PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research

University Abou Bekr Belkaid –Tlemcen-
Faculty of Natural, Life, Earth and Universe Sciences
Department of Forest Resources

Laboratory N°. 31,
Management and Conservation of Water, Soil and Forests and Sustainable Development of mountain areas in the Tlemcen region

Thesis for the Doctorate in Forestry

Theme:

Analysis of the effect of cork carbonization on the resilience of cork groves in the Tlemcen region

Presented by : **Mr. BENHALIMA Yacine**

In front of the jury composed of :

Mr Haddouche Driss	President	Pr.	University of of Tlemcen
Mr DEHANE Belkheir	Supervisor	Pr.	University of of Tlemcen
Mr Medjahdi Boumediene	Examiner	Pr	University of of Tlemcen
Mr Mouissa Habib	Examiner	MCA	University of of Djelfa
Mr Anteur Djamel	Examiner	MCA	University of of Saida

2023-2024

Résumé : Analyse de l'effet de carbonisation du liège sur la résilience des subéraies dans la région de Tlemcen

La sensibilité accrue du chêne liège au feu a été étayée par des tests d'inflammabilité en laboratoire. Des échantillons (de liège mâle et de reproduction) représentatifs du massif forestier Hafir-Zariffet ont été soumis à un flux thermique contrôlé par épiradiateur, analogue à un feu de faible et de moyenne intensité. Les résultats du test définissent l'embrasement de l'écorce externe comme une opération très compliquée, où s'interfèrent deux couches morphologiquement et physiologiquement distinctes. La première ligneuse, comprenant la croûte, accomplie couramment les quatre paramètres d'inflammabilité, à l'égard des autres végétaux. Une ignition courte de la flamme (IF: 37,16s-liège mâle ; 39,87s-liège de reproduction) et une consumabilité totale (RMF, 0% liège mâle; 0%-liège de reproduction). Le rayonnement thermique de la croûte se propage ensuite par conduction au niveau de la deuxième couche non ligneuse, qui est le liège. Il s'est révélé, une inflammabilité lente du suber par rapport au autres combustible forestier (des temsp d'ignition lents >60s et une faible consumabilité (RMF :47,10% -liège mâle et 32,12%-liège de reproduction). L'analyse thermogravitrique a montré que la dégradation thermochimique du liège est fortement imputée à son son épaisseur et à son taux de suberine. Celle ci, commence sa désagrégation à des temperatures léthales >200°C. Il s'agit bien d'une carbonisation lente du liège et non d'une simple infalammabilité. Cette majeure constatation a été renforcée sur le terrain sur 850 arbres résiduels de l'incendie de 2005, avec un délai de résilience de 15 années (2005-2020). Des taux de carbonisation allant de 16,18% à 11,52% (arbres exploités et non exploités) sont associées aux sujets récupérables, vigoureux sans stratégie de résilience. Une forte carbonisation du liège variant de 42,38% à 34,95%, est synonymes d'arbre dépérissante et irrécupérables à cause des dommages perpétrés sur le tronc et le houppier, la régénération se produit dans le houppier, à la base ou mixte. Une très forte carbonisation du liège (75,95% à 71,42%) est susceptibles de disloquer complètement le lien entre les racines de l'arbre et la cime, provoquant la mortalité de la tige principale et une régénération uniquement par souche. Les variables de croissance et de qualité du liège ont été aussi validés selon l'état de résiliences des arbres résiduels. Une résilience du premier degré est similaire d'une bonne activité méristématique du cambium et des arbres récupérables induisant une croissance subéreuse annuelle normale (2,02 mm/an), bien corrélée à une densité volumétrique (283,55 kg/m^3) et à un bon indice de qualité (8,56). La meilleure gstion des peuplemenst résilients est l'étalement du durée de cycle de production, et la récolte du liège en mode irrégulie, en plus du recépages des arbres morts ur pied.

Mots clé: Liège, carbonisation, Hafir- Zarieffet, incendie, résilience, ACM.

Abstract : Analysis of the effect of cork carbonization on the resilience of cork groves in the Tlemcen region

The increased sensitivity of oak cork to fire was supported by laboratory flammability tests. Samples (virgin cork and reproduction) representative of the the Hafir-Zarieffect forest massif were subjected to a thermal flow controlled by an epiradiator, analogous to a low and medium intensity fire. The results of the test define the burning of the outer bark as a very complicated operation, where two morphologically and physiologically distinct layers interfere. The first woody plant, including the corkback, commonly accomplished the four flammability parameters with respect to other plants. Short ignition of the flame (IF: 37.16s-virgin cork; 39.87s-reproduction cork) and total consumability (RMF, 0% virgin cork; 0%-reproduction cork). The thermal radiation from the corkback then propagates by conduction at the level of the second non-woody layer, which is the cork. It was found that suber was flammable slowly compared to other forest fuels (slow ignition times >60s and low consumability (RMF: 47.10% - virgin cork and 32.12% - reproduction cork). Thermogravitric analysis has shown that the thermochemical degradation of cork is strongly attributed to its thickness and its level of suberin. This begins its disintegration at lethal temperatures >200°C. This is indeed a slow carbonization of the cork and not a simple flammability. This major observation was reinforced in the field on 850 residual trees from the 2005 fire, with a resilience period of 15 years (2005-2020). Carbonization ranging from 16.18% to 11.52% (exploited and unexploited trees) are associated with recoverable, vigorous subjects without a resilience strategy. A high carbonization of cork varying from 42.38% to 34.95%, is synonymous of weaking trees and unrecoverable due to damage to the trunk and crown, regeneration occurs in the crown, at the base or mixed. Very strong carbonization of the cork (75.95% to 71.42%) is likely to completely dislocate the link between the roots of the tree and the crown, causing mortality of the main stem and regeneration only by stump. The growth and quality variables of the cork were also validated according to the state of resilience of the residual trees. First degree resilience is similar to good meristematic activity of the cambium and recoverable trees inducing normal annual corky growth (2.02 mm/year), well correlated with volumetric density (283.55 kg/m^3) and a good quality index (8.56). The best management of resilient stands is to spread out the duration of the production cycle, and harvest cork in irregular mode, in addition to the coppicing of dead standing trees.

Keywords: Cork, carbonization, Hafir-Zarieffect, fire, resilience, ACM.

ملخص: تحليل تأثير كربنة الفلين على صمود غابات بلوط الفلين بمنطقة تلمسان

تم دعم الحساسية المتزايدة لبلوط الفلين للنار من خلال اختبارات الاشتعال المعملية. تم تعريض عينات (الفلين الذكر والمتكاثر) ممثلة لغابة حفير-زريفت إلى تدفق حراري يتم التحكم فيه بواسطة جهاز اشعال مشابهًا لحريق منخفض ومتوسط الشدة. تبين من نتائج حرق اللحاء الخارجي بأنه عملية معقدة للغاية، حيث تتداخل طبقتان مختلفتان شكليا وفسيولوجيا. عادةً ما يستوفي النبات الخشبي الأول، بما في ذلك القشرة، معايير القابلية للاشتعال وقت القابلية للاشتعال قصير للهب (37.16 ثانية - فلين ذكر؛ 39.87 ثانية - فلين المتكاثر) وإجمالي الاستهلاك ، 0% فلين ذكر؛ 0% - فلين المتكاثر) .وينتشر بعد ذلك الإشعاع الحراري الصادر من القشرة بالتوصيل على مستوى الطبقة غير الخشبية الثانية وهي الفلين. لقد وجد أن مادة الفلين قابلة للاشتعال ببطء مقارنة بأنواع وقود الغابات الأخرى (مدة اشتعال بطيئة > 60 ثانية واستهلاك منخفض: فلين ذكر (47.10%) وفلين تكاثري32.12%). أظهر التحليل الحراري الوزني أن التحلل الكيميائي الحراري للفلين يعزى إلى سمك الفلين ومستوى السوبرين فيه. ويبدأ هذا في التحلل عند درجات حرارة مميتة تزيد عن 200 درجة مئوية. وهذا بالفعل عبارة عن تفحيم بطيء للفلين أو كربنة وليس مجرد قابلية للاشتعال. وقد تم تعزيز هذه الملاحظة الرئيسية في الميدان على 850 شجرة متبقية من حريق عام 2005، مع فترة صمود تبلغ 15 عامًا (2005-2020). ترتبط الكربنة التي تتراوح من 16.18% إلى 11.52% (الأشجار المستغلة وغير المستغلة) بالأشجار القوية القابلة للاسترداد دون استراتيجية مرونة. نسبة الكربنة العالية للفلين من 42.38% إلى 34.95%، وهي مرادفة للأشجار الضعيفةوغير قابلة للاسترداد بسبب تلف الجذع والتاج، ويحدث التجدد في التاج أو عند القاعدة أو مختلطًا. من المرجح أن تؤدي الكربنة القوية جدًا للفلين (75.95% إلى 71.42%) إلى خلع الرابط بين جذور الشجرة والتاج تمامًا، مما يتسبب في موت الجذع الرئيسي والتجديد من الجذع فقط. تم أيضًا التحقق من صحة متغيرات النمو وجودة الفلين وفقًا لحالة صمود الأشجار المتبقية. الصمود من الدرجة الأولى على علاقة مع الأشجار القابلة للاسترداد التي تحفز نمو الفلين السنوي الطبيعي (2.02 مم / سنة)، وترتبط بشكل جيد بالكثافة الحجمية (283.55 كجم / م 3) ومؤشر الجودة الجيد (8.56). إن أفضل إدارة للغابات القادرة على الصمود هي تمديد مدة دورة الإنتاج، واستخراج الفلين بشكل غير منتظم وليس في كتلة واحدة، بالإضافة إلى تقطيع الأشجار الميتة لبداية جديدة للنمو.

الكلمات المفتاحية: الفلين، الكربنة، تأثير حفير زريف، النار، المرونة، ACM.

Thanks

I would first like to express my respect and my most sincere thanks to my thesis director Professor DEHANE Belkheir of Abou Bekr Belkaid University of Tlemcen for having offered me the opportunity to carry out this work, I will not thank him never enough for his encouragement, for the everlasting guidance and advice, as well as for his experience, his extraordinary support throughout my PhD. Without him, this work would not be completed. I hope that he finds here the expression of my deep gratitude.

I would also like to thank Mr. Driss Haddouche, Professor in the Department of Forest Resources at the Abou Bekr Belkaid University of Tlemcen for doing me the honor of chairing my thesis jury. My warmest thanks also to the members of the jury: the Professor Mr Boumediene Medjahdi from the Abou Bekr Belkaid University of Tlemcen, the Doctors Mr.Habib Mouissa from the University of Ziane Achour of Djelfa and Mr.Djamel Anteur from the Moulay Tahar University of Saida who were kind enough to examine this work.

I would also like to thank some people from the Fire Test Laboratory in Croatia (Faculty of Forestry, University of Zagreb) with whom I had the opportunity to work or chat. I am thinking in particular of Prof. Celjko Španjolic, Dr. Blanca Seravic and Magda Lucavic.

A special thank you goes to the ICTvsCC research team mainly Vicky, Edgar, Oliverand Celia for the great time and the high bounding friendship we developed. Another special thank you to Akli Benali, for the flexibility; guidance and mentorship.

Thank you also to all my teachers in the forestry resources department and long-time friends who recognize themselves here. I express my deep sympathy to them and wish them well.

Dedication

It is with deep gratitude that I express my sincere thanks to my parents, for their support and joy despite the circumstances.

To my brothers and sisters who helped me in the ups and downs, provided me with advice and emotional support, I am grateful to them.

To all my Family. To all my Friends…

Yacine

List of figures

List of tables

Lists of abbreviations

- A.E.F.C.O: Oran cantonment management booklet
- ACC: Canonical Correspondence Analysis
- ACM: Multiple Correspondence Analysis
- ANOVA: Analysis of variance
- APCOR: Portuguese Cork Association
- AUC: Area under the curve
- BNEDER: National Bureau of Studies for Rural Development
- C.O.I.T.: Cantonment of Oran, Inspection of Tlemcen
- Crb: Corkback thickness class
- Crb(%): Carbonization rate
- Crk: Cork thickness class
- CWFT: Conservation of Forests in the Wilaya of Tlemcen
- ddl: Degree of freedom
- DGF: General Directorate of Forests
- DSC: Differential scanning calorimetry:
- DTA: Differential Thermal Analyzer
- FAO: Food and Agriculture Organization of the United Nations
- IPCC: Intergovernmental Panel on Climate Change
- ha: Hectare
- HF: Fire temperature
- Hotspot: Biodiversity hotspot
- IPROCOR: Institute of cork, wood and vegetable carbon
- ISO: International Organization for Standardization
- kW m^{-2}: Kilowatt per square meter
- KW: Krskall Walis test
- MJ/kg: Meter joule per kilogram
- Mg. Ha^{-1}: Megagram per hectare
- P: Rainfall
- p: Significance threshold
- PNT: Tlemcen National Park
- qx: quintals
- Raster A grid, or matrix, composed of cells organized in rows and columns
- GIS: Geographic Information System
- T: Temperature
- TGA: Thermogravimetric Analysis
- t/ha: ton/hectare
- IUCN: International Union for Conservation of Nature

Table of contents

Chapter I
The cork oak in the face of fires

Chapter II
Forest fires in Algeria

Chapter III
Study of the environment

Chapter IV

Spatial analysis of forest fire risk in the Hafir-Zarieffet forest massif

Chapter V
Study of cork carbonization mechanisms in the laboratory

Chapter VI
Study of the process of carbonization of cork in cork oak grove

Chapter VII

Study of the resilience parameters of cork oak after fire

Scientific production of the PhD student

Communications

-Prticipation au seminaire national :"8emes journées nationales des sciences de la nature et de la vie" par communication affichée :"la resistance du chene liege aux incendies est un garant pour la protection de la biodiversité et de l'environnement" . Mostaganem 9-10 Mai 2018.

URL:https://www.facebook.com/Univ.Mostaganem/photos/a.381589958576499/1694301703971978/

-Participation au seminaire international: the IX International Agricultural Symposium "Agrosym 2018" par communication affichée :"cork oak resistance to forest fires in the region of tlemcen (northwestern Algeria) "Agrosym 2018".4-7 octobre 2018. URL:*http://agrosym.ues.rs.ba*

-Participation au seminaire international OILB par communication Orale :Characterization of flammability parameters of cork by the mass loss calorimeter technique".8-11 Octobre 2019. Characterization of flammability parameters of cork by the mass loss calorimeter technique - IOBC-WPRS

-Participation au seminaire international :"Proceedings of the X International Scientific Agricultural Symposium "Agrosym 2019"par communication affichée :"flammability of certain conifers and oak species of north west algeria". 3-6 Octobre 2019.

URL :file:///C:/Users/KIMEDIAS/Downloads/BOOKOFABSTRACTS2019-Complet%20(13).pdf

-Participation au seminaire national:"1er seminaire national de l'apport des biotechnologies su la protection de l'environnement" par communication affichée: "Rôle du chêne liège et du liège dans la lutte contre les incendies de forêts".15-16 decembre 2019.

URL:https://num.univ-msila.dz/DWE/public/attachements/2020/02/27/1er-seminaire-national-de-lapport-des-biotechnologies-sur-la-protection-de-lenvironnementpdf-igxa5got1582818991.pdf

-Participation au seminaire international : "Etude de l'impact du taux de carbonisation du liège sur la régénération post-incendie du chêne liège"par communication affichée:International Journal of Human Settlements".19-20 Février 2021. URL:https://www.aneau.org/ijhs/

-Participation au webinar international : "The risk of forest fires in the western Mediterranean basin: new issues in a context of global change" avec une communication orale "Etude des défauts du liège post-incendie selon le taux de carbonisation.".24 Mai 2022.

URL:https://iast.univ-setif.dz/documents/Webinaire24mai2022IAST.pdf

Participation au webinar international : "The risk of forest fires in the western Mediterranean basin: new issues in a context of global change" avec une communication affichée Impact des Incendies sur la Productivité et la Qualité du Liège dans la Suberaie de Zarieffet (Wilaya de Tlemcen)." URL:https://iast.univ-setif.dz/documents/Webinaire24mai2022IAST.pdf

Published papers:

- Benhalima Y & Dehane B., 2018- Cork oak resistance to forest fires in the region of tlemcen (northwestern Algeria). *Proceedings of the IX International Agricultural Symposium "Agrosym 2018", 2096-2107.* *http://agrosym.ues.rs.ba*

- Benhalima Y & Dehane B., 2019- Characterization of flammability parameters of cork by the mass loss calorimeter technique. IOBC-WPRS, 8-11. Characterization of flammability parameters of cork by the mass loss calorimeter technique - IOBC-WPRS

- Benhalima Y & Dehane B., 2019- Flammability of certain conifers and oak species of north west Algeria. *Proceedings of the IX International Agricultural Symposium "Agrosym 2019",1062-1871*. URL :https://agrosym.ues.rs.ba/article/showpdf/BOOK_OF_PROCEEDINGS_2019_FINAL.pdf

- Benhalima Y & Dehane B., 2023- Etude de l'impact du taux de carbonisation du liège sur la régénération post-incendie du chêne liège. Geo-Eco-Trop, 46 (2), 275-284

  https://www.geoecotrop.be/uploads/publications/pub_462_09.pdf

- Benhalima Y., Frihi M.E. & Dehane B., 2023- Study of the resilience parameters of cork oak after fire in north-western Algeria. *International Journal of Environmental Studies,* 80(6), 1875-1887.

  https://doi.org/10.1080/00207233.2023.2190282

General introduction

General introduction

According to the FAO (2013), forests on a global scale provide food for more than a billion people and provide salaried jobs for more than 100 million individuals. They contain more than 80% of the planet's terrestrial biodiversity and help protect watersheds, essential to the supply of clean water to the majority of humanity. In contrast to these ecological and economic benefits, the forest remains very vulnerable to fire. Forest fires are considered the most serious phenomenon that man and nature remain without definitive capacity to fight (Guyette et al. 2002; Keeley 2002).

In agreement with a study by the World Resources Institute WRI (2021), globally, each year, more than 350 million hectares of afforestation are decimated by fires, which represents 9% of the total area of forests and areas. non-forest. Very pessimistic reports from experts at the United Nations Environment Program (UNEP) concluded that climate change and land-use change are expected to make forest fires more frequent and more intense (megafires), predicting a global increase in extreme fires of up to 14% by 2030, 30% by 2050 and 50% by the end of the century (Unfccc, 2023). The European Space Agency (ESA) estimates that forest fires produce between 25% and 35% of greenhouse gas emissions.

Mediterranean forests are at the core of this spiral, since more than 55,000 fires run through on average each year, destroying between 500,000 and 700,000 ha and perpetrating enormous ecological and economic damage, as well as loss of human life (Angelidis, 1994 , Fulé et al. 2008).

Algeria, like all the countries of the Mediterranean basin, share the same biogeographic distribution of vegetation types, and thus suffer the same evidence of global warming, and its unfortunate impacts on the forced desiccation of plants, particularly during the summer season. The occurrence and frequency of fires in this region are mainly due to a high concentration of flammable substances in the foliage of deciduous and coniferous trees during intense drought sequences, notably volatile oils and resins (Kazakis & Ghosn, 2008).

Numerous studies have discussed the impact of fire severity on forest species. All this research supports that the physiological responses of trees subjected to such stress vary according to the fire regime, which is the complex combination of several parameters: frequency, intensity, seasonality and the type of fuels consumed (Keeley et al ., 2012; Rosell, 2016). The frequency of fires defines the temporal interval of return of the fire to the same area in relation to the longevity of the plant, the intensity characterizes the height of the flames on the ground in relation to the height of the canopy, the seasonality of the fire varies according to the coincidence with the phenology of forest trees (budburst or vegetative arrest), and finally the forest fuel which includes the litter, the undergrowth and in particular the outer bark of the trees.

The outer bark or corkbackt is considered a major factor in the resistance of the tree trunk to fire and its propagation towards the crown (Lawes et al., 2011). Indeed, species adapted to the fire regime generally have a thicker corkback (Rosell and Olson, 2014). According to research by Hare (1965) and Bauer et al. (2010), this dead phloem can protect internal tissues against temperatures above 60°C, the commonly accepted temperature above which cambium death occurs.

In the case of the cork oak and unlike other forest species, the corkback is physiologically attached to the suber, and both form the protective outer bark of the cork oak trunk (Pereira, 2007). This specific ability of *Quercus suber* L. ranks it among the evergreen sclerophyll Mediterranean species, the least vulnerable to fire than other oak species (Vallette, 1997). In this context, Pausas (1997) as well as Silva & Catry (2006) categorize the cork oak and place it as the most resilient species of Mediterranean forest trees (aerial resprouts at the crown and base level by the stump).

This protection at the time of fire offers good regeneration to dormant buds after the stress has passed (Amandier and Santelli, 2004). Conversely, when the outbreak of fire coincides with the period of srtipping and renewal of the bark of the cork oak, the damage is significant, directly leading to the total death of the tree (Pausas, 2017).

In a purely scientific concern linked to the understanding of this fire-forest fuel duality, several studies have evaluated the insulating capacity of the bark of different species based on experimental burning carried out in the field (Pinard and Huffman, 1997; Lawes et al ., 2011); in laboratory tests (Bauer et al., 2010; Odhiambo et al., 2014); or combined, in the field and in the laboratory, to determine the temperature distribution along the tree trunk (Costa et al., 1991). Other studies have assessed the flammability of forest fuels (Madrigal et al., 2009) or the relationship between flammability and chances of survival after a forest fire (Frejaville et al., 2013). But the two studies addressed by Dehane (2015 and 2017) remain the best suited to designing the resistance of cork oak (cork and foliage) to thermal flow simulated by suitable devices (mass loss calorimeter or epiradiator).

The Hafir-Zarieffect forest massif, the subject of this work covers an area of 4000 to 4500ha, well known for its production of quality cork, is also becoming very renowned for the number of fires which characterize it, particularly the Zarieffect forest. Colonial and Algerian forestry archives report 10 occurrences of fire in Hafir (1892-2015), including three large fires (>100 ha) having burned through the cork grove between 1892, 1994 and 2005, i.e. a total burned area of the order of 2273.5 ha of cork oak (Bouhraoua, 2013).

In Zarieffect, the observation is more serious, the fire repeated during 27 events from 1882 to 2022 including 7 large fires (>100 ha): 1882, 1903, 1964, 1983, 1994, 2005, 2015, i.e. a cumulative total area and burned on the order of 3475 ha (CWFT, 2022). In support of this alarming observation, cork production has also fallen, going from 20,000 quintals between 1939 and 1951 to 600 quintals in 2015 (CWFT, 2017). Moreover, the flowering cork landscape of yesteryear is currently veering towards a very regressive appearance, with disturbed subjects showing different forms of post-fire resilience.

The main objective of this study is to affirm that the degree of resilience of cork oak is a consequence of the rate of carbonization of its cork; where several physicochemical variables interact, notably the thickness of the bark and the chemical composition of the suber.

To do this, we have structured our thesis into seven chapters:

1- Bibliographic approach linking cork oak to forest fires (chapter I).

2- History of forest fires in Algeria, updated statistics (chapter II).

3- Study of the physical environment, the Hafir-Zarieffect forest massif (chapter III).

4- Cartographic characterization of the fire risk in the study area (chapter IV).

5- Study of cork carbonization mechanisms in the laboratory (chapter V).

6- Study of the carbonization processes of cork in cork groves (chapter VI).

7- Monitoring of the cork oak resilience parameters through the growth and quality characteristics of the cork (chapter VII).

Chapter I

The cork oak in the face of fires

I.1-The cork oak

I.1.1-Origin and systematics

The oldest trees identified as cork oak show that they have existed for several million years (Lumaret et al., 2005). Its existence has always been reshaped by the climate. The alternation of episodes of extreme cold and heat have had a decisive influence on the geographical distribution and genetic diversity of the cork oak. Quezel (2000) notes that the Pleistocene ice age about 1.8 million years ago forced it to take refuge in areas with a less harsh climate, while the interglacial mildness favored its territorial expansion. The end of the last ice age, about 10,000 years ago, allowed the cork oak to colonize the area it occupies today (Amandier, 2002).

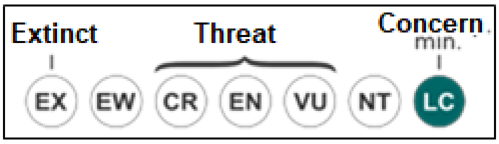
The genetic origin of cork oak is still debated (Magri et al., 2007). Moreover, Aime (1976), announces that the genus *Quercus* poses a polygenetic problem which is still not solved. Phylogenetically, the cork oak is considered to be closely related to three Asian oak species, all of which are deciduous. These are *Q. cerris* from Southwest Asia, *Q. acutissima* from East Asia and Chinese cork oak (*Q. variabilis*) (Manos and Stanford, 2001).

Moreover, recent genetic studies suggest that the evolutionary origin of the cork oak was quite east of its current distribution area (Lumaret et al., 2005). Indeed, fossils of cork oak ancestors, in the *Q. sosnowsky* group, have been found in France, Poland, Romania, Bulgaria, Turkey and Georgia (Bellarosa, 2000).

The tree was described for the first time by Linee in 1753. The cork oak is relatively polymorphic, 40 varieties have been described and then grouped into four original varieties (Nativadade, 1956). These are the following four varieties: genuina, subcrinita, macrocarpa and occidentalis which produce 14 forms or races: vulgaris, clavata, subintegrifolia, macrophylla, microcarpa, macrocarpa, suboculata, dulcis, pendula, parvifolia, grandifolia, microphylla, macrophylla, oleaefolia (Natividade, 1956). There is also a form of eternal natural hybridization between *Q. suber and Q, ilex* resulting in new races (Boavitta et al., 2001). The taxonomy retained for the cork oak according to the APG III classification (2009) is as follows:

Reign	Plantae
Clade	Angiosperms
Clade	True dicots
Clade	Nucleus of the true dicots
Clade	Rosidae
Clade	Fabidae
Order	Fagales
Family	Fagaceae
Genus	*Quercus*
Species	*Quercus suber* L., 1753

The conservation status of a species is an indicator that makes it possible to assess the extent of the risk of extinction of the species at a given time. The cork oak is considered a species of least concern (LC) for which the risk of extinction is low. This is one of the statuses used by the IUCN Red List.



Pausas (1997) sounds the alarm and instead states that the surface area of cork oaks is decreasing in many regions of the Mediterranean basin and the species is considered threatened.

Recently, several independent and complementary studies on cpDNA variation have been conducted and have revealed a clear geographic pattern for cork oak populations (Belahbib et al. 2001; Jiménez et al. 2004; Lumaret et al. 2005; López de Heredia et al. 2007) (Fig.1).

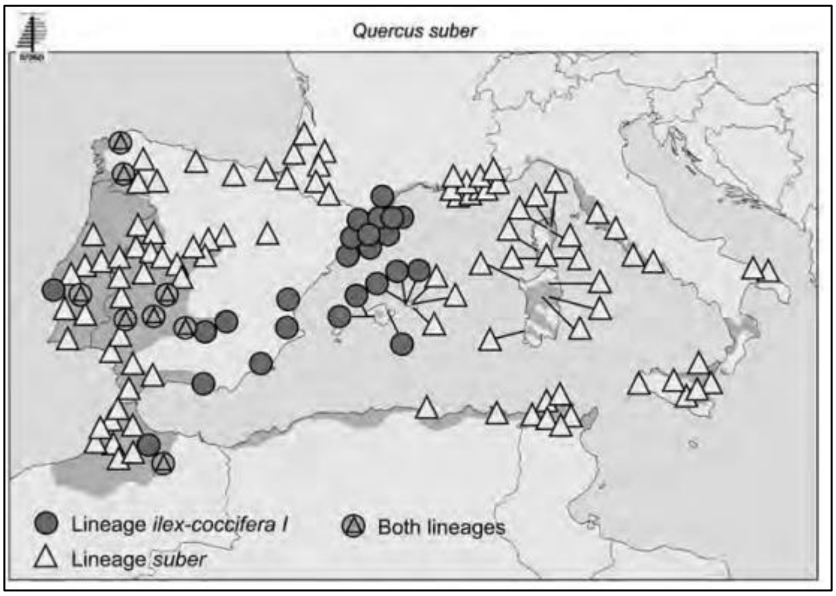


Figure 1. Distribution of lineages based on cpDNA in cork oak populations. (Distribution map of cork oak, European Forest Genetic Resources Programme, 2004, www.euforgen.org.)

I.1.2-Geographical distribution

The cork oak (*Quercus suber* L.) is a forest species typical of the western Mediterranean-Atlantic region, having developed spontaneously in Europe (in the Iberian and Italian peninsulas, and in scattered parts of southern France and some coastal plains and hilly regions), and in three North African countries (northern part of Algeria, Morocco and Tunisia) between 33 and 45°N (Pereira, 2007; Santos Pereira et al., 2008).

Currently, the global area totals less than 1.5 million hectares in Europe (67%) and less than 0.7 million ha in the Maghreb (33%) (APCOR, 2012).

This decline seems very plausible because of the abundance of forests, overgrazing, which limits regeneration, and the expansion of town planning, arable agriculture in managed forests, in addition to the severity of the climate, generator of water stress and fires (WWF, 2007) (Fig.2).

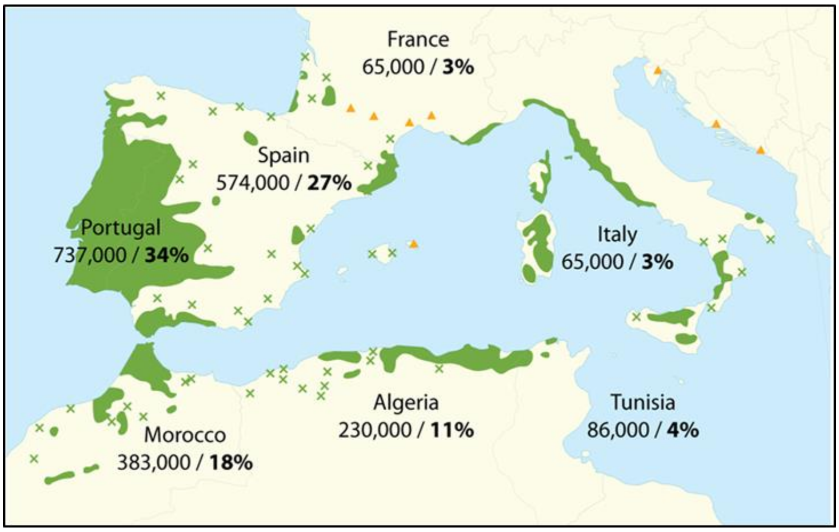


Figure 2. Distribution of cork oak (*Quercus suber*) across the Mediterranean rim by country (area ha/cork area %) and its respective cork production. Source: cork quality council (https://www.corkqc.com/) (accessed on September 2023)

Since the 1990s, the surface area of cork oak has been in clear decline, especially in Algeria compared to Portugal (740,000 ha) and Spain (600,000 ha) (Costa-e-Silva et al., 2021). In Algeria, the potential cork oak forest currently occupies 450,000 ha of which only 220,000 ha are productive (DGF, 2013) (Fig.3).

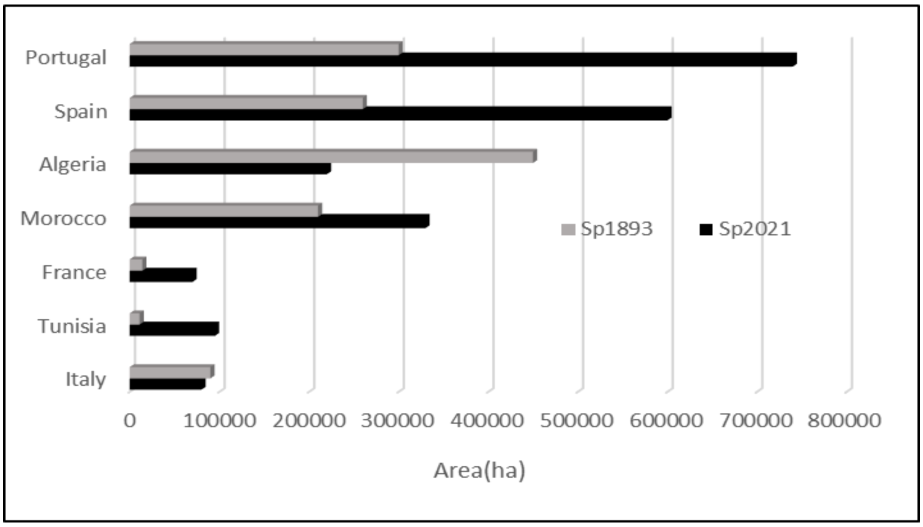


Figure 3. Evolution of the area of cork oak in the Mediterranean between 1893 and 2021
Source: Lamey(1893), FAO(2013) and Costa-e-Silva et al.(2021)

Faced with the fire, the Mediterranean periphery is a privileged observatory of forest fires. Under extreme climatic conditions (drought) and taking into account the properties of fuels, a simple, even small, increase in heat can easily be the cause of a fire and its spread. (Kazakis and Ghosn, 2008).

Over the past 12 years, out of a total area of 8,850,000 km^2, no less than 256,000 km^2 have been affected at least once by a fire (2.9%) (Darques, 2013) (Fig.4). This reality is confirmed by the annual average of 0.2% of burned areas for the entire basin (Quintano, 2011; FAO, 2013).

