Evaluation of two silvicultural treatments and terrestrial photogrammetry in *Quercus suber* stands, North-East Spain

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Abstract

Cork oak (*Quercus suber*) is a highly appreciated tree in Mediterranean forests for its values: economic and environmental. Cork extraction is the main activity due to the economic value of the cork. For this reason, this project has the aim to promote the sustainable production of cork. The first objective has been a comparison between two silvicultural treatments. The silvicultural treatments tested were: total and partial clearing combined with a selective thinnig of low intensity, to consider advantages and disadvantages of each scenario. Knowing pros and contras, we wanted to make a general management proposal depending on the target wanted for the cork oak forest. The second aim, related with the first one, has been evaluating the utilization of a technic called terrestrial photogrammetry or 3D photogrammetry, to reduce costs and gather data as diameter or cork caliper faster. Both aims are related because this project tries to search a reduction of costs in data collection and an increment of revenues producing more cork. Parameters studied to compare both treatments are tree size, cork production, biodiversity, fire, work, costs and young individuals. It has been possible to observe that total clearing is better in fire and young individuals, while partial clearing wins in all the other features. About terrestrial photogrammetry, it consists in taking photos of a plot to process them later and create a 3D model. From this model, it is possible to collect data using a computer. This allows a reduction of costs and permits a faster data obtaining. It has been observed that in dense forests it is not possible to use this technology due to a lack of reference points. However, in forest with low density, the point cloud obtained respects the real shape and proportions, so it is possible to collect data from it. For that reason, in low density forests, we propose a partial clearing using terrestrial photogrammetry to gather data, because we would have a higher economic yield without compromising forest health.

Resum

L'alzina surera (*Quercus suber*) és un arbre altament apreciat als boscos mediterranis pels seus valors: econòmic i ambiental. L'extracció de suro és la principal activitat que s'utilitza per obtenir diners a partir d'aquesta espècie. És per això, que en aquest projecte s'ha volgut trobar una forma d'obtenir un rendiment econòmic elevat, sense malmetre el medi ambient. El primer objectiu ha estat la comparació de dos tractament, estassada total i parcial amb aclarida d'arbres en els dos casos, per veure quins avantatges i inconvenients presentava cada un i així poder fer una proposta de gestió general segons el tipus de surera que es vulgui. El segon objectiu, relacionat amb el primer, ha estat avaluar la utilització d'una tècnica anomenada fotogrametria terrestre o fotogrametria 3D, per tal de reduir costos i anar més ràpid en la recol·lecció de dades com el diàmetre o el calibre del suro. Els dos objectius estan relacionats, ja que el que es busca és reduir costos en l'obtenció de dades i augmentar els ingressos produint més suro. Els paràmetres observats per comparar els dos tractaments són la mida de l'arbre, la producció de suro, biodiversitat, incendis, feina, costos i individus joves. S'ha pogut observar com l'estassada total presenta avantatges pel que fa a incendis i individus joves, mentre que l'estassada parcial és millor en la resta de paràmetres. Pel que fa a la fotogrametria terrestre, consisteix en tirar fotos a les parcel·les per poder processar-les i recrear el bosc en tres dimensions i prendre les mesures per ordinador. Això fa reduir costos i també permet augmentar la velocitat

d’obtenció de dades. S’ha observat que en boscos densos no és possible utilitzar aquesta tecnologia, degut a la manca de punts de referència. En canvi, en boscos poc densos, el núvol de punts que s’obté respecta la forma i les proporcions reals, fent possible l’obtenció de dades. És per això, que en boscos poc densos, es proposa una estassada parcial utilitzant aquesta tecnologia, fet que permetria un alt rendiment econòmic respectant el medi ambient.

Resumen

El alcornoque (*Quercus suber*), es un árbol altamente apreciado en los bosques mediterráneos por sus valores: económico y ambiental. La extracción del corcho es la principal actividad que se realiza para ganar dinero con esta especie. Por esta razón, este proyecto pretende encontrar una manera de obtener un rendimiento económico elevado, sin dañar el medio ambiente. El primer objetivo ha sido la comparación de dos tratamientos, desbroce total y parcial con tala de árboles en los dos casos, para ver qué ventajas e inconvenientes presentaba cada uno y así poder proponer un modelo de gestión en función del objetivo que se tenga para el bosque. El segundo objetivo, relacionado con el primero, ha sido evaluar la utilización de una técnica llamada fotogrametría terrestre o fotogrametría 3D, para abaratar costes e ir más rápido en la obtención de datos como el diámetro o el calibre del corcho. Los dos objetivos están relacionados ya que lo que se pretende es reducir costes en la recolección de datos y aumentar los ingresos produciendo más corcho. Los parámetros seleccionados para comparar los dos tratamientos son la mida del árbol, la producción de corcho, la biodiversidad, incendios, trabajo, costes e individuos jóvenes. Se ha podido observar como el desbroce total presenta ventaja por lo que refiere a incendios e individuos jóvenes, mientras que el desbroce parcial es mejor en el resto de parámetros. Por lo que refiere a la fotogrametría terrestre, consiste en sacar fotos de la parcela para poder procesarlas luego y hacer una recreación del bosque en tres dimensiones, para medir los arboles desde el ordenador. Esto hace reducir costes i permite aumentar la velocidad de obtención de datos. Se ha observado que en bosques densos no se puede utilizar esta tecnología por la escasez de puntos de referencia. En cambio, en bosques de baja densidad de árboles y matojos, la nube de puntos que se obtiene respeta la forma y proporciones reales, haciendo posible la obtención de datos. Por estos motivos, en bosques poco densos, se propone un desbroce parcial utilizando esta tecnología, hecho que permite un mejor rendimiento económico respetando el medio ambiente.

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1. Introduction

Cork oak (*Quercus suber*) is a well-known appreciated tree, reaching 20000 Km^2 of forest area in EU. Portugal, Spain, France and Italy have 65% of cork oak forest area of the world [4]. Unfortunately, these countries are widely affected by climate change, which is a serious threat for the conservation of this tree.

The main manifestations of climate change in Western Mediterranean are: reduction of rainfall, increase of temperatures and more extreme weather events. In consequence, cork oak forests will have less water, lower vitality and productivity, increase of pests especially *Coraebus undatus* and more frequency of wildfires [4]. Pests do not affect the quantity of the main product, the cork, but the quality [Vericat et al. 2013]. *Coraebus undatus*, also known as cork woodworm, is a cork parasite highly present in Mediterranean cork oak forests reaching 15 mm of length at the imago stage. Larvae of this species attack the cork generating layer, which is located between cork and wood. They dig galleries, and these damages cause a declination of cork quality and, in consequence, a reduction of cork value.

