trees were marked to release a free space of 2 meters around the crop trees (in French *dètourage*).

[Here Fig. 3]

One year after the girdling, the effects on the treated competitors were evaluated by observing the following parameters and their differences among the tree species:

(i) the tendency to reconstitute scar cords able of restoring a continuity of phloem and bark (Fig. 4)

(ii) the tendency to produce epicormic sprouting under girdling wounds (Fig. 5)

[Here Fig. 4]

[Here Fig. 5]

To evaluate the presence and the vigour of the girdling effects, the competitors were classified in four different classes (1-4) with increasing relevance (Tab. 1).

[Here Table 1]

Effects of silvicultural treatment on canopy cover

The variations of light under the canopy of selected trees were estimated in Summer measuring the photosynthetic active radiation (PAR) under 15 trees (5 trees per each treatment) and in open space close to the study area, by using a ceptometer AccuPAR LP-80 (Decagon Devices, Pullman, WA, USA) at midday on sunny days. Transmittance was calculated as percent fraction of below-canopy light, divided by the incident radiation (Chianucci and Cutini 2013, Cutini et al. 2015). The measurements were carried out in 2015, before thinning, and repeated after thinning for consecutive 3 years (until 2018) and again in 2022.

Monitoring of the selected service trees

In February 2020 (after 5 years from the beginning of the trial) a second inventory of the sporadic selected trees was carried out to verify the effects of the silvicultural treatments on the growth (DBH, H, H/D ratio and crown diameter) and to evaluate the damages caused by silvicultural operations on the selected crop trees.

Data analysis

The mean dasometric characteristics of the stand and their standard deviation were calculated averaging the data of the 3 plots. The following parameters were calculated: stem density (N), mean DBH, basal area (BA), mean height (H) calculated by the DBH and H relation, dominant height (HD), tree diversity by Shannon index (SH), number of sporadic species (NS) and importance value (IV) of Turkey oak and Service tree. The effects of girdling were evaluated by observing the ability to reconstitute scar cords, and the tendency to sprout epicormic branches of the girdled competitors. The efficiency of the two girdling tools was analysed evaluating the differences among tree species by performing χ^2 Pearson test. The effects of the silvicultural treatments on the growth of the selected service trees were evaluated by the analysis of variance (ANOVA) of the main dasometric parameters after checking the normality and homoscedasticity by Kolmogorov-Smirnov (KS) and Lilliefors tests. The significant differences among the average data were evaluated by HSD Tukey test and the differences in stem quality classes were evaluated by performing χ^2 Pearson test. All the analyses were conducted using the software Statistica 7.1 (StatSoft USA).

Results

Stand characterization

The coppice stand had a mean density of 1,528 stools, 3,278 shoots and 103 standard trees per hectare (Tab. 2). The total basal area (BA) reached 16.46 m^2 ha^{-1} (stools 79% and standard trees 21%). In the whole 7 tree species were present: 5 species in the top part of the forest compartment, 4 species in the central part and 6 in the lower part close to the river. Despite the presence of 7 different tree species, the stand was mainly characterized by Turkey oak. This oak species presented the highest importance value (IV = 0.79); the other tree species were less frequent and had an IV that ranged from 0.13 for narrow-leafed ash, to 0.03 for service trees and 0.01 for field maple. These results caused also a relatively low Shannon index (SH =0.70).

[Here Tab. 2]

Selection of sporadic crop trees and experimental trials

In the whole, 126 sporadic trees were selected (41 favoured by thinning, 41 by girdling and 44 kept as control). The main dasometric parameters of all the sporadic crop trees selected in the first inventory were reported in Table 3. Overall, 1,090 competitors were felled with localized thinning, while 835 competitors were girdled (633 with Cut-G and 202 with Chain-G).

[Here Tab. 3]

Effects of girdling, evaluation of the two different girdling tools and working times

The cutting girdler (Cut-G) was used mainly on the small and medium trees (DBH classes 5-10 cm) while chainsaw girdler (Chain-G) was used in the medium and big trees (DBH classes 15-20). The analysis of girdling effect with the *cutting girdler* showed that 26% of competitors presented scar cords (classes 2, 3 and 4), while only 2% of competitors treated with *chainsaw girdler* showed scar cords. The comparison of the two girdling tools by χ^2 Pearson test was realised only for Turkey oak, the most representative specie (Tab. 4). This test pointed out a superior and significative development of scar cords using the Cut-G due to the higher difficulty to clean the girdling wound by removing all the residues of phloem and bark. After the evaluation all the scar cords were removed.