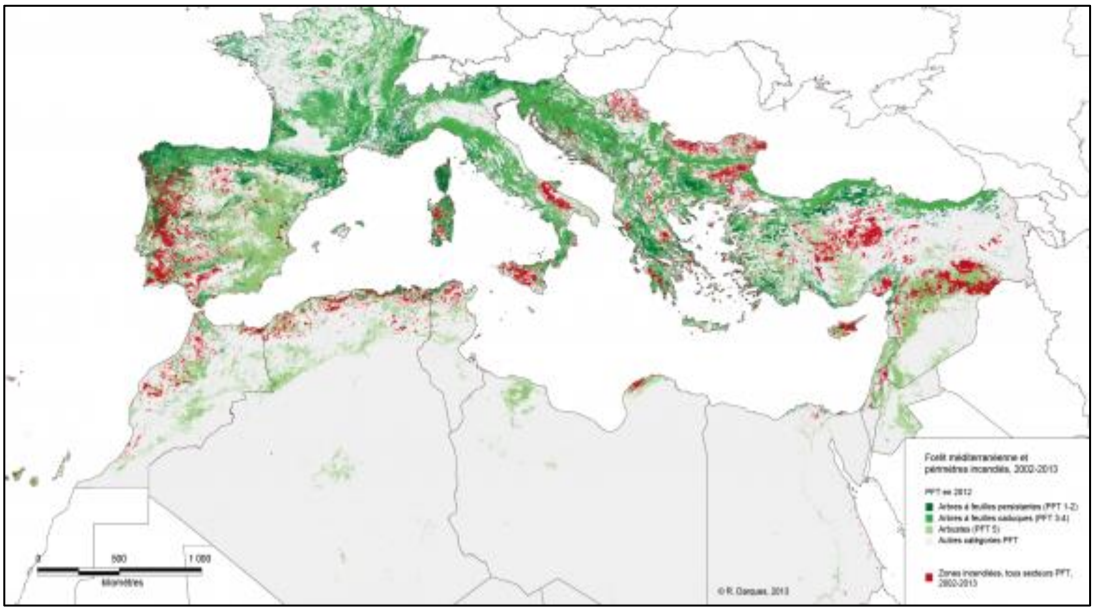


Figure4. Mediterranean forest and fire zones, 2002-2013 (Source: MODIS data, NASA EOSDIS)

The vast majority of fires are caused voluntarily and are part of a process of economic development of the territories. Fires whose spatial footprint exceeds 10 km^2 have destroyed 44% of the listed areas (Table). This figure must be compared to the 18% of forest fires recorded previously (Darques, 2013).

Table 1. Large forest fires in the Mediterranean basin, by size (2002-2013)

Perimeters burned	Number of fires	Areas (km^2)
<10km^2	33285	26679
10 à 25 km^2	432	6512
25 à 50 km^2	112	3865
50 à 100lm^2	45	3232
>100 km^2	24	7144
Total	33898	45432

As of 2020, the total area burned in Mediterranean countries is estimated at around 600,000 hectares per year. In 2021, the cumulative area of fire cover in the Mediterranean countries of the European Union was two and a half times higher than the average (434,591 hectares on August 18, 2021, compared to an average of 183,852 hectares during the 2008 period (Breteau, 2021).As an indication, between 2008 and 2020, southern Spain was hard hit, with 1.6 times more forests going up in smoke (64,269 ha, compared to 40,008 ha on average). Algeria has seen an increase in fires with the same multiplication by 1.6 of the areas burned (3,857 ha, against 2,425 ha on average) (Fig.5).

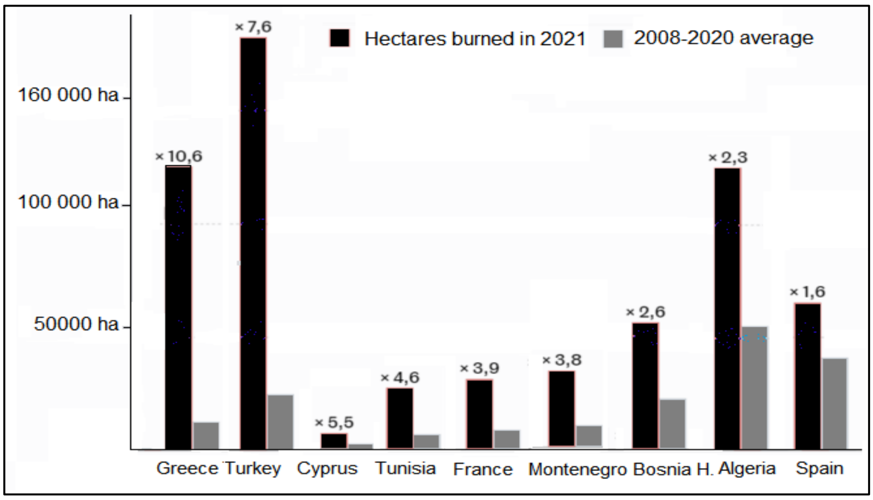


Figure 5. Areas burned in 2021 and compared to the average established between 2008 and 2020 (Breteau, 2021)

With 50,000 fires and 600,000 ha burned on average each year, forest fires in the Mediterranean basin represent a significant part of the planet's fires. According to various sources, the total annual cost of fire-fighting and security measures in the region exceeds US$1 billion. (Le Houérou, 1987).

The effects of global warming on the accentuation of the “fire” phenomenon are now beyond doubt. Moreover, the Mediterranean cork oak space has paid a heavy price, during the period 1980-2005, the number of fires (1,304,126) and the burnt area (12,813,165 ha) are attributed particularly to cork oak fires (Cardillo et al., 2007). Portugal, the leader in terms of area and production, has lost between 15 and 20% of cork oak since 1990 (Catry et al, 2012).

In Algeria, despite this striking fact, the histogram of burnt cork oak areas reveals a very bitter state of this situation (Fig.6).

Figure 6. Burnt cork oak areas in Algeria (1985 2020)

Despite the implementation of major forestry programs for reforestation and rehabilitation at the national level, the cork oak forest lost a total of 217598ha between 1985 and 2020, with an annual average of 6500 ha/year taking into account the six peaks>10000ha recorded during the years 1990, 1993, 1994, 2000,2007 and 2012 (Fig.6). These six atypical years (alone) account for 132,564 ha, or 60.92% of the total decimated by fire. The year 1994 marked the spirits of foresters forever, with no less than 63,328 ha lost in a few days. The trend line seems to correlate perfectly with the security events that shook the country between 1990 and 2001 (Dehane et al., 2013).

I.1.3-Botanical description

I.1.3.1-Flowers and leaves

Closely like all other oaks, the cork oak produces male and female (unisexual) flowers in different inflorescences on the same individual (monoecium).

Pollination is by wind (anemogamy) or insects (entomophilous), and the ovaries of fertilized flowers mature into acorns (i.e., dry fruits with a single seed) (Read and Stokes 2006).

The cork oak has a unique foliage phenology, which lasts one year (transition between old and new leaves), much shorter than in other holm oaks (3 to 5 years), such as the holm oak (*Q. ilex*) or kermes oak (*Q. coccifera*), (Pereira et al. 1987; Escudero et al. 1992,).

According to the classification of Raunkiaer (1934), the species is a mesophanerophyte with a flowering period between April and May (Boavida et al., 1999).

To resist the constraints of the environment (drought, attacks by insects and herbivores), the leaves of the cork oak (length between 3 to 7cm) are more or less thick, less rich in nutrients, heavier (higher mass per unit surface) called 'sclerophytes' (from the Greek, skleros = hard and phyllon = leaf) (Salleo and Nardini 2000).

Transpiration in the summer period is controlled by the closure of the stomata (pores), generally found on the underside of the leaves, which control gaseous exchanges with the air: the entry of CO_2 for photosynthesis and the exit of vapor from water during sweating (Santos Pereira et al.,2008) (Fig.7).

Figure 7. Young cork oak tree with current year leaves and catkin inflorescence

Faced with fires, the flammability of *Quercus suber* remains slightly lower than other Quercus species and this species is only flammable during the summer season (Velez, 1991; Vallette, 1997; Pausas, 1997).

Hachemi et al (2011), in their laboratory study on 50 Mediterranean forest fuel species (leaves and twigs) estimate that *Quercus suber* is the only species that has a flame height greater than or equal to 22 cm and an ignition time average less than or equal to 4 seconds, and therefore a highest flammability index equal to 2.97.

According to valette (1990), the leaves of fresh twigs are slightly to moderately flammable depending on their water content than those of seasoned twigs which are highly flammable. Flammable. Moreover, the same author supports that the dry leaves which remain for two weeks in May on the trees during the renewal of the foliage present a similar flammability.

According to Dehane et al (2017), the fuel moisture content of *Quercus suber* is significantly lower than that of other more flammable species (e.g., *P.halepensis*). Despite being highly flammable (due to its high surface-to-volume ratio), cork oak does not store volatile compounds, so it ranks as less flammable than conifers. The same authors state that cork oak in relation to its foliage is considered intermediate between "non-flammable" and "highly flammable" according to the new evolutionary concept defined by Pausas et al (2017).

I.1.3.2-Morphology

-The average height of the tree varies between 10 and 15 m in most cork oak stands (Seigue, 1985). On suitable, deep soils and with adequate rainfall, the tree can reach up to 20 meters in height and live for several centuries (300 years) (Pereira, 2007).

- The circumference of the trunk varies from 60 cm for young trees to 4 meters for old trees (Saccardy, 1937). The two main branches branch out an average of 3 m in height from the ground

-The crown is wide >4m well spread over solitary trees and open stands. In overgrown stands with competition from the undergrowth, the appearance becomes slender monopodal (Vignes, 1990).

- The bark is gray in color, which splits vertically on wide layers of cork, especially for male cork or very often for reproduction cork (Maire, 1961). This bark is usually found from the roots, trunk and branches as soon as the tree has reached the age of five (Natividade, 1956).

Faced with fires, the morphology of the cork oak is widely discussed as being a natural barrier against the spread of flames from the base to the top. Pausas et al (2009), highlight tree age, they find that some young trees may die from fire because the bark is still too thin to provide thermal heat protection for dormant buds in the rod. They add that trees with a trunk diameter greater than 12 centimeters often survive a fire and regenerate epicormic crown buds. Dubois (1990) recommends that a survival rate of 50% is achieved when trees have a basal diameter of 7 cm (Fig.8 and 9).

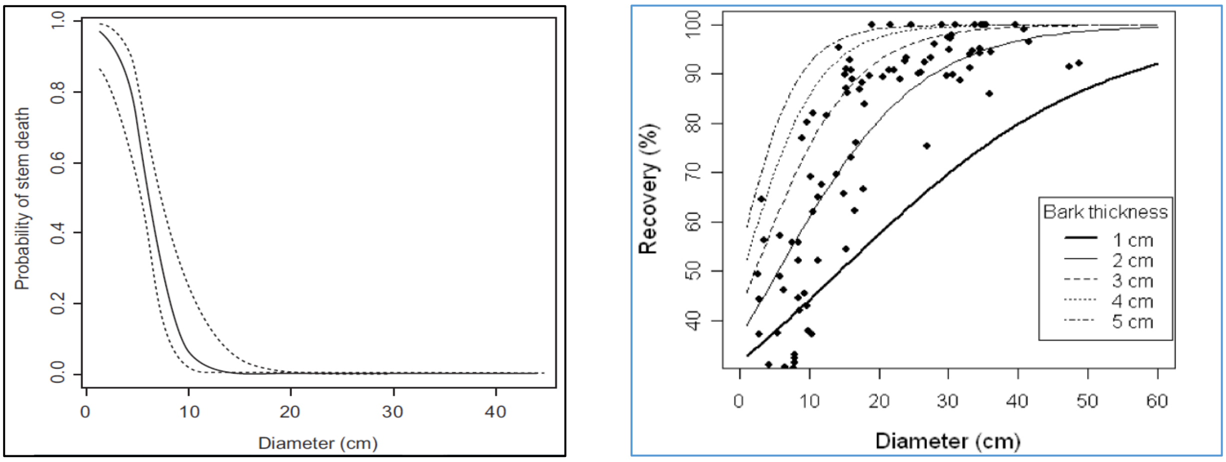


Figure 8. *(a)* Probability of postfire stem death mortality and *(b)* postfire height recovery from stem resprouts in cork oak. Height recovery is expressed as the percentage recovery from prefire height 1 year after the fire, in relation to stem diameter and bark thickness. (From Pausas 1997)

Figure 9. Role of morphology (diameter and height) in the protection of the tree (a; Young subject flamed from bottom to top; b: large adult tree superficially affected by fire)

Bertrand (2007), states that cork oaks undergoing fire disturbance are less slender than undisturbed trees until the circumference reaches about 150 cm and the height 11 m. Consequently, the trees that have survived the fires are essentially of large diameter and height exceeding 12m. Indeed, the fire burns the branches (especially the ends) which can lead to them breaking, thus reducing the size of the tree and its crown (Dubois, 1990).

I.1.4-Climatic and edaphic tolerances

The species vegetates near the coast, in hot and humid areas with 450 to 1200 mm of annual precipitation, at altitudes ranging from sea level to 2000 m asl. In the mountains, average annual rainfall greater than 600 millimeters and average temperatures around 15°C are the most suitable for its growth (Blanco et al., 1997).

The minimum adaptation of the species is limited to -12°C occasionally, but -5°C for several days will be fatal to it, which explains its zonality (Amandier, 2002). Moreover, cork oak leaves are less tolerant to frost (Larcher, 2000; Garcia-Mozo et al., 2001). At temperatures >40°C for several days, the species enters into intense water stress. In such a situation, the tree protects the organs and tissues sensitive to dehydration by closing the stomata on the leaves, limiting water loss, and the deep roots of the tree can draw water from the soil or the deeper basement (Pereira et al., 2006).

In general, rising summer temperatures can negatively affect cork oak carbon balance by increasing plant respiration relative to carbon uptake and assimilation (Medlyn et al., 1999).

The xerophilic temperament of the cork oak does not exclude its voracity towards air humidity; it requires atmospheric humidity of at least 60%, even in the dry season. During the period of vegetative activity, from March to November, average temperatures are around 22°C with air humidity of 75% near the coasts, and 35 to 50% inland (CRPF, 2015). These typical conditions are only found near the sea in the Mediterranean region, and up to 200 or 300 km inland on the Atlantic coast (Aronson et al., 2009).

Cork oak adapts well to altitude. It is found from sea level to 1650 m. Pausas et al. (2009) mention that the most suitable altitude for the cork oak is at 800 m throughout its distribution area. In high altitudes, Natividade (1956), cites in Algeria the cork groves of Téniet el Hâad (1550m), in Morocco, its upper limit is 2400 m at Djebel Tirardine.

Climate change can also indirectly affect cork oak through soil processes. Low temperatures inhibit organic matter decomposition, winter soil warming can increase the rate of nutrient mineralization, increasing plant productivity, which is often limited by poor nutrition. For example, when rain occurs after a long rainless period, soil rewetting stimulates heterotrophic respiration and mineralization of organic matter (Jarvis et al., 2007).

The cork oak is heliophilous, thermophilic, xerophilic and mesophilic, grows in full sun and heat. In Algeria, acclimatizes on crystalline soils in the wettest regions of the tell (Harfouche et al, 2004). It also grows in stony and poor, acidic, sandy soils, on granitic, schistose or sandstone substrates or, more rarely, in calcareous substrates of soils or neutral soils covering dolomitic rocky substrates, it strongly fears hydromorphy (Aronson et al., 2009). The adaptation of the cork oak to xericity did not mean its indifference to global warming, which stimulates the risk of forest fire episodes. This theory has been well confirmed by 57 scientific studies published since the fifth report of the Intergovernmental Panel on Climate Change (IPCC) published in 2013 (Mayer, 2020). This result is the combination of unfavorable phenomena: high temperatures, low humidity, low rainfall and often strong winds. According to IPCC experts, the probability of "wildfires of catastrophic scope" is expected to increase between 30% and 60% by the end of the century (Atmo, 2023).

The Mediterranean region, a favorite terrain of cork oak, is also an area particularly prone to fires, natural disasters closely linked to climatic conditions. According to Ray (2018), if temperatures increase by 1.5°C, the surfaces that will go up in flames could increase by 40% in this region. Proposed models of surfaces likely to be affected by fires in the years to come, according to different scenarios of global warming: +1.5°C, +2°C and +3°C conclude that the more the climate is hot, the drier the vegetation and the more likely it is to catch fire. For an additional 3°C of temperature, the surfaces affected by the fire should almost double regardless of the prevention measures (Ray, 2018; INA, 2022).

Faced with fires, the soil that generates the fertility of the cork oak undergoes significant changes under a high intensity fire. Affected soils produce crystallizations and blocks of clay, blackening up to 10 centimeters deep and causing desiccation of the lower horizons, denudation of the middle, and changes in the microclimate (Certini, 2005; Shakesby & Doerr, 2006). Organic matter and nutrients are lost to the atmosphere by volatilization in gaseous form or by convection of fine particles in the smoke (Trabaud & Gillon, 1991).

On the other hand, the opposite effect can arise after a fire, Trabaud (1990), observes that in a *Quercus* stand, the increase in the rate of organic matter by the contribution of ashes and charred snags incorporated into the surface soil. This impact can range from the total destruction of organic matter to a 30% increase compared to its rate before the fire (Gonzalez-Pérez et al., 2004). Trabaud and Galitie (1996) observed that, in areas burned three times, the surface occupied by *Quercus suber* was reduced in favor of the undergrowth and that, in areas where fires are less frequent, the distribution of *Quercus suber* was higher, as is the diversity of species in the ecosystem.

Bekdouche (2009) emphasizes the installation first of legumes which enrich the soil with nitrogen thanks to the symbiotic association with rhizobia, then a few years later the therophytes superimpose themselves on the species of the cork oak forest and try to s 'install to occupy the empty space created by the passage of fire, then disappear, eliminated by the competition exerted by the endogenous species especially the woody ones and the bushy communists.

Figure 10.Dehydrated and depleted soil (3 months after the fire)

Figure 11. Installation of vegetation according to the time elapsed after the fire(after one year)

The cork oak forests are also excellent carbon sinks, fighting against the greenhouse effect. The cork oak possesses a unique and specific cellular structure that enables it to absorb carbon dioxide (CO_2) up to 30% more than other trees. (Forgues, 2008)

In Portugal alone it sequesters 4.8 Mg. ha^{-1}. year^{-1} of CO_2 (736000 ha of area), that is, 5% of national emissions. All together, these cork oak forests represent 32% of the world's cork oak forests, and absorb 14 million tons of CO_2 per year (APCOR, 2015).

In Spain the cork oak forest account for almost 500.000 ha. Over the period of 158 years (a forest life cycle) these forests were able to offset a total of 220.77 Mg. ha^{-1} and the cork accounted for an additional 105.93 Mg. ha^{-1} (Bravo, 2008).

In Italy it is estimated that cork oak extract on average 5 Mg. ha^{-1}. year^{-1} per tree (Spampinato et al., 2019).

In the southern rim studies on the carbon offsetting by the Mediterranean forests are scarce, especially for cork oak. In Tunisia the cork oak forests constitute 18000 ha,the average carbon offsetting per hectare ranged from 73 to 69 Mg.ha^{-1}.year^{-1} (Houcine Sebei et al., 2001) .

Where in Morocco the cork oak occupies an area of 377 500 ha with a range of 35.8-66.9 Mg ha^{-1}.year^{-1} (Laaribya et al., 2021) In Algeria the studies are focused on a myriad of topics more focused towards protection against different disturbances, however studies on Cork oak offsetting had no special attention until now.

With higher fire frequencies, many chemical and biological parameters are permanently altered (nitrogen, carbon cycle). In this context, U beda et al. (2009) found that at ground fire temperatures > 300°C, total carbon was higher in the ash produced from litter and could correspond to black carbon formation. The same authors argue that at 450°C, complete combustion is observed and there is a higher reduction of total carbon in the ash.

Cork oak forets, on the other hand, have a great potential for carbon storage in the event of non-breeding for more than a century. Thus, Vennetier (2008), believes that firefighting could thus contribute indirectly to the fight against the greenhouse effect.

I.2-Cork

In addition to the ecological aspect of cork oak, its cork is a valuable periodic forest product that ensures the economic, social and industrial sustainability of cork oak stands (Bugalho et al., 2011). Currently, cork is the second most important tradable non-timber forest product in the Western Mediterranean (Mandes and Graca, 2009), and the world cork market exports represent nearly US$2 billion per year (APCOR, 2009; Khalip, 2017). It is a renewable natural material constituting a valuable and versatile raw material for the chipboard, bottle stoppers and leather goods industry (Dehane, 2012).

I.2.1-Formation and harversting

Cork oak bark is generated by phellogen (cortical cambium) initiated by the cambium (vascular cambium), a secondary meristem that maintains its activity throughout the life of the tree and forms successive annual cork layers (Nativididade ,1956) (Fig.12).

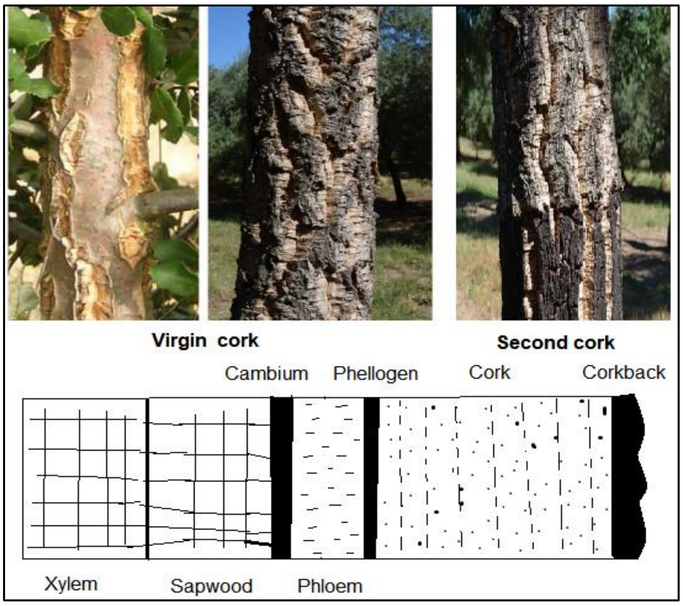


Figure12. Meristematic growth in cork oak

Cork stripping is traditionally done every 9 years to obtain commercial quality cork. It is removed for the first time (virgin cork) when the tree is 18-25 years old and then, depending on the country, successively every 10 or 15 years (second cork). After cork debarking, the phellogen dies and a new one forms almost immediately (25-35 days) (Pereira, 2007). A productive tree can provide cork 12-20 times over the life of the tree (150-200 years).

Cork lifting is a delicate manual process, requiring skilled workers, armed with great knowledge to remove the cork with an ax without reaching and damaging the vascular cambium (the mother of the cork) underneath. phellogen (Fig.13).

Figure13. Periodic campaign for the exploitation and storage of cork in Portugal (Pereira, 2017)

When cork has accumulated sufficiently (up to 3 centimeters of cork in 9-12 years), the harvest can take place between May 15 and September 15. Beyond this time, no action is permitted, otherwise the tree will fall ill and decline (Costa et al., 2004).

In the Mediterranean region, this period coincides with an intense water deficit, linked to a high demand for air evaporation and a low availability of soil water. Under these conditions, cork emergence can be considered an additional stressor due to immediate carbon and water losses that lead to changes in photosynthate allocation and water balance of trees. Rough estimates of daily water loss from raised surfaces suggest that they can equal transpiration at crown level (Correia et al., 1992, Oliveira and Costa, 2012).

Faced with fires, cork constitutes an insulating barrier to the thermal energy released by the flames. This peculiarity is due to its special anatomical structure (high proportion of air (90%) that resembles CO2, its low humidity, in addition to its high suberin content (Natividade, 1956).

The mother's cells, located under the cork, die when faced with a temperature above 55-60°C. The damage will therefore depend on the intensity of the heat released by the fire, as well as on the cork barrier (Berdón Berdón et al., 2015).

The survival of cork oak following a fire is estimated at 70%, thanks to the protection that its bark provides and its great capacity of regrowth. This percentage increases when the cork layer reaches a thickness greater than 20 mm, sufficient to provide the tree with adequate protection against fire (Dubois, 1990).

Cork oak bark (corkback+cork) provides effective protection to dormant buds on the trunk and the crown, it has been proven a close relationship between cork thickness and post-fire regeneration (Barberis et al., 2003 ; U´beda et al., 2006) (Fig.14).

On the other hand, when the fire coincides with the period of exploitation, the resistance of the cork becomes insignificant (up to almost 100% probability of mortality), then it increases with time when the bark grows back until that the cork is 3-4 cm thick, which is usually reached at the end of the cork production cycle (9 to 15 years) (Lamey 1893; Cabezudo et al. 1995).

Moreover, several studies mention the vulnerability to fire of exploited trees than those unexploited because of the long duration with a thin bark in the production cycle (Dubois, 1990; Paussas, 1997) (Tab.2 and Fig.14). According to Barberis et al. (2003), a follow-up of 200 burnt trees of different ages, showed that mortality was lower by more than 10% for trees not exploited during the last 30 years and 40% for old trees that have been lifted several times.

Table 2. Survival capacities of trees according to the age of the cork (Lamey, 1893)

Age of breeding seccond cork	Trees mortality
1 year	100%
2 years	90%
3 years	70%
4 years	50%
5 years	25%
6 years	15%
7 years	10%
8 years	4%
9 years	2%

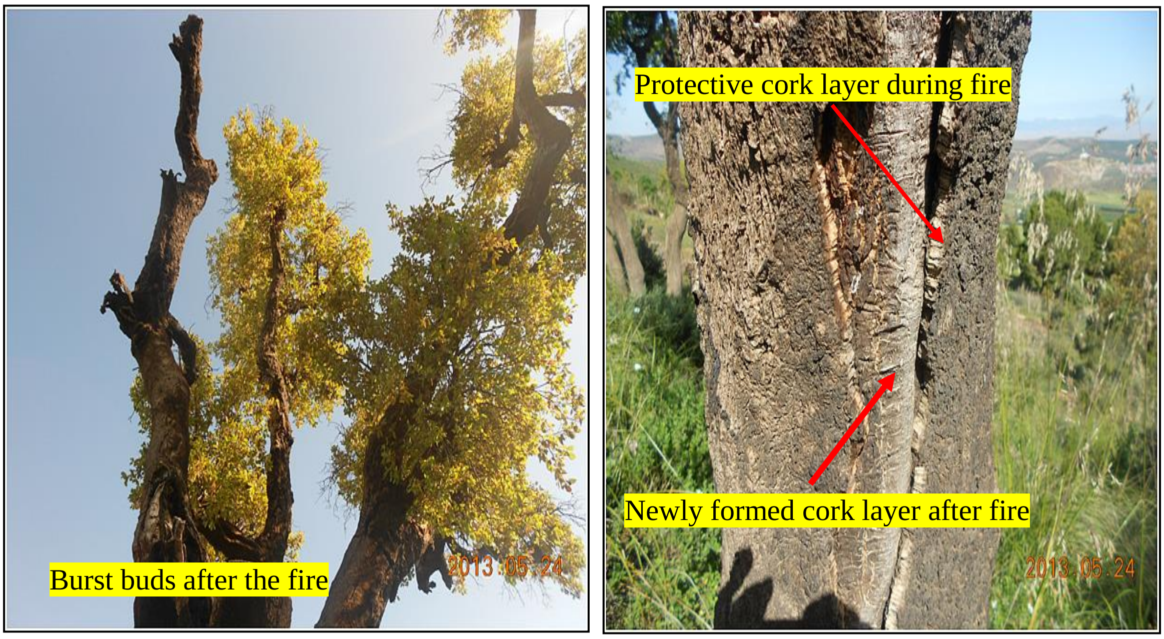


Figure 14. Thick cork stimulates dormant buds and protects the trunk from damage

Debarking height appears to be a precursor to fire spread, with fire vulnerability increasing dramatically with increasing debarked area. Catry et al (2009) highlight that a minimum debarking height was the most important variable for the probability of good crown regeneration and that a maximum height was more an indicator of fire severity and consequently a very altered architecture of the crown (Fig.15).

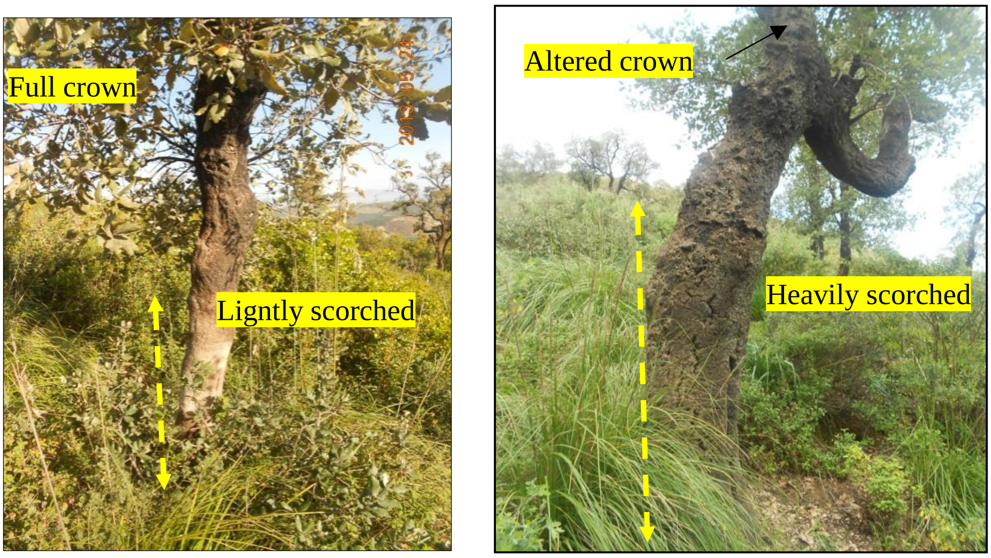


Figure 15. Scorched surfaces of sample trees at time of fire

Faced with fire, the quality of cork depreciates enormously because of the carbonization of the cork. A negative economic impact is announced in productive stands. Buckled boards lose their market value and productivity is reduced to 50%. The time required to exploit good quality cork on heavily burned stands is estimated at 40 years for dead standing trees (Pereira, 2007).

I.2.2-Production and quality

Due to genomic introgression between cork oaks, the same exploited stand can provide different thicknesses of cork, ranging from the thinnest to the extra thick (Tab.3).

Table 3. Commercial classes of cork intended for the processing industry (Pereira, 2007)

Commercial class	Thikness (mm)
Extra thin	0-22mm
Thin	22-27mm
Half standard	27-32mm
Standard	32-40mm
Large(Thick)	40-54mm
Extra large (Very thick)	>54mm

In Portugal, the merchantable thickness of 27 mm represents 75% of the nine-year cycle, while in Algeria it does not exceed 45% (Dehane, 2012) (Fig.16).

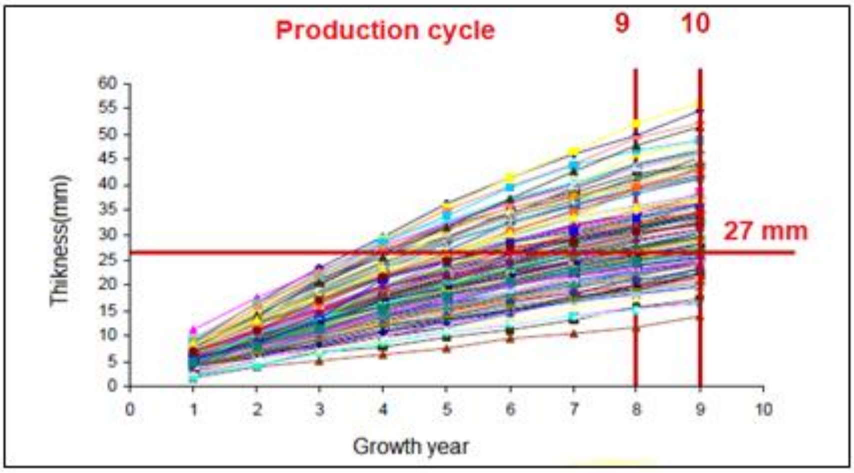


Figure16. Cumulative thicknesses of cork in a cycle of 9 to 10 years (Pereira, 2017)

As an indication, in Algeria, under favorable environmental conditions, one hectare of cork oak is likely to produce between 80 and 120 kg every 10 years, against 200 to 250 kg in Portuguese cork oak forests (Dehane, 2012).

During the 1990s, Algeria ranked third among cork producers (7% of world production), but far behind Portugal (57%) and Spain (23%). National cork production has experienced sometimes significant annual fluctuations. During the colonial period, it fluctuated on average between 9,000 tons (1867-1925) and 32,000 tons (1930-1960) (Marc, 1930). After independence, since 2010, there has been very little stability in production at around 9,000 to 10,000 tonnes/year (Dehane, 2012) (Fig.17).

Cork production is closely correlated to the height of debarking applied. This very rigid exploitation rule is managed by laws and procedures, linked to the type of development to which the cork oak stands are subject. In semi-arid regions (<400mm/a), the cork oak is debarked at low heights synonymous with a stripping coefficient varying between 1 and 1.5. In the sub-humid bioclimatic stage (>600mm/year), the trees are lifted with coefficients ranging from 1.5 to 2 and can cross the coefficient 3, in very favorable climatic and plant conditions (Boudy, 1955).