In Catalonia (North-East Spain), optimal conditions for *Quercus suber* are located in areas with an average annual rainfall over 600-700 mm and during summer always over 100 mm. Shady or semi-shady orientations are better, but sunny orientations are affordable if the summer rainfall is enough. Altitude can reach 1000 m.a.s.l., but only in cases where the sea regulates temperatures [Piqué et al. 2011]. Most of cork oak stands are located between 0-400 m.a.s.l. in Catalonia. [2]

Cork oak forestlands in Catalonia are multifunctional, they present different functions simultaneously. These functions are classified in three different categories: productive, social and environmental. Productive function is based mainly on cork extraction and, in a lower measure, timber, fungi, game and grazing. Social function basically focuses on landscape composition, which is unique, and recreational activities. Environmental functions are water regulation, mitigation of erosion, CO_2 fixation and biodiversity preservation [Vericat et al. 2013]. However, cork production is the main economic activity in Quercus forests, due to the high value of cork and its application in industry and handicraft. In this sense, forest management guidelines were developed to improve sustainable cork production of Catalan Quercus forests [Vericat et al, 2013].

In addition, experts are developing and evaluating new methods for forest management, not only for cork oak stands, but for a wide range of other useful species [Mikita, et al., 2016]. That is the reason why this project will combine two kinds of measure methods. The first one is the traditional; it basically consists in measure different parameters with a measuring tape [Forsman et al, 2012]. The second one is 3D photogrammetry, which consist in processing pictures of the stand in a computer software to obtain a 3D photo model. Point cloud software's (Agisoft PhotoScan, LAStools, 3D Point Cloud Viewer, etc.) can afford faster measures with the advantage that the field work takes only few hours to take pictures and allows more time to put efforts in tree measures. As Korpela, et al. [12] said, conventional ways of measurement are giving way to methods that combine in-situ observations with remote-sensing data, such as 3D photogrammetry, also called terrestrial photogrammetry.

Photogrammetry is a remote sensing technic which consist on obtaining geometric properties of objects determined from measurements of photographic images [Linder et al. 2003]. This technology is spreading among foresters and other professionals of other study fields [Roncella et al. 2005].

In this study, we evaluate two kind of silvicultural treatments using especially in-situ data, with some support of terrestrial photogrammetry. The treatments are a total and a partial clearing of the understory. Clearing systems are practices used to remove fuel to prevent the spreading of forest fires, to enhance tree vitality and cork production by reducing interspecific competition for resources and to facilitate natural regeneration [Balandier et al., 2005]. If a clear-cut is applied in a forest stand, the density of shrubs will decrease and remaining individuals will have more water and nutrients available in the soil. A part from that, new seedlings will grow thanks to the open canopy, to ensure a good future of the forest [Hunter, 2001]. Clearings can also be combined with other treatments, depending on the objective required, for example thinning to remove fuel for fire prevention and to improve forest structure and cork production.

In case of cork oak stands, owners want to obtain the maximum yield in cork production terms. For that reason, we think that less competence will mean bigger trees and more cork eventually. But it is very important to keep in mind that this is a treatment thought to obtain economic income from cork. If the forest management strategies benefit one species, other ones are harmed. Thus, a partial clearing could give equilibrium between economy and sustainability to the forest.

2. Objectives

With the realization of this project we were looking for two main aims: manage a cork oak stand and evaluate new forest mensuration technologies.

In the first one, the target was a comparison between two silvicultural treatments in a cork oak stand, assuming that both treatments are better than non-intervention management. Actions were a total clearing with thinning and a partial clearing with thinning. Knowing the results, a management proposal was done according with them.

The second one consisted on evaluating a new technic spread among foresters, 3D photogrammetry. We wanted to see in which situations this technology can be useful or not, always taking into account sustainability and economic aspects.

Both aims were located in the same place, and plots that were used for the first aim were also used for the second one.

3. Methodology

3.1. Study area

This project is located in North-East Spain (Catalonia), in 4 different massifs with different ecological features. The first one is Alt Empordà, a place with wet Mediterranean climate, windy and little presence of *Coraebus undatus*. Second one is Gavarres, it have warm climate with dry summers and presence of *Coraebus undatus*.

The third one is Montseny-Guilleries, colder and rainy climate due to the altitude. The presence of *Coraebus undatus* is linked with the altitudinal gradient. Last one, Montnegre-Corredor, with a calid rainy climate, high humidity and influence of the sea and important presence of *Coraebus undatus* [5]. The choice of these locations was made according two reasons, firstly, because these are the main locations of *Quercus suber* in Catalonia, and secondly, because the need of having different natural conditions.

Figure 1. Localization of the plots inside each massif.

3.2. Plots

Inside each massif four plots were distinguished, all of them with a unique code. As the table 1 shows, two plots were applied with a total clearing, and the other half with a partial clearing.

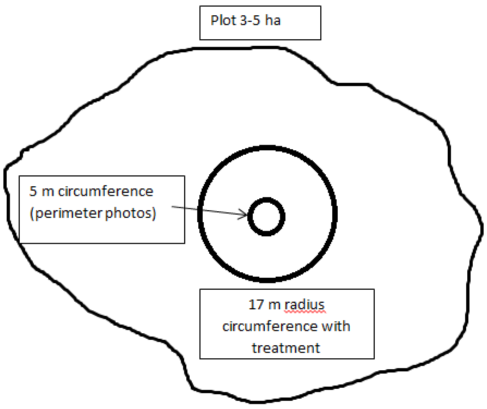

Figure 2. Distribution of the measurement circumference inside a plot.

Table 1. Studied plots with codes, UTM position and action. *(Plots with 3D photogrammetry). Plots written in italic letters do not have available data post treatment.