[Here Tab. 4]

The analysis of the epicormics sprouting effects induced by girdling on the treated competitors, pointed out a significant difference between the two girdling tools: respectively for Cut-G and Chain-G (Tab. 5) 8% and 11% of the treated competitors did not have epicormics (class 1), 54% and 63% of competitors presented only few epicormics (class 2), 33% and 25% of competitors presented many epicormics (class 3) and only 4% and 1% presented many and vigorous epicormics (class 4).

[Here Tab. 5]

Monitoring of selected service trees

The results of ANOVA and HSD Tukey test are showed in Fig. 6. In the first inventory no differences were found for DBH, H, H/D ratio and crown diameter among the selected service trees in the three silvicultural treatments. Five years later (2020) no differences were found in H, while significant differences were found in DBH, H/D ratio, crown diameter, and in DBH increment among the two types of treatment (T and G) and the control. In particular, selected service trees subjected to crown thinning showed higher DBH increment in comparison both to the service trees favoured by girdling and to the control.

[Here Fig. 6]

The distribution in stem quality classes was similar in both two inventories: no significant differences were noticed among the silvicultural treatments in 2015 and in 2020 (Tab. 6). Stem quality of service trees favoured by crown thinning presented, in both inventories, a similar percentage of stem belonging to the best classes (A+B) while the stem quality was slightly deteriorated in service trees favoured by girdling and in the unthinned control.

[Here Tab. 6]

Effects of silvicultural treatment on canopy cover

The transmittance measurements conducted between 2015 and 2018 pointed out an abrupt increase of the values after the localized thinning (from 6% to 61%) while the progressive reduction of canopy cover under the crown of sporadic selected trees favoured by girdling caused a more progressive increase of transmittance (from 8 to 22%) (Fig. 7). In 2022 the transmittance values both in the thinned and the girdled theses decreased (from 61% to 26% in the first case and from 22 to 9% in the second) as a result of the crown expansion of the selected trees as well as of the neighboring standing trees (Fig. 7).

[Here Figure 7]

Discussion

The first results of this trial have pointed out a higher efficiency of crown thinning in comparison to girdling. Crown thinning resulted surely easier to apply for the workers who have more familiarity with the use of the chainsaw while some difficulties were met with the use of the two girdling tools. The comparison of the two different tools (Cut-G and Chain-G) has showed a superior efficiency of Chain-G in reducing the risk of scar cords creation. The correct use of the Chain-G requires to realize two rings around the trees reaching the wood, spaced about 8-20 cm one from the other, and to peel off the bark between them (Smith et al. 1997, Roth et al. 2007). This procedure permits to remove easily all the residues of phloem and bark reducing the risk of creation of scar cords. With the cutting girdler particular attention should be paid to cleaning all the residual of phloem and bark present in the girdling wound using the iron brush of the cutting girdler. Regarding to the epicormics production, the girdling realized in June determined the sprouting of numerous epicormics in about 30% of the Turkey oaks competitors. This effect could perhaps be better controlled by making the girdling in August as already verified for common Oak (*Quercus robur* L.) by other authors (Wignall et al. 1987). The effects of the silvicultural treatments on canopy cover pointed out an abrupt increase of transmittance after crown thinning (about 50-60% in comparison to the light in the open field). This rapid isolation of the crown and the consequent change in the lighting of the selected trees did not create evident sprouting of epicormics shoot in service trees but could stimulate their emission in other tree species causing a worsening of the stem quality. Furthermore, the first year after the thinning a reduction of the crown and variations in the diameter growth are frequent due to the sudden shock. Instead, the progressive reduction of canopy cover of the competitors caused by girdling (from 8 to 22% in three years) permits a constant increase of DBH which is a plus for valuable products and reduces the risk of epicormics sprouting or windthrow. For this reason, it could be more suitable for other tree species such as valuable oaks and wild cherry which are more subjected to the emission of epicormic shoots (Smith et al 1997, Reque and Bravo 2007). The influence of the silvicultural treatments on the growth of selected service trees pointed out a higher effect of crown thinning in comparison to girdling and control. In this site condition this thinning type has stimulated a progressive increase of the DBH growth with mean annual increment of 3-4 mm and a development of crown diameter by 10 cm per year. In similar experiences (Manetti et al. 2016) and more fertile sites the crown thinning applied to bigger crop trees (DBH $\cong$ 10 cm) permitted a superior growth (DBH increment 5-6 mm per year).