A cork oak tree can only be demasked if its cork perimeter is 70cm at breast height (22cm DBH), and can go down to 60cm in the case of slow radial growth. In Algeria, the exploitation of the main branches is strictly prohibited, unlike what is practiced in Portugal and Spain (Dehane, 2012).

Cork quality is a very complicated discipline in the field of forestry scientific research. It appeared during the early 1990s under the name of “Cork Technology”, closely associated with the industrial field dealing closely with the transformation of raw cork.

It took an important spring after the appearance of several products competing with cork such as plastic, polyethylene and aluminum. In order to neutralize this polluting industry, European cork manufacturers joined forces in the European Confederation of Cork

(C.E.LIÈGE) between 1992-1996. This solidarity in favor of cork saw the birth of the *Quercus* project in 1996 (Cork Information Bureau (CIB, 2008).

The year 1999 saw the appearance of an association between industrialists and scientists bearing the name of Certification of International Conformity "SISTECODE". This industrial compliance organization issues ISO standards to owners and companies in the cork industry and certifies that products made from cork comply with the rules of quality for exploitation in forests and processing in factories. These are the following standards: ISO 633, ISO 9002, ISO 9001 (Quality), ISO 14001 (Environment) (Dehane, 2012).

In the forest, the cork oak, subject to strong allogamy, grows in different climates and soils, which gives it increased heterogeneity, making the exact definition of its quality the proven skill of cork professionals (Molina and Campo, 1993). This operation of classification into different quality classes is made according to two variables: the thickness of the cork and their appearance (cork defects) (Benkirane et al., 2001).

The aspect of the cork remains very subjective because it is assessed visually, very often leading to classification errors and economic losses for both sides (producers and industrialists) (Dehane, 2006). Since the 2000s, particularly in Portugal and Spain, enormous scientific progress at the level of research institutes on the quality of cork has made it possible to establish convincing classification methods, the best known being that of the ICMC-IPROCOR institute (IPROCOR, 2006) (Tab.4).

Faced with fire, the quality of cork depreciates enormously because of the carbonization of the cork. A negative economic impact is announced in productive stands. Buckled boards lose their market value and productivity is reduced to 50%. The time required to exploit good quality cork on heavily burned stands is estimated at 40 years for dead standing trees (Pereira, 2007)(Fig.18 and 19).

Figure18. Samples of cork flared by cork carbonization rate

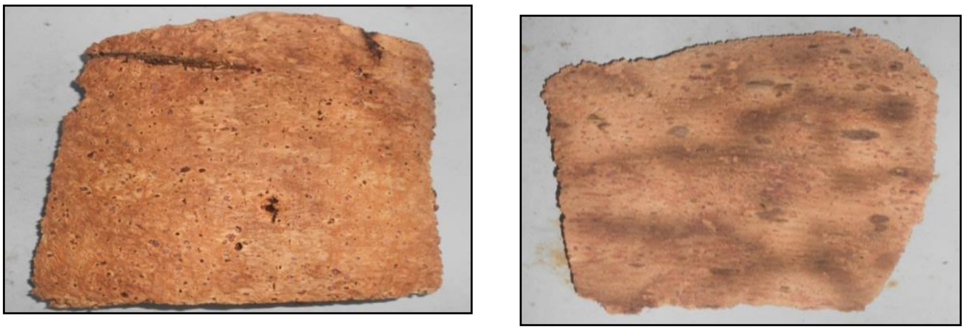


Figure19. The same samples after scraping the charred corkback

Although cork is a very flame-resistant material, it can succumb like any product following continuous inflammation. Indeed, cork carbonizes at temperatures close to 200ºC (Reis, 2003).

Abric (1974), states that cork undergoes a triple depreciation due to fire:

- The burnt forest will not give “stopperable” cork during a whole revolution. This loss in the quality of the cork will therefore be repeated for 12 years, the revolution time generally accepted for the formation of a "merchantable" cork 27 mm thick.
- The depreciation of flamed cork can be estimated at 15% of the value of “white” cork. Because the one that remains of the cork is the "black cork" which has a very low value. The cumulative loss can reach 50% of the value of the standing cork;
- It will be necessary to add to this the additional cost of the exploitation of the burnt cork, very dirty and irritating work, therefore little appreciated by cork lifters, estimated at 20%, and that of its transport.

Dubois (1990), adds that burnt cork weighs less than white cork, for a volume, estimated between 12 and 15%. Piazzetta (2011) considers that fire has little economic impact on virgin cork because the tree has not yet been brought into production. On the other hand, on the second cork one attends a loss of the value of the production. Sum of everything, if the tree dies, loss of interest (= the cork) and capital (= the tree).

In terms of money, losses have been estimated at €40 million in the nine-year cycle following the fires. In addition, for the affected producers, the damage was estimated at more than €100 million with regard to protection investments (Elena Rosselló, 2004).

Basically, we can say that in the face of current climate change, individual tree mortality will increase due to the frequency and intensity of forest fires. The cork oak forest stands out as a typical biodiversity ecosystem with a strong capacity for resistance but with poorly understood post-fire mortality.

For its future protection, it requires predictive models based on the study of the intensity of the damage, the supposed intensity of the fire and their repetition and the dynamics of the regeneration of the stands. This knowledge will enable practical measures to be taken to minimize this damage and improve post-fire management planning. The fundamental question that concerns forest managers after a fire: it is to let nature take its course by regeneration by stump or by crown or to proceed by coppicing damaged trees to reduce delayed mortality and increase the rate of recovery from live strains (Fig.20).

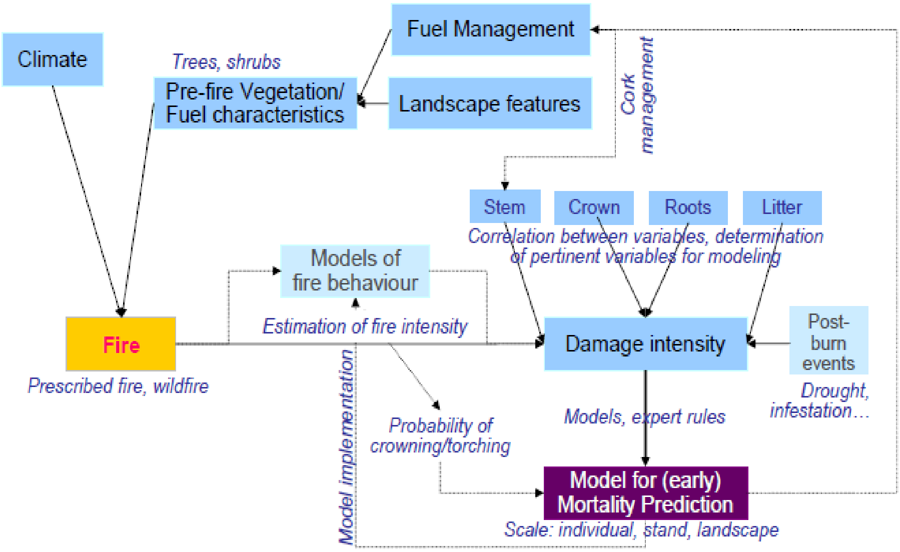


Figure 20. Model for predicting cork oak mortality after fire and management method (Curt, 2010)

Chapter II

Forest fires in Algeria

I.1-Country context

In Algeria, forest fires reduce disproportionate areas of forest cover to ashes and cause significant damage, which can have serious ecological, social and economic consequences. Annually more than 2,000 fires consume approximately 33,615 hectares (DGF, 2022).

The global changes plaguing the region are capable of intensifying wildfire regimes, causing fires to multiply in size. The last decades have been fatal, marked by heavy damage to the Algerian forest ecosystem, and have placed these natural threatsat the forefront of risk management.

For a better understanding of the phenomenon on the scale of past and present time, we conducted a descriptive approach of the data acquired over a chronological period of 146 years. It was a question of drawing up numerical and graphic summaries of the temporal and spatial evolutionary trends of the phenomenon by applying several usual indices relating to forest fires.

II.2-Approach

In Algeria, the history of forest fires including causes and decimated areas dates back more than a century, it is one of the exceptional countries to have uninterrupted statistics for 146 years. (1876-2022). In addition to articles published on daily newspapers, the main archives and notes used are those of Marc (1916 et 1930) ; Boudy (1948) ; Grim (1989) ; Meddour, (2015) and DGF (2022).

Recent specific data on forest fires in Algeria for the 40 forest wilayas in Algeria are available for a total period of 37 years from 1985 to 2022. These data have been published by the Directorate General of Forests (DGF), in format paper and digital in Excel files, in the form of monthly and annual reports in two phases from 1985 to 2009 and from 2010 to 2022.

Thanks to the analysis of the statistical data of the forest fires in Algeria (area burned and the number of fires), it is possible to follow the history and to know the tendency of development of this phenomenon on the scale centenary, annual and monthly. However, as pointed out by Alexandian and Esnault (1998), long statistical series must be interpreted with caution because of social events and recurrent security situations affecting the forest sector.

II.3-Forest area

The exact), who restricts it to 2,910 000 ha currently, of which 2 million are made up of irrecoverable forests (maquis and scrubland), with an afforestation rate that has fallen from 27.17% to 11%. (Boudy, 1955; Mate, 2003).

In the same context, Maire (1925) and Boudy (1955) claim that the Algerian forest was deprived of 1.815 million (forests + maquis) which was around 3,013,000 ha.Subsequently, Louni (1994) evokes an area around 3,000,000 ha according to the account of Quezel and Barbero (1985) (Table 5). The DGF estimates the current total area at 4,100,000 ha (Abbas, 2013).

Highly influenced by the bioclimatic stages that compose it, the Algerian forest is made up of a variety of Mediterranean and desert species, ranging from the humid climate to the Saharan. At each distance from the coast, the semi-arid stage takes over and the forest facies changes from north to south of the country. We can see two main areas that are very different:

- The coastal chains in the east of the country such as: Bejaïa, Grande Kabylie, Jijel, Collo, El Milia, El Kala. Those regions with annual rainfall of more than 700mm, encompass the densest and most pleasant forests. Obviously, it is the favorite area of two main species, namely: cork oak and zeen oak.
- Further inland, the high continental plains, more arid represented by the steppe regions located between the coastal chains and the Saharan Atlas. These areas are dotted with large expanses of Aleppo pine and holm oak (Aurès, Djelfa and Saïda) (Fig.21).

The DGF (2013), communicates that the national heritage is generally based on protection forests, composed of holm oak, cedar and juniper. The predominant species is the Aleppo pine which occupies 881,000 ha and is found mainly in semi-arid areas. Potentially, the cork oak with 450,000 ha is mainly located in the northeast of the country. The zeen oak with 43922 ha occupy the most humid environments with the quercus. The cedars are scattered over 16,000 ha in discontinuous blocks in the central tell and the Aurès. The maritime pine grows naturally in the northeast of the country and covers 31,000 ha. Eucalyptus, species introduced since colonial times in the north and especially in the east of the country, occupy 43,000 ha and the Other formations (Thuja + Juniper + Ash) 124,000 ha.

It should be noted that:

- 91% are public forests belonging to the State (3,700,000 ha)
- 9% private forests: 350,000 ha
- 43% of these forests are located in the East: 1.8 million ha
- 29% in the West: 1.2 million ha
- 27% in the center: 1.1 million ha
- 1% at the level of the Saharan atlas

For its part, the BNEDER (2009), relies on other figures; specifying the predominance of maquis and wooded maquis which cover 2,413,090 ha (i.e. 58.7% of the total forest formations) and which are divided into:

- Clear maquis = 1,262,118 ha
- Dense maquis = 444,609 ha
- Open scrubland 435,940 ha
- Dense wooded maquis 270,423 ha

II.4-Assessment of forest fires in Algeria: Temporal analysis (1876-2022)

According to Houerou (1980) and Boubkeur (2016), personal agricultural or pastoral purposes. However, the low agricultural yields obtained forced him to constantly conquer new lands. Fire was then associated with two major traditions, clearing or burning (Kunholtz-Lordat, 1958).

II.4.1-Forest fires in Algeria since the end of the 19th century (1876-1961)

The colonial period was more marked by social unrest, especially during wars and popular uprisings, however, it is known that in periods of political unrest, forests always pay a heavy price for fires (Marc, 1916; Bensaïd et al. al., 2005). Moreover, the French colonial authors in their accounts, deny any correlation between the peaks of forests ravaged by fire and the political insurgencies of the Algerians.

The figure 22 traces the historical evolution of forest fires in Algeria during the colonial period (1876-1961):

The colonial period was the most disastrous, the colonial archives show a cumulative surface of 3,516,499 ha erased by fire, ranging from 1876 to 1961. The annual average of 40,889 ha is identified in a, 1918, 1956, 1957 and 1958, which occurred with periods of popular uprising and repression (Meddour, 2015).

More specifically, the Algerian forest was the battlefield during the national liberation war (1954-1961) where whole fell prey to the flames, following the scorched earth policy imposed by the colonizer (Trabaud, 1980).

Sari (1976) presents a dark image of the occupier, no less than 435,646 ha were destroyed between 1956, 1957 and 1958, with an However, Grim (1989) stands out and considers that it remains to be proven that the burnt surfaces recorded during this period correspond to reality.

II.4.2-Burned areas in independent Algeria (1962-2022)

According to the data recorded in the figure 23, the total forest area burned during the period 1962- of 33,615 ha/year with an average inter-annual variation of around 132%. This great variation oscillated between placid years of low burnt area (<10,000ha/year) to stormy years of high rate of flames (>50,000ha/year).

Paradoxically, some disastrous years marked the minds of foresters including 1965, 1967, 1971, 1977, 1978, In some atypical years, the Algerian forest was shaken by large fires, far exceeding the average for the period 1In some atypical years962-2022, i.e. between 40,000 and 60,000 ha (Fig.23)

The catastrophic fires of 100,000 to 150,000 ha mark the annals of forest fires in our country. Moreover, two very difficult years disturbed the national forest heritage, in this case the years 1983 and 1994, with respectively 221,367 ha and 271,598 ha, greatly exceeding that of 1956 (204,220 ha). These two years, i.e. a rate of 32% of the total of the current chronology (60 years).

According to several authors, these two record years (1983 and 1994) were attributed on the one hand to the great drought, where the water deficit reached a critical level evaluated at less than 25% of the annual volume on average; on the other hand, to the security situation experienced by Algeria from 1992 to 2001, at the origin of several fires that ravaged vast forests, particularly in Kabylie (Ramade 1997; Ait Mouhoub, 1998).

Despite this alarming observation, the average area burned by fire in Algeria (33,615 ha/year) seems to be These efforts will never be able to make up for this loss of plant cover, even if the success rate of these actions is 100%.

II.5-Frequency of fires in Algeria

Forest fires increase with the presence of forest fuel and favorable conditions. Thus in Algeria, this scourge is concentrated much 2013). The wilayas which have a high rate of forest cover record the greatest number of fires (Fig. 24).

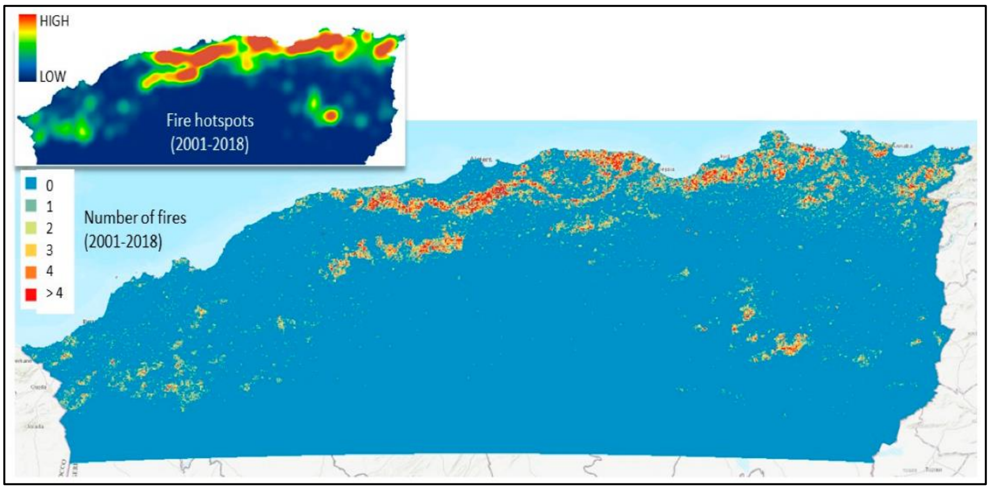


Figure 24. Maps of fire occurrence in Northern Algeria (number of fires, 2001–2019). The enclosed Figure (upper left) indicates the fire hotspots and their level of density (Curt, 2020).

II.5.1-Colonial period

The data available from the colonial period only concerns the period 1876-1915, i.e. over 40 years (Meddour -Sahar et al., 2008) (intensification of the annual frequency of fires during this period (the trend line has categorically doubled.

II.5.2-Current period 1980-2022

Data on the frequency of fires for the period of independent Algeria, are available since 1980, i.e. a (Fig. 26), where it recorded an accumulation of 84,878 fires, i.e. an average fires /year.

This represents, compared to the colonial period (of 2 322 lights. Very high annual fire frequencies occurred again later and for 4 successive years from 1997 to 2000 and from 2004 to 2007 (1,400 to more than 2,000 fires/year).

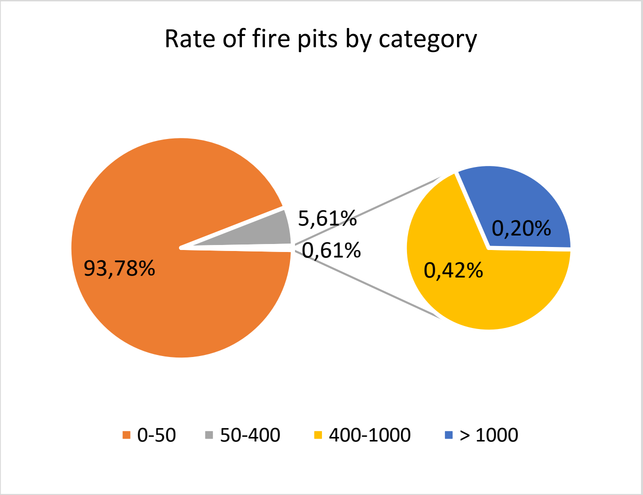
An interannual comparison for the period 2010-2022 brings out a bitter reality of the situation of forest fires in 43,918 ha was generated by 3,493 outbreaks of fires, i.e. an average of 23 outbreaks/day and an area of 12.57 ha/ hearth.

The general trend for this period is unfortunately unequivocal: an exponential increase in the annual frequency of fires, i.e. multiplied by 3 according to the trend curve.

II.6-The average fire and characteristics of hearths of fires

The average fire is (1876-1915). However, two “unusual” maximum values of 223.6 ha/fire and 118.8 ha/fire are recorded, corresponding respectively to the worst years, 1983 and 1994 (Fig.). The general trend for this period is clearly upward.

For the period 2010-2022, the 50ha class, 128ha in the 50-400 class, 604ha in the 400-1000 class and finally 2261ha in the>1000 class (Fig.27).


Rate of fire pits by category

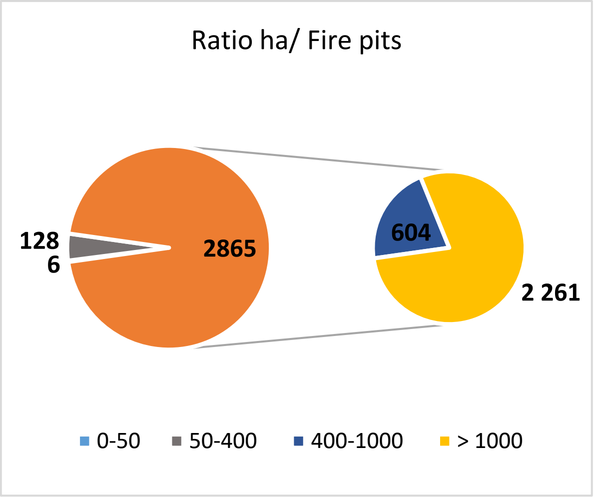

Ratio ha/ Fire pits

Figure 27..Evolution of the number of households and hectare ratio by category of area burned (2010-2022)

II.7-Distribution of forest fires by region and forest formation

The climate (precipitation and temperatures), and human activities (mainly grazing) remain the two factors imposing the rate of afforestation, (expressed by the ratio between the forest cover and the total area of the wilaya). An impressive case, the wilayas with low population density generally record a high rate of afforestation. Similarly, there is a decrease in forest cover the further one goes towards the Oranie sector.

According to Djellouli (1990), Bouaoune and Dahmani (2010), there are two spatial variations in Algeria that limit rainfall. A longitudinal according to which precipitation decreases from west to east (450 mm/year in Oran and more than 1000 mm/year in Annaba); and the other latitudinal according to which the rainfall increases from 50 mm in the M'Zab region in the South to 1500 mm in Jijel in the North.

The rate of forest cover follows the rainfall pattern and the further east you go, the greater it is, precisely in the wilaya of El Tarf with the forest block scrolling from the wilaya of Ain Defla to El Tarf has a rate of afforestation exceeding 31%, with the exception of the wilaya of Blida. The wilayas whose afforestation rate exceeds 40% are Jijel, Skikda, and El Tarf (Boukerker, 2016).

According to the figure 28, for also affected by fires on 312 hectares per year, or 0.89%. It clearly appears that the extent of the burning of forest massifs is in close correlation with the rate of afforestation and the floristic composition of stands of very combustible species, in particular the Aleppo pine (Benderradji et al., 2007, Madoui, 2013).

Moreover, the wilayas of the western region (20%) remain the least affected by fire than the center (37%) and the east of the country (43%), which remain the most sensitive. The current prevention measures must be allocated to, Bejaia, Annaba, Skikda) and central (Tizi Ouzou, Boumerdes, Algiers, Tipaza) and the other mountainous wilayas on the Tell and the high plateaus (Bouira, Medea, Ain Defla, Batna, Khenchela, Souh Ahras, Setif, Constantine) (Fig.29).

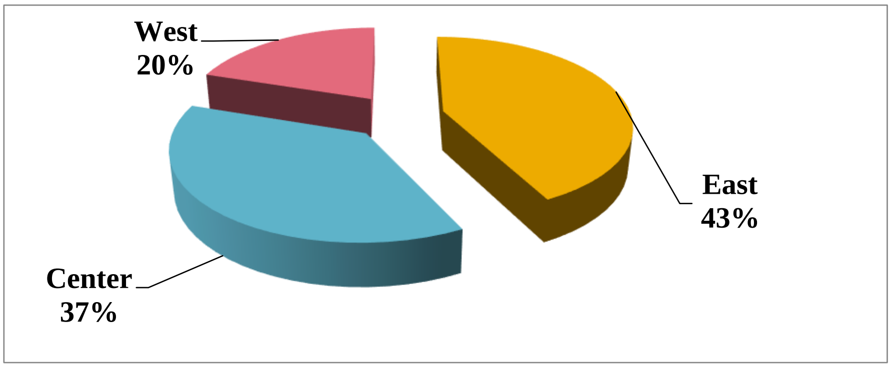


Figure 29 . Fire frequency by region in Algeria

II.8-Breakdown of fires by species

In Algeria, the flammability of forest formations is almost attributed to the main species, the Aleppo pine (*Pinus* chain and also because of the exaggerated resinousness inside the noble stands with regard to the cork oak. The very fragile temperament of the Aleppo pine in fire (very rich in resin) makes it a species with very high flammability, in particular the very rapid propagation at the level of the crowns (Valette, 1990) (Fig.30).

According to the figure, the cork oak comes in second place with 36% of the total area burned. It represents 21% of the total forest area, mainly in the northeast of the country. Its dense undergrowth infiltrated by the Aleppo pine and the oxycedral juniper gives it a very high flammability, allowing the fire to spread quickly (Boudy, 1948, Paussas, 2004).

In addition, industrial eucalyptus plantations represent 1% of Algeria's forest cover, have recorded a significant burnt area compared to pine. Eucalyptus, in particular Eucalyptus globulus, a tree introduced during the 1970s that became very widespread, is a very fire-sensitive species due to the large amount of highly flammable oil in its leaves (Varela, 2004).

II.9-The causes of the fires

In Algeria, the explanations and investigations relating to the real causes of the outbreak of forest fires for the period 1962-In addition, intentional fires, which are difficult to discern, represent a significant rate (16%) for the number of fires, although this figure is far from reality. Many fires categorized as unknown cause are actually intentional, because the perpetrator of the fire was not arrested or there was no clear evidence of a fire of this nature. nature (Dimitrakopoulos, 1995).

Unintentional fires (accidents and imprudence) rally various causes in Algeria (incineration of brushwood, regeneration of rangelands, burning of stubble, seekers of wild honey, shepherds, vehicle exhaust, smokers, etc.) and represent only 3% of the all the lights identified. It should be noted that wild honey seekers can endanger the forest massifs, since the traditional and artisanal method they use consists of fumigating the swarm of bees discovered in a tree, setting the base on fire of the tree trunk (Delacre and Tarrier, 2000).

The colonial era was well governed by voluntary causes, which Boudy did not mention in 1952. Velez (1990) clearly notes the increase, in the Mediterranean region, in the number of fires ignited voluntarily with the simple aim of destroying and revenge.

In Algeria, urban sprawl and socio-urban dropout during the last two decades (2010-2022) is a cause of these acts. and the Algerian forest is once again subjected to the mercy of the fires, thus recalling the fifties under the French occupation (Fig. 31).

.

In another context, natural causes can occur, Trabaud (1980) and Madoui, (2002) affirm that it is according to the meteorological conditions which occur during the year that depend, among other things, the surfaces covered by the fires and their number decreases exponentially as the amount of precipitation and the degree of air humidity increase.

In another context, Balch et al. (2017) and Cattau et al. (2020) estimate that anthropogenic factors remain the main causes of changes in the outbreak of forest fires. Moreover, vegetation does not catch fire alone, even in severe drought, the only natural cause known in the Mediterranean Basin is lightning. Barlow et al. (2020) associate lightning with roads and exotic grasslands, which are more flammable than natural forest vegetation. This phenomenon, very widespread in the boreal forest (dry storms), is relatively rare in Algeria.

II.10-Assessment of fire risk at the level of wilayas in Algeria

The recurrence of fires is a natural phenomenon that is part of the forest landscape in the Mediterranean. From the historical study of fires, it may be relevant to draw up risk maps at the level of the wilayas, for a given period. It is thus possible to analyze, in view of the wilayas marked by the repeated passage of fires, to know if there are more sensitive zones than the others (Esnault, 1995).

To do this, we used two types of risk, namely the total frequency risk (IRF) and the average annual risk (RMA), at the level of the wilayas.

II.10.1-Frequency risk index

According to the work of Dimitrakopoulos and Mitsopoulos (2006), Meddour-Sahar and Derridj (2012), the fire frequency risk index is expressed as follows:

Where:

– Practically all the wilayas of the East have a high to very high degree of risk, corresponding to 10-23 fires on an annual average per 10,000 hectares, such as, for example, Jijel, Skikda, El Tarf, Annaba,.
– In the Centre, the wilayas of Boumerdes, Tipaza, Tizi Ouzou and Béjaia, which are experiencing urban and tourist activity, foresee
such as Ain Temouchent, Tlemcen, Mostaganem and Chlef, the frequency risk is lower, with 2-5 fires/year, foresee an average risk, which attests to a low anthropogenic pressure and less coastal development.
– The wilayas of the Tell Atlas are far from exempt: Constantine, Souk Ahras, Bouira, Blida, Medea, Ain Defla and Tissemsilt are classified with a high risk, while Guelma, Bordj Bou Arreridj, Mila, Setif, Oum El Bouaghi are at medium risk.

II.10.2-Average annual risk (RMA) or degree of severity of the fire (period 1985-2022)

To measure the scope and extent of fires in the Mediterranean region, the average annual risk is frequently used, expressed as a percentage of the area burned on average each year in relation to the forest area of the massif in question (expressed as a percentage by the following formula (De Montgolfier, 1989; Peyre, 2001)

– SMA: average area burned per year (hectares);
– SCM: area of the forest massif (hectares).

The RMA (%) is calculated according to the wooded area of the different wilayas and the average areas burned annually. The aim is to bring out areas of high repetition of fire, which are advantageous in terms of DFCI.

The figure 33 stands out, the wilayas of Constantine, Annaba, Tizi Ouzou, Bejaia and Boumerdes with a high RMA of 2-4% and adjusts to that reported by Meddour-Sahar and Derridj (2012). Moreover, the same authors sound the alarm and point out that the forest lands located in the wilayas sheltering the megalopolises of Algeria, such as Constantine, Annaba Boumerdes, Tizi Ouzou and Bejaia, are to be systematically declared as red zones.

In these red zones, a periodicity of 2 fires, every 25 to 50 years on the same wooded area, can lead to less forest recovery and favor vegetation composed of high scrub, very sensitive to fires. With 4 fires in the space of 50 years, the forest area is seriously compromised (Shaffhauser , 2009).

II.10.3-The Average Area per Fire (SMI) (period 1985-2022)

The average area per fire is an indicator of the strong environmental disturbances experienced by a forest ecosystem, exalted by severe drought conditions, an increase in temperature and a reduction in precipitation during the year of the fire and previous seasons.

The wilayas (60 ha), Annaba (47 ha), Guelma (46 ha), Mascara (45 ha), contribution to the national average of 19,80 ha.

Furthermore, the wilayas with an SMI adjoining the average are: Relizane (39 ha), Skikda (36 ha), Bejaia (38 ha), Saida (35 ha),

Paradoxically, the wilayas with a lower SMI than the national average are among the most burned with a number of fires greater than 2000 fires in relation to: Tissmsilt (18 ha), Oran (12 ha) Bourdj Bou ariridj (11.5ha), Bouira (11ha), Blida (10ha).

The current fire situation is changing rapidly due to ongoing climate change, landscape evolution (agricultural abandonment, landscape closure, land clearing) and urban development. Over the decades, all of these developments have led to an increase in the area of fires, longer fire seasons, and of course an increase in large fires or fires with extreme behavior.

Chapter III

Study of the environment

III.1. General Introduction

With a total area of 902,000 ha, the Wilaya de Tlemcen extends from the coast in the north to the steppe in the south, thus constituting a diverse landscape where four distinct physical ensembles are found (PNT, 2015):

- The northern zone, made up of the Monts des Traras and Sebaa Chioukh, appears as a massif at high altitude, characterized by quite remarkable erosion and insignificant rainfall.

- The area of the Maghnia plain, the lower valleys of Tafna and Isser and the plateaux of Ouled Riah are characterized by strong agricultural potential.

- The Monts de Tlemcen, stand as a real natural barrier between the high steppe plains and the Tell. By its extent, its geological configuration, its vegetation cover and its rainfall. This mountainous massif constitutes one of the most important hydraulic reserves at the regional level.

- The southern zone is made up of the high steppe plains, most of which have been degraded following several factors (overloading of the routes, clearing, desertification, etc.).

Forest land occupies an important place in the Wilaya of Tlemcen. It covers an area of 217,000 ha, including reforestation, i.e. 24% of the total area of the Wilaya, more than 80% of the forestry potential is concentrated at the level of Mounts of Tlemcen. Forest distribution by species (CFWT, 2004) (Table.6):

Table 6. Distribution of forest area per specie (CFWT, 2023)

Species	Area occupied (ha)
Aleppo pine	83 000 ha
Holm oak:	82 000 ha
Cork oak:	4 800 ha
Cedar:	16 500 ha
Juniper:	13 000 ha
Other:	17 000 ha
Alpha:	154 000 ha
Reforestation:	17512 ha

The Wilaya of Tlemcen has an important wood, but remains however insufficient compared to the existing potentialities. In the short term, these forests do not offer great prospects that can be developed for regular long-term exploitation.

III.2. Presentation of the study area

III.2.1. Geographic location

The Hafir-Zarieffet forest massif is an integral part of a state protection system, namely the Tlemcen National Park (PNT). The latter is located in the far west of Algeria, in the Wilaya of Tlemcen. Its area is 8225.04 ha and it was created by decree on May 12, 1993. It extends over seven municipalities: Tlemcen, Mansourah, Sabra, Terny, Ain Fezza, Beni Mester and Ain Ghoraba and is limited by the Lambert coordinates North (x = 137.4 km; y = 183.7 km), South (x = 120.9 km; y = 172.5 km), West (x = 118.2 km ; y = 174 km) and East (x = 144 ,2 km; y = 180.7 km)(PNT, 2015) (Fig.34).

The Hafir-Zarieffet forest massif is also under the direction of the forest services (Conservation des Forêts de la Wilaya de Tlemcen (CFWT). It is subject to the forest regime in 1891 for the Hafir state forest, and in 1883 for the state forest de Zarieffet (C.O.I.T., 1900).The two forests forming the massif have the geographical coordinates indicated in the following table.

Table 7. Geographical coordinates of the two state forests

Names of the forests	Coordonnées géographiques		Distance to the sea (km)	State cards major
	Latitude	Longitude		
Hafir	x_1= 105.2 km x_2= 127.1 km	y_1= 163.6 km y_2= 178.3 km	60	Terny, sheets 299 and 300
Zarieffet	x_1= 123.3 km x_2= 129.8 km	y_1= 177.2 km y_2= 180.5 km	50	

The two adjoining forests form a continuous massif of approximately 12,000 ha, located southwest of the city of Tlemcen, 5 km from Zarieffet and 15 km from Hafir. They are limited to the north by the commune of Mansourah, to the south by the ridges of Béni Bahdel, to the east by Terny and to the west by Zelboun and Béni Mester (CFWT, 2004).