Zone	Action	ha	Plot name	UTM central X	UTM central Y	CODE
Empordà*	B1.1	3	Gatets_1	2.83948031	42.36074289	**B1.1.11**
Empordà	B1.2	3	Gatets_2	2.83495242	42.36124978	**B1.2.12**
Empordà	*B1.1*	*5*	*ST Esteve del Llop*	*2.8082357*	*42.37145572*	*B1.1.13*
Empordà	B1.2	5	Gatets_3	2.833443	42.362516	**B1.2.14**
Montseny	*B1.1*	*3*	*La Mola Grossa*	*2.563162*	*41.826236*	***B1.1.21***
Montseny*	*B1.2*	*3*	*Fogueres de Montsoriu*	*2.53234511*	*41.780949*	***B1.2.22***
Montseny	*B1.1*	*5*	*Can Massaneda*	*2.62980353*	*41.87855106*	***B1.1.23***
Montseny	B1.2	5	Saleres	2.50493322	41.84311142	**B1.2.24**
Gavarres*	B1.1	3	Can Llach - Mas Punset	2.98209997	41.86244661	**B1.1.31**
Gavarres*	B1.2	3	Fitor	3.09314503	41.91441664	**B1.2.32**
Gavarres	B1.1	5	Mas Cabré	3.100891	41.896887	**B1.1.33**
Gavarres	B1.2	5	Bosc de les Oliveres	2.95238231	41.90950956	**B1.2.34**
Montnegre	B1.1	3	Can Burgada_1	2.65972144	41.67913272	**B1.1.41**
Montnegre	B1.2	3	Fuirosos	2.57944797	41.67324311	**B1.2.42**
Montnegre	B1.1	5	Can Burgada_2	2.65728544	41.67999233	**B1.1.43**
Montnegre	B1.2	5	El Molinot	2.594447	41.691181	**B1.2.44**

There were plots of different sizes, ranging from 3 to 5 ha and all surface had the clearing. However, we only gathered data from a little plot inside each one. These smaller plots were a circumference of 17 meters radius and 908 m^2. Figure 2 explains how it was made.

3.3. Treatments

Plots under study where applied with two different kinds of treatments:

Total clearing, which affect all the surface of the ground. Shrub cover is reduced under 10%. A selective felling was carried out to reduce tree density and eliminate diseased trees.

Partial clearing, which affect just a part of the forest surface. Shrub cover is reduced to 40%. Shrubs competing against cork oak stems were removed (individuals surrounding them, basically). A selective felling was carried out to reduce tree density and eliminate diseased trees.

Both treatments help in different measure the growth of regenerations, because shrubs compete directly with new individuals that try to achieve a place in the stand. Moreover, a clearing mitigate the wildfire risk, as it works as a fire wall. We also eliminate intraspecific competition between *Quercus suber* individuals reducing the density of the plots.

3.4. In-situ measurements

There are dasometric measures before and after the treatment within a period of two years approximately. Also perimetric and hemispheric photos were taken, but it will be explained in the following pages.

Diameter was measured with a metric tape at breast height (1,3 meters above the ground), when a relevant slope was present the measure was made at the highest part of the trunk. As *Quercus suber* species has cork, this is included in the diameter, but only in cases where the tree is not uncorked and in debarked trees were the cork reaches 1,3 meters above the soil. Dead trees were measured as well. Individuals with a diameter below 7,5 cm, basically regenerations, are not measured in this paper.

Cork caliper is the thickness of the cork from the timber to the bark. It was an important measure to know the surface of cork capable to produce the stand. If the tree was debarked in the last year, it was measured with a metric tape. In case that the individual was not uncorked, it was measured with the incision of a bark calibrator. In some cases measures were estimated using cork cracks because it was impossible to use the bark calibrator or other mechanical method.

In case of uncorked trees the stripping height is needed to know the amount of cork extracted. It was measured with a metric tape from the highest point of the ground next to the tree to the beginning of the bark in the stem.

With these data that we collected, some other features were obtained: basal area, cork producing surface, % cork representing basal area and tree density.

Tree density was obtained dividing the number of trees by the surface of each plot. Basal area is the area of a given section of land that is occupied by the cross-section of tree trunks and stems at the base. It is calculated with the sum of the cross-section surface of each trunk of the stand. Cork producing surface (CPS) is the cork area of the cross-section of tree trunks and stems at the base. It is obtained with the difference between basal area (cork included) and the trunk area (without cork).

To obtain the percentage of cork representing the basal area, we divided CPS with basal area. Then we multiplied it by 100 to obtain the percentage of basal area that cork represents [Montero et al. 1989].

3.5. Perimetric photos

A part from these measures, there are perimetric photos that have been treated to obtain a 3D model for the different plots. In table 1 there are the four plots with photos. They were taken before and after the treatment, to compare the differences as we did in case of dasometric measures. To obtain the models we used computer software called AgisoftPhotoscan. It consists on entering the pictures in the software to arrange them in a circle and with some manual and automatically calibration the model is obtained.

Around the center of the plot there is a subplot with 5 meters radius. From this perimeter a set of photos are taken looking at the center of the plot, approximately one or more per meter of perimeter. If the height of the shrubs is high, some photos can be taken more elevated than the others. It is not a problem to take pictures with different height as long as the camera is located at the same place. It is not necessary to keep a regular distance between photos, but knowing that we need at least 40 pictures surrounding the circumference. It is highly recommended to use a spray to paint some spots on the ground across the circumference. It is useful to know where to start and finish and to avoid getting lost in the circumference while doing pictures.

For the appropriate modeling of the 3D, some referent points have to appear in the pictures. In this study we used small white squares (4x4 cm) hooked on the stem inside the plot temporarily, only while taking the photos. These squares can appear in different pictures, but is always needed that a square appears at least in 3 consecutive pictures before being moved to another place in the stem.

The presence of referent points is the most important aspect of 3D photogrammetry. Without good referent points, the 3D model will not be useful for data obtaining.

For an appropriate treatment of the photos to obtain a good 3D model, a digital camera of at least 12 megapixels is needed. Less megapixels do not ensure enough quality in post treatment software. The program used to process the photos was Agisoft PhotoScan© software (Version 1.2.2, 2015).

3.6. Hemispheric photos

To quantify the sunlight penetrating and the canopy, some hemispheric photos were also taken. We took 3 hemispheric photos for each plot with the camera looking up and the eye located 15 cm above the ground. One picture is taken in the middle of the plot and the others 10 meters from the center on each edge of the plot.

To obtain this kind of photos, a fisheye lens is needed. This lens allows pictures capturing 180º, so, the final result is a circumference picture that deforms objects while going from the center to the edge. But this is not important, because we are only interested in the canopy.

3.7. Description of plots

The following pictures are different plots after the treatment.

Figure 3. From left to the right and from top to bottom: Can Llach (B1.1.31), Fitor (B1.2.32), Gatets 1 (B1.1.11) and Fogueres de Montsoriu (B1.2.22).

because of the absence of shrubs and understory. A part from that, the number of trees is also lower in B1.1 plots. These 4 pictures will be processed to obtain 3D photo models.