It is important to specify that the presence of dead trees in the forest helps to create a network of habitat trees which provide ecological niches for animals giving value to the stand in terms of biodiversity.

Conclusion

In this trial the crown thinning resulted easier to realize by the forest workers and permitting to obtain a production of firewood which can be conveniently harvested if an adequate network of forest tracks is available. Furthermore, in the first years this type of thinning presented a superior effect on growth, stimulating the increase of DBH and the development of crown.

The girdling system resulted more difficult to realize probably because of the lack of an adequate training period of the forest workers and their better habit in the use of the chainsaw. The lower effects on the growth of the crop trees could be only temporary in the girdling treatment because it will tend to decrease with the progressive death of the girdled competitors. This must be evaluated through further monitoring. It is important to consider that the progressive decay and death of the girdled trees generally first causes the progressive collapse of the branches and secondarily of the stem. For this reason, girdling must be avoided close to the streets or in forests interested by a high tourist activity. Besides, the high presence of deadwood could cause a higher fire risk.

Nevertheless, the use of girdling technique presented some positive aspects: the work is less dangerous for the workers in comparison to the use of chainsaw (danger of injury, less rumours and pollution) and no specific personal protective equipment is necessary. This technique can be conveniently applied in areas where the harvesting of the firewood produced by thinning resulted complicated and expensive. The girdled trees, remaining standing in the forest, continue to perform their function in soil protection and in providing shelter for wild fauna and avifauna. The transitory protection of soil and understorey layers and the gradual change in the forest light regime permit to realize localized intervention more intensive, reducing the risk of epicormics and windthrow. In conclusion, girdling can be properly used to favour crop trees with high risk of epicormics sprouting, in areas with a low density of forest tracks and where an increase of standing death trees does not represent a higher risk for forest fire while the crown thinning technique resulted the best option if the objective of the management is to stimulate fast growing and enhancement of sporadic valuable trees. The results of this research are only initial and further insights are certainly needed.

Acknowledgements

The authors thank the Unione dei Comuni della Val di Merse which financed this research (Project: COVALAPREG). A special thanks goes to the two forest operators Andrea Sozzi and Roberto Brogelli, who supported us in carrying out the experimental treatments, and to the PhD Forestry Doctor Angelo Vitone who participated in the first stages of this research.

References

Bernetti G., Mondino G. P. 1998 - *I tipi forestali. Boschi e macchie di Toscana*. Edizioni Regione Toscana. 358 p.

Chianucci F., Cutini A. 2013 - *Estimation of canopy properties in deciduous forests with digital hemispherical and cover photograph*y. Agriculture and Forest Meteorology 168: 130–139. https://doi.org/10.1016/j.agrformet.2012.09.002

Cutini A., Chianucci F., Giannini T., Manetti M.C., Salvati L. 2015 - *Is anticipated seed cutting an effective option to accelerate transition to high forest in European beech (*Fagus sylvatica *L.) coppice stands*? Annals of Forest Science https://doi.org/10.1007/s13595-015-0476-7

Damiani M., Sansone D., Pelleri F. (2011). *Il ciavardello nel comune di Monticiano (SI): indagine conoscitiva sulla diffusione e selle potenzialit*à. Sherwood - Foreste e Alberi Oggi 172: 15-20.

Hasstedt S.L., Annighöfer P. 2020 - *Initial survival and development of planted European Beech (*Fagus sylvatica *L.) and Small-Leaved Lime (*Tilia cordata *Mill.) seedlings competing with Black Cherry (*Prunus serotina *Ehrh.)*. Plants 9 : 677. 17 p. doi:10.3390/plants9060677

Manetti M.C., Becagli C., Sansone D., Pelleri F. 2016 - *Tree-oriented silviculture: a new approach for coppice stands*. iForest 9: 791-800. doi: 10.3832/ifor1827-009

Manetti M.C., Becagli C., Bertini G., Cantiani P., Marchi M., Pelleri F., Sansone D., Fabbio G. 2020 - *The conversion into high forest of Turkey oak coppice stands: methods, silviculture and perspectives*. iForest 13: 309-317. doi: 10.3832/ifor3483-013

Mason F., Nardi G., Tisato M. 2003 - *Proceedings of the International Symposium Dead wood: a key to biodiversity. 29th-31st May 2003 Mantova (Italy)*. Sherwood - Foreste e Alberi Oggi 95. 100 p.