The forest of Hafir has between 9,872 and 10,156 ha divided into 24 cantons (C.O.I.T., 1900) and that of Zarieffet 990 ha divided into 3 to 4 cantons (Bouhraoua, 2003). The first comes under the forest district of Tlemcen and the second under the districts of Tlemcen (623 ha), Maghnia (7,586 ha) and Sebdou (1,750 ha) (B.N.E.D.E.R., 1979).

III.2.2. Relief and topography

The region covered by our study is located in the western part of western Algeria, being part of a mountainous sector called "Monts de Tlemcen", particularly in its southwestern part.

The Monts de Tlemcen have a general orientation W SW-ENE, they are affected by more or less transverse faults. According to the works of Doumergue (1910), Lucas (1952) and Benest (1971), it is the Oued Chouly cross-section, the Tafna Magoura cross-section and the Ain Tellout cross-section.

The highest altitudes are on average 900-1000 m and culminate at Dj Nador 1579 m (Commune of Terny) in the South-West. They present 44% of the forests, the rangelands remain the main constraint for the dynamic state of the forests and meadow forests. They extend over 317,600 ha or 37% of the entire Wilaya (CFWT, 2004).

The reliefs are very rugged representing slopes generally greater than 25%. In this case, the significant risk of erosion is always imminent regardless of the cultivation system which then requires effective protection measures (Ammar, 2001) (Tab. 8)..

Table 8. Distribution of slope classes in the Tlemcen mountains (Ammar, 2001)

Slope class	Area in (%)	Type of terrain
0-3% (plain)	4.1	Agricultural
3%-6% (lower foothills)	7.2	Agricultural-Forestry
6%-12.5% (bas piémonts)	16.3	Agricultural-Forestry
12.5%-25% (upper piedmont)	45.3	Forestry
> 25% (mountain)	27.1	Forestry

III.2.3. Geology and Pedology

Boudy (1948) notes that the study area is attached to the Tell chain, forming part of "a Jurassic system" which begins in Morocco (Moulouya) with the causses of Debdou and Zekkara, then extends in a chain on 300 km to Tiaret, by those Tlemcen, called on the maps "Monts de Tlemcen". That is to say a false tabular chain formed of dolomitic limestone with karstic relief.

The geology of the Tlemcen mountains was subsequently a vast field of investigation by French and Algerian geologists, including in particular the work of Lucas (1952) Elmi (1970); Claire (1973) Pouget (1980); Dahmani (1984); Benest (1985); Bouabdellah (1991); Benest & Bensalah (1995). All these authors agree on the fact that the northern massifs of the Monts de Tlemcen are essentially made up of ancient geological formations ranging from the Upper Jurassic to the Lower Cretaceous, while those ranging from the Lower Miocene to the Quaternary are considered recent. According to their respective geological age, these formations are juxtaposed as follows (Fig.35):

- The Sequanians Sandstones (“Grés de Boumediene”) located in the mountain range of Zariffet and Hafir
- Limestones with echinoids intercalated in the upper base of the Sequanian sandstones and forming a continuous horizon of blue limestones, the Dolomites of Tlemcen.
- Marl and limestone with Pterocera (“Marno-limestone of Raourai”) which spread out in plateaus (Meffrouche plateau).
- The Dolomites and Limestones of the Terny plateau (“Terny Dolomites”) which spread out over the plains of Terny.
- The Boumediene Sandstone (Upper Oxfordian - Upper Kimmeridgian) in the Zarieffet forest to the south-west of Terny.
- The Zarieffet Limestones (Upper Kimmeridgian).

- The Terny Dolomites (Lower Tithonian) which extend over a large area around the town and are the summit of the highest reliefs (Dj Nador 1579m).
- The Lato limestones (Basal Tithonic) correspond to the cornice underlying that of the Terny dolomites.

The pedology of the study area is not studied enough, however, the different phases of erosion, sedimentation, pedogenesis that the soils have known during their history, make their pedological interpretation quite delicate. However, there are some works that characterize this region (Gaouar, 1980; Hadjadj-Aouel, 1995; Dahmani, 1997). The pedology reveals that the soils are generally shallower of the brown forest type. The main soils associated with cork oak are (Fig. 36):

- fersiallitic brown soils, leached or not. These soils are subject to erosion phenomena, especially in areas exposed to precipitation and whose slopes have a steep gradient.
- fersiallitic brown soils with a podzolic tendency reflecting the permeability of the parent rock (Séquanian sandstone).
- The rendzines under the degraded green oak groves of the Monts de Tlemcen, on calcareous-marly substrate.
- Low erosion soils are therefore found wherever the stripping phenomenon is faster than pedogenesis.

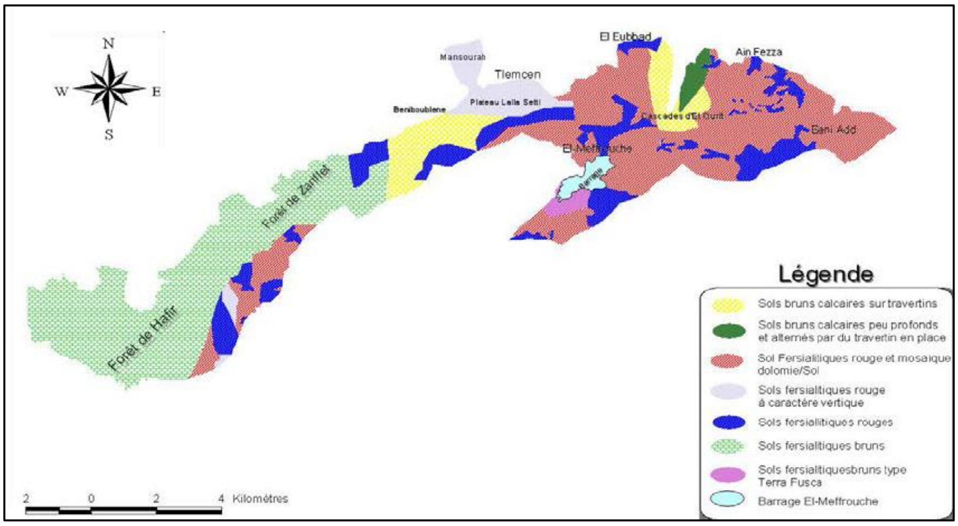


Figure 36. Soil map of the study area (P. N. T, 2009)

III.2.4-Hydrology

The study area is an integral part of the Tlemcen mountains where highly karstified Jurassic carbonate rocks (80%) outcrop. They are fairly well watered (500 to 700 mm/year) and infiltrate (200 to 400 mm^3/year) (Collignon, 1986).

The Hafir-Zarieffet forest massif has a smaller hydrographic network, comprising three wadis (Oued Tlet, Oued Fernane and Oued Zarieffet). They are generally dry in the summer and temporarily flowing in the winter due to drought. We also note the existence of 6 springs, 2 of which are located in the forest (Aïn Baghdad and Aïn Dar Ghelem). Their flow rate is respectively average from 10 to 20 liters. Elmi (1970), cites that the southern part of the Hafir region is crossed by a single wadi called “Oued Boumeroune” which flows from East to West, its flow corresponds to the Tafna basin (Fig. 37).

The existence of these sources plays a significant role in the feeding of cork oak stands in moisture and soil water reserves, and consequently on cork yield, because they help to mitigate the excesses of extreme temperatures and drought.

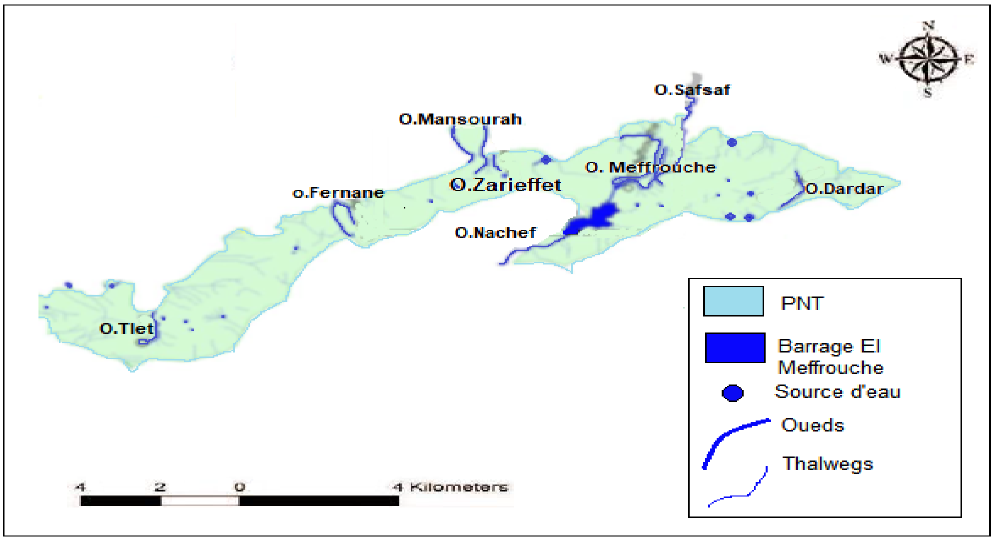


Figure 37.. Hydrographic map of the Hafir-Zarieffet forest (PNT, 2009)

III.2.5-Climate analysis

According to the World Meteorological Organization (WMO), climate is most concerned with changes in the statistical distribution of conditions in the Earth's atmosphere in a given region during a given time period. These statistics are generally observations and daily measurements representing average values and variations of parameters such as temperature, precipitation and sunshine duration... The explanatory climatology of a region can only be validated over a period thirty-year benchmark (Byun and Wilhite, 1999).

The unexpected succession of extreme heat waves and the occurrence, in recent decades, of major droughts occupying large territories on all continents reveals the seriousness of climate change with which both humanity and the various ecosystems are confronted (Beaudin , 2007).

The Hafir-Zarieffet forest massif is an integral part of the Mediterranean forest ecosystem most threatened by disastrous climatic and ecological phenomena such as drought, aridity and desertification. To argue this situation, we used a diversified collection of meteorological data extrapolated over the same reference period. These data were provided by the services of the National Meteorology, Hydraulics (Basin Agencies), Agriculture and Water and Forests, or more precisely certain websites specialized in the field of global climatology. These climate data are spread over a period of 29 years, from 1992 to 2001.

The climatic characterization of the massif has been defined according to the application of several climatic indices which combine precipitation and temperature and even other climatic factors. This is how several authors have proposed numerical and graphic syntheses such as: Long, De Martonne, Koppen, Emberger; in the interest of highlighting the importance of the vegetation factor.

III.2.5.1-Precipitation and temperature variability

Precipitation is of paramount importance for climate analysis since it regulates the spatial distribution of vegetation. Their monthly and annual irregularity are indicators of the climatic contrast experienced by the region (Fig. 38).

The figure 39 shows a marked variation in fluctuations >100mm/year compared to the average (541.89mm), for the period 1992-2021. These fluctuations total 12 negative and 7 positive occurrences. The situation remains very critical from the year 2016, with a succession of six years typically with a deficit of an average of around 214.93mm compared to the annual average of 29 years. Statically speaking, this is a negative linear regression.

As for temperatures, the figure highlights annual variations during the period 1992-2021 with linear upward trends. The annual averages vary from 11.35°C (minimum temperature) to 24.68°C (maximum temperature) and 18.01°C (mean temperature).

- Average annual temperatures are stable with a slight upward trend from 2012.
- This is explained by the variations in maximum hot temperatures, the first two decades (1992-2001) and (2002-2011) respectively record stable average temperatures of around 24.52°C, they take on a increase during the last decade (2012-2021) with an average of 24.91°C, an increase of 0.91°C.
- The days of cold minimum temperatures also decrease, they go from 10.74°C (1992-2001) to 11.15°C (2002-2011), and progress towards 12.14°C (2012-2021).
- In terms of climate balance, the results obtained diverge significantly between the first, second and third decades. From 1992 to 2001 and from 2002-2011, minimum temperature anomalies show a weak negative trend compared to normal (-0.27°C and -0.16°C). On the other hand, from 2012 to 2021, they indicate a positive trend compared to normal, with an average of 0.62ºC.

III.2.5.2-Seasonal variation in precipitation

The cumulative rainfall according to the vegetative season is represented in the figure 40.

Over a period of 29 years, the figure identifies the summer season as the wettest (28.35mm) of the year, and the wettest winter (203.40mm, followed by autumn (189.44mm) and spring (120.69mm).

We are facing a HAPE-type climate which is experiencing a regression in winter seasonal rainfall, which goes from 230.19mm (1992-2001) to 190.65mm (2002-2011) to 188.61mm (2012-2021).

III.2.5.3-De Martonne index

The aridity index of De Martonne (1926) makes it possible to characterize whether the climate is dry or humid favorable for a type of vegetation (Fig.41):

$$\mathrm{IDM} = \frac{\mathrm{p}}{\mathrm{T}+10}$$

Where
P: the annual precipitation heights in mm
T: average annual temperatures in °C

The figure shows a marked interannual variation of the De Martonne index. A general average of around 20 for the 29-year period, i.e. a regressive trend towards semi-arid and aridity in general.

During the first decade (1992-2001), the index recorded an average equal to 20.15 varying between sub-humid and semi-arid climate, with a maximum of 25 recorded during the year 1995 and a minimum in 2000. Conversely, the second decade (2002-2011) experienced a certain freshness, resulting in an index of around 20.94. The maximum displays 28.26 reported in 2003, and the minimum 12.01 in 2006.

The third decade seems drier than the previous two, with an index of around 18.1. A peak of humidity was reported during the year 2013 (41.02) then a significant regression turning towards semi-arid and arid was triggered from the year 2016.

Overall, the study area is characterized by a dry Mediterranean climate, favorable for low woody vegetation, always requiring external drainage.

III.2.5.4-Emberger xerothermic index (1942)

The intensity and importance of the dry season in the Mediterranean climate led Emberger (1942) to propose a new index called the xerothermic index (Is).

$$\mathrm{Is} = \mathrm{P}/\mathrm{M}$$

P: Total average summer precipitation in (mm).
M: Average thermal maxima for the summer period (°C).

The author points out that this index does not exceed "7" for the Mediterranean climate. To differentiate the Mediterranean climate from the oceanic climates, Daget (1977), limits this index to “5”. The variations of the drought index for the reference period are recorded in the figure 42.

Figure 42 . Summer drought index variability 1992-2021

The figure tells us that the summer drought indices fluctuate annually but without exceeding the threshold of 5 and therefore less than 2. The recorded average is around 0.80.

In Oranie (Western Algeria), a study conducted in 1969 by Alcaraz, which indicates the existence of plant species adapting to an index lower than 2; this same author indicates that this index can be lower than 1. This figure supposes a dryness of the area largely exceeding the usual summer season of three months. Indeed since 2016, the aridity has become very apparent and the summer drought very accentuated.

On this subject, work carried out by Bouazza (1995), made it possible to draw up a list of indicator species in relation to the drought index and summer water stress (Tab.9).

Table. 9. Forest species adapted to the summer dryness index (Bouazza,1995)

Ampelodesma mauritanicum.	0.80< Is<1.28
Quercus sp	0.69< Is<1.28
Rosmarinus officinalis.	0.67< Is<1.08
Juniperus oxycedrus subsp rufescens.	0.56< Is<1.38
Chamaerops humilis subsp argentea.	0.54< Is<0.80
Calycotome spinosa.	0.52< Is<0.77
Ziziphus lotus.	0.51< Is<0.92
Tetraclinis articulata.	0.40<Is<0.91 (Alcaraz,1969)
Thymus ciliatus subsp coloratus.	0.40< Is<0.71
Stipa tenacissima	1.23<Is<1.28

III.2.5.5-Thornthwaite climate classification

Thornthwaite's formula, stated in 1931, is defined by the following expression (Fig.43):

$$I = \frac{\mathrm{P}^{10/9}}{(T + 12{,}2) *^{10/9}}$$

P: The annual precipitation heights in mm

T: Average annual temperatures in °C

Figure43. Annual variation of the Thornthwaite climate index

According to the climate classification of Thornthwaite, with the average of 25.5; the study area is defined as a region with a semi-arid climate allowing the regrowth of light woody vegetation, mixed with certain steppe species such as Alfa (*stipa tenacissima*). This finding is an additional indication of the aridity that is settling in the study area.

III.2.5.6-Bagnols and Gaussen ombrothermic diagrams

Bagnouls and Gaussen, 1953 developed a climatic classification satisfying the needs of plant ecology. To do this, they imagined comparing rainfall curves (umbric curve) and temperatures (thermal curve).

From the graph, the xerothermic index (number of biologically dry days) is established, determining the period during which the umbric curve does not exceed the thermal curve (Fig.44).

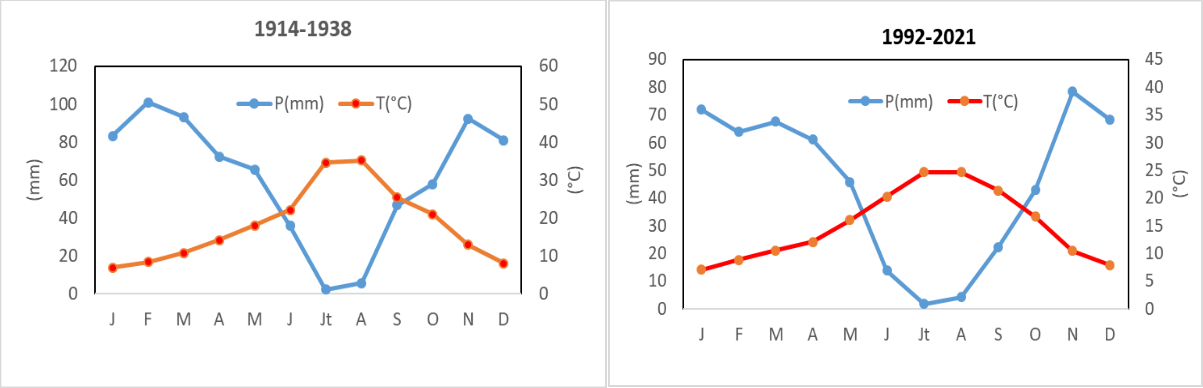


Figure44. Ombrothermic diagrams for the old and new period

The comparison of the two curves highlights an elongation of the summer dry season (June, July and August) which goes from three months during the old period to 6 months in the current period ((June, July, August, September and October).

III.2.7-Taylor rainfall climogram

This is a diagram of cartesian coordinates in which the average monthly rainfall is represented on the abscissa and the average monthly temperatures on the ordinate. The concordance or discordance between the two variables (P,T) makes it possible to define whether the area is favorable to the growth of a species or not. According to Taylor (1918):

- Months with temperatures above 20 fall under the "excess heat zone".
- Months with temperatures below 5°C characterize the "excess cold zone".

Likewise,

-months with average rainfall of less than 40 mm are in the “moisture shortage zone”
-months over 160mm are in the “excess humidity zone”.

The principle of the comfort zone can be summarized as follows:

“40mm < P < 160mm and 5ºC < T< 20ºC = “Comfort zone for the species”

From the figure 45, we find that the comfort zone of the cork oak (green color) is between the months of January, February, March, April, May, November and December where the monthly average rainfall exceeds 40mm and the monthly average temperatures is between 5 and 20°C. Indeed, the correlation coefficient between rainfall and temperature "r" is negative (r = -0.97 with R2 = 0.94), this means that each time we enter the wet season (autumn , winter and late spring) temperatures drop and water reserves increase and just otherwise. On the other hand, the months of June, July, August, September and October represent the months of water stress for the species.

III.2.6-Vegetation

The Hafir-Zarieffet forest massif is in the form of two contiguous cork oak forests with a total area of 4990 ha. In recent decades (1990-2020), the state of stand degradation has increased following several natural constraints (prolonged drought and dieback) and anthropozoic constraints (repeated fires and overgrazing). This forest massif presents itself in pure or mixed natural formations, composed of old high forests, distributed in a heterogeneous way (average to low density) (Domanial forest of Hafir). In the national forest of Zarieffet, the forest situation is worrying, composed mainly of high and low maquis interfered by bushy communities based on thorny calycotome and cistus (Dehane, 2012).

In Hafir, cork oak stands previously covered an area of around 3,500 ha (Boudy, 1955) to 4,000 ha (Thintoin, 1946; Sauvagnac, 1956). They are located in many cantons, 11 in number, the most important of which are Oued Tlet (414 ha), Tidjit (264 ha), the Hafir forest house (188 ha). Half of the stands (2,300 ha) are pure while the others are mixed with holm oak and zean oak. The forest also includes 24 cultivated enclaves totaling approximately 170 ha and 200 ha of unexploitable land (CFWT, 2004).

The Zarieffet forest initially covered a total area of about 990 ha, of which nearly half (453 ha) was occupied by the main species (holm oak and cork oak) and the rest by brushwood of secondary species (246 ha). ha) and voids (291 ha) (A.E.F.C.O., 1914). It comprises the following townships: Zarieffet (535 ha), Fernana (58 ha), Guendouza (63 ha), and Aïn Merdjen (306 ha) (C.F.W.T., 1996) (Fig. 46).

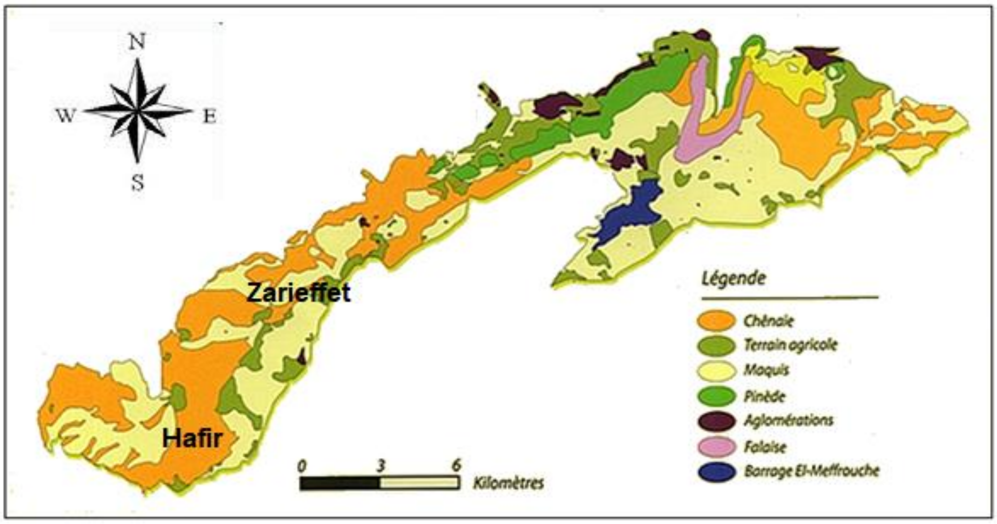


Figure 46. Distribution map of ecological and forest units (TNP, 2015)

Natural regeneration by seed is low to non-existent, particularly at Zarieffet, due to various factors (absence of acorns, drought, abundance of maquis, fire, etc.) (Dehane, 2012). Currently the forest is a clear matorral rich in thorny species and shrubs over 2 m high, covering between 25 and 50% of the ground. Since 2002, it has benefited from a vast rehabilitation program covering 500 ha (C.W.F.T., 2008).

In Hafir, aging prevents any operation of rehabilitation, with its subjects more than bicentenarians is clearly in decline. This state of degradation linked to harsh climatic conditions aggravated by the physiological state of (old) stumps, lack of soil fertility, erosion, lack of regeneration, fires and human action.

Another important factor has intervened in the elimination of the cork oak from certain stations. The oak-zeen (*Q. Faginea ssp.Tlemcensis*) is in fact capable of dominating in humid places by forming a very dense coppice under high forest. But the behavior of this tree, which replaced the cork oak where it had disappeared, allowed the reconstitution of a forest cover which thus hindered the invasion of the maquis. On the other hand, in the dry sites, it is the holm oak (*Q.ilex*) which, because of its robustness and its plasticity, has invaded the old cork oak forests, especially after the fires (Bouhraoua, 2003; Letreuch Belarouci, 2010).

The undergrowth is very rich in plants, some of which are characteristic of high humidity and others of the presence of maquis, a symbol of degradation. The latter is often poorly developed but rarely absent. In stations degraded by fires, however, it is very abundant. Among the most frequent plants, let us mention: ivy (*Hedera helix* L.), honeysuckle (*Lonicera impaxa*), sarsaparilla (*Smilax aspera* L.), elm-leaved bramble (*Rubus ulmifolius* Schott.), daphne or wood laurel or garou (*Daphne gnidium* L.), strawberry tree (*Arbutus unedo* L.), holly (*Ruscus aculeatus* L.), tree heather (*Erica arborea* L.), rosemary (*Rosmarinus officinalis* L.) and bracken (*Pteridium aquilinum* L.).

In degraded, warmer areas, there are more secondary species such as kermes oak (*Quercus coccifera* L.) and oxycedar juniper (*Juniperus oxycedrus* L.), but also Cists (*Cistus ladaniferus*

L., C.*salviaefolius* L., *C.monspeliensis* L.), the diss (*Ampelodesmos mauritanicus*) and the doum (*Chamaerops humilis* L.). *Phillyrea angustifolia* L., *Calycotome intermedia* C.Presl, *Olea europea* L., *Cistus ladaniferus* L., *Cystisus triflorus* Lam, *Cistus salvifolius* L., *Lavandula stoechas* L. *and Asphodelus microcarpus* L.(PNT, 2015).

The complete floristic procession accompanying the cork oak at the level of the massif is recorded in the following table

Table 10. Inventory of the accompanying flora of the cork oak and recovery rate of species and strata

Strata	**Hafir-Zarieffet**						
Tree	5	4	3	3	4	3	2
Quercus suber	5	4	3	3	3	3	1
Quercus faginea	-	1	-	-	-	-	1
Pinus halepensis	-	-	-	2	-	-	-
Quercus rotundifolia	-	-	-	-	3	-	-
Shrubby	2	2	3	3	2	2	4
Quercus suber	2	2	2	2	1	2	3
Quercus faginea	-	-	1	-	-	-	1
Quercus rotundifolia	-	-	1	-	2	-	-
Pinus halepensis	-	-	-	1	-	-	-
Olea europaea oleaster	-	-	-	-	-	-	-
Juniperus oxycedrus	-	-	-	1	-	-	-
Fraxinus oxyphilla	-	-	-	-	1	-	-
Tall subshrub	2	2	3	3	1	2	4
Quercus suber	2	1	1	2	-	1	4
Quercus faginea	-	1	1	-	-	1	3
Quercus rotundifolia	1	1	1	-	1	1	1
Quercus coccifera	-	-	-	-	-	1	-
Genista tricuspidata	-	-	-	-	-	-	1
Calycotome spinosa	-	-	-	-	-	-	1
Asparagus acutifolius	-	-	-	-	-	-	1
Phillyrea angustifolia	-	-	1	1	1	1	-
Crataegus monogyna	-	-	-	-	-	1	-
Olea europaea oleaster	-	-	-	-	-	1	-
Rubus ulmifolius	-	-	-	-	-	1	-
Pistacia lentiscus	-	-	-	-	-	-	-
Juniperus oxycedrus	1	2	3	1	1	-	-
Arbutus unedo	1	1	-	1	-	-	-
Rosa carina	1	-	-	-	-	-	-
Pinus halepensis	-	-	-	1	-	-	-
Smilax aspera	-	1	-	-	-	-	1
Hedera helix	1	1	-	-	-	-	-
Lonicera implexa	-	1	-	-	-	-	1
Low subshrub	4	4	5	5	3	4	5
Quercus suber	3	+	+	1	-	-	1
Quercus faginea	-	-	1	-	-	1	2
Quercus rotundifolia	1	1	2	-	2	-	1
Quercus coccifera	1	3	2	1	1	1	1
Genista tricuspidata	-	-	-	-	-	1	2
Phillyrea angustifolia	-	1	2	+	+	2	1
Daphne gnidium	1	2	1	1	+	2	1
Cistus ladaniferus	-	-	3	1	-	3	2
Cistus monspeliensis	3	4	2	4	2	3	1
Cistus salvaiefolius	-	-	+	1	-	-	-
Calycotome spinosa	-	-	1	-	1	3	3
Ampelodesmos mauritanicus	1	4	4	2	2	4	4
Chamaerops humilis	+	-	1	1	1	3	2

Arbutus unedo	1	1	1	-	-	-	1
Rosa carina	-	-	-	-	-	-	1
Lonicera implaxa	-	-	-	-	1	1	1
Scilla maritima	-	1	-	2	2	4	2
Asparagus acutifolius	1	-	1	-	1	2	+
Crataegus monogyna	-	-	-	-	-	1	1
Lavandula stoechas	-	1	3	5	1	4	-
Rubus ulmifolius	1	-	-	-	-	2	-
Olea europaea	-	-	-	-	-	1	-
Ulex panliflorus	-	3	1	3	-	2	1
Juncus maritimus	-	1	-	-	-	1	-
Pistacia lentiscus	-	-	-	-	-	-	-
Juniperus oxycedrus	-	1	3	3	1	-	-
Erica arborea	1	1	4	1	-	-	-
Pinus halepensis	+	-	-	1	-	-	-
Halimium halimifolium	-	-	-	-	1	1	-
Crataegus oxyacantha	-	-	-	-	-	2	2
Asphodilus microcarpus	-	-	-	1	-	1	-
Cytisus triflorus	-	1	-	-	-	-	1
herbaceous	5	2	2	4	3	4	5

Source : Bouhraoua (2003)

III.2.7. Cork production

Since long ago, cork from the Hafir-Zarieffet forest massif has been considered the best non-timber product of Algeria and the Mediterranean (Lamey, 1893; Saccardy, 1937). It represents 2/5 of local production. According to Boudy (1955). Production reached 20,000 qs between 1939 and 1951 while male cork represented only 1/3 of the total (6,300 qs). Forestry services estimate current production at between 300 and 700 quintals/year (CFWT, 2023) (Fig.47).

Figure 47. The cork harvest in Hafir during the companion of the year 2019

In the cork oak forest of Hafir, merchant cork was lifted regularly, with an average yield of 792 qs/year, i.e. a total production of 11,880 qs in 15 harvests (1940-1956). The rest of the production was limited to flambé cork (248 qs harvested 5 times after the fires of 1940, 1941, 1943, 1952 and 1956). Scrap represented 4 to 35% of annual production depending on the campaign, totaling an average harvest of 207qs (Bouhraoua, 2003; Dehane, 2006).

After independence, cork mining work only resumed in 1970 (HafIr) and continued until 1996 (last mining), but at a very irregular pace corresponding to two major periods of 5 years : 1970-1974 and 1982-1986. Since then, production has slowed down for various reasons (climatic accidents, insect attack and others) until 1995 when harvests then resumed timidly and on very limited areas. The overall production of this period is around 13,000 qs, i.e. an average of 1,180 qs (Fig.48). During the year 2019, the cork oak forest provided 500 qs of reproduction cork (Chorana, 2021).

In the Zarieffet cork forest, between 1897 and 1996, a total volume of reproduction cork was extracted in the order of 28,300 qs (Dehane, 2006). The best productions are archived during the period of the second world war and the national liberation war: 1954 qs in 1948 and 993 qs in 1952. The rest of the production (2767 qs) is divided between male cork (2020 qs) , waste cork (747qs) and flamed cork (48qs)(Dehane, 2012).

After independence, lifting operations began regularly only from 1972 until 1984, i.e. a production of 1320 qs. It was from 1991 to 2007 that production took on a regular rhythm recording a total cork of the order of 10586 qs including 8026 qs of virgin cork (C.W.F.T., 2007). The fires that the forest experienced in 1996 and 2007 had a negative influence on the production of cork, which did not exceed 518 quintals (C.W.F.T., 2008))(Fig.49)..

III.2.8. Wildfires

A drought-generating climate and strong anthropization greatly affect the survival of cork oak stands and make them vulnerable to fires. Quezel and Barbero (1990) reveal that disturbances of anthropic origin are largely responsible for the current state of vegetation structures in the Maghreb.

In a purely ecological and forest framework, Barbero et al., 1990 estimate that the disturbances resulting from the xericity of the climate are numerous and correspond to increasingly severe levels ranging from matorralization to desertification and desertization passing through the steppization and therophytization. Schaffhauser (2009), emphasizes that repeated fires lead to open cork oak stands which promote the development of maquis, thus increasing the risk of future fires.

The history of fires in the Hafir-Zarieffet forest massif was always closely linked to the fervor of man for clearing land and revenge, the slump of colonization and popular uprisings.

The fire data collected from the forest services of the wilaya are illustrated in the form of a graph (Fig. 50).

According to Figure 50, the Zarieffet subgrade has up to 27 fire occurrences on the same site during the period 1882-2022, lasting 140 years, decimating a total of 3475 ha. The most frequently burned areas are always superimposed on the roadway. This observation argues the social type in the determinism of fires. This phenomenon is identified as one of the main causes of fires in the Mediterranean basin during the 20th century (Pausas, 1997; Moreira, 2001; Diaz-Delgado et al., 2004).