4. Results

4.1. In-situ

4.1.1. Diameter and caliper

After the diameter and caliper measurements in-situ, table number 2 has been obtained. There, it is possible to see the diameter and caliper for each plot before and after the treatment with the standard deviation. An ANOVA test with R-cmdr was carried out to find differences between pre and post treatment.

There is a significant difference in three cases. The caliper is bigger before the treatment in plot B1.1.33 (p-value 0.0102), plots B1.2.12 and B1.2.14 present bigger diameter after the treatment (p-value 0.00715 and 0.000834 respectively), and both plots are located in Empordà massif. Despite the absence of significance, the diameter is bigger after the treatment in all plots but in B1.2.44.

When comparing diameter of both treatments, total and partial clearing, we do not observe big differences. Plots B1.1 have a diameter mean of 21.9 cm, while for B1.2 plots it is 19.4 cm. After treatments the difference gets reduced from 2.5 cm to 2.2 cm.

Table 2. Comparison of diameter and caliper before and after the treatment with standard deviation for each plot.

Plot code	Pre treatment		Post treatment	
	Diameter (cm)	Caliper (cm)	Diameter (cm)	Caliper (cm)
B1.1.11	25.1± 13.6	1.6± 1.5	33.8 ±11.3	1,5± 0.8
B1.1.31	24.9± 8.1	3.2± 1.2	25.8± 8.2	3.0± 1.2
B1.1.33	21.5± 7.2	2.4± 0.7	22.1± 6.8	1.9± 1.0
B1.1.41	18.5± 5.9	3.0± 0.8	18.7± 6.0	3.0± 0.8
B1.1.43	20.2± 5.2	3.1± 0.8	20.3± 5.2	3.0± 0.9
B1.2.12	21.8± 7.7	2.2± 1.7	25.8± 7.3	2.0± 1.8
B1.2.14	21.6± 7.8	2.7± 1.6	26.7± 5.6	2.5± 2.0
B1.2.24	17.8± 5.8	2.6± 1.0	19.3± 5.4	2.6± 1.1
B1.2.32	16.8± 6.8	1.2± 1.0	17.4± 7.2	1.2± 1.0
B1.2.34	22.4± 6.7	4.2± 1.2	24.2± 6.1	4.4± 1.1
B1.2.42	17.4± 7.6	2.9± 1.1	19.4± 7.8	3.2± 1.1
B1.2.44	19.2± 6.0	3.4± 1.2	18.7± 5.9	3.4± 1.1

Cork caliper do not show any important difference comparing the initial state with the final state. Differences do not follow any pattern, sometimes the mean is bigger before the treatment, and in other cases it is bigger after it. However, it is true that the general tendency is that B1.1 present smaller caliper in the second inventory, while B1.2 present bigger or the same caliper in the second one.

4.1.2. Density, cork producing surface and basal area

Density of each plot appears in table 3. Important differences have been found. In all cases, the number of trees per hectare decreases after the treatment. It happens especially in B1.2 plots, with partial clearing, where the mean of the differences is 227 trees/ha less. In case of total clearing, the mean of the differences is 42 trees/ha less. It means that partial clearing plots present a greater declination compared with total clearing plots. During the silvicultural treatments in plots, thinning activity was done to reduce intraspecific competition among *Quercus suber*.

Calculus explained in the methodology has been done to obtain table number 3. Basal area calculated is always only for *Quercus suber.* Percentage of basal area that cork oak occupies in the plots is always bigger than 80%, except in two cases: plot B1.2.32 (52%) and plot B1.1.44 (68%). It means that a part from these two plots, the others are forests dominated by cork oak.

The quotient between trees/ha and basal area gives the number of trees needed to obtain 1 m^2 of basal area. A difference has been detected in treatments. Statistically it is not significant, but after treatment this quotient is always smaller than before it. That means that the stand needs fewer trees to achieve 1 m^2 of basal area after the treatment. This result could have two reasons. The first one is that trees after treatment present bigger basal area, and the second one is that the smallest individuals were took off in the clearings and tree felling. This is proved by figure 4, where columns show that after treatment this quotient is smaller.

Table 3. Comparison between density, cps (cork producing surface), cork volume and basal area before and after the treatment. CPS: Cork Producing Surface, BA: Basal Area.

	Before				After			
Plot	trees/ha	CPS (m^2/ha)	Basal area (m^2/ha)	% Cork BA	trees/ha	CPS (m^2/ha)	Basal area (m^2/ha)	% Cork BA
B1.1.11	230	1,45	14,62	9,94	130	0,53	12,88	4,15
B1.1.31	430	9,02	23,02	39,21	360	7,93	20,71	38,27
B1.1.33	460	6,70	18,57	36,05	450	4,61	18,80	24,52
B1.1.41	460	6,81	13,56	50,21	440	6,61	13,25	49,91
B1.1.43	480	8,06	16,35	49,30	470	7,72	16,16	47,77
B1.2.12	740	8,86	30,97	28,60	410	5,23	23,13	22,62
B1.2.14	690	9,79	28,54	34,30	350	5,74	20,44	28,06
B1.2.24	1200	14,80	32,88	45,00	820	11,48	25,72	44,63
B1.2.32	520	2,86	21,32	21,32	440	2,48	20,36	20,36
B1.2.34	500	12,30	57,41	57,41	400	10,99	56,08	56,08
B1.2.42	1040	11,03	37,51	37,51	730	8,89	35,50	35,50
B1.2.44	450	6,60	46,31	46,31	400	5,76	48,11	48,11

About the percentage of cork representing the basal area, we see that cork have more importance in the initial state, having always more cork at the beginning than at the end of the process. As it happened with diameters, differences are not always significant. Significant plots were B1.1.11, B1.1.33, B1.2.12 and B1.2.14. However, taking into account that in all cases the percentage of cork is bigger before the treatment, we consider that it is relevant. Only in one case (plot B1.2.44) the relevance of cork increase after the treatment, but this is because smaller trees were found in the second scenario in this plot (see table 2).

An explanation of this could be that in the second inventory, more trees were debarked, but this theory has been discarded because before treatment 53 % of trees were uncorked, and after it the number increases to 56 %. As the difference is only 3%, it is considered not important.