Mattioli W., Di Santo D., Barbati A., Portoghesi L., Burrascano S., Sabatini F.M., Giuliarelli D. 2017 - *Manuale di buone pratiche per la gestione degli habitat 9210* e 9220**. Progetto LIFE+ FAGUS. 72 p.

Moore G.M. 2013 - *Ring-barking and girdling: how much vascular connection do you need between roots and crown?* In: Proceeding 14th National Street Tree Symposium 2013: 87-93.

Mori P., Buresti Lattes E., Bruschini S., Giulietti V., Grifoni F., Pelleri F., Ravagni S., Berti S., Crivellaro A. 2007 - *Selvicoltura delle specie sporadiche in Toscana*. Agenzia Regionale per lo Sviluppo e l'Innovazione nel settore Agricolo-forestale (ARSIA) della Toscana. 352 p.

Mori P., Pelleri F. 2014 - *Selvicoltura per le specie arboree sporadiche. Manuale tecnico per la selvicoltura d'albero proposta dal progetto LIFE+PProSpot*. Compagnia delle Foreste, Arezzo, Italy. 144 p.

Nosenzo A., Boetto G., Berretti R., Travaglia P.M. 2012 - *Applicazione dell'indice di qualità su un campione di impianti di arboricoltura da legno del Piemonte*. Sherwood - Foreste e Alberi Oggi 183: 21-25.

Paoloni R. 2016 - *Valorizzazione di specie sporadiche in un ceduo della Val di Merse (SI). Confronti tra cercinatura e diradamento localizzato*. Tesi di laurea in Scienze Forestali ed Ambientali. Anno Accademico 2015/2016, Università degli Studi di Firenze, 86 p.

Pelleri F., Becagli C., Sansone D., Bianchetto E., Bidini C, Manetti M.C. 2021 - *New silvicultural approaches for multipurpose management in beech forests.* Annals of Forest Research 64 (2): 87-103. https://doi.org/10.15287/afr.2021.2226

Peri P., Martínez-Pastur G., Vukasovic R., Diaz B., Lencinas M., Manuel-Cellini J., 2002 - *Thinning schedules to reduce risk of windthrow in* Nothofagus pumilio *forests of Patagonia, Argentina*. Bosque 23 (2): 19-28.

Reque G.A., Bravo F. 2007 - *Viability of thinning sessile oak stands by girdling*. Forestry 80 (2): 193-199.

Roth V.B, Bucher H.U., Schutz J.P, Ammann P. 2007 - *Cercinatura: vecchi metodi nuove utilizzazioni.* Sherwood - Foreste e Alberi Oggi 135: 19-22.

Sansone D., Bianchetto E., Bidini C, Ravagni S., Nitti D., Samola A., Pelleri F. 2012 - *Selvicoltura d'albero nei cedui giovani: interventi di valorizzazione delle specie* *sporadiche nell'ambito del Progetto LIFE+ PProSpoT*. Sherwood - Foreste e Alberi Oggi 185: 5-10.

Schütz J.P. 2006 - *Opportunities and strategy of biorationalisation of forest tending within nature-based management*. In: "Nature based forestry in central Europe. Alternative to industrial forestry and strict preservation". Studia Forestalia Slovenica 126: 39-46.

Smith D., Larson B., Kelty M., Ashton P. 1997 - *The Practice of Silviculture*: *applied forest ecology*. 9th edition. Wiley, New York. ISBN 13: 9780471109419. 537 p.

Spiecker H. 2006 - *Minority tree species: a challenge for a multi-purpose forestry*. In: "Nature based forestry in central Europe. Alternative to industrial forestry and strict preservation". Studia Forestalia Slovenica 126: 47-59.

Wignall T.A., Browning G., Mackenzie A.D. 1987 - *The physiology of epicormic bud emergence in Pedunculate Oak (*Quercus robur *L.) Responses to Partial notch girdling in thinned and unthinned stands*. Forestry 60 (1): 45-56**.**

Wilhelm G.J. 2003 - *Qualification-grossissement: la stratégie sylvicole de Rhénanie-Palatinat*. RDV, Office National des Forêt 1: 4-9.