As shown in figure 50 , there are 7 main jumps of more than > 100 ha of burnt surfaces over the course of 133 years (1882-2015):

The cork forest of Hafir seems less affected than Zarieffet, despite the communal road n°52 which crosses it. From 1892 to 2015, the fire consumed a total area of about 2273.5 ha during 10 occurrences similar to 123 years of disturbance. Three jumps of more than 100 ha were identified over the 113-year period (1892-2005) (Fig. 51):

At Zarieffet, the average recurrence interval between the 7 jumps is estimated at 20.5 years (± 1) during the period from 1882 to 2015.

In Hafir, the average interval of recurrence between the 3 jumps is estimated at 56.5 years (±1) during the period 1892 - 2005. These intervals (20.5 and 56.5 years) fall within the norm for Mediterranean ecosystems (10 to 60 years) according to Thonicke et al., (2001).

These intervals (22 and 61 years) fall within the norm for Mediterranean ecosystems (10 to 60 years) according to Thonicke et al., (2001).

Schaffhauser (2009), establishes a critical threshold for subéraies (4 fires in 50 years), in the case of the Zarieffet forest, it is indeed 5 large fires in 49 years (1966 to 2015). In contrast, this threshold seems reduced to Hafir, it is 3 big fires in 41 years (from 1964 to 2005).

The same author argues that an average fire frequency (1 fire every 25 to 50 years) allows good resilience of the ecosystem, but at a low level of potential remaining at the breaking point. The stock of organic matter is limited to the top cm of the soil. With 2 fires every 50 years, the vegetation is often a high maquis dominated by tree heather.

All these observations remain a reality in the Hafir-Zarieffet forest massif. The cork oak of the massif is an emblematic species in western Algeria with a tourist attraction due to the landscape it provides, despite the fact that cork cultivation is in sharp decline due to fires. The preservation of this species and its habitat remains a matter of moral order, a commitment of peace of society towards this very expensive forest heritage.

Chapter IV

Spatial analysis of forest fire risk in the Hafir-Zarieffet forest massif

IV.1-Introduction

Fire is one of the most common disturbances that affected forest along the history and around the world (Abatzoglou et al., 2019; Bowman et al., 2017; Van Lierop et al., 2015). In the Mediterranean region fire is a common disturbance that played an important role in shaping the landscape and its functioning as most of the vegetation succession depends on it (Pausas, 2015).

Nevertheless over the past 30 years with the increased land abundance coupled with the warmer and drier conditions, fire regime shifted and number of large wildfires increased (>400 ha) (Ruffault et al., 2020) threatening people's lives, causing more damage and degrading the forest cover (Rego et al., 2021). Nowadays, is an expensive incident to control escaping the firefighters and governments resources. In addition the projection of the yearly average burnt area in the Mediterranean region is predicted to increase by approximately 150–220% by 2090 relative to 2000 (Khabarov et al., 2016).

Remote sensing and GIS has been widely used in forest fire research especially in forest fire risk assessment (Chuvieco & Congalton, 1989; Leblon et al., 2012; Szpakowski & Jensen, 2019).

Overall vegetation, topo-morphology and human infrastructure always accounted as the most influential factors with varying parameters that construct them according to data availability and complexity of the analysis (Chuvieco & Congalton, 1989; Dagorne et al., 1994; Fang et al., 2015). As a result various models were developed taking into consideration these factors eg: dong model (Dong et al., 2005) erten (Erten et al., 2004), chuvieco (Chuvieco & Congalton, 1989), RFF (Adab et al., 2013) and applied in many study areas in the Mediterranean and abroad.

In Algeria, many areas burned across the country in affecting many regions, leading to big losses in forest cover and often death cases were registered. As a consequence many fires risk assessment mapping researches took part in different regions of the country (Anteur et al., 2021; Belgherbi et al., 2018; Belhadj-Aissa, 2003).

Despite these extensive works, insufficient attention has been paid to vegetation as it is the central parameter in every model and often taking the highest weight (Benguerai et al., 2019; Bentekhici et al., 2020; Talbi et al., 2018). Its estimation was only by using NDVI as a proxy for vegetation density/presence omitting the vegetation types differences that is a fundamental part in their ignition and fire risk propagation (Dehane et al., 2015; Madrigal et al., 2011).

Whilst others used models developed based on a study done for vegetation combustibility based on vertical continuity and species studied elsewhere Rahmani & Benmassoud, 2020). Moreover, the validation using historical data seem to be absent in most of the works. In addition the weights of these factors as is always considered a challenge when adopting the model standard weights directly, some authors took local experts opinion into consideration in order to weight these factors by importance (AHP methodology) (Bentekhici et al., 2020).

Nevertheless, the revision of the final weights along with the contribution of the factors to the model output wasn't assessed to better reveal the reality of the study area and propose management strategies.

IV.2-Aim of the study

In light of this challenges mentioned above and the current alarming situation the objective of this study is to:

-Assess fire risk in the Hafir-Zarieffet cork oak forest using above mentioned factors, taking into consideration empirical studies on species flammability in the region, and using biomass as a proxy of fuel load, with the revision of the weights attributed to each factor and the determination of the most contributing factor to fire risk model .

- Validation of the above-mentioned model by the use of historical burned areas and ignitions to propose management actions.

IV.3-Materials and methods

IV.3.1-Study area

The study area is located in Hafir-Zarieffet cork oak forest massif in the southern part of Tlemcen mountains. The massif connects various villages to the state capital and its known by its tourist attractions (Lala Setti park nearby) which makes it a highly frequented site. In addition the massif contains dispersed pastureland and agriculture land which constitute 10% of the area. On the other hand urban facilities inside the forest are rare (1%) and they are mainly governmental agencies or attraction sites (Letreuch-Belarouci et al., 2009).

The forest resources are essentially represented by cork oak and other formations in the form of mixed stands (cork oak (Qs), holm oak (Qi), zeen oak, Aleppo pine (Ph), oxycedar juniper(Jo)…) (Fig.52).

IV.3.2-Data collection and analysis

According to various authors (Adab et al., 2013; Chuvieco & Congalton, 1989; Dagorne et al., 1994; Dong et al., 2005; Erten et al., 2004), the fire risk index is determined by the the conjunction of three principal factors and their spatial distribution : vegetation type with respect to its vulnerability to fire and quantity (Vegetation Index) , specific site characteristics (the topo morphology), the human related facilities and infrastructure (Human Index).

The model (Eq 1) (Erten et al., 2004) was adopted in this case as it was applied in similar Mediterranean woodlands in Algeria and elsewhere (Anteur et al., 2021; Bentekhici et al., 2020; Talbi et al., 2018) and showed promised results.

Where:

VI represent vegetation index, MI: the topo-morphologic index and HI: the human index.

However, for the ratings structure chosen for each factor, the classification took into consideration the study area extent and in some cases additional information was added in some parameters (vegetation index) using empirical data available from other studies done previously.

These factors englobe a set of parameters that influence forest fire risk of ignition and propagation, taking into account the data availability and its simplicity as it will be a product for local authorities. Each index is the product of multiple parameters (Eq 2).

Where:

VT: vegetation type; B: biomass; S: slope; A: aspect; E: elevation; Dr: Distance to roads; Ds: distance to settlements or built-up areas (urban); Da: distance to agriculture

The final risk map produced ranged from one to four risk classes. The results were subject to validation by previous incidents data and investigation of the most contributing factor to the risk and their effective weight.

IV.3.3-Vegetation index

In the scope of this work vegetation index was divided into 2 important parameters: species intrinsic ability to generate fire (flammability), and the biomass available for each species composition in the field.

A field survey was launched in order to collect biomass data, a total of 62 plots of 10m radius were analyzed on the field and measurement of height (H) and diameter at breast height (cm) were taken,then biomass (t/ha) was calculated using the allometric equations described by Calama et al.(2012), Drexhage & Colin (2001) and Ruiz-Peinado et al.(2011) for the species of interest.

Sentinel 2 image 2A 10m resolution raster were downloaded using google earth engine on the period that coincide with forest fires season and maximum vegetation activity (from June to October)(Galidaki et al., 2017). The raster image was then used for scaling the biomass data from plot to landscape level (Smith et al., 2004), a total of 13 composite indexes were tested and the one with the best fit was used.

The resulting map corresponds to biomass (t/ha) for each species composition, and ranked into 3 categories: low, medium high biomass table (Tab.11).

Using data from Dehane et al. (2017), a laboratory-scale flammability analysis was performed for cork oak accompnator species in the region with respect to the following characteristics (TTI: time to ignition, MLR:mass loss rate, HRR: heat release rate :PHRR: peak heat release rate, AEHC: average effective heat of combustion). As part of this this work, peak heat release rate(PHRR) was taken as a measure of the risk that species can generate in case of a fire , these species were ranked according to that following the extreme case scenario(Tab.11).

The final vegetation risk index is the sum of these 2 parameters ranked into 4 categories (Tab.12).

Table12. Rates and risk class assigned to vegetation index

Vegetation Index	Rating	Risk level
	1	Low
	2	Medium
	3	High
	4	Very high

IV.3.4-Topo-morphological index

Topography is an important physiographic factor, it predisposes the region to fire risk and contribute to its propagation. The most important factors to consider are: slope, altitude and aspect (Chuvieco & Congalton, 1989).

Elevation data was downloaded from Aster data at a resolution of 30m using google earth engine. Slope and aspect were generated as a byproduct. All layers were ranked according to table 13.

The final Topo-morphologic index is the conjunction of the 3 parameters ranked into 4 categories (Tab.14).

IV.3.5-Human index

Human factor is considered the main factor contributing to fire ignition (Meddour-Sahar & Bouisset, 2013), either as an act of negligence or pyromania. All vicinities to human activities are considered a major threat. For this analysis proximity to urban settlements, roads and agriculture were considered for assessment.

Urban data was extracted land use/landcover map from forest general directorate and verified using google earth, a buffer was made following the table 15 and rated by importance of risk.

Roads constitute an important factor for the nature of the landscape, its position (located between villages and connecting them to the state capital, to agriculture,) and vocation (touristic places nearby in the park). Roads were digitized to have a better depiction of the reality with google earth taking into consideration highways, primary and secondary roads. A buffer was made following table 14 and ranked accordingly into 4 classes. Agriculture was extracted by LULC/landcover and verified by google earth, then a buffer was made (Tab.15) and ranked.

The final human index factor is the result of the sum of these three parameters ranked into four categories of fire risk (Tab.16).

IV.3.6-Fire risk map

Fire risk index (FR) describe the high Fire risk probability associated when combining all mentioned indexes and unable to trace the causes and degree of the risk (highly flammable vegetation, high slope, proximity to a road, etc.). The fire risk calculation was carried out with the “map calculator” function of the analyst spatial extension. This involves applying the formulas (eq 1 and 2) of the model and the weights associated for each parameter/index. The latter was ranked following table 17.

IV.3.7-Sensitivity analysis

Despite the fact that parametric models are widely used in risk modeling and analysis ,the high uncertainty remains an issue when it's about weights assigned to each parameter/indicator and its influence (contribution) to the final index (Napolitano & Fabbri, 1996; Pourkhosravani et al., 2021; Saidi et al., 2021). As the former is often assigned either by experts opinion (eg: AHP) or by the author opinion based on empirical studies done elsewhere and the latter in some cases can take into consideration many parameters that proved to influence the final risk index but not necessarily in the study area.

Sensitivity analysis is considered an important step for the model assessment and its widely used between authors in different fields (Barber et al., 1993; Pourkhosravani et al., 2021; Saidi et al., 2021). The input parameters of the model are changed and the system response to these changes is evaluated. As a result, the sensitivity of each parameter is determined.

Using the spatial analysis function of GIS platform, vegetation index, topo-morphology and human index are assigned to each point of fire detected in the period from 2000 to 2022. This allowed us to perform this analysis and evaluate the effectiveness of each of the indices and the weights assigned using: the one map removal analysis and single indicator sensitivity analysis.

IV.3.7.1-One map removal analysis

The map removal sensitivity analysis describes the sensitivity of the vulnerability index when removing one or more indicators from the model (Lodwick et al., 1990). It is calculated by the following equation (Eq. 3):

where:

Sa: sensitivity analysis: the unperturbed risk index (risk index without removing any indicator).

R': the perturbed risk index (risk index after removing one or more indicators);
N and n are the numbers of data layers used to calculate R and R', respectively.

IV.3.7.2-Single indicator sensitivity analysis

It aims to compare between real weight and "theoretical" or standard weight (Napolitano & Fabbri, 1996) (Eq. 4):

where

W: "effective" weight of each indicator; Pr and Pw are the rating value and weight for each indicator respectively, and R is the overall risk index.

IV.3.10-Validation

In order to see the importance and reliability of the model's results, the final fire risk model was inspected in its efficiently to explain two important fire risk:

-Impact of the fire by overlap of historical areas burned with the fire risk classes. This can shed the light in the areas to prioritize infrastructure and personal in the fire season.

-Sources of ignition risk: by overlapping parameters that composed human index with historical fire ignition points. This gives more insights about where human causes more ignitions to prioritize any management action to reduce it.

The identification of these areas is a valuable aid to managers and decision-makers in order to specify the appropriate sites for the positioning of fire observers and to install the necessary monitoring elements. Fire burned area database 2000-2023 generated using BA tool (Roteta et al., 2021) on GEE (google earth engine). The tool uses a stratified random sampling of burned and unburned areas polygons defined by the user then a random forest classifier is launched over a large Sentinel or Landsat temporal series.

The algorithm ends keeping Patches of pixels with a burn probability higher than 50% using a 4-node connection (the only group of pixels that share an edge), as long as they contain at least one seed pixel inside (pixels with higher probability than the average of the mean RF probabilities obtained for the training polygons). The algorithm was tested in two areas with commission and omission error below 12%. A total of 16 fire perimeters were found and fire perimeters with less than 20 ha were considered agricultural fires and were put off the database. Finally, an intersection between area burned and fire risk map classes was done. For the assessment of which human index parameter contribute the most to ignition risk in order to do so, an intersection was made between the wildfires distributions and coordinates are obtained from FIRMS MODIS Fire and VIIRS/Hotspot, NASA (https://firms.modaps.eosdis.nasa.gov/) and each parameter in human index (agricultural, urban, roads) separately.

Fire perimeters with less than 20 ha were considered agricultural fires and were put off the database. Finally, an intersection between area burned and fire risk map classes was done. For the assessment of which human index parameter contribute the most to ignition risk an intersection was made between the wildfires distributions and coordinates are obtained from FIRMS MODIS Fire and VIIRS/Hotspot, NASA (https://firms.modaps.eosdis.nasa.gov/) and each parameter in human index (agricultural, urban, roads) separately.

IV. 4-Results

IV.4.1-Vegetation index

The Biomass map shows that the landscape is mainly dominated by the medium risk class (48%), low (27%) and high (25%) shows near equal proportions (Fig.53).

The vegetation type map indicates that the majority of the areas displays a low and very low fire risk (78%). These classes are mostly condensed as one single patch. Medium class occupies 8%, high and very high risk represent 9% and 5 % of the area respectively (Fig. 54)

The vegetation index shows that the middle class was the most dominant in the landscape (60% of the surface area), followed by high and very high risks, where they occupied 7 and 28% of the study area respectively. Finally, the low-risk class presented 4% (Fig. 55)

IV.4.2-Topo-morphology index

Topo-morphology index represents all terrain factors influencing fire behavior. The slope map produced reveals that the low and very low classes represent a minor proportion of the study area (4% and 11% respectively). On the other hand, medium class dominated the landscape (around 50%). High and very high classes occupied 22% and 14% respectively (Fig. 56).

The aspect map of the study area reveals high and very high classes represented 26% and 37% respectively. Medium and low classes occupied 13% and 24% (Fig. 57).

With respect to elevation very high-risk class dominated the landscape (60 %) followed by high (14%). Medium (11%), low (9%,) and very low risk class (6%) (Fig. 58).

The resulting Topo-morphology index map demonstrates that high risk class dominates the landscape (60%) followed by very high (24%). Medium risk class represented (14%). low and very low classes represented roughly 1% (Fig. 59).

IV 4.3-Human index

Regarding distance to roads, almost 40% of the study area represents a high to very high risk, the medium risk occupies 16%, the low risk represents 44% (Fig.60).

For agriculture as a whole, most of the area presents low to very low risk (19% and 39% respectively), while the middle class characterizes 21% of the total area. High and very high risks form 5% and 16% respectively (Fig.61).

With regard to distance to urban (built-up) areas nearly 88% of the landscape represented very low risk, low risk represented 7%, medium and high risk presented roughly 1% while very high risk covered 4% (Fig.62).

The human index map shows that the majority of the area is split between two: medium and low risk (43% and 37% respectively), followed by high and very high risk (19% and 1% respectively) (Fig.63).

IV 4.4-Fire risk map

The combination of forest fire hazard mapping model parameters and the application of Eq. (1) resulted in the final risk mapping. The calculation was done using the Raster Calculation function in GIS software then reclassified into four risk classes: low, medium, high and very high (Tab.16).

As shown in the figure 64, the average fire risk dominates most of the study area (60%). In contrast, the high and very high-risk classes hold 21% and 31% respectively. The low fire risk class represented only 6%.

IV 4.5-Sensitivity analysis

Sensitivity analysis of one map removal (layer removal) shows that the human index has the greater variability with an average rate of variation of 8.93 followed by Topo-morphology and vegetation are subsequently ranked with close average evolution values (4.99 and 5.11 respectively) (Tab.18).

The effective weight of the parameters constructing the fire risk model results shows that topo-morphology ranked first with an average effective weight of 42%, followed by 33.3 % and 20% (Tab.19).

IV 4.6-Validation

A total of 16 fire perimeters were found in the period from 2000-2023(Fig.65). Medium risk explained the majority of the burned areas (61%). 4% for were on the low category, high and very high zones explained 23% and 12% respectively of the area burned (Fig.66)

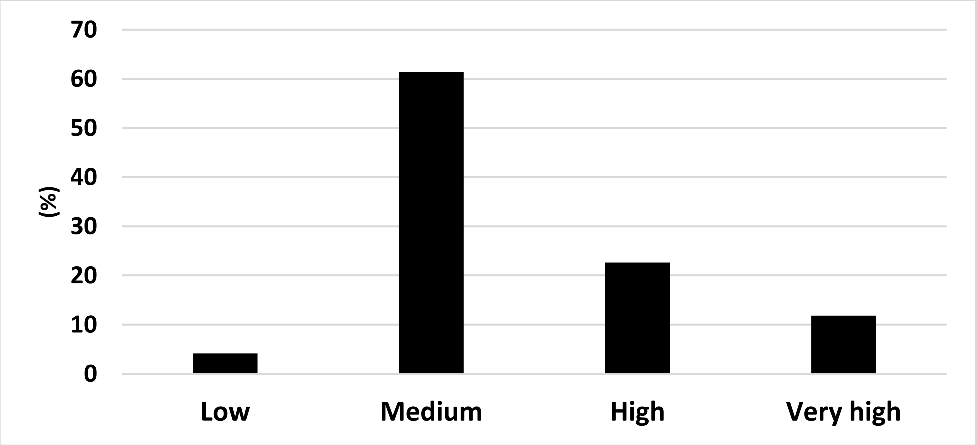


Figure 66. Burned areas (%) per fire risk class

IV 4.7- Ignition probability analysis

The inspection of human index risk was done with overlapping the ignition points generated with each parameter component separately.

For road network, 26% of the ignition points were present in the very high-risk class, 16 % at high risk, 21% at medium,13% at low and 23% at very low risk. Whether for agricultural areas the percentages were 16%, 4%, 18%, 30%, 32% for very high, high, medium, low and very low risk classes respectively. For the same respective classes urban areas had 0%, 1%, 9%, 11%,79% (Fig.67).

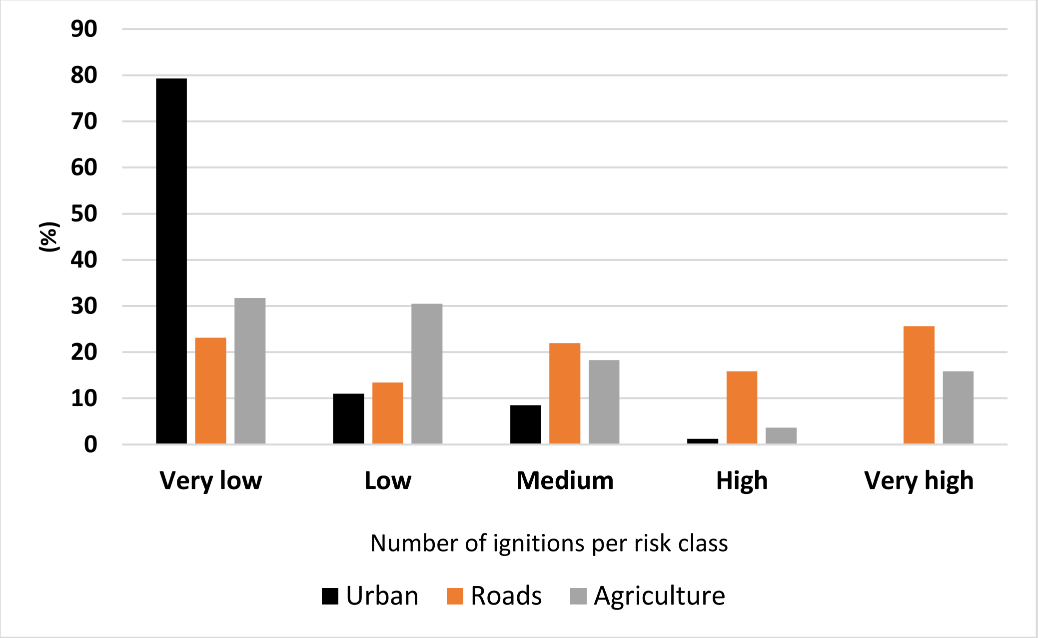


Figure 67. Ignitions (%) per risk class for urban, roads and agriculture parameters

IV.5- Discussion

IV.5.1-Vegetation index

Vegetation plays a critical role in determining the risk and behavior of forest fires. Biomass constitute the organic material that fuel the fire, the more the biomass the more the fuel load available for fire, thus the higher the fire risk, however not all biomass burns equally. The type, composition can influence spread, and intensity of fire. Intrinsically each species burns differently and have different properties with regards to fire (Dehane et al., 2015; Fares et al., 2017; Madrigal et al., 2011).

The resulting biomass map shows that the risk classes varied spatially across the study area, but mostly medium and low classes were present in mixed oaks stand, whether for high biomass it was mainly present in cork oak pure stand and its association with coniferous species (Aleppo pine, oxycedar juniper). These areas contains more dense trees/ha than the mixed oaks stands as mostly the former is formed by an open sparse woodland (Appiagyei et al., 2023). It worth noting that oak stands tends to have a higher biomass when considering understory shrubs , especially for unmanaged areas that has experienced recurrent fires ,but to the limit of the study understory shrubs weren't considered and only overstory trees were taken into account (Acácio et al., 2009; Bugalho et al., 2011).

The vegetation type map showed that low and very low risk dominates the area. These risk classes are mainly present in the mixed oaks stand. The risk rise gradually when coniferous stands are present where medium class were present where cork oak and oxycedar juniper are present, additionally the association of cork oak-Aleppo pine shows the highest risk class. Juniperus and Aleppo pine companion species are considered highly flammable in the Mediterranean region (Dimitrakopoulos et al., 2013). On the other hand, pure cork oak stand shows a high risk, despite being resistant and inflammable, their understory shrubs are more prone to wildfire risk (*Cistus* spp, *Arbutus unedo*, etc) (Della Rocca et al., 2015). The association of understory shrubs can get the flames to reach the leaves making them ignite and start crown fires even though their leaves contains no volatile organic compounds (Madrigal et al., 2011).

The vegetation index is a product of the biomass and vegetation type indexes. It allows the identification and classification of the population by major categories of combustibility and flammability of the plant species encountered in the study area as well as by their potential fuel load. The majority of the high risk was present in stands of cork oak mixed with conifer species (juniper, pine), while the very high risk was present only in pure cork oak mixed with Aleppo pine. Moreover, the middle class was the most dominant in the landscape (60% of the surface area). This class dominated the part where mixed oaks were. Finally, the low-risk class coincide with agriculture and pastureland.

IV.5.2-Topo-morphology index

Topo-morphology index represents all terrain factors influencing fire behavior. The slope map showed that low and very low risk areas represented a minor proportion of the study area but their spatial disaggregated and dispersed on the study area with regions of high and very high risk on the vicinity. These areas represent a low threat and can be advantageous in case of fire suppression and containment at early stages (Della Rocca et al., 2015). Nearly half of the study area is at a medium risk (almost 50%). The high and very high classes occupy 37%. The slope is the topographic factor with the greatest influence on the speed of fire propagation (Scott & Burgan, 2005). Fire moves faster uphill. In fact, for every 10-degree increase in the slope, a fire will lead in a two time increase in fire spread (Scott & Burgan, 2005; Wagner, 1988). In addition it influence the flame inclination contributing to pre-heating the vegetation and allowing It to ignite more quickly (Wagner, 1988).

The aspect map of the study area reveals that most of the surface are south faced, representing 26% and 37% for south-east and south-west respectively. These categories pose a high and very high risk. Whilst medium risk surface (northwest) represented 13% of the area. The lowest threat of all classes (northeast) represented 24% of the area studied. Southern and eastern slopes receive more direct sunlight, drying soil and vegetation more than northern or western slopes. Fuels on northern and western slopes are typically drier and less dense. In contrast, southern slopes have higher fuel temperatures and flammability, posing a greater risk of fire (Campbell, 1995). In addition, it constitutes a clear factor that act like acceleration in the fire front and poses difficulties to have solutions in terms of effective control.

Greater elevations are correlated with higher availability of fresh air and increased chances of rainfall, which in turn leads to a reduced risk of fire. Fire risk tends to be less severe at higher altitudes(Wildland Fire Behavior, 2022). More than 70% of the landscape relies between high and very high-risk classes which in fact shows that the landscape has more chances to have more drought and dry air circulation. Low and very low risk classes represented roughly 15%.

IV.5.3-Human index

Fire outbreaks recorded in the region are mainly the consequence of an act of negligence or pyromania (Meddour-Sahar & Bouisset, 2013). This human factor can increase the potential for ignition (in the event of waste deposits in forest dump sites, forest camping sites, roads, cigarette throwing), and facilitate the rapid spread of fires (in the case of agriculture and pastures), by burning crop residues or sparks from machines.

Almost, 40% of the study area represents a high to very high risk while low and very low risk accounted for the other 40% of the area. The former appears to be more condensed where cork oak and coniferous species mix. In general, the area is very rich in road network, with a high traffic especially in the summer season as it connects several villages nearby with each other.

On the contrary, for agriculture, low to very low risk accounted for 58%. It should be noted that agriculture is dispersed in the study area and constitutes the most common interface with the proximity of the forest. Built-up areas presented no real threat, 96% of the area defined low to very low risk and did not constitute a common interface with forests

The human index is retained as one of the risk assessments factors. It is linked to human presence and activity (anthropogenic factors).

The majority of the area is represented by the medium class (43%), followed by low risks (37%), high and very high-risk classes represent only 20%. This demonstrates that there is a good chance of a fire appearing and igniting, since the index shows a strong spread of these two classes (medium and high) in the landscape.

IV.5.4-Fire risk map

The combination of forest fire hazard mapping model parameters and the application of Eq. (1) resulted in the final risk mapping.

The average fire risk class dominated most of the study area (60%). This class is concentrated in the area where mixed oak forest is with relatively tough terrain. In contrast, the high and very high-risk classes hold 21% and 31% respectively. These two classes were close and intertwined, additionally they were mostly concentrated where pure cork oak and mixed oak, coniferous species are with a high road network and rough topo-morphology. The low fire risk class represented only 6%, spatially it was located where agriculture and pastureland were present.

IV.5.5-Sensitivity analysis

Sensitivity analysis of one map removal (layer removal) shows the sensitivity of the fire risk index to each constituent component (Tab.18). The results highlight that the most important parameter that explains the greatest variability in the final fire risk index is the human index, which presents the greatest variability, although it had the least theoretical weight in model (3). Topo-morphology and vegetation are subsequently ranked with close average values of 4.99 and 5.11 respectively. Despite the fact that these two parameters had the highest theoretical weights, particularly for the vegetation index (7 and 5 respectively). They are placed in the following ranks after the human index. This is probably due to the high variability of the human index present in the study area, in particular the distance to roads.

The “effective” weight is a function of the other three parameters as well as the weight assigned to it by the fire risk model. The “effective” weights of the fire risk parameters showed some deviations from the “theoretical” weight. According to the results of table 19, surprisingly the parameter topo-morphology was the most effective parameter in fire risk assessment with an average effective weight of 42% exceeding the theoretical weight 33%. Vegetation and human index parameters scored last with a lower effective weight than the theoretical one (40% against 46%, and 18% against 20% for the theoretical and effective weight respectively for both layers).

Comparing the “theoretical” weights to the “effective”, topo-morphology showed the highest deviation. The terrain roughness showed to be with a great influence on the fire index model.

IV.5.6-Validation

Over the last 23 years the superposition of burned area perimeters over the fire risk index shows that mainly more fires are present in the area where pure cork oak stand and cork oak with prickly juniper are present. However, two main outbreaks in the area where mixed oak species led to the highest burned area registered.

Medium risk explained the majority of the burned areas, this area coincide with *Quercus* mixed species area. Even though *Quercus* mixed species area known by low flammability (Dehane et al., 2017). It should be noted that two unusual fires were classified as a criminal took over this area. Fire surpassed the suppression and containment efforts due to the difficult topo morphology present this area. The installation of fire breaks and vigilance towers for early detection, would help prevent such scenarios from happening again.

On the contrary, high and very high zones were subject to repetitive fires and explained near the third of the area burned. These two classes are located in areas with pure cork oak stand and where it’s mixed with Juniperus and Aleppo pine. Both companion species are considered highly flammable in the Mediterranean region and their risk accentuate as weather conditions gets drier (Madrigal et al., 2011). Low risk area represented roughly 4% of the area burned.

Juniperus oxycedrus has a high volatile organic compounds accumulation (Dimitrakopoulos et al., 2013). On the other hand, *Pinus halepensis* stores a high amount of terpene oil and resine which makes it extremely flammable (Dehane et al., 2017).

Additionally, pure cork oak forest has mostly high flammable shrub species (*Cistus* spp, *Arbutus unedo*, etc) (Della Rocca et al., 2015). This promotes the spread of fires and consequently the appearance of crown fires as the fire takes over the leaves. cork oak leaves are known with their high surface area to volume ratio but they contain no volatile organic compounds (Madrigal et al., 2011). However, areas with pure cork oak and mixed with prickly juniper show to be the most affected. This is mainly due to the high human risk present, possibly the rich road network of this area, including the national road 22 that connects two wilayas (South of Sidi Belabbes and Tlemcen), and also near the municipality of Mansourah.

IV.5.7-Ignition probability analysis

Most of the ignition's sources started in the vicinity of roads. In a cumulative manner, 26% of the ignition points were present at 50m range, 42% at 100 m range, and almost 63% at 200 m range. These ranges represent very high, high and medium risk respectively. On the other hand, 37% of the ignitions started far from 200 meters roadsides. This can be mainly due to the high traffic and the position of this forest (between several villages and connecting them to state and recreational areas).

Shrub clearing of 25m between roadsides can reduce the risk of ignition by 26% and alternatively by 63%, if applied on a lateral range of 50m each side. Nevertheless, this action may sometimes not be feasible, due to the difficult terrain conditions (high slopes), and also the long road network present in the forest. Further analysis of traffic hotspots should be carried out to prioritize roads with a higher probability of flame ignition risk and high traffic.

Regarding agricultural areas the highest ignition threat was found between 100 and 200 m range, and accounted for 19% of ignitions. Areas between 50 and 100m range held 4% of the ignition risk. In fact, 16% of the risk was localized for areas of less than 50 m. Moreover, areas more than 300m away constitute nearly 60% of the risk of ignition (Low and very low risk had 31% and 30% respectively).

This shows that the risk of a fire breaking out in agricultural areas or spreading from agricultural areas to forest areas is low, but still possible. Fire is commonly used in agricultural areas, to clear vegetation and enrich the soil for the next crop. It can be responsible for a major fire outbreak because farmers are unable to control it when it is ignited despite the low height of the flames, it has a high spread rate.

In more practical manners a possible clearing near agricultural/forest interface of a 50m range radius can reduce the ignition risk by 16% whilst clearing a 100m reduce that risk by 20% especially in summer where the fuel is dry in the forest.

Built-up areas (urban) pose nearly no ignition threat nearly 90% of the ignitions were more than 500m far.

IV.6-Conclusion

As fire is becoming the most important disturbing threat in the Mediterranean region, mapping areas with high fire risk and how it can behave in the landscape is a must for planification and management in order to avoid its catastrophic incidents.

In the present study, Hafir-Zarieffet cork oak forest was subject of fire risk assessment using remote sensing and GIS. For this purpose parameters are integrated in GIS environment and some indexes judged important in fire risk assessment are generated according to literature namely vegetation (flammability by species type, biomass), topo morphology (slope, aspect, elevation), and human indexes (distance to: roads, agriculture and built-up areas).

The resulting models shows that areas cork oak and mixed cork oak coniferous stands present high and high risk. On the other hand, mixed oaks present medium risk. The single parameter removal analysis identifies the human index as the most contributing factor to the final risk model.