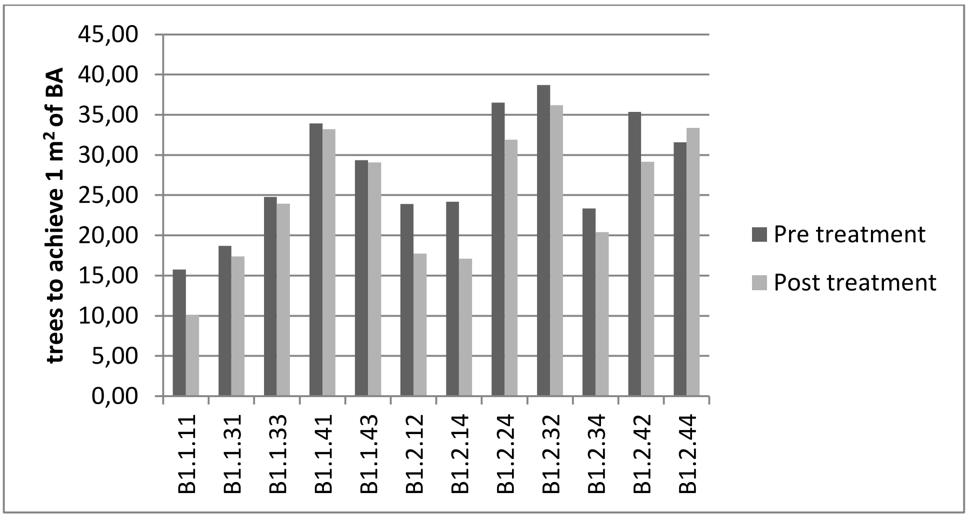

Figure 4. Number of trees that each plot needs to get 1 m^2 of basal area. Comparison before and after the treatment.

Figure 4 demonstrates that in almost all plots, the second inventory (post treatment), seems to have bigger trees, because the number of trees that stands need to obtain 1 m^2 of basal area is smaller than in the first inventory. It is true that the second inventory was made two years after, thus, the forest is two years older and it means that trees can be bigger because of the natural growing.

In spite of the natural growing, the effect of the clearing can influence the forest. The less shrubs and trees, less competition for nutrients and water. For that reason, remaining individuals can grow more rapidly than in the initial state.

A difference between treatments has been recognized. Total clearing show less differences than partial clearing. Mean of differences between pre and post treatment of figure 4 have been calculated, and for B1.1, the difference is 2.5 trees. For treatment B1.2, the difference is 4.4 trees. We also found divergences between treatments regarding de percentage of cork in the basal area. Mean of differences between pre and post scenarios are 7.5 % for B1.1 and 2.7% for B1.2. It means that a partial clearing provide bigger trees with a small loss of cork, while a total clearing provides bigger trees (but less compared with partial clearing) with an important loss of cork.

Finding the correct intensity of thinning and clear-cutting, it is possible to obtain more cork with fewer trees and respect the natural processes of the forest.

4.1.3. Diameter at breast height distribution

A diameter distribution has been done to compare before and after treatment. Plots applied with a total clearing are presented in figure 5 as a DBH (diameter at breast height). Several contrasting differences were found.

We noticed that plots pretreatment do not have presence of young stems, also called regenerations, while plots post treatment have presence of small trees with a diameter below 0 centimeters, specially plot number B1.1.41 located in Montnegre massif, which have 10 regenerations.

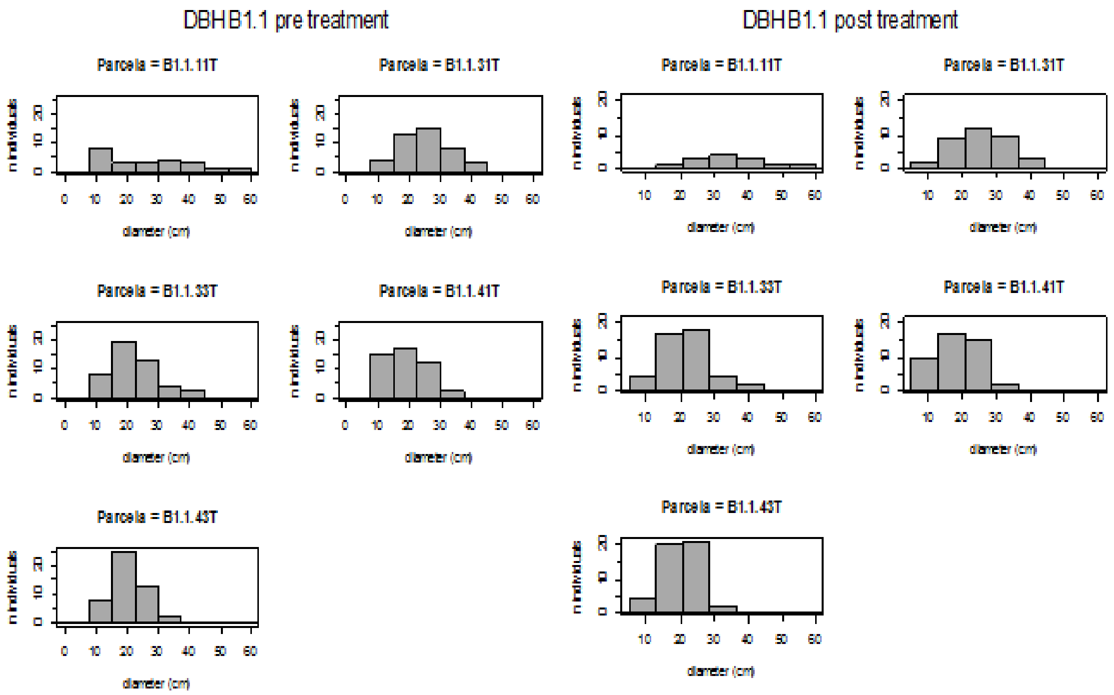

Figure 5. DBH distribution of B1.1 plots before and after the treatment. X axis shows the diameter class, and y axis shows the number of individuals belonging to each diameter class.

It is not possible to see any difference in bigger trees; plots that have presence of bigger stems do not differ after the treatment, maybe because it is difficult to find stems with diameters reaching more than 50 centimeters of diameter in Catalonia.

About medium classes, they present more individuals after treatment. These result fits with table number 2, where bigger diameters where founded after the treatment. Medium size individuals make the average increase respect the initial state.

With this information, and the previous one located in table 2, we can see that plots after treatment present a bigger number of medium size trees and regenerations. This have an importance related with the future of the stands because, founding young individuals means that the forest will be able to grow in the future and it will keep producing cork.