Wilhelm G.J., Rieger H. 2017 - *Stratégie QD: une gestion de la forêt basée sur la qualité et les cycles naturels*. CNPF et Forêt Wallonne asbl. Pris. 192 p.

Figure 1 - Selected tree targeted by crown thinning.

423x564mm (72 x 72 DPI)

Figure 2 - Girling of the competitors around a selected service tree.

219x143mm (120 x 120 DPI)

Figure 3 - Manual tools used for girdling: Cutting girdler (A) and Chainsaw girdler (B).

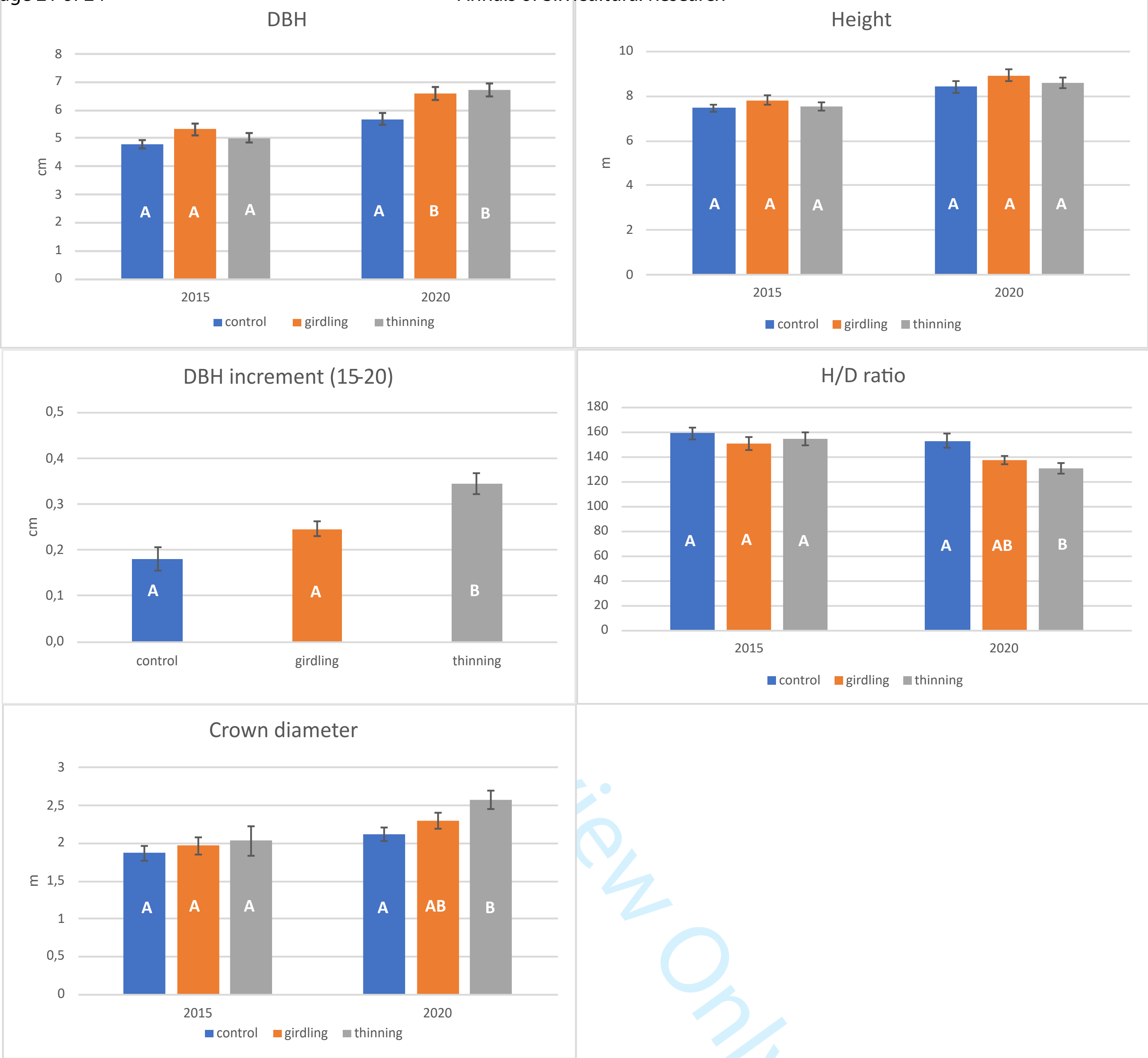
1223x550mm (96 x 96 DPI)