Single indicator sensitivity analysis shows that theoretical weight attribution overweight vegetation index and underweight the topo-morphology index. Superimposing historical burned areas on the fire risk model show that nearly two-third of burned areas relies in medium risk. These areas are characterized by mixed oaks with rough topo-morphology and low flammable species.

This area was identified by less fire occurrence and but more area burned, secondly high and very high risk of the burned area presented almost one third and were located specifically in pure cork oak and mixed coniferous (oxycedar juniper and Aleppo pine) and cork oak stands where fires were more recurrent.

These areas hold the highest risks in all indices (highly flammable vegetation, high biomass load, rich road network and uneven morphology. Low risk represented less than 5% of burned areas. With regard to ignitions roads appeared to be the highest ignition source and posing the biggest threat due to its high variability in the study area followed by agriculture. Paradoxically, urban areas pose virtually no threat.

The study suggests that installing vigilance towers in mixed stands and would save these areas with medium % from big fires propagation and help in early detection and suppression. Fuel breaks may also be effective in that manner, also they can provide an opportunity for fire suppression as it lowers fireline intensity (Salis et al., 2016).

Clearing around roads for 25m sideways may reduce 26% of ignitions and 63% if applied for 50m range sideways. However, reducing ignitions doesn’t imply reducing burned areas as one ignition outbreak is sufficient to start a fire.

It should be highlighted that this work took into consideration only trees as dominated species in the biomass calculation and didn’t involve lower understory strata, the lower understory strata is very important and can vary in the landscape according to multiple natural and anthropogenic factors (recurrence of fires, grazing, favorable conditions) thus affecting biomass and eventually fuel load. In such landscape the recurrence of fires is the most influencing factor so in areas with pure cork oak and mixed coniferous cork oak stand may account for high and medium biomass respectively, where mixed oaks come last. Further works should include understory strata level.

The application of different fuel treatment strategies (eg: clearing) requires more understanding of fire and its behavior in the landscape for better resources management. Where and for how much to clear is of a high importance. Further works should focus on finding effective fuel treatment that comply with the study area vocation and resources in order to reduce its exposure to fires.

Chapter V

Study of cork carbonization mechanisms in the laboratory

V.1-Introduction

Among the valuable and endemic Mediterranean forest species, *Quercus suber* appears to be the best adapted to the recurrent phenomenon of forest fires. In certain cases it provides rapid regeneration when other species that compete with it easily collapse in the flames of fires (Elena Rossello, 2004).

It is the bark of the cork oak which is responsible for this remarkable resistance to fire, with a thickness of the cork which can reach 30cm in the life of the tree, constitutes in itself a natural product with excellent insulation properties (Natividade, 1956). Moreover, Jackson et al. (1999) and Brando et al. (2012) see in this property a clear mechanism to protect the cambium and vascular tissues of the tree against the thermal heat emitted by fires.

Bernal Chacón and Cardillo Amo (2005) agree with the same idea, against a low and medium intensity fire, the protective power of cork is proportional to its thickness, a cork caliber > 20 mm implies a survival of 80% trees. On the other hand, the subjects, more or less recently stripped or debarked, will die immediately (Santiago Beltrán, 2004).

The flammability of forest fuel can be defined as the spontaneity with which the material can catch fire, both spontaneously and when exposed to certain conditions (Zhan et al., 2011). To simulate field conditions, several standardized tests and experimental protocols were undertaken in the laboratory to characterize the flammability and describe the thermal conductivity of the bark of different of forest species. In this context, we cite the work of Pinard and Huffman (1997) on the insulating capacity of the bark of different species at different temperatures; the small laboratory tests by Bauer et al. (2010) and Odhiambo et al. (2014) by determining the temperature distribution along the trunk. Other studies have assessed the flammability of forest fuels (Madrigal et al., 2009), or the relationship between flammability and chances of survival after a forest fire (Frejaville et al., 2013; Catry et al. , 2012; Pausas and Moreira, 2012).

In general, the first studies on the flammability and combustion of forest fuels in the laboratory were carried out with different techniques tested mainly on construction materials (TGA, DTA, DSC). The recent use of epiradiator (EPI) and mass loss calorimeter (MLC) techniques have made it possible to closely monitor the combustion parameters of forest species and to quantify them according to variations in temperatures automatically regulated by the operator and instrument. This has had a significant scientific impact on the classification of species according to their sensitivity to thermal heat (Vallete, 1990; Dimitrakopoulos, 2001; Babrauskas, 2003, Madrigal et al. 2009, 2013).

Indeed, these instruments have contributed in a simplified way to explaining the flammability process initiated by Anderson (1970): ignitability or the ease of producing the ignition of flame; the durability or ability of a material to maintain combustion and produce energy; combustibility or the rapidity with which combustion occurs; and consumability or the proportion of biomass consumed during combustion.

V.2- Aim of the study

The main objective of this chapter is to assert that the flammability of cork is indeed a carbonization of its internal structure. We based ourselves on unexploited cork oak bark (virgin cork) and exploited cork oak (reproduction cork) from a region in northwest Algeria, well known for the recurrence of fires

It was a question of: knowing the difference between the combustion of the corkback (woody tissue) and the cork (non-liginified corky tissue)) under the conditions tested in the laboratory; to conceive the role of the corkback by its thickness in the transfer of thermal heat towards the layers of cork; to link the external variables of fire outbreak (temperature and exposure to heat) to flammability parameters; to detect the resistance of cork to fire in relation to its physical structure and its chemical composition; and finally to know the lethal limits of heat likely to alter the corky tissue.

V.3-Materials and methods

V.3.1- Study site and samples

The cork samples used in the study were taken from the Zarieffet-Hafir forest on the basis of extensive field surveys. To ensure a certain normalcy in the sampling, the exploited and unexploited trees were hierarchised according to the three levels of the terrain: ridge, slope and lowland. In each level, a zig zag itinary was undertaken to locate the sample trees. The length of the itinary depended on the density of the trees on the relive encountered. In front of the first tree chosen at random and the exhibition offered, a square of cork measuring 20x20cm2 is carefully extracted from the trunk at a height of 1.30 without hurting the mother of the cork.. Each sample is labelled according to its topographical position and operating condition (stripping or unstripping). According to the flammability testing laboratory, the number of samples was limited beforehand, due to the volatile odors exhaled causing severe migraines to the operators. In total, we collected 10 samples per topography level, 30 samples of virgin cork and 30 samples of reproduction (Fig.68).

Figure 68. The square of cork extracted from the sample tree

V.3.2- Devices and protocols

To study the carbonization of cork in the laboratory, we used a system with vertical configuration EPI (Epiradiator) (Fig.69).

The epiradiator remains a benchmark instrument for studying flammability in the laboratory. It consists of an electrical resistance embedded in an opaque silica disk 100 mm in diameter. The device is completed with a silica handle welded to the case to protect the power cable. The heating disc emits a fast constant heat flux of 500W set by a radiometer (Control console with color touch screen display and calibration radiometer) and constantly measured and monitored at fixed point using a K-type temperature probe connected to a digital thermometer. The radiation develops vertically from the bottom up.

The epiradiator is mounted on a universal support fixed by means of pliers so that it forms a horizontal plane with the sample holder, according to the method applied by Dehane et al., (2015). The latter is fixed on a metal frame and placed 25 mm from the heating disc during the test. A sparkle genrator a few centimeters above the sample holder makes it possible to check the ignition. to measure the various flammability parameters. Graduate rule, calibrated to the sample holder level, is vertically maintained beyond the apparatus in order to measure the maximum flame height.

V.3.3-Adaptation of the device to cork

The cork bark is a very heterogeneous material where two layers, one woody and the other non-timber, are mixed together, the corkback and suber. In cork grove, these two tissues effectively cover the tree against fire from the base to the top.

The simulation of such a pattern according to the conditions of the experiment requires the use of homogeneous specimens in shape and size adapted to the porous sample holder of the epiradiator (Madrigal, 2009; Dehane et al.,2015). Each 20x20cm^2 sample was divided into four equal 10x10cm^2 pieces and cut using a jigsaw (to adapt the dimensions to bench-scale devices) (Fig.70).

Before the calas are inserted into the porous sample holder, 1cm of thickness is subtracted from the four sides of each sample (), then preserved for further testing.

A total of 120 virgin cork sample and 120 second cork sample were collected for flammability testing. Flammability tests were conducted in september, with each sample tested four times, once per replicate.

Before the start of the tests, the 120 test samples were subjected to thickness measurements of the corlback and cork using a digital caliper. A morphometric classification of the corkback has been established according to the thickness of the virgin or reproductive cork (Tab.20).

Table 20. Distribution of corkback classes according to cork thickness and flammability parameters

Samples were stabilized at room temperature (20°C) till constant weight. The mean moisture content of the sample was 5.1%, the maximum was 6.5% and the minimum was 4.5%. These values are very close to forest moisture. The samples have not been treated to preserve the natural characteristics of the cork.

The EPI, was calibrate in order to generate different heat fluxes values (HF, kW m^{-2}). As an indication heat power of 400 W wield à heat flux of 25 kWm^{-2} corresponding to air temperatures

of 225°C.These temperatures are within the range of températures defined low to medium fire intensity.

Several flammability variables were measured by the device. Time variables were measured using a stopwatch. As defined by Anderson (1970) and Dehane et al.,(2015):

According to Kauf et al. (2014) and Moro (2004), IF and IT is a measure of the ignitability of flammability. The structure of forest fuel resists ignition when exposed to heat (IF) by triggering a heat ignition (TI). FH and MT are indicators of combustibility. According to its anatomical satructure, its organic or chemical component, the fuel burns by emitting an intense light (FH) by releasing a strong heat (MT). In this stud, FD and FET represent the durability of the inflammation of the cork bark. This is the extent to which a fire will continue to burn (FD) with or without the heat source until the flame is extinguished (FET). Finally, consomability (RMF) is only the cumulation of antecedent parameters by the proportion of mass remaining at the end of the test.

V.3.4-Chemical analysis of cork

For chemical analysis purposes, the 1 cm of each labelled sample classified by cork type was ground. The dead phloem and the rest of the phélloderme were removed from the cork before the grate to avoid contamination. A fraction of 40 to 60 cells was used for the analysis. Summative chemical analyses included the determination of extractives, suberin, lignin, cellulose and hemicellulose. The extraction method is based on a well-defined conventional approach in the literature (Pereira, 1988 and 2007; Conde et al., 1998; Sen et al., 2010, Dehane et al., 2014 ; Pereira, 2015).

Extractives were determined by successive Soxhlet extractions with dichloromethane (6h), ethanol (8h) and hot water (20h). After each extraction step the solution has been evaporated and the solid residue was weighed with an analytical balance.

Suberin content was determined in extractive-free material by use of methanolysis for depolymerisation. A 1.5 g of extractive-free material was refluxed with 100 ml of a 3% methanolic solution of $NaOCH_3$ in CH_3OH during 3 h. The sample was filtrated and washed with methanol. The filtrate and the residue were refluxed with 100 ml CH3OH for 15 min and filtrated again. The combined filtrates were acidified to pH 6 with 2M H2SO4 and evaporated to dryness. The residues were suspended in 50 ml water and the alcoholysis products recovered with dichloromethane in three successive extractions, each with 50 ml dichloromethane. The combined extracts were dried over anhydrous sodium sulphate (Na2SO4), and the solvent was evaporated to dryness. Suberin extracts were quantified gravimetrically, and results were expressed in percent of cork dry weight.

The lignin, contents were determined on the extracted and desuberinised materials. Sulphuric acid (72%, 3.0 ml) was added to 0.35g of extracted and desuberinised sample and the mixture was placed in a water bath at 30°C for 1 h after which the sample was diluted to a concentration of 3% H2SO4 and hydrolysed for 1 h at 120°C.The residue was washed with hot water dried, and weighed as lignin.

The cellulose content in cork has been estimated at approximately 10% of the mass of structural components and the hemicelluloses content has been estimated at about 12% (Pereira 1988). The ratio of cellulose-to-hemicelluloses in cork, about 1:1.2, is very different from the 1:0.4 ratio in wood, stressing the much less important role of cellulose in cork.

V.3.5-Thermochemical degradation of cork

. The instrument is controlled by a weighing module (a microbalance), a thermocouple to measure the temperature and a computer to control and record the data.

The determination of the chemical composition (extractives, lignin, suberine, cellulose et hemicellulose) of the twice cork and of the treated samples followed methods previously described (Pereira, 1988 and 2007). The monosaccharides in the hydrolysis liquor were separated and determined as alditol acetates by gas-liquid chromatography. IR spectra were recorded using KBr pellets.

The effect of the thermochemical degradation on the cellular structure of the cork was detected by observation. Observations were made of the tangential, radial and transverse sections while contemplating the size of cells and damage caused by thermo- degradation of cork.

V.3.6-Statistical Analysis

Mean and standard deviation were used to indicate the variability of the calculated parameters. Xlstat Free and IBM SPSS Statistics 21 software were used for statistical analysis of gathered data. As all flammability parameters were normally distributed and had homogeneous variances on the species level one-way ANOVA was performed to determine differences between species based on single parameters. Two-way ANOVA model was applied to test the effect of parameters of carbonisation and chemical composition. Regression analysis was performed to determine if any of the physical parameters influenced flammability and to what extent different flammability parameters were related. A correlation matrix was developed between the iflammability variables and the chemical composition.

V.4-Results

Given the complexity and fragility of the tests carried out in the laboratory, eight months of work allowed us to stabilize on a multitude of results.

V.4.1-Dimensional characterization of cork samples

The results of measurement of the corkback thicknesses are mentioned according to the type of cork and argued by a statistical analysis (Fig.71).

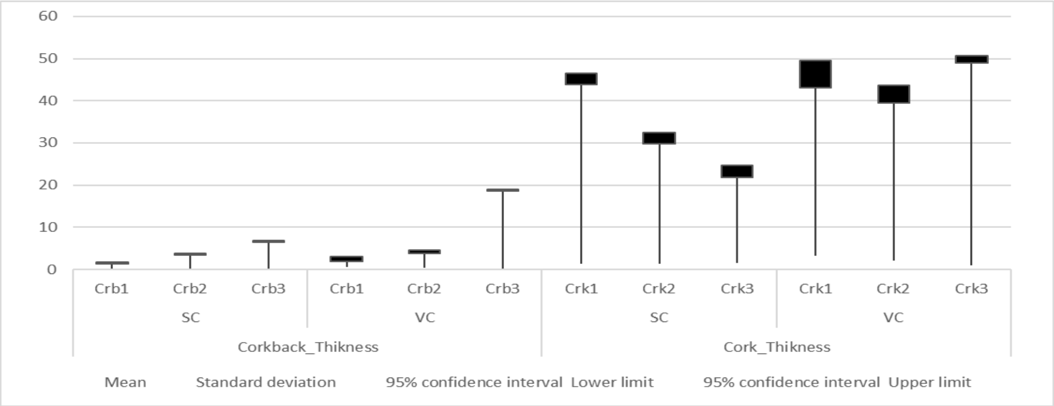


Figure 71. Estimated marginal averages of crust and cork thicknesses

V.4.1.1-Virgin cork

The distribution of the 120 samples according to the thickness of the corkback and cork is illustrated in the figure (Fig.72).

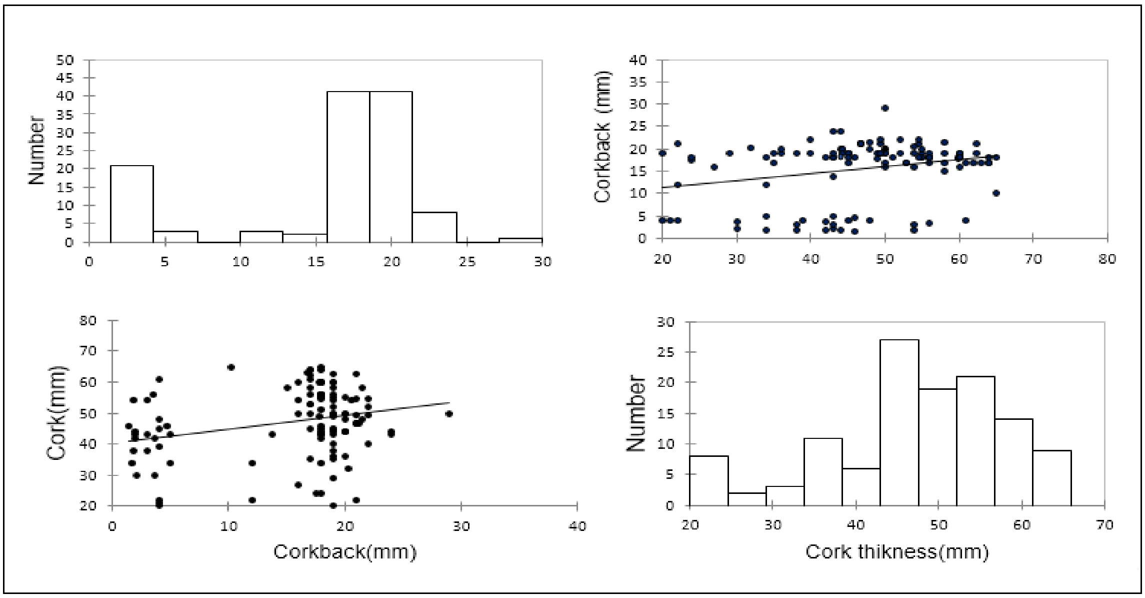


Figure 72. Scattergrams and diagrams of corkback and virgin cork thicknesses

The figure 72 highlights the dominance of corkback thickness of class 3(>5mm) with 80% of the total. This is due to an average cork thickness of 48.87mm (>40mm) and an average corkback thickness of 18.68mm. The other two corkback thickness classes (<2mm and 2-5mm) together hold 5.80% and 14.17% of the total population and are linked to average cork thicknesses of 43mm and 39.52mm and average cork back thicknesses of 1, respectively.81mm and 3.79mm.

The scatter of the cloud of points of the two variables in the x and y plane shows a small dependence between the thickness of the crust and the growth of the male cork (r=0.26).
The proposed mathematical model (Fig.73) is only explained by R^2=7% only, the information provided by the explanatory variables (corkback thickness) is significantly low compared to what would be explained by the only mean of the dependent variable.

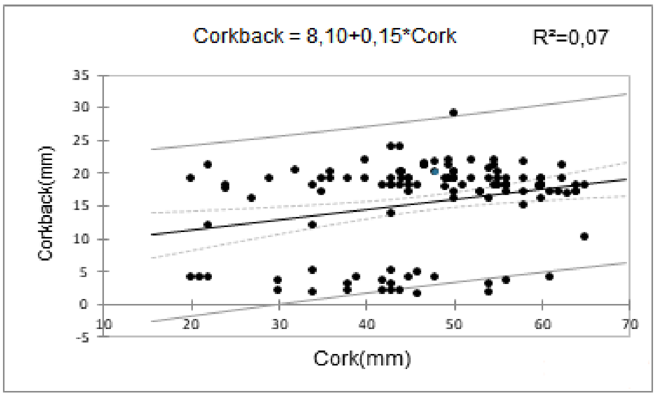


Figure 73. Linear regression of corkback thickness by cork thickness (virgin cork)

V.4.1.2-Second cork

The figure 74 highlights the statistical distribution of the thicknesses of the corkback and the second cork (N=120).

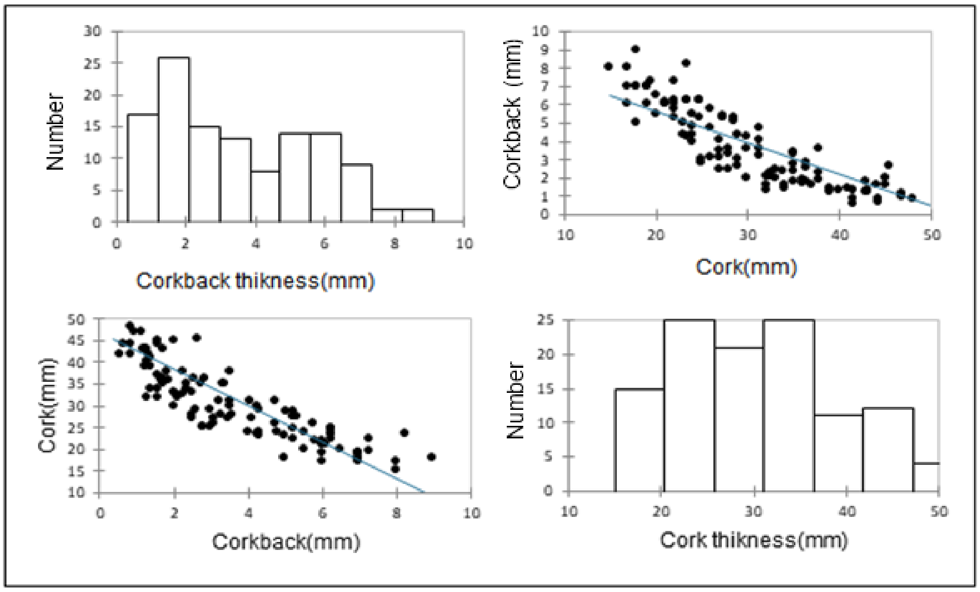


Figure 74. Scattergrams and diagrams of corkback and second cork thicknesses

The figure 74 highlights a dominance of corkback thicknesses of class 2(2-5mm) with 36.66% followed by class 1(<2mm) and 3(>5mm), respectively with 31.66%. The 120 samples have an overall average of 3.52mm, with a maximum of 9mm and a minimum of 0.35mm.

The best representativeness of the cork thickness is limited to class 2 (20-40mm) with a rate of 65.83%, while it only exceeds 23, 33% for class 3 (> 40 mm) and 10.83% for class1 (<20mm). An average of 32.18mm is counted between a maximum of 67.60mm and a minimum of 15mm.

The point cloud expressing the distribution of the two variables (corlback and cork) in both planes x and y shows a tendency to decrease the thickness of the corkback each time the growth of the cork is clearly increasing, A strong negative correlation is recorded between the thickness of the corkback and that of the cork (r=-0.85).

The proposed mathematical model (Fig.75) is explained by $R^2=72\%$, the information provided by the explanatory variables (corkbak thickness) is significantly better compared to what would be explained by the only mean of the dependent variable($p<0.0001$).

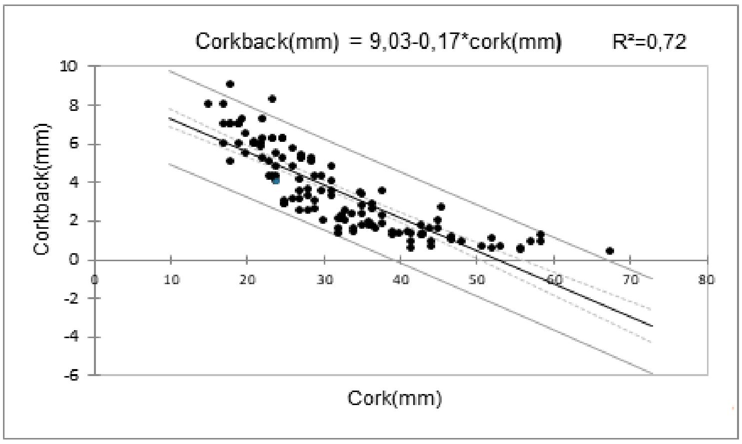


Figure 75. Linear regression of corkback thickness by cork thickness

V.4.2-Study of the flammability of bark in the laboratory

The mean values of the flammability parameters were calculated according to laboratory conditions similar to a fire of low to medium intensity under a low humidity similar to the summer period (heat flow of 225°C, moisture content between 4,5% and 6.5%). The careful control of the various tests of the flammability of cork has been divided into two parts depending on whether it is corkback and cork.

V.4.2.1-Flammability of corkback

Under natural conditions, cork oaks are covered by a thin layer of outer bark called the crust or corkback, which is removed for industrial purposes. However, this dead tissue is important for assessing flammability in the field because it has a different composition to that of cork (Pereira, 2007), and there is a lack of information on its reaction to fire, and its contribution to thermal conduction through the cork layer.

This first protective barrier for the circulation of sap in the bast is in reality a deposit of several tissues that have become non-functional, composed mainly of substances resulting from photosynthesis such as organic and mineral reserve substances and tannins.

Meticulous follow-up of the flammability tests during the replica repeats allowed us to establish the chronology of the flammability phases of the corkback (Fig.76):

According to the definition established by Anderson (1970), flammability includes:

- Ignitability: the structure of the forest fuel (corkback) resists ignition when exposed to heat (IT), by triggering a flame ignition (IF).
- Combustibility: according to its organic and chemical component, corkback burns by emitting intense light that lasts over time and emits high heat (FD, IT and MT);
- Durability: the extent to which a fire will continue to burn with or without the heat source (FD and FET),
- Consumability: the proportion of mass or volume consumed by the fire.

V.4.2.1.1-Ignitabilty

The majority of the authors drew on Valette's work (Valette, 1990) on the method of testing the flammability of forest vegetation by applying the epiradiator as a reference. This method assigns a flammability rank ranging from 0 (lowest flammability) to 5 (extreme flammability) based on the combined average ignition time information (mean time elapsed between the placement of a sample on the surface of the epiradiator and the appearance of the flame) and the frequency of ignition (percentage of tests in which the flame occurred).

For most of the forest fuel, the decrease in ignition time results in an increase in flammability measurements, while the decrease in ignition frequency results in its decrease. This theory cannot be easily applied to cork, which is the superposition of two layers, one lignified and the other suberified.

The table 21 shows the average values of the ignition parameters obtained during the tests of the flammability of the corkback according to the type of cork (virgin and second cork).

The results of the table clearly show that flame initiation for the three Corkback classes is statistically different. Samples attributable to class 1 (<=2mm) for either virgin cork or second cork have the longest ignition (IF) and are considered the least ignitable (56 and 47 second).*

Paradoxically, the corkback belonging to class 3 seem to have a rapid ignition and an increased sensitivity to ignite with high heat, an average of 35,14 and 38,09 second for both types of cork. Whether for the virgin cork and the second cork all ignitions are positive below 60 second. It is obvious that the ignition of the flame at the level of the corkback causes a progressive propagation of the latter in the dead tissue, which is reflected by a release of heat (IT). The results of the table highlight a crescendo temperature ignition from class 1 to class 3 whatever the type of cork. The recorded averages ranged from 254.28 to 359.25°C (virgin cork) and from 216.49 to 319.22°C (second cork) (Fig.77).

The two parameters studied (IF and IT) made it possible to establish a causal link between the ignition of the flame and the thickness of the crust on the one hand and between the heat released after the initiation of the flame on the other hand. A strong negative correlation coefficient was found between FI and peak thickness (r=-0.74) for male cork, and for second cork (r=-0.81) (Fig.78).

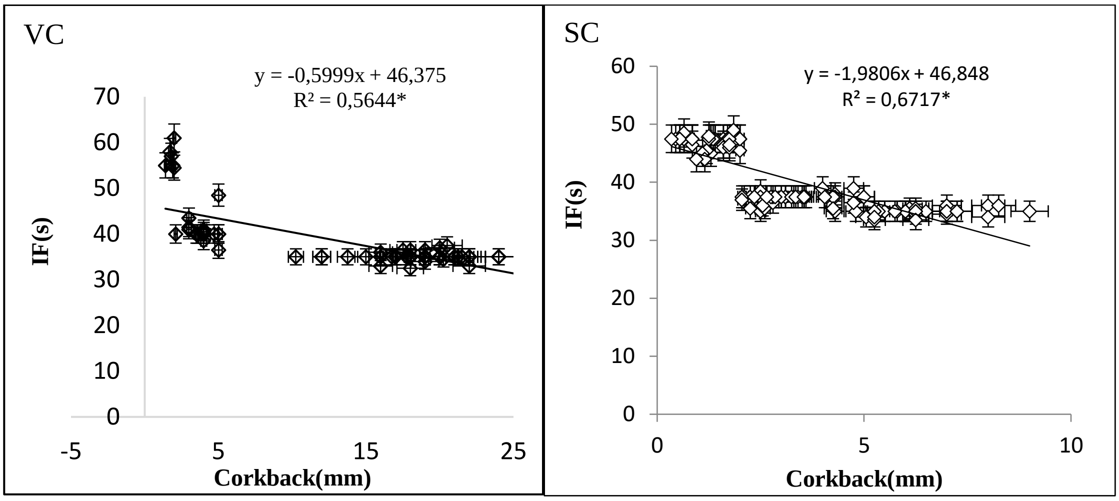


Figure 78. Significant liner regressions between ignitability parameters (IF and corkback). Points indicate mean values and error bars represent standard error.VC: virgin cork; SC: second cork.

The results obtained also highlight the significant influence of flame ignition on temperature ignition in relation to crust thickness. A short and sudden initiation of the flame directly generates a beginning of heat that will take an exponential pace in time and space (R^2 = 77% for the male cork and R^2 = 76% for the reproduction cork) (Fig.79).

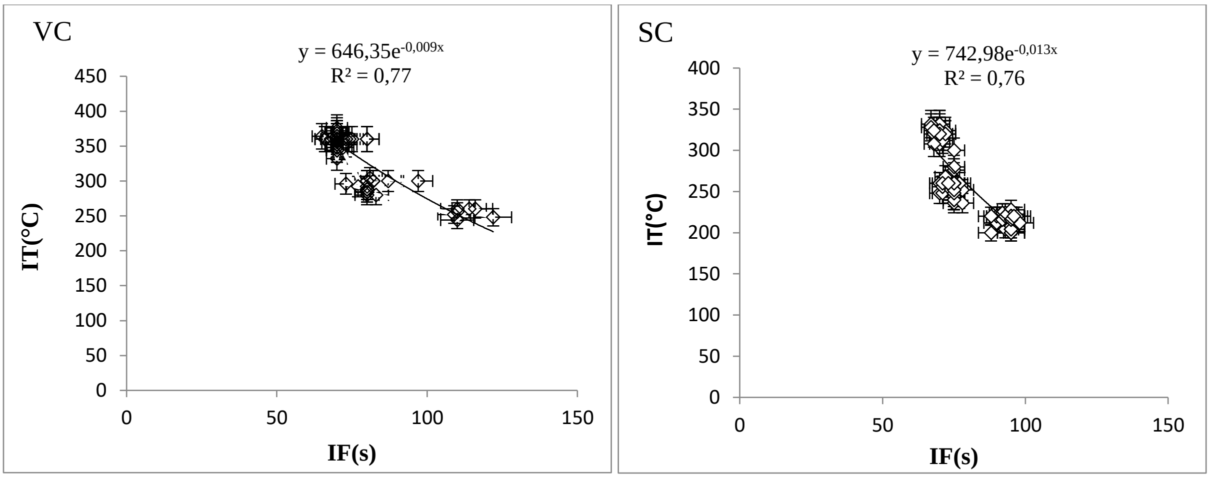


Figure 79. Linear regression between ignitability related parameters ignition delay (FI) and ignition temperature (IT). Points indicate mean values and error bars represent standard error. VC: virgin cork; SC: second cork.

V.4.1.1.2-Combustibility, durability and comsumabilty

The flammability of forest fuel has been defined according to three parameters: the ignition time, that is, the time it takes for the fuel to ignite after being exposed to a source of heat; the combustibility, that is, the rate of fire after ignition, and durability that is the ability to maintain combustion after ignition. The average values of these three parameters are shown in the table 22 according to corkback and cork type.

The mean values in the table indicate a large variation between the combustion parameters and the corkback thickness.

As for the variable flame height (FH), a clear difference between the repetitions of each class is observed. For virgin cork, the mean FH was 11.9 cm, ranging from 3.14 to 13.84 cm. It follows the same pattern for second cork but with reduced FH averages, ranging from 3.18cm (class 1), to 8.05cm (class 2) and 7.36cm (class 3).

These values should be taken with caution since the parameter 'flame height' is associated with the expansion of heated gases that are emitted during combustion in the radiator. Further studies are needed to identify the volatile organic compounds present in the dead phloem which is the crokback. A positive correlation was found for both bark types, strongly significant for virgin cork (R^2=0.65) than second cork (R^2=0.32) (Fig 80).