In case of DBH distribution of partial clearing (Figure 6), results are more diverse than in the total clearing. Regenerations had a relevant presence in the initial state, but after the treatment, a decrease of seedlings is found almost in all plots. This can be explained because a partial clearing, do not take off all shrubs and understory of the forest, for that reason, new seedling have competence and cannot develop appropriately.

As it happened in total clearing plots, the distribution of old classes is similar, it almost have 100% of coincidence in all plots. This corroborate that it is very hard to find trees with diameters above 50 centimeters in Northeast Spain cork oak stands.

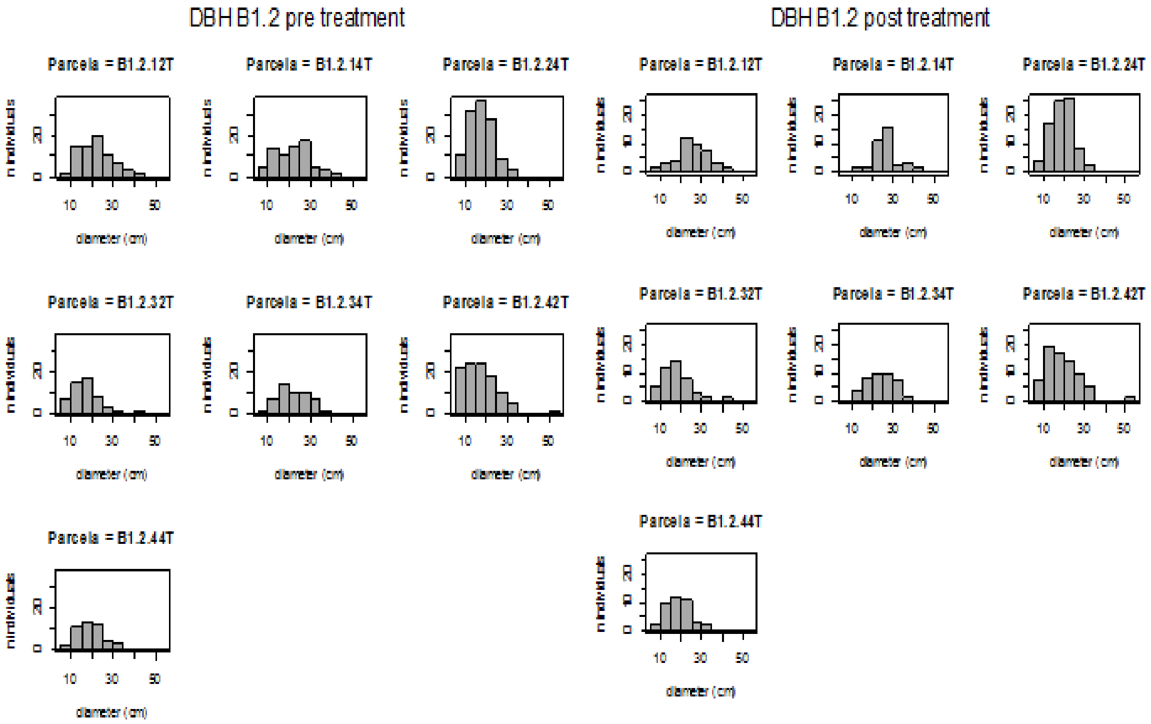

Figure 6. DBH distribution of B1.2 plots before and after the treatment. X axis shows the diameter class, and y axis shows the number of individuals belonging to each diameter class.

Plots that have significant bigger diameters after treatment (B1.2.12 and B1.2.14), dominate in medium diameter classes. They present a small number of regenerations, but a huge number of medium size individuals, which make the average more considerable than in the original state. The other plots have similar proportion of medium stems, with the difference that after treatment they do not show young individuals, thus, the diameter class is smaller before the treatment.

We noticed differences in DBH distributions between treatments. Regenerations are more present in total clearing. About medium size individuals, the proportion is alike;

they are majority in both cases. The amount of trees with a diameter bigger than 40 cm is greater in the partial clearing, but, keeping in mind that it is the same number if we compare before and after treatment. So, plots B1.2 have more big trees because they were already present before our study. According with the results, between treatments we only found differences in small individuals, being more numerous in the total clearing.

4.2. Terrestrial photogrammetry

After obtaining pictures in the field, photos were processed using Agisoft Photoscan. The following pictures are two 3D photo models result of data processing.

Figure 7. Point cloud view of plot B1.1.11 (Gatets 1) after treatment.

Both plots are very realistic. The good arrangement of the photos allows a good point cloud. This is really important to measure the stand using the software.

Figure 7 is the point cloud obtained from plot B1.1.11 after the treatment. This plot was applied with a total clearing, and the presence of stems was reduced from 230 trees/ha to 130 trees/ha. The visibility inside the plot is very high. In the point cloud, we are able to distinguish stems and branches, but not leaves. It is also possible to distinguish the corked part with the uncorked part of the tree trunk. Understory is visible in the center of the plot, but it gets blurry at the edge of the model.

Figure 8 is the point cloud obtained from plot B1.1.31 after the treatment. A total clearing was executed in this plot. The density of trees was reduced from 430 trees/ha to 360 trees/ha. Visibility inside the plot is very high, but worse than plot B1.1.11. The point cloud allows us to distinguish stems clearly and branches with blurriness. Leaves are not visible. Corked and uncorked parts are differentiates without much clarity. Understory is visible in the center of the plot, but it gets blurry at the edge of the point cloud.

Figure 8. Point cloud view of plot B1.1.31 (Can Llach) after treatment.