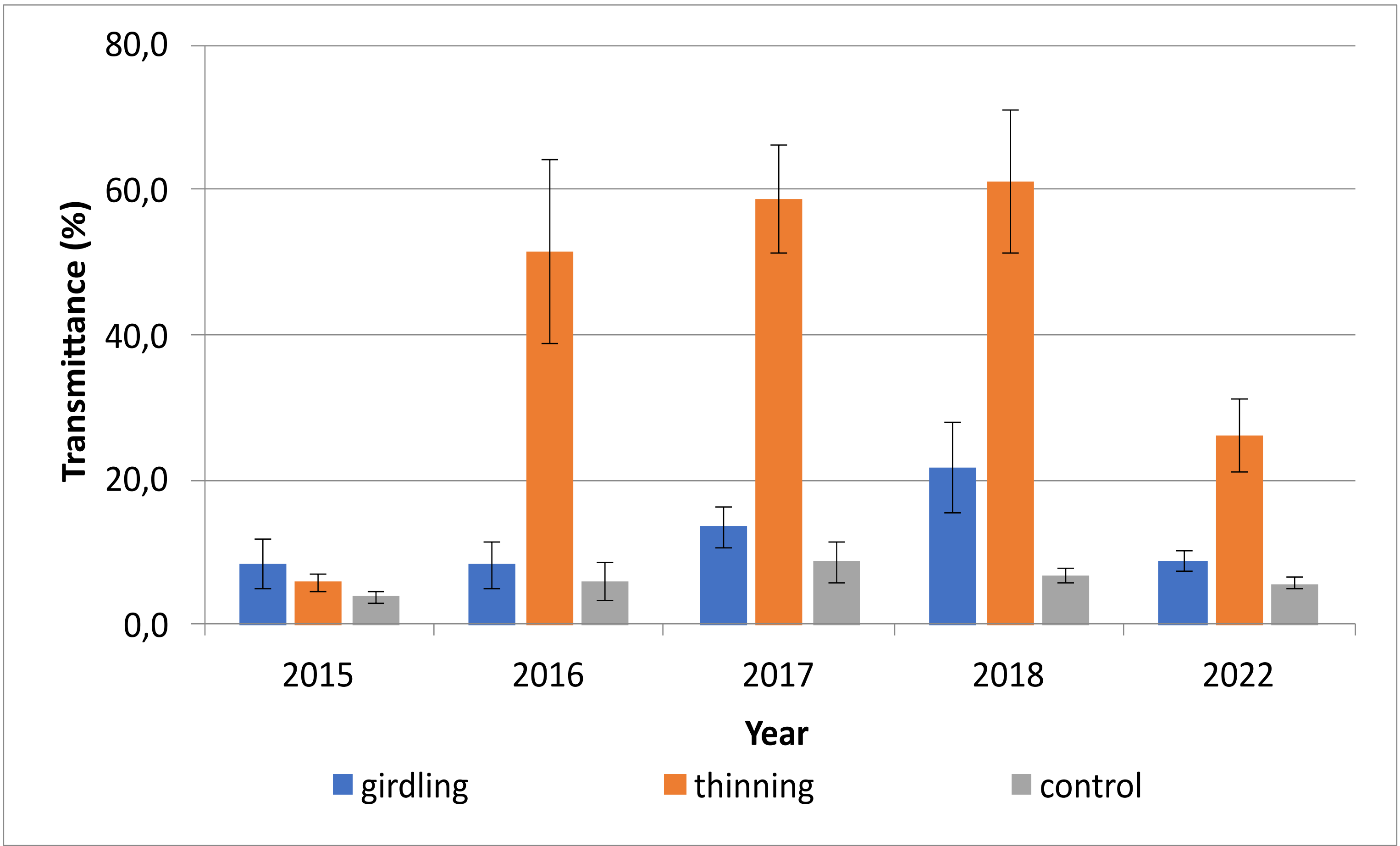
Figrue 4 - Scar cords on girdled direct competitor.

602x901mm (120 x 120 DPI)

Figure 5 - Emission of epicormic sprouting on girdled direct competitors.