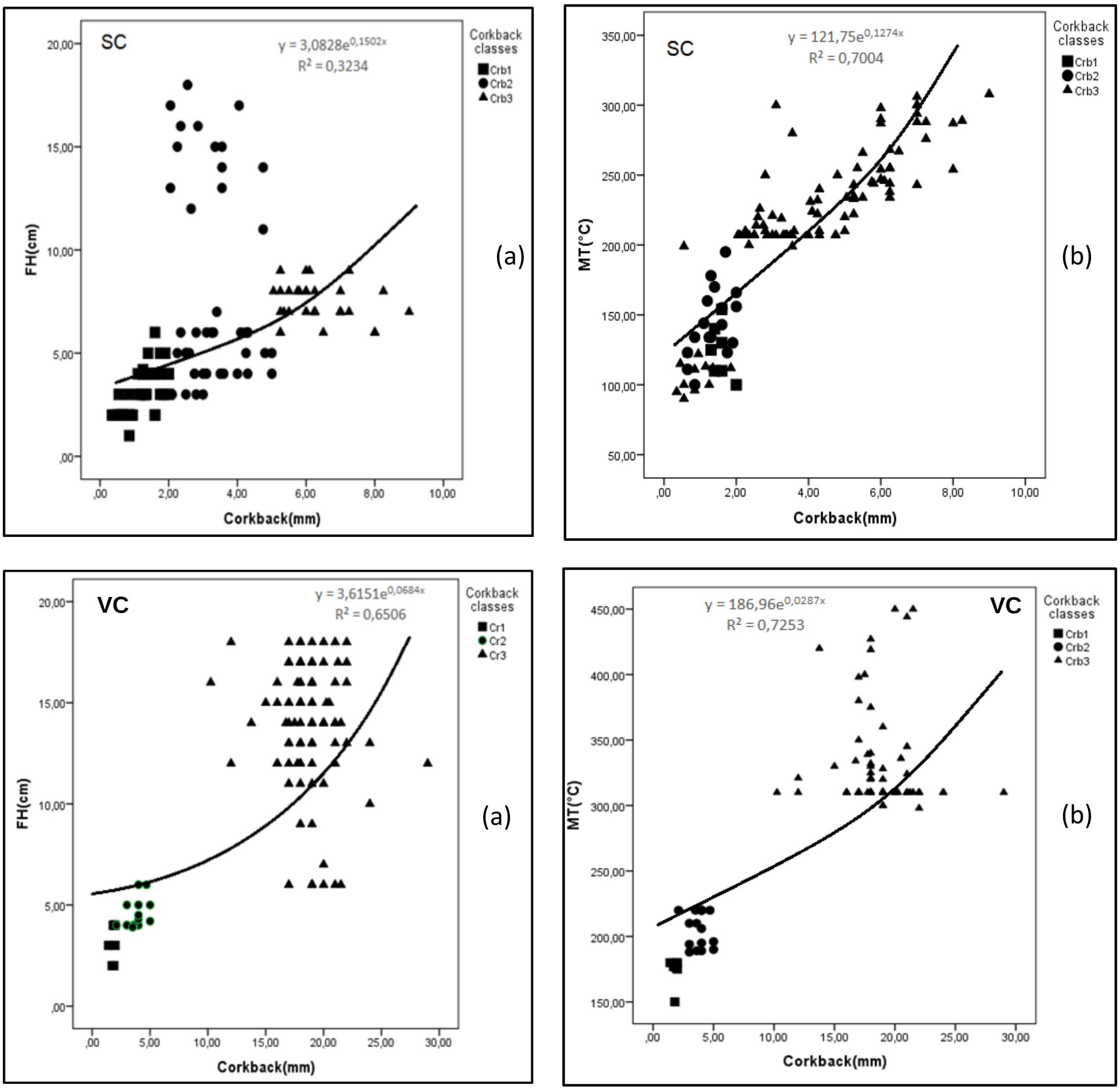


Figure 80. (a) relationship between corkback thickness classes and flame residence time (FD); (b) relationship between corkback thickness classes and maximum temperature (MT); VC: virgin cork; SC: second cork

In order that there is durability in the time of inflammation of the corkback, it is accepted that the time of extinction of the flame is greater than the time of its ignition. This situation remains valid for both types of cork. Samples from class 3 have the greatest durability in terms of flame duration (307.85 and 103.12 second) and extinction time (345.01 and 142.98 second)(Tab.23).

An almost perfect positive exponential regression regulates the relationship between FD and FET (R^2>0.95) (Fig.81).

Moreover, it is clear that the final flame extinguishment heralds the beginning of the internal combustion of the dried mass, that is, the total consumption of the corkback, expressed in a rate of very low residual mass, close to 0% for all the samples.

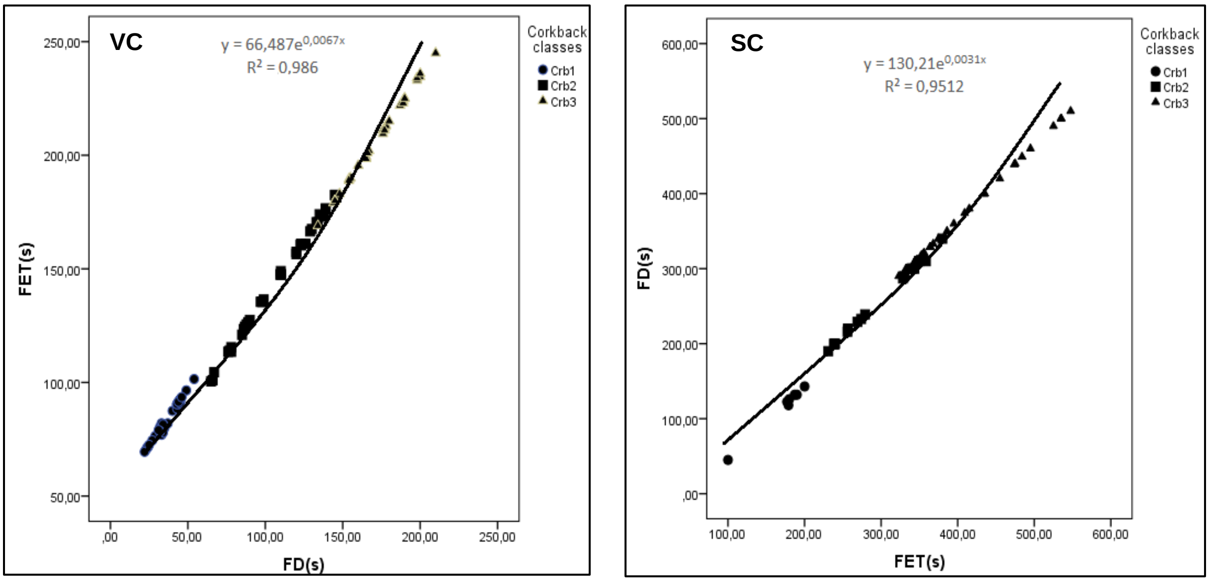


Figure 81. Expenentiel regression between sustainability related parameters flame extinguish time (FET) and flame residence time (FD)

V.4.3-Flammabilty of cork

The flammability phases of cork are in fact only a contained diffusion of the heat released by the corkback. The flammability steps of the cork are illustrated in the figure 82.

Once the consumability of the corkback tissue comes to an end, a new ignition of the flame is starded in the cork with a marked slowness, negatively affecting the ignition of the temperature and its propagation in the suberous tissue with a low temperature peak. The height and duration of the flames in time and space indicate a high durability of the intra-cork flammability. In fact, cork burns slowly and is difficult to burn due to the increased resistance of its microscopic architecture and its particular chemical components.

The internal heat released by the corkback is automatically intercepted by the cork which will start its performance of resistance to flames. The parameters regulating the flammability of the suberel tissue are totally different from those of the corkback. The average measurements recorded by the radiator are shown in the table by type of cork.

From the table above,the averages recorded for both types of cork express a low flammability compared to other forest fuels. This non-timber material is strongly opposed to rapid flame ignition (IF)

Conversely, the durability of the flammable cork appears to be very high by the extended time of the flame (FD), an second (virgin cork) and 2574.03 seconds (crk1, second cork). This means that the increased resistance of the suberous tissue to quench the flames' temperatures is more related to its structure than its thickness.

Combustibility is also low, with an average of 160.65°C (virgin cork) and 181.10°C (second cork). The heat released (MT) by the suberous tissue is not proportional to the thickness of the virgin cork, and rises in crescendo for the. During the tests, a maximum of 345°C was raised for class 3 cork (Crk3) and a minimum of 133°C for Crk1.

The consumability averages show a very slow deterioration of the cork (47.10% (virgin cork) and 32.12% (second cork). In addition, classe 3 contain the high averages of RMF (crk3-virgin cork = 50.98% against crk1-second cork =42.50%). The proportion of residual mass (RMF,%) moderately high for both types of cork is a strong indication that the suber’s flammability is more a form of carbonization of its structural compounds.

V.4.4-Carbonization of cork according to its chemical composition

The results obtained from the infammability tests of cork support its great resistance to heat inergy emanating from the corkback. Indeed, we can argue that cork carbonizes very slowly instead of igniting quickly like other forest fuels. This typical cork carbonization can only be identified through chemical analysis of the main components of male and reproductive cork.

To do this, we opted for a homogenisation of the flammability parameters in relation to the carbonisation classes and the chemical composition of the two types of cork. The results of this analysis are illustrated in the table 25 .

Table 25 shows that the average chemical composition of the samples studied contains 37.43 nd 41.90% suberin, 21.46 and 20.01% lignin and 16.28 and 15.28

The average values of the contents in suberin show important differences according to the thickness of corkback and cork on the one hand and according to the degree of carbonization on the other hand, oscillating between 38.67% (virgin cork) and 44.54% (second cork) (crb3, crk3, low carbonisation) and 31.43% (virgin cork)- 38.39% (second cork)(crb1, crk1, high carbonisation).

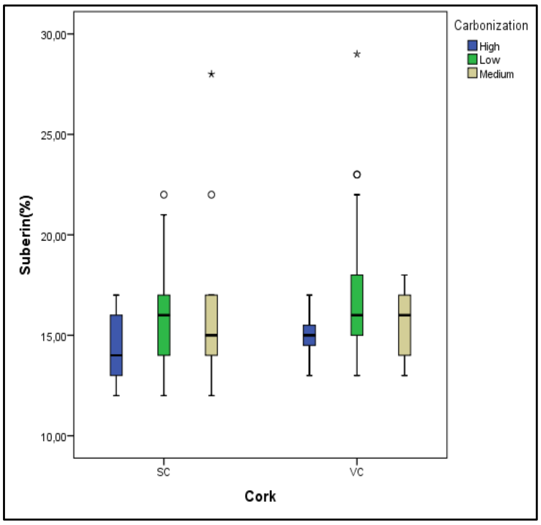
The variations are small for the lignin content, respectively 20.68%-20.14% (virgin-second cork, crb1, crk1, low carbonisation), and 18.43%-19.47% (virgin- between 15% (virgin cork, crb1, crk1, high carbonisation) and 15.80% (second cork, crb1, crk1, low carbonisation).

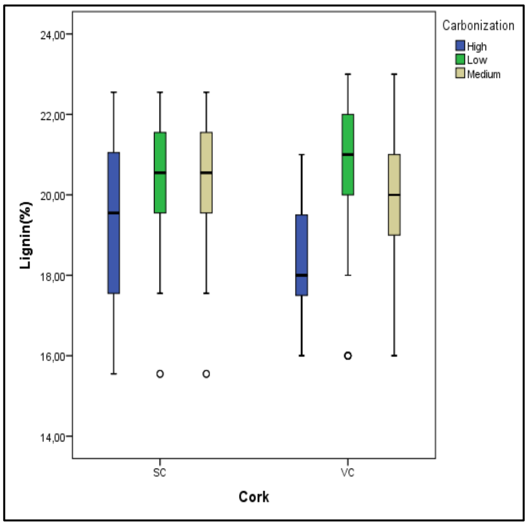
.4.5-Chemical composition

The chemical composition of cork cannot be limited to a simple presentation of the rates of the main contents found. In reality, this composition is very similar to the physical and anatomical structure of cork (Pereira, 2007). To support our results, a statistical study was carried out including the chemical composition at the thickness of the cork at its carbonization degree. The results of the analysis of variance (ANOVA 2) are illustrated in the table 26 and 27.

The results in Table 26 confirm that for virgin cork, suberin and lignin ($p < 0.001$) (not cork thickness ($p > 0.05$)) have a very highly significant influence on the degree of carbonisation. The extractive content does not seem to influence the carbonisation of virgin cork ($p > 0.05$). The interaction between the thickness of the cork and

The results of the table 27 show that the three chemical compounds of the second cork have a significant influence on the carbonization of the cork ($p < 0.05$). Only suberine and extractives are governed by thickness. The interaction between the thickness of the cork and the carbonisation is without effect by including the three variables (subérine. lignin and extractives) ($p > 0.05$) (Fig.83).





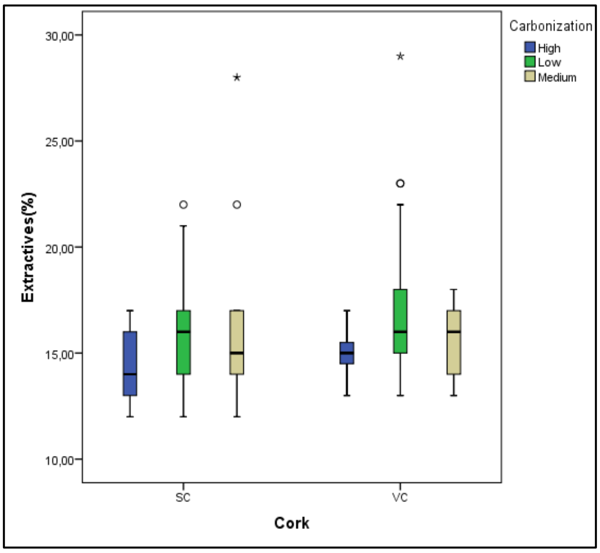


Figure 83. Distribution of the degree of carbonisation according to the chemical composition of two corks

The figure reflects the trend towards increasing the carbonisation of cork in parallel with the decrease in the rate of the three compounds. This trend is best appreciated on the second cork mainly for the suberin.

V.4.6-Relationship between chemical and carbonisation aspects

For the purposeto to identify probable relationships between the parameters of the carbonization of cork and its chemical composition, a correlation matrix was created in this sens(Tab. 28 et 29).

The results of the table 28 show that the suberin and lignin content are positively correlated with FD(r=0.475, r=0.279) and RFM (r=0.283, r=0.200). The long duration of the flame in the cork generates a strong heat (r= 0,030) but which will be slow down because of the resistance of these two compounds which will lead to a slow consumption of the suberous tissue (r=0.53). In other words, the thermal destruction of suberin and lignin requires a strong combustibility and a great durability for there is a total consumption of cork (r=0,255).

The chemical structure of the second cork seems very different from that of the virgin cork. Moreover, a very strong positive correlation links the contents in suberin to the thickness of the cork (r=0.557). Similarly, the parameters of carbonisation, namely IF,FD and RMF, are strongly correlated with suberin (0.46 ; 0.52 ; 0.46), and with lignin (0.20; 0.20; 0.25) and extractives (0.20 ; 0.16; 0.20). The same principle observed for virgin cork is also observed for second cork: the thermal alteration of suberin, lignin and extractives is related to a high flame duration (r=0.52; 0.20; 0.16), to a high combustibility (-0.49;-0.11;-0.27) so that there is a perfect consumability of the cork.

These results lead us to wonder a lot about the thermochemical degradation of cork. This means knowing the behaviour of the cell structure at different stages of pyrolysis.

V.4.7- of cork

The gravimetric decomposition of the cork was achieved by mass loss at temperatures of 150ºC to 500ºC, and with processing times of 5 to 300 minutes. The results of this test are given in the figure 84.

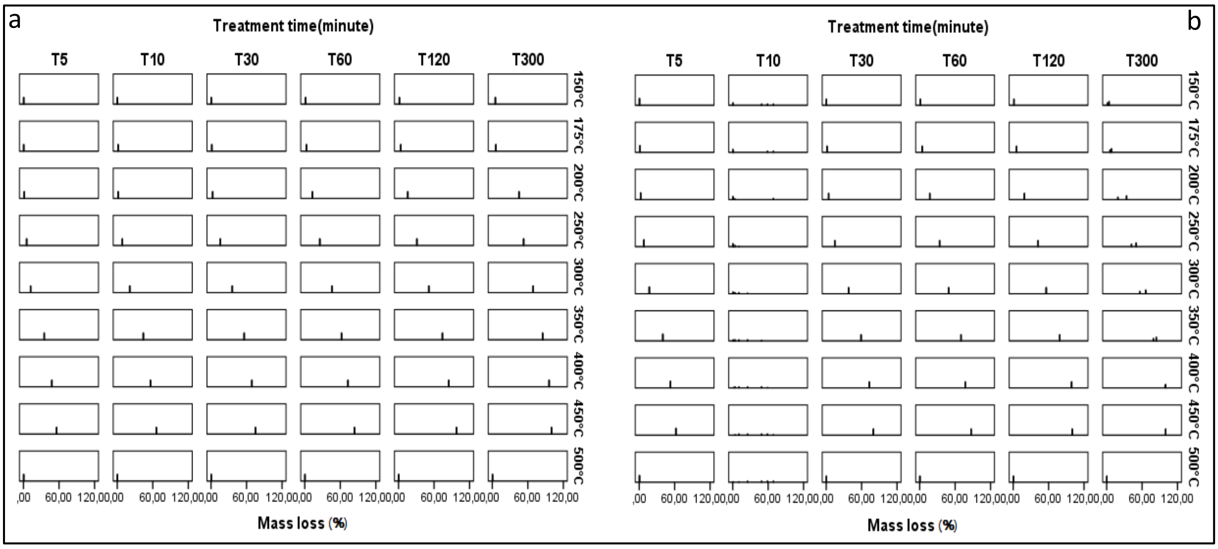


Figure 84. Scatter diagram of mass loss at different temperatures and times (a : virgin cork, b : second cork)

second cork. At 450ºC, the combustion process is completed, leaving an ash residue of 2.60 to 2.9% of the initial cork.

.

The results presented in Table 29 show that, during heating, the contents of the extractives only retain 5.6% at 300°C.

The rapid loss of polysaccharides in heat-treated samples is also clearly visible in the table. At 200ºC, losses range from thermal degradation of insoluble lignin takes an exponential trend, it degrades by a rate ranging from 42.1% and 52.0% (cork turns and second cork) to 250°C and finally reaches 97.6% and 98.5% to 400°C for both types of cork.

V.5-Disussion

The composition and structure of corkback of virgin cork are totally different from that of second cork. In the virgin cork never exploited, it constitutes the deposit of several compounds resulting from the operation of photosynthesis during the rise and fall of the sap in the living tissues of the tree namely the sapwood and the liber. Its thickness constantly increases in relation to the thickness of the mother of the cork and the activity of the phellogen. The rough texture of the corkback is strongly related to the tangential stress experienced by the virgin cork during radial growth.

On the other hand, in the second cork, the corkback follows the periodical rhythm of the harvests, its texture becomes smooth, its thickness decreases with the successive lifts, and it is considered as a quality index of the second cork.

Corkback is the first natural protective barrier for cork oak, like other forest species, to prevent the penetration of light rays from the fire. This sometimes short or slow resistance is influenced by several factors, which can be classified into two groups: the macroscopic form of the dead phloem, namely the thickness, roughness and fineness of the external tissue; and the physio-microscopic elements (tannin, suberin, mineral content, moisture content and volatil products).

It should be noted that most authors who have studied the flammability of forest fuel agree that low-flammable plants are generally drought tolerant, with a high leaf mass, favorable for abundant water transport or high moisture content, whereas highly flammable plants have oily or waxy resinous leaves and a chemical composition containing lignin and water (Batista and Biondi 2009).

These observations were also supported by White and Zipperer (2010) who associated mineral and volatile content with these factors. The dilemma for the cork oak bark is quite

complicated: it is a particular structure composed of corkback (more similar to the bark of other species) and cork (a thermal insulating fabric) enough to explain this divergence.

The bibliography gives very little information on the flammability of corkback. The great sensitivity of corkback to fire is mainly due to its chemical and mineral content. Pereira (1987) describes corkback as a more lignified material than cork (32.5 versus 23.0%), with a high mineral content (9.8% ash), calcium being the most present element (5.7%), glucose and xylose, 50% and 40% respectively of monosaccharides.

2006; Madrigal et al., 2019). This results in a rapid ignition of the temperature, which will reach its significant peak on the corkback of the virgin cork (299.08°C) than that of the second cork (200.88°C). The results also showed that the high durability resulting from the burning of the corkback is responsible for a strong expulsion of the level of radiation in the cork, which will gradually become carbonized.

The suberin content is low compared to cork (4.3% versus 39.4%). The degree of corkback roughness not mentioned in this work does not seem to have an accelerator or inhibiting effect as indicated by some authors, for other species other than cork oak (Frejaville et al. (2013).

This observation was also comforted during the tests by a long duration of the flame ranging from 2868. of mass loss.

Indeed, the high durability of the flammability of cork is deeply typical of this non-timber product. The strong heat energy released by the corkback is directly intercepted by the suberous tissue, but with a very slow propagation of the heat from its structure and thickness.

In other words, the long flammability duration is related to the low combustion of the cork that tramples in front of these two fundamental aspects: its very low thermal conductivity coefficient (0.0427 W/m°C) and its microscopic structure.

In this sense, Pereira (2007) states that each cork seat is a closed unit with no empty space between the other adjacent cells, which are therefore hermitic units. Cells can be described as hexagonal prisms, with basic columns parallel to the radial direction of the tree.

The structural characteristics of cork were mainly described by Gibson et al. (1981) and examined in detail by Pereira et al. (1987). Its formation and development were characterized by Graça and Luminy,2009 ; Silva et al .,2005).

Pereira (2015), under scanning microscope observation, associates the cell membrane with two contiguous bases, formed by a five-fold polyhedral-shaped paroy: two of cellulosic nature, two layers of suberine and wax, and a final woody layer.

During the flammable phases of the virgin cork or the second cork, it is this insulating component that will prevent the propagation of thermal radiation. In other words, this resistance derives from the chemical structure of the components of the cork cell.

The chemical composition of and soil conditions, genetic origin, tree size, age (virgin or reproduction) and growing conditions).

Explaining the composition of the suberine, Pereira(2007) indicates that it is a glycerol-based polymer with linear-type units that are assembled forming ribbon-like structures responsible for elastic properties such as bending and compression of cells under stress. Marques et al. (2015) makes lignin an isotropic polymer in a network, responsible for the structural rigidity of cells and their resistance under compression. Pereira et Marques (1988) mentions that cellulose and hemicellulose have a minor role in the construction of the cell wall of cork than in that of wood.

A tendency to increase the carbonisation of the cork in parallel with the decrease in the rate of the three compounds was observed for both types of cork. This trend is best appreciated on the second cork mainly for the suberin. Positive correlations were found between suberin and lignin content and carbonization parameters FD, RFM and MT.

Cork, like other natural or synthetic materials, cannot resist the destructive phenomenon of fire forever. Results from the thermochemical decomposition measured by mass loss revealed that virgin or second cork resists temperatures up to 150°C. At -Beyond this range, mass loss is significant at 200ºC and increases rapidly at higher temperatures, up to total calcination at 450 and 500°C. Polysaccharides are the components most sensitive to the heat of cork. At 200ºC, the hemicellulose disappears and the cellulose is considerably degraded.

It is known that hemicelluloses have lower thermal stability than cellulose and lignin, and that their degradation starts at approximately 180ºC (Nguyen et al. 1981). The degradation of cellulose takes place within a broader temperature interval, ranging from about 160ºC to 360ºC, with significant mass loss at temperatures considerably higher than for hemicelluloses.

The suberin is more resistant and decomposes only after 250ºC (between 40.7 and 42.5% of residual mass) and alternates completely only after 350 and 400°C (only 1.3% residu). This conclusion is also validated by Pereira and Marques (1988) which stipulate that suberin is a structural component of the cell wall, and its removal destroys the cellular integrity of the cork.

Our results for thermochemical decomposition coincide with those of Pereira (1992), they effects were also observed on certain anatomical aspects of virgin and second cork. Cell expansion and flattening of wall corrugations occur at the beginning of heat treatment.

The microscopic structure of untreated and never removed virgin cork is characterized by very wavy vertical-walled cells stacked from base to base in radial direction in a regular arrangement of rows, while on the second cork, these corrugations are less compressed, mainly due to successive harvesting operations (Dehane 2012) (Fig.85).

When the cork is subjected to heating temperatures, the cells increase their dimensions, and the walls for experiments using hot water during cork boiling (Pereira and Ferreira 1989; Rosa et al. 1990 ; Dehane, 2012).

At degradation, the structure of the cell walls is largely destroyed. In the later stages of pyrolysis, cell structure is lost.

Second cork (Tangential section)   Virgin cork (radial section)

Figure 86. Maximum cell size and wall straightening at 250°C

At temperatures ranging from 250-300°C, the damage appears on the cork tissue as a result of excessive stretching which will tear the suber and crack the cell walls, the number of cracks found in heat-treated samples increases with temperature(Fig. 87).

In the temperature deep chemical alterations and the formation of a completely charred product, as indicated in the table 30.

We can attest that the carbonization of cork under laboratory conditions is a very complicated operation deriving is balanced and dominated by the suberin; consequently, the insulating properties become more pronounced and the flammability parameters (IF, FD, RFM and MT) record their highest averages resulting in low carbonization, and just the opposite (Fig. 88).

High carbonization of seond cork

Thick corkback (>5mm)
Thin cork (<20mm)

Low carbonization of secon cork

Thin corkback (<2mm)
Thick cork (>30mm)
igh suberin content
Low flammability

By suppressing the results of the carbonizatio of cork in the laboratory to the reality of the field, he asserts that the vulnerability to fire is a temporal coincidence. In the cork production cycle (9-15 years), it is highest for trees with thin bark (young or recently debarked) and decreased with the thickness of the bark until the al.(2015), the bark of *Quercus suber* has a hard belt around the trunk of the tree from bottom to top, forming a thermal insulation for the cambium during the passage of the fire and promoting the appearance of dormant buds after fire.

V.6-Conclusion

We can attest through the study of the carbonization of virgin and second cork in the laboratory conditions (by epiradiator) that it is a complicated process where intervene two morphologically and physiologically different types of structures. The first 'corkback' dead tissue totally outside the bark playing the role of primary protection of the liber against external aggressions grows in thickness according to the activity of the mother of the cork and the longevity of the phellogen.

In virgin cork, it appears raw and rough while in the second cork smooth and fine. Faced with is immediately intercepted by the dead suberous tissue, the latter playing the role of second rampart for the liber and the cambium acts according to its insulating performance acquired from its anatomical structure and chemical composition.

The high averages of the flammability parameters of virgin and second cork, namely ignitabiity, durability and the destruction of its structure and chemical compounds. The study revealed a strong correlation between the contents in suberin and the carbonization of cork, this finding was also validated in the tests of thermochemical degradation.

The results of this study show that the thickness of corkback and cork are two unavoidable elements in the flammability of cork in the forest, as they are protective tissues for the radial and suberous growth of cork oak. The appropriate management of the debarking and the periodical bark harvesting in front of the fire, must improperly avoid the cork production in regular system and give priority rather the operations of production in irregular system, but with alternating and extending years for trees forming the same stand. This type of management remains the best solution to reduce vulnerability to fire and preserve the ecosystem of cork oak.

Chapter VI

Study of the process of carbonization of cork in cork oak grove

VI.1-Introduction

Among the species of the genus *Quercus*, the cork oak proves to be the best adapted to the recurrent phenomenon represented by forest fires. In some cases it provides rapid regeneration when other species that compete with it easily collapse in the flames of fires (Elena Rossello, 2004).

It is the bark of the cork oak which is responsible for this remarkable resistance to fire, with a thickness of the cork which can reach 30cm in the life of the tree, constitutes in itself a natural product endowed with excellent insulation properties. (Natividade, 1956). Moreover, Jackson et al. (1999) and Brando et al. (2012), see this property as a clear mechanism to protect the cambium and vascular tissues of the tree against the thermal heat emitted during fires.

Bernal Chacón and Cardillo Amo (2005) align themselves with the same idea, against low and medium intensity fire, the protective power of cork is proportional to its thickness, a cork caliber > 20 mm implies a survival of 80% trees. On the other hand, the subjects, more or less recently stripped or debarked, will die immediately (Santiago Beltrán, 2004).

Several authors have studied the strategies and physiological responses adopted by forest trees after a fire (Pausas & Keeley, 2019; Lamont & Pausas, 2017; Moreira et al., 2012). In this context, Bond and Midgley (2001) define post-fire regeneration as a mechanism allowing individual plants to regenerate after the removal of aboveground biomass and to persist in ecosystems with recurrent disturbances. Bowen and Pate (1993) believe that this resistance to mortality after fire is attributed particularly to protected buds, using carbohydrates stored in their tissues.

The cork oak does not deviate from this rule, all the authors who have approached this theme affirm that the thicker the layer of cork, the more difficult it is for the fire to completely consume the tree, which allows it to remain vigorous and optimize rapid canopy regeneration (Paussa, 1997; Catry et al., 2012). On the other hand, when the cork layer is thin, the mortality rate of the tree (both trunk and canopy) increases and regeneration occurs mainly from the base of the tree through the intermediary of stump shoots. These two resilience strategies have been identified in this chapter by three types of residual trees; recoverable, unrecoverable and standing dead.

VI.2-Aim of the study

The carbonization of cork in cork oak has never been mentioned in the bibliography, we focused more on the impact of fire on the bark of cork oak and its post-fire resprouting. Moreover, in a burned cork grove, it is very clear for the observer to notice that the intensity of the fire is directly imprinted on the cork layer and remains an indelible bio-indicator of the physical and mechanical resistance of the cork, at the time of the fire.

The main objective of this chapter is to certify that the degree of individual or collective post-fire regeneration is largely linked to the carbonized thickness of the cork, in other words to its carbonization rate.

It was a question, through field measurements, of detecting a probable relationship between the rate of carbonization of the cork and the post-fire resilience variables, namely the morphology, the characteristics of physiological response, the electrical conductivity of the trunk, the rate dead crown and finally the characters of meristematic response.

VI.3-Materials and methods

VI.3.1-Sampling

To characterize the response of cork oak to post-fire stress according to the rate of carbonization of cork we based ourselves on the reports of fires collected from the forest services of the wilaya and especially the disastrous fire of the year 2005 (Hafir: cantons S'Rutou and Oued El Fernane, Zarieffet: cantons Zarieffet and Guendouza) (Fig.89).

After thirteen years of the passage of this fire (2018), we began our investigation in search of the mechanisms of resistance of cork oaks to fire. We were interested in rescued subjects peddling a virgin or reproductive cork according to two variables (unexploited and exploited trees). To do this, we followed the natural limits traced by the fire by operating through random sampling approached by Itinary. The latter is materialized on the ground by zigzag lines of 100m according to the three levels of the land (ridge, slope and low ground), given the large void created by the fire between trees and the dominance of bushy communities and maquis (Fig.89 and 90).

Figure 90. Itinerant sampling method in resilient stand during the year 2020

VI.3.2-Measures and description

On each intercepted tree (exploited or not exploited), we noted several variables referring to the morphology of the residual trees (the diameter at 1.30 m from the ground (DBH), the total height, the height of debarking, the thickness of the cork (measured on both sides using the coveless). Jointly, other measures related to the physiological response after fire were also counted on the trees according to two compartments (trunk and canopy): the state of the trunk, the state of the cork mother, the electrical conductivity of the cork measured by the Preciva conductivity meter . The post-fire meristematic response was also identified by the degree of regeneration on the crown, on the trunk and by stump sprouts(Table.31). For a certain fluidity and objectivity, some measurements were confirmed by analysis of digital images of photos taken in the field by the imagej software. In the table 31 are inumered the variables of measurements made on the sample trees.

Considering the previous parameters , trees are classified into three categories (Fig.91) :

1) tree with reversible damages.
2) tree with irreversible damages.
3) : a dead trunk (physiologicaly dead) with a living stump and roots.

Through the table 32 above, we note that the subdivision of trees into two types (unexploity-virgin cork tree and exploited-second cork) is also divided into three categories of post-fire damage :

- Standing dead trees (of the main stem): the death here in this sense refers to physiological death of the main trunk with a functional basal area, as noted « standing dead tree» are the cork oak trees with the trunk severely burned and damaged showing appearant basal sprouts. The total death on the trunk and the basal area is very rare.

- Living trees: they show areal sprouts on the canopy and the trunk, and sometimes on the basal area. according to the degree of fire disturbance affecting the tree they are divided into two categories:
  -Trees still alive but with irreversible damage on the crown, on the trunk and showing crown and basal sprouts. These subjects are unrecoverable whose survival time in the medium and long term is unknown.
  - Live trees with reversible damage (there was no apparent damage to the tree either on the canopy or on the barrel, no physiological response to stress (no sprouts). These subjects are recoverable in the long term.

For purely administrative reasons rather than preventive, the concerned forest services didnt authorize the cork sampling for more than 400 exploited and 450 unexploites trees. Squares of 5cmx5cm dimensions were premarked with chalk on the trunk at 1.3m height and subsequently cut using a battery-powered saw or hammer and chisel taking care not to induce any damage to the cork mother.

Once the operation is done each sample is extracted from the trunk using a screwdriver and labeled according to the sampled tree category (Fig.92).

.

In the laboratory, the 850 samples were dried in the surrounding environment for one week. The four sides of each cube were sanded and then cleaned with compressed air to reveal the carbonized cork area of the intact surface. The quantification of the carbonization rate was carried out by the imagej software, thanks to the digital image analysis method and according to the resolution of the scanner, transferring the pixels in mm. The carbonization rate is therefore estimated by the report:

Every calculated carbonization rate is affected to ist respectif class acording to the table 33:

I.3.3-Statistical Analysis

The various results of the measurements were subjected to statistical treatments based on position measurements (mean and median, coefficient of variation, etc.) and dispersion measurements (including standard deviation and interquartile interval). Parametric and non-parametric tests were also performed such as Anova variance analysis, Kruskal Wallis test, single and multiple regression, ACC analysis, binary logistic regression by SPSS software,21. In order to better explain the relationship between the cork carbonization rate and certain parameters surrounding the cork oaks rescued from fire, a Multiple Correspondence Analysis (MCA) was performed by the biai of the XlStat software.