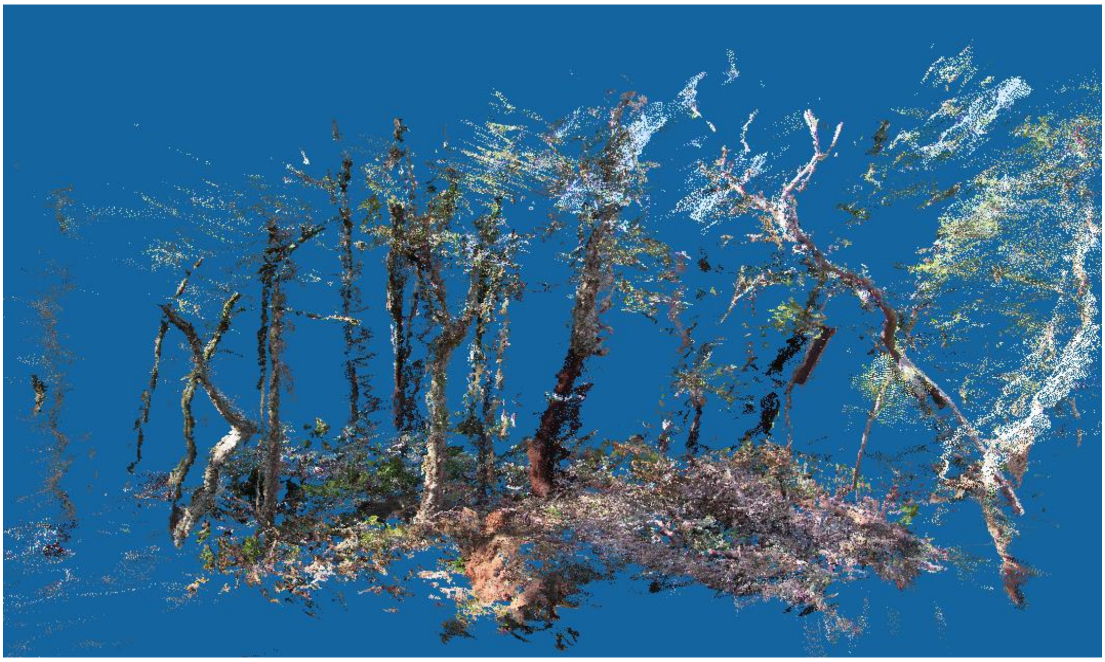

Figure 9. Point cloud view of plot B1.2.32 (Fitor) after treatment.

In contrast with figures 7 and 8, 3D photo model obtained after treatment in plot B1.2.32 (Figure 9) is not realistic. A partial clearing was applied in that case. Density was reduced from 520 trees/ha to 440 trees/ha. Visibility inside the stand is not enough. It is possible to observe stems, but they are blurry, so, it makes impossible data obtaining with the same precision as the others plots or in-situ . Branches and leaves are not well defined. The model allows the visualization of the understory, but with a high blurriness compared with figures 7 and 8.

Success in 3D photo models is clearly determined by tree density and presence of vegetation. Before treatments, the density of trees was higher in all stands of the project, and the presence of vegetation was 60-90% higher, so, in these cases, the percentage of success in photo processing is 0%. On the other hand, the percentage of success after treatments is 75%, because of the reduction of biomass. To this information we can also add another difference between treatments. Total clearing present 100% of success, while partial clearing present 50% of success, and less resolution. Thus, the less biomass, the more quality of the final point cloud to make measures.

4.3. Hemispherical photos

Hemispherical photos were taken with a digital camera using a fish eye lens (allows 180º pictures) to compare the canopy before and after treatments. Figures 10 and 11 are two examples of these differences.

Figure 10. Hemispherical view of plot B1.1.11 (Gatets 1). Left: Pre-treatment, Right: Post-treatment.

In both figures it is possible to notice important differences between photos. Photos taken in the initial state are clearly darker. The reason is that tree density was bigger at the beginning. The presence of branches and leaves decreases after the tree felling and clearing. This allows the sunlight to penetrate inside the forest. In consequence, regenerations of *Quercus suber* can develop more rapidly and this ensure the time continuity of the forest.

Hemispherical photos show, not only the canopy, but also the shrubs surrounding the fisheye lens, because of it is a 180º picture. It let us see the presence of shrubs at the edge of pre-treatment photos.

Figures 10 and 11 are just two examples. The same happened at the others plots. Figure 10, which was applied with a total clearing, present more gaps in the canopy. This is what we expected, because the intensity of the clearing was higher, thus, we do not observe too many shrubs in the picture. A part from that, the number of trees per hectare is lower in B1.1 plots, and this cause more open gaps in the upper layer of the stand. About figure 11, applied with a partial clearing, it is possible to see more open canopy in the second stage, but, when comparing with plot B1.1.11 (and others B1.1 plots), open gaps are clearly fewer. This result fits with what we expected: the intensity of the clearing is lower, thus, more shrubs in the picture are present. A part from that, tree density of B1.2 plots is higher and that cause less open canopy in the stand.

Figure 11. Hemispherical view of plot B1.2.32 (Fitor). Left: Pre-treatment. Right: Post-treatment.

5. Discussion

Our results respect what we expected. In both cases, silvicultural treatments and terrestrial photogrammetry evaluation, results fit with our predictions and with other studies made before this one.

5.1. Treatments evaluation

A bigger mean of diameters was observed in all cases after treatment. A part from that, only in two cases was significant, and both were partial clearings in Empordà massif. It makes think that the environmental conditions and the climate at this place favor the growing of Cork oak. The annual average of temperatures is around 15ºC, with relatively cold winters and hot summers. During summer, there are dry periods with irregularity in rainfall [6]. We should consider the comparison between these four different massifs in future studies, to know if this divergence is caused by climate or not. However, considering that all plots except by one (B1.2.44) had bigger diameters after treatment; we consider that treatment had an effect to trees. Maybe, the reason of the absence of significant differences was because two years is not such a long time to observe important differences, but it is known that clearings and thinnings promote the growth of the trees. In addition to that, in the tree felling carried out, smaller individuals were cut mainly. We also found a small difference between treatments: the increment of diameter of B1.2 plots was bigger than the increment of B1.1 plots by 0.5 cm. So, partial clearing makes trees growing faster.

Luque et al. [2004] said that a clearing make diameters and basal area of individuals increase more rapidly; even more than tree felling to reduce intraspecific competition. This is exactly what happened in this project, in the second inventory, as it is demonstrated in figure 4, the number of trees that a stand needs to achieve 1 m^2 of basal area is smaller after treatment. A part from that, we found that a partial clearing makes trees growing more, even with a higher tree density. Related with this information, Torres and Montero [2000] found out that despite the increment of tree size when applying a clearing, the quality and the quantity of cork is not affected. We did not test the quality, but we have seen that the percentage of cork representing the basal area decreases after treatment. It means that trees grow more, but only the woody part of the stem; the bark (cork in case of *Quercus suber*) is not affected with this treatment. But according with Vericat et al. [2013], an increment of tree size due to a clearing is beneficial for the tree, even though the cork production do not increase; this is because the vitality of the individuals increases and thus, they become more resistant to pests and diseases.

A difference between treatments has been noticed, the percentage of cork in the basal area decreases less in B1.2 plots. It means that partial clearing have been more productive than total clearing. It presents bigger trees with less loss of cork. Taking into account that B1.2 plots have more trees and more shrubs, biodiversity loss is lower and cork production stays the same or decreases slightly. In future studies, it would be interesting to measure the biomass present, in order to find a relation between forest biomass and cork production.