245x170mm (120 x 120 DPI)


DBH
cm
0
1
2
3
4
5
6
7
8
2015
2020
A A A
A B B
control girdling thinning
Height
m
0
2
4
6
8
10
2015
2020
A A A
A A A
control girdling thinning
DBH increment (15-20)
cm
0,0
0,1
0,2
0,3
0,4
0,5
A A B
control girdling thinning
H/D ratio
0
20
40
60
80
100
120
140
160
180
2015
2020
A A A
A AB B
control girdling thinning
Crown diameter
m
0
0,5
1
1,5
2
2,5
3
2015
2020
A A A
A AB B
control girdling thinning


80,0
60,0
40,0
20,0
0,0
Transmittance (%)
2015
2016
2017
2018
2022
Year
girdling
thinning
control

Tables

Table 1 - Qualitative evaluation on girdling effects on the treated competitors in classes.

Girdling effects	Class 1	Class 2	Class 3	Class 4
Scar cords	absent	few	many	many and evident
Epicormics branches	absent	few	many	many and vigorous

Table 2 – Mean dasometric and compositive characteristics of the stand ± standard deviation.

		Quercus cerris	*Sorbus domestica*	Other species	Total
Stools	n ha^{-1}	1,125±366	85±120	318±261	1,528±391
Shoots	n ha^{-1}	2,408±493	127±194	743±860	3,278±344
Standard trees	n ha^{-1}	90±32	8±14	5±9	103±42
DBH	cm	8,3±0,7	5,0±0,2	6,7±1,0	7,9±0,9
Hm	m	9,3±0,4	6,6±0,2	8,1±0,8	9,0±0,5
HD	m	--	--	--	13,8±0,9
BA	m^2 ha^{-1}	13,57±4,21	0,27±0,38	2,62±3,40	16,46±2,24
Importance Value	IV	0,79±0,20	0,03±0,04	0,19±0,22	--
N° of species	NS	--	--	3±0,6	5±1
Shannon index	SH	--	--	--	0,70±0,37

Table 3 - Main dasometric parameters (± st. dev.) of the selected sporadic trees measured in the first inventory 2015.

Tree species	N°	DBH cm	H m	H insertion m	Crown diameter m	Crown deep m	H/D
Sorbus domestica	87	5,00±1,6	7,61±1,3	3,45±1,0	2,05±1,0	4,62±1,2	155±27
Sorbus torminalis	15	6,10±1,6	7,06±1,3	2,54±0,7	2,22±1,5	4,51±1,1	123±24
Fraxinus angustifolia	6	9,30±1,7	10,90±1,5	4,23±0,8	3,07±0,8	6,67±1,2	119±13
Pyrus pyraster	12	6,00±1,6	7,83±1,3	2,53±0,7	1,85±1,1	5,31±1,2	137±35
Acer campestris	3	5,40±1,9	8,90±1,4	3,70±0,7	1,80±0,8	5,20±1,2	167±21
Ulmus minor	3	6,90±1,8	9,43±1,3	2,97±0,7	2,42±0,5	6,47±1,0	138±15

Table 4 - Scar cords distribution in classes for different girdling tools in Turkey oak competitors.

Girdling tools	Class 1 absent	Class 2 few	Class 3 many	Class 4 many & vigorous	Total
Cut-G	323	19	21	6	369
Chain-G	187	1	1	1	190

$p<0.01$ $\chi^2 = 18.83$

Table 5 - Epicormics distribution in classes for different girdling tools in Turkey oak competitors.

Girdling tools	Class 1 absent	Class 2 few	Class 3 many	Class 4 many & vigorous	Total
Cut-G	31	201	122	15	369
Chain-G	20	120	48	2	190

$p<0.05$ $\chi^2 = 8.52$

Table 6 – Stem quality distribution in the inventories 2015 and 2020.

2015 treatments	A+B	C+D	total	A+B %	C+D %
girdling	15	14	29	52	48
thinning	13	14	27	48	52
control	14	17	31	45	55
total	42	45	87	48	52

$\chi^2 = 0.259$ n.s.

2020 treatments	A+B	C+D	total	A+B %	C+D %
girdling	7	21	28	25	75
thinning	12	15	27	44	56
control	9	22	31	29	71
total	28	58	86	33	67

$\chi^2 = 2.641$ n.s.