We found that B1.2 plots present less young individuals after treatment comparing with B1.1 treatment. It could be possible that the open canopy and the less shrub competition in a total clearing encourage the growth of seedlings. However, Cardillo and Bernal [2005] made a research and they found that cork oak seedlings are shade tolerant because of the big size of theirs seeds. Davis et al. [1998] found that competition between young individuals and shrubs is not determined by the number of competitors, but the supply of resources. It means that if the soil conditions are good (enough nutrients, water,…) the demand of the biomass is not important. For that reason, we think that a lot of components regarding with seedlings affect their growth. In our study we did not analyze the soil, so, we cannot find a well-reasoned opinion about this. The same happens with bigger trees.

We also think that a partial clearing is more vulnerable to wildfires comparing with total clearing. If we cut all of the shrubs and grasses, fire will not have fuel to move forward. It means that, somehow, a total clearing act like a firewall. Despite being better than a non-interventional management, partial clearing let the fire move forward, and this is an important threat in Mediterranean forests.

About work and costs, partial clearings are faster and cheaper since the biomass removed is smaller than in a total clearing. The last one takes off almost all of the shrubs and grasses and in consequence workers spend more hours in the forest.

Knowing all of this information, the following table (number 4) was made to compare both treatments with different inputs that can affect the decision making. Inputs are tree size, cork production, biodiversity, fire, field work, costs and regenerations. All of these are discussed in the previous pages, and this table is the summary of the discussion.

Table 4. Qualitative comparison between total and partial clearing. Positive (+) means that the treatment beats the other one in the input. Negative (-) means that the treatment loses against the other one in the input.

Parameters	Total clearing	Partial clearing
Tree size	-	+
Cork production	-	+
Biodiversity	-	+
Fire	+	-
Work	-	+
Costs	-	+
Regenerations	+	-

These features have demonstrated that in general, partial clearings are better than total clearings. However, before making any decision it is important to know the target, because depending on it, the decision can vary. Total clearing wins in protection against fires and regenerations (new individuals) and partial clearing wins in tree size, cork production, biodiversity, work and costs.

5.2. Terrestrial photogrammetry evaluation

Mikita et al. [2] concluded that one of the main drawbacks of terrestrial photogrammetry is the occlusion of reference points in very dense canopies. In our project, the plots had a high density of shrubs that caused a lack of reference points, especially in the first inventory. That is the reason why the photo processing was impossible in those cases; we could not obtain a correct point cloud. However, after the treatment, the visibility inside the stand increases and in consequence it is easier to obtain reference points. These cases have something in common, good arrangement of the pictures and low density of shrubs. Successful 3D models are visually very realistic. In this project, we did not collect data from them, but Mikita et al. [2] and Surový et al [5] found out that the accuracy of this method when taking measures of trees is very high and trustable. They compared the computer measures with field measures obtaining a high percentage of reliability.

A part from the loss of reference points inside the stand in very dense forests, another drawback could be the focus of the camera. Inside plots with high density, when someone wants to take a photo, it is needed to focus the camera always to the same point. However, the high density makes this very hard and sometimes the camera focus foreground when the forester needs to focus background or vice versa. Then, when photos get processed, the blurriness of the main point makes the point cloud useless or even impossible to create. This problem is nearly nonexistent in low densities because of the absence of disturbing shrubs or trees.

Panagiotidis et al. [2016], compared terrestrial photogrammetry with another technology, terrestrial laser scanner (TLS). TLS allows higher precision and has the ability to create more matching points from fewer positions and thus, the quality of the final point cloud is better. In dense forest structures, TLS is capable to detect more points and for that reason it is highly used. However, it is also know that this technology is much more expensive than taking photos with a digital camera, so, if the conditions of the forest afford digital photogrammetry, it is trustable and not expensive, and so, it is enough. In our project we decided to test terrestrial photogrammetry because of the simplicity of photo obtaining and the small budget needed comparing with TLS. Panagiotidis et al. [2016] also concluded that in above point of the point cloud, the quality decreases because of the loss of overlapping potential and the decrease in clarity of shapes. In spite of the absence of error quantification, this effect is pretty clear in figures 7 and 8, so, our results follow this theory.

Forsman et. al. [7] said that using a camera rig could help in the measurements. We did not use a rig to test this, but in other projects in cork oak stands could be interesting the use of a rig in order to compare the quality of the point cloud. The rig helps to take more stable photos, and maybe, this would delete blurriness in some cases and in consequence, the final point cloud would have more quality.

Terrestrial photogrammetry, may be a good alternative to traditional measurements, being more time efficient and cheaper [Mikita et al. 2016]. We agree with this sentence. In forest with such a high economic value as cork oak stands, people working on it must safe money to make the final income bigger. If the aim is cork production, it is not worth it to put a lot of efforts in measures and spend money on it, because the final income will be small. For that reason, 3D photogrammetry is a good option when the forests conditions allow it. It is respectful with the environment, because it can be done by one person taking photos with a camera. Quality of them let a good decision making, as the final point cloud is very reliable and respects the real shape and proportions of the forest. Obviously, the impact on nature will be determined with the final decision, but actions like tree felling or clearings (both total and partial) every 10-12 years are not damaging forest wellness and can prevent wildfires because of the loss of biomass to burn.

7. Conclusions

Despite the absence of big differences, we propose that a partial clearing is better to manage a cork oak stand. Apparently, it presents bigger trees (we should gather data during the next following years to make sure that the increment of diameter was not only due to the selective thinning of smaller trees) with less loss of cork than total clearing, having more density of trees and in consequence, more cork. Besides that, the manual work that a partial clearing represents is lower, because workers have to remove less biomass.

Terrestrial photogrammetry is a very trustable method to manage a forest with sparse population of individuals. We have demonstrated that it is a faster and cheaper way to do it with very acceptable results.

When the owner of the stand wants a huge final revenue, the combination of a partial clearing (two years before the cam cork and 6 years after it) and using terrestrial photogrammetry to manage it could be the best way to earn money keeping as much biodiversity as possible since a partial clearing is more respectful with the nature and the biomass removed is lower.

We know that a perfect management is very difficult to achieve, a lot of inputs influence the forest, and sometimes what works in a stand do not work in another stand, because some parameter changes. In this project we tried to found a general pattern or recommendations to manage a cork oak stand for cases where the budget is small, but land owners and foresters have to keep always in mind that to do a correct management they have to know the place and the inputs that can affect it and change results.

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