VI.4-Results

VI.4.1-Characteristics of the surviving sampled trees

Measurements on the sample trees were ordered according to morphology, physiological response and primary (I) and secondary (II) meristematic response

VI.4.1.1-Morphological characteristics

The following table 34 illustrate the different morphological measures of the sampled fiveteen years after fire.

By referring to the table 34 above there is a noteworthy variability within the trees for both types (exploited and unexploited) with coefficient of variation that goes from 16% to 19.50% and between 46% to 44.74% for the thickness and the diameter respectively.

The average thickness is between 24,35 mm et 26,36mm, showing a weak cork production activity in the forested area. Overall, it is mainly the adult trees, of a medium diameter on cork of the order of 36,18cm to 35.42 cm (cork included). The mean total height is on the range of 1.10m to 7,39m similar to thin trees in a constant competition for light because of the dense shrubby formation.

Regarding the debarking height it appears that it’s not well respecting the norms and regulations, it oscillates between 1.50m and 3,50m.The mean debarking coefficient adopted for the whole study area is 3m, which seems to affect negatively with the degraded ecological and forest conditions present (drought, dense understory shrubs and frequent fires).

The distribution of variables according to their absolute frequencies follows a Gaussian distribution, this means that the sample trees do not belong to a single Itinary or a single stand (Fig. 93 and 94).

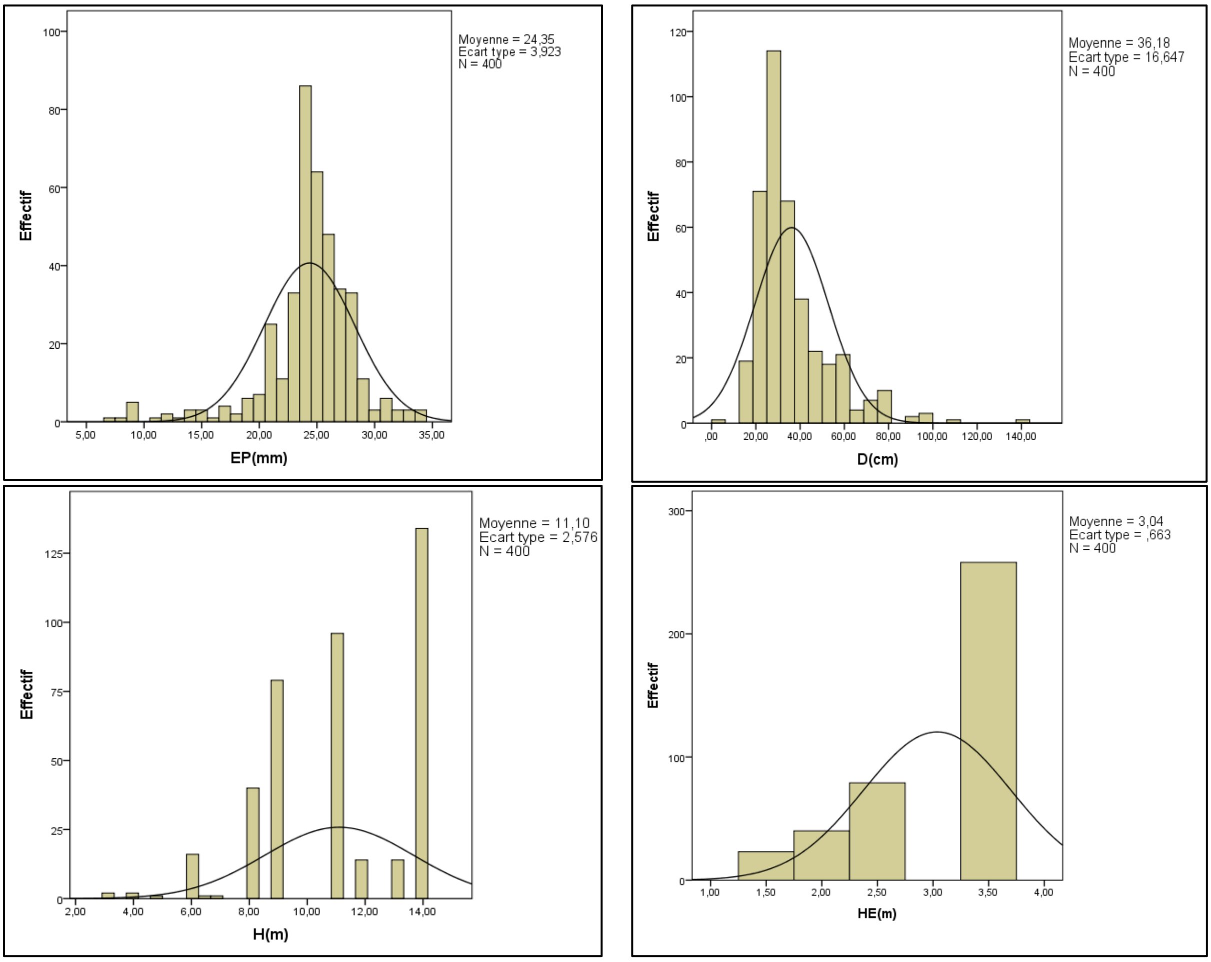
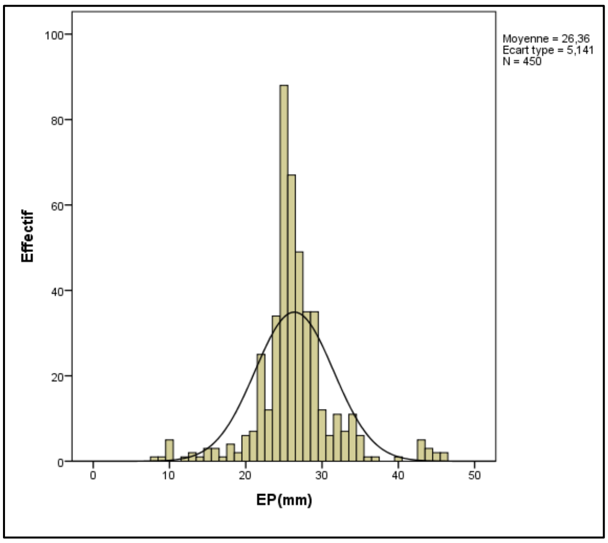
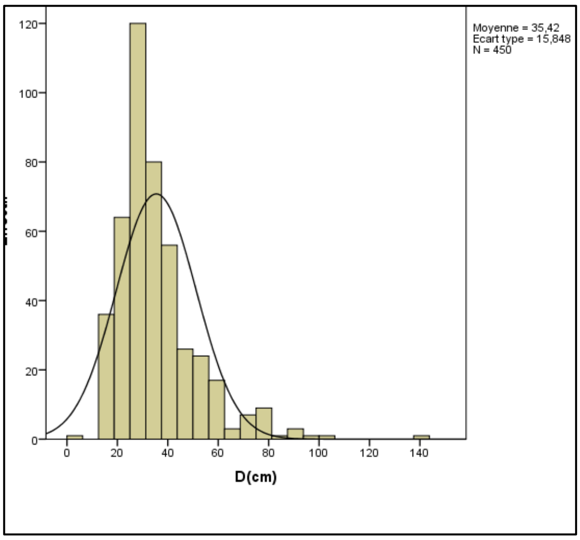


Figure 93. Distribution of the morphologic variables measured for the exploited trees (cork thickness (EP), diameter(D), height (H) et debarking height (HE)) (N=400)





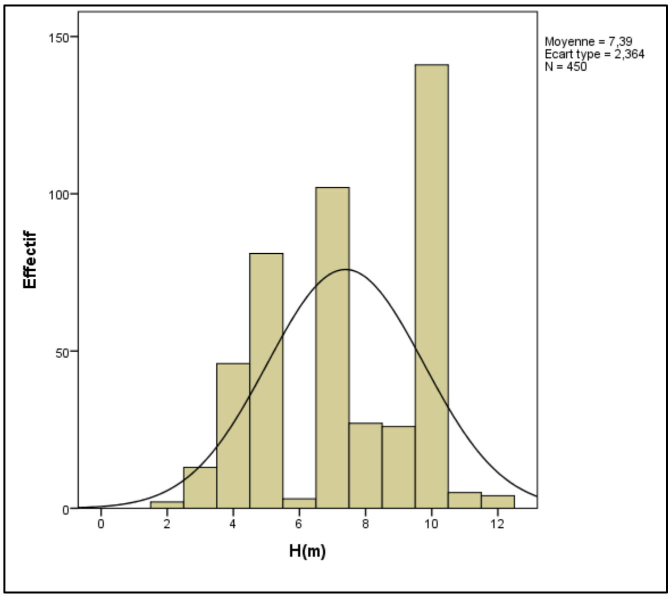


Figure 94. Distribution of the morphologic variables measured for the unexploited trees (cork thickness (EP), diameter(D), height (H) et debarking height (HE)) (N=450)

The graphical representation of the Canonical Correspondence Analysis (Fig.95) makes it possible to visualize simultaneously the variables at the sites (Hafir-Zarieffet) and at the objects (the exploited or unexploited trees).

Figure 95. Distribution of morphology variables in the factorial plane (exploited and not exploited)

From the figure above it appears clear that morphologic variables scores are more linked to standing dead tree category; and distinguish between the recoverable and non-recoverable trees on the factorial space where the best morphologic are attributed to the recoverable category (Tab.35 and 36).

Table 35. Synthesis of descriptive analysis results for each surviving category of exploited trees

	Recoverable (258)				Unrecoverable (119)				Standing dead (23)			
	EP	D	H	HE	EP	D	H	HE	EP	D	H	HE
Mean	25.41	43.53	12.72	3.38	22.67	23.91	8.66	2.33	21.17	17.27	5.58	1.57
Median	25.00	37.26	14.00	3.50	24.00	24.20	9.00	2.50	24.00	17.83	6.00	1.50
Variance	8.27	269.07	1.99	0.14	19.37	9.60	0.23	0.06	39.70	9.81	1.08	0.12
SD	2.88	16.40	1.41	0.38	4.40	3.10	0.47	0.24	6.30	3.13	1.04	0.35
Min	15.00	28.66	11.00	2.56	8.00	19.11	8.00	2.00	7.00	3.18	5.00	1.00
Max	34.00	142.36	14.00	4.00	29.00	28.34	9.00	2.50	29.00	18.79	6.80	1.90
Interval	19.00	113.70	3.00	1.44	21.00	9.23	1.00	0.50	22.00	15.61	3.80	1.50
Skewness	0.22	2.05	-0.30	-1.25	-1.63	-0.18	-0.70	-0.70	-1.13	-4.50	-1.70	-1.34
Kurtosis	1.31	6.03	-1.83	0.52	2.50	-1.41	-1.53	-1.53	0.30	20.97	1.87	0.08

SD : Standard deviation

Table 36. Synthesis of descriptive analysis results for each surviving category of unexploited trees

	Recoverable (275)			Unrecoverable (121)			Standing dead (54)		
	EP	D	H	EP	D	H	EP	D	H
Mean	27.96	35.43	8.8	25.85	24.69	5.21	19.35	22.74	4.48
Median	27.00	37.22	10.00	25	24.48	5	22.50	18.27	4.00
Variance	22.09	250.10	2.10	18.63	28.8	1.97	30.08	54.39	3.63
SD	4.61	6.24	1.39	2.78	5.43	1.40	5.48	7.58	1.91
Min	20.00	27.66	6.00	9.00	18.11	4.00	8.00	2.18	2.00
Max	46.00	141.36	12.00	34.00	41.00	10.00	30.00	41.04	10.00
Interval	26.00	113.70	6.00	25.00	22.89	6.00	22.00	38.86	8.00
Skewness	1.87	2.12	-0.20	-1.26	1.25	1.89	7.50	0.90	1.67
Kurtosis	4.28	6.65	-1.48	3.52	1.62	2.94	-0.82	1.50	2.73

SD : Standard deviation

The principal information taken from both tables presented above supports the factorial analysis presented earlier and consequently the observations done on the field. In fact regarding the recovered and exploited individuals, the mean production cork thickness (25.41mm) is superior to the one registered on unrecoverable (22.67mm). and standing dead trees (21.17mm). This same observation is also valid for the male cork of non-exploited subjects.

After thirteen years of radial growth, the variables of meristematic activity namely trunk diameter and total height (Dcm-Hm) are reduced by more than 50% within unrecoverable and dead standing trees, as an indication, for the exploited trees it goes significantly from 43.53 cm-12:72m to 23.91cm-8.66m and 17.27cm-5.58m. For the exploited subjects, a highly significant difference was observed for the four variables ($p<0.001$).

For both cork types (exploited and unexploited) , figures 96 et 97 highlights a relative frequency of 77,40% to 88,10% for the recovered individuals where the thickness is higher than 25mm (dense cork) while it represents 19,71 to 72,77% and 2,88% to 22,22% for the recoverable and standing dead trees.

The fire did not act radically on all the sizes of the trunks, on the recoverable individuals, we record a relative frequency of 36% to 13.45% of cases whose diameter is more than 42,5cm, it remains almost zero in the category of sunk and dead standing. Moreover, the total heights of the rescued trees follow the same path, no trees above 11m were seen on the disturbed subjects, unlike the first category which are majority 100% (exploited trees).

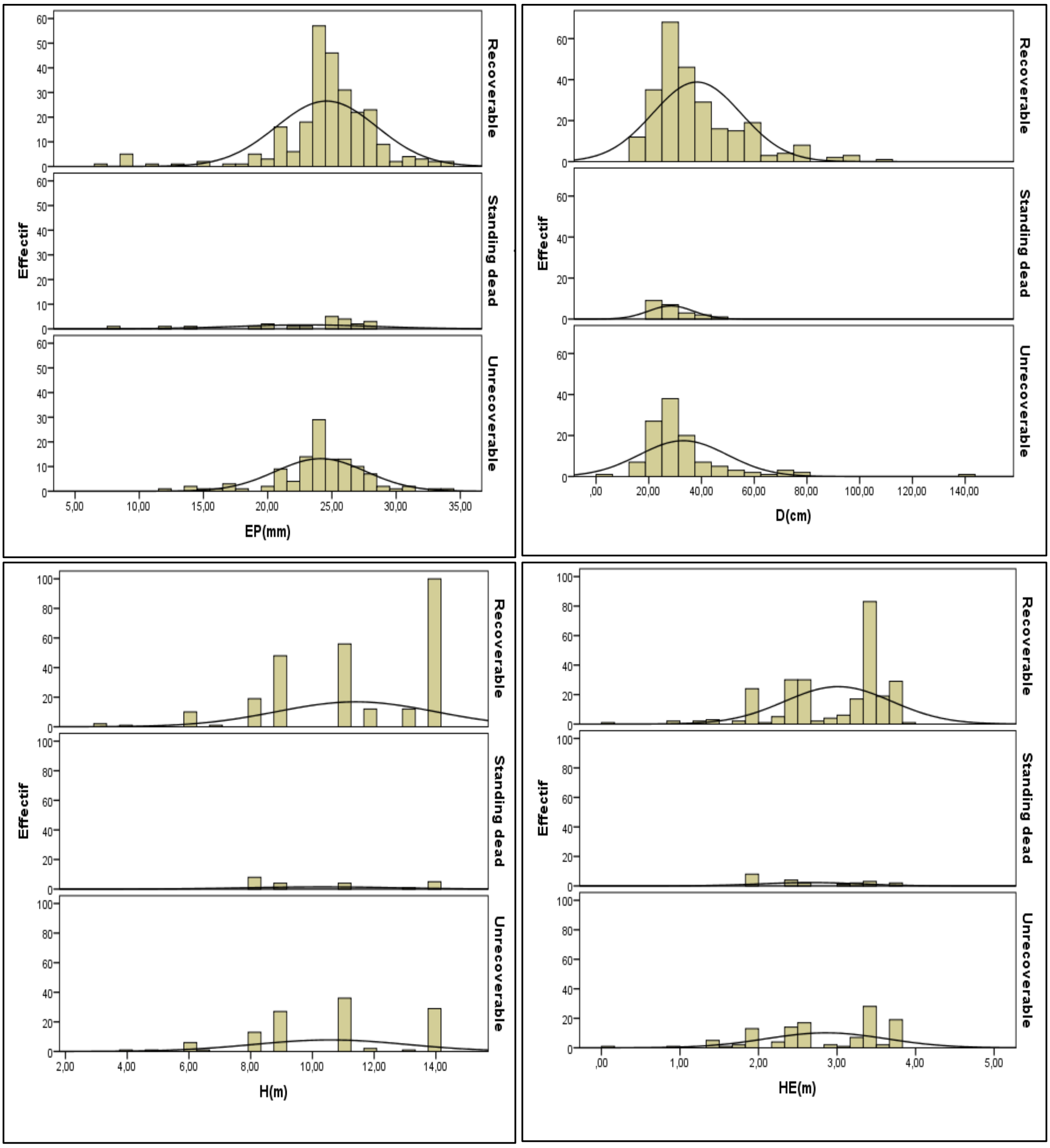


Figure 96. Distribution of the morphologic variables measured for the exploited trees by tree category

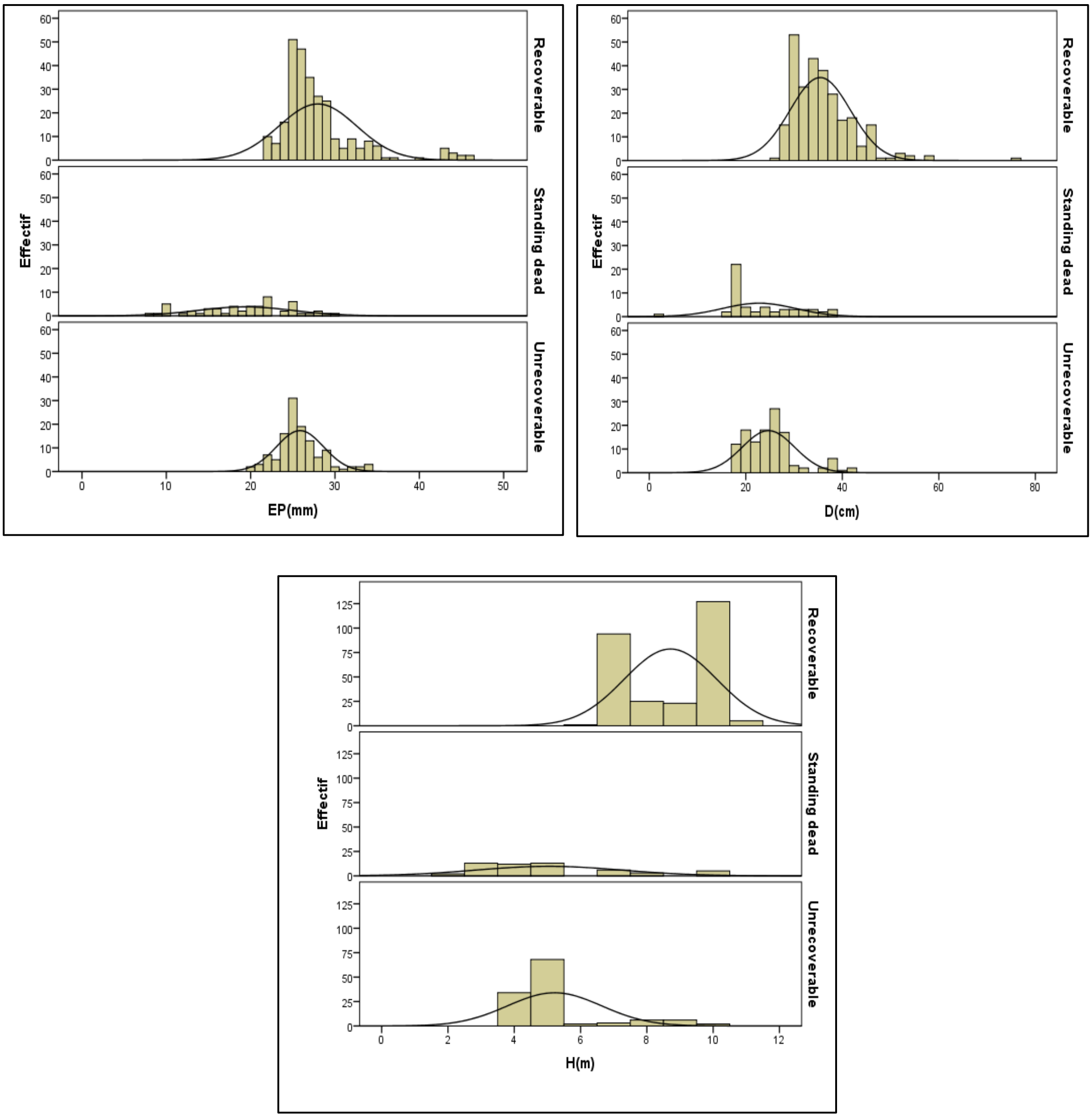


Figure 97. Distribution of the morphologic variables measured for unexpoited trees by tree category

In light of what has been measured and observed in both exploited and unexploited surviving trees, our results don't come in accordance with what has been reported in other fire-damaged cork oak forests in the Mediterranean. Our remarks follow those of Betrand (2007), indicating a strong action of fire on the morphology of small trees as those of large size whose part is higher than a high probability of being spared by the flames. Furthermore Barberis et al (2003), confirms that low scorched individuals are characterized by a higher height growth compared to strongly burned individuals.

Other statements go in this direction, the morphology of the trees (thickness, diameter and height) is known to be a very good indicator of the resistance of cork oak to fire (Uhl and Kauffman, 1990; Ondonez et al.,2005; Gonzalez et al.,2006). In this context, Pausas (1997) and Bertrand (2007) predict for the circumference a minimum and maximum mean survival varying between 37.68 and 150cm, and an average survival height varying between 5 and 12.66m, compared to our results (43.53 -23.9cm and 12.72-8.66m) exploited trees.

According to the results obtained it appears clear that cork thickness is a determinant factor for the cork oak post fire response for exploited and unexploited trees equally, trees vulnerability to fires increases considerably with the reduction in cork thickness until a threshold of 3cm. Trees with thick cork (more than 3 to 4cm) are well protected against direct damages caused by fire and consequently dieback of the tree trunk. In fact, the bark thickness role in protecting the tree from fire was confirmed by many scholars (Brando et al., 2012; Pausas et al., 2012; Ryan, 1988; Whelan, 1995). Catry et al (2012) shows that even with cork thickness lower than 3cm, the likelihood of death is still lower than other Mediterranean deciduous trees. This is probably due to high thermal insulating property that cork exhibit as a material by itself (Silva et al., 2005). The cork thermal diffusion of 20% lower than any other wood of similar density and two times lower than of the air (Martin , 1963). In a global context, all authors agree on the same conclusion: in exploited cork oaks, the thickness of the bark remains the most determining variable of post-fire survival (Lamey 1893; Pausas 1997; Barberis et al., 2003; Moreira et al., 2007; Catry et al., 2009).

VI.4.1.2-Physiological characters

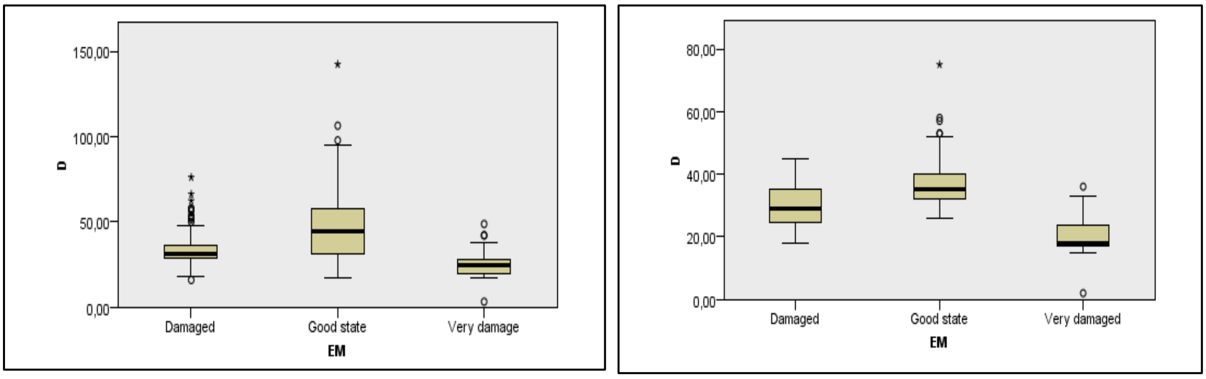
VI.4.1.2.1-State of the cork mother (EM)

The state of the cork mother is an indicator of the fire intensity. The two figures 98 and 99 shows the absolute frequencies of cavities present on trees trunks .

With respect to recoverable trees of the two types exploited and unexploited, results of figure 99 show that about 44.19% to 56% of trees with good cork good cork mother state and has diameters between entre 45-101 cm and 29-52cm.in this category the percentage of damaged cork mother appears to be highly represented by 47.67% and 43.63% for diameters ranging between 25-65cm and 28-42cm.On the other hand very damaged cork mother represented solely 8.14% and 0.36%,particularly for the diameters<20cm.

For unrecoverable and standing dead trees, damaged and severely damaged cork mother represented 31.09%-91.73% and 56.52% -8.26% respectively. On the contrary for dead on stand trees the proportions were 38.88% and 61.11 for damaged and very damaged cork mother respectively.

Overall, among the 400 subjects taken into account, 35% of cases were recorded in good state (diameter between 17.5 and 142 cm), 41% damaged (diameter between 15.92 and 76.11 cm) and 24% very damaged (diameter between 3.5 and 48.73 cm). On the 450 unexploited subjects, 34.22% of the mothers were in good condition (diameter between 28 and 53cm), 56% damaged (diameter between 19 and 45 cm) and 9.77% very damaged (diameter between 17 and 37cm). These results confirm the high intensity of the 2005 fire. The difference is highly significant for both the three categories of exploited and non-operated trees ($p<0.000$) (Fig. 100 and 101)..



Total	400	Total	450
Test statistic	121.239	Test statistic	161.848
Degrees of freedom	2	Degrees of freedom	2
Asymptotic sig. (bilateral test)	0.000	Asymptotic sig. (bilateral test)	0.000

Figure 100. Box-plot distribution representation of cork mother state for the exploited and unexploited trees .

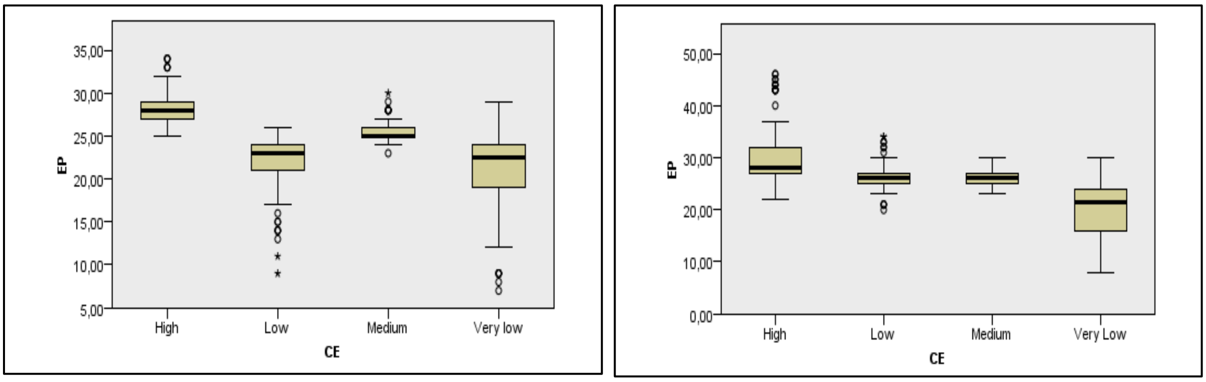
VI.4.1.2.2-Electrical conductivity (CE)

The physiological activity of the liber, intercepted by the conductivimeter is illustrated in figures 102 and 103, according to the three categories of residual trees.

The electrical conductivity for unexploited and exploited residual trees shows that recoverable trees represent a large proportion with intact and healthy phloem (30.62%- 56% of the cases) followed by non-recoverable (16.81%-0%) and standing dead (0%).

The low and very low proportions are significantly present in non-recoverable and standing dead trees with frequencies that varies between 31.40% -26.05% and 71,90%-8,26% for exploited and unexploited trees respectively. The very low conductivity class is nearly absent in the recoverable individuals. Same applies for the high and very high classes with respect to standing dead trees.

A good relationship was found between electrical conductivity and cork thickness, the highest electrical conductivity was related to thicknesses that ranged between 25mm to 35mm (exploited) and 22mm to 42mm (unexploited) whereas the weakest were related to thicknesses between 12 mm to 27mm (exploited) and 8mm to 30mm (unexploited).A very high significant difference was found between the three categories for the exploited and unexploited trees (p<0.000) (Fig.104).



Total	400	Total	450
Test statistic	273.346	Test statistic	179.395
Degrees of freedom	3	Degrees of freedom	3
Asymptotic sig. (bilateral test)	0.000	Asymptotic sig. (bilateral test)	0.000

Figure 104. Box-plot distribution representation of electrical conductivity for the exploited(Right) and unexploited trees (Left)

VI.4.1.2.3-Proportion of dead houppier (TCM)

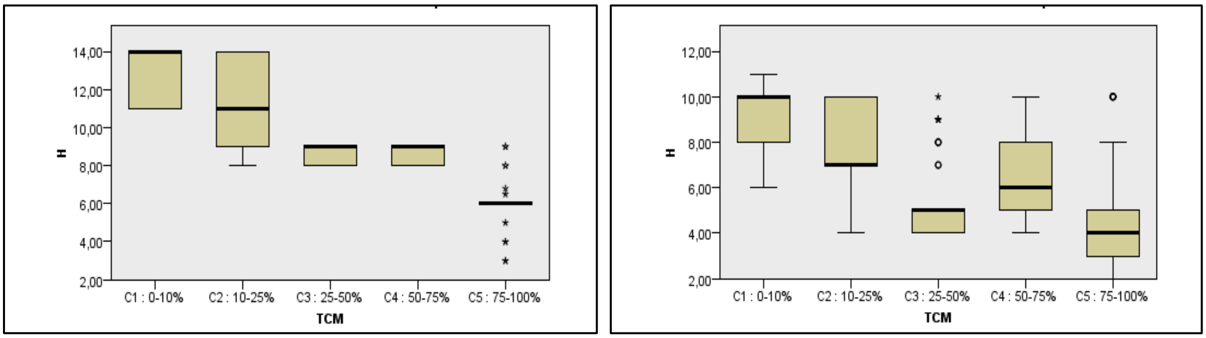
Thirteen years after fire, crown structure was heavily changed either to the initial like state (high cover and completely green) or irreversible (change of the shape, cover with presence of desiccated leaves and branches). Results of the field observations are present in the figure 105 and 106.

With regard to debarked trees, the figure shows a high dominance of class C1(0-10%) with the recoverable category, with a percentage of 94.18% of crowns completely green .with respect to the non-recoverable category the following proportions were registered : 9.24% ; 80.67% ; 6.72% ; 3.36% for the classes C2(10-25%), C3 (25-50%), C4(50-75%) and C5(75-100%) respectively.in the case of standing dead trees , the class C5 was over 100% of the cases.

As it concerns recoverable unexploited trees, the figure highlights the strong presence of trees with canopies of class C1(0-10%) representing 55,8%, followed by class C2(10-25%) representing 44,2%. For the non-recoverable category, the class 3 dominates the scene (71,90%) followed by the classes C2(10-25%), C3 (25-50%) representing 12.39% each. On the contrary standing dead trees dominates the C5 class (100%).

Overall, the survival of the crown seems to depend significantly on the height of the tree for both exploited and unexploited subjects. As an indication, for heights ranging between 11 and 14m (trees exploited) and between 6 and 11m (trees not exploited), the corresponding peaks are alive and well filled with leaves and branches C1 (0-10%).

For heights between 7 and 9m the tops appear open and dried losing between 50 and 75% of their foliage. The situation becomes chaotic for heights below 5m. The difference is highly significant for both the three categories of exploited and unexploited trees (p<0.000) (Fig.107)..



Total	400	Total	450
Test statistic	279..667	Test statistic	227.588
Degrees of freedom	4	Degrees of freedom	4
Asymptotic sig. (bilateral test)	0.000	Asymptotic sig. (bilateral test)	0.000

Figure 107. Box-plot distribution representation of dead canopies proportion for the exploited (Right) and unexploited trees (Left)

In general, we can attest that fire exerts a similar effect on the exploited and not exploited trees. Once subjected to repeated disturbance, a cork oak can no longer produce such a developed crown because of damage to the sapwood, cambium and living phloem.

This means that the raw and elaborate sap supply is very difficult and does not allow the assimilation of reserves by the periderm (suber - phelloderm - phellogen association), which explains the low to very low electrical conductivity on the burned trunks.

This also implies that the canopy mortality is the highest for the burnt trees because of the decline that follows immediately after fire .it mainly shows up by a complete drying out of the small branches, leaves and twigs regenerated after fire because of the loss in hydric conductivity due to the cavities destroying the conducting vessels giving opportunity for pest ,disease and insects to take place (Abdenbi, 2003 ; Bryan et al.,2012).

Catry et al.(2009), states that over-exploited trees , that are often subject to periodic cork debarking ,accumulate many injuries and scares that becomes vulnerable after fire (Costa et al., 2004) (Fig.108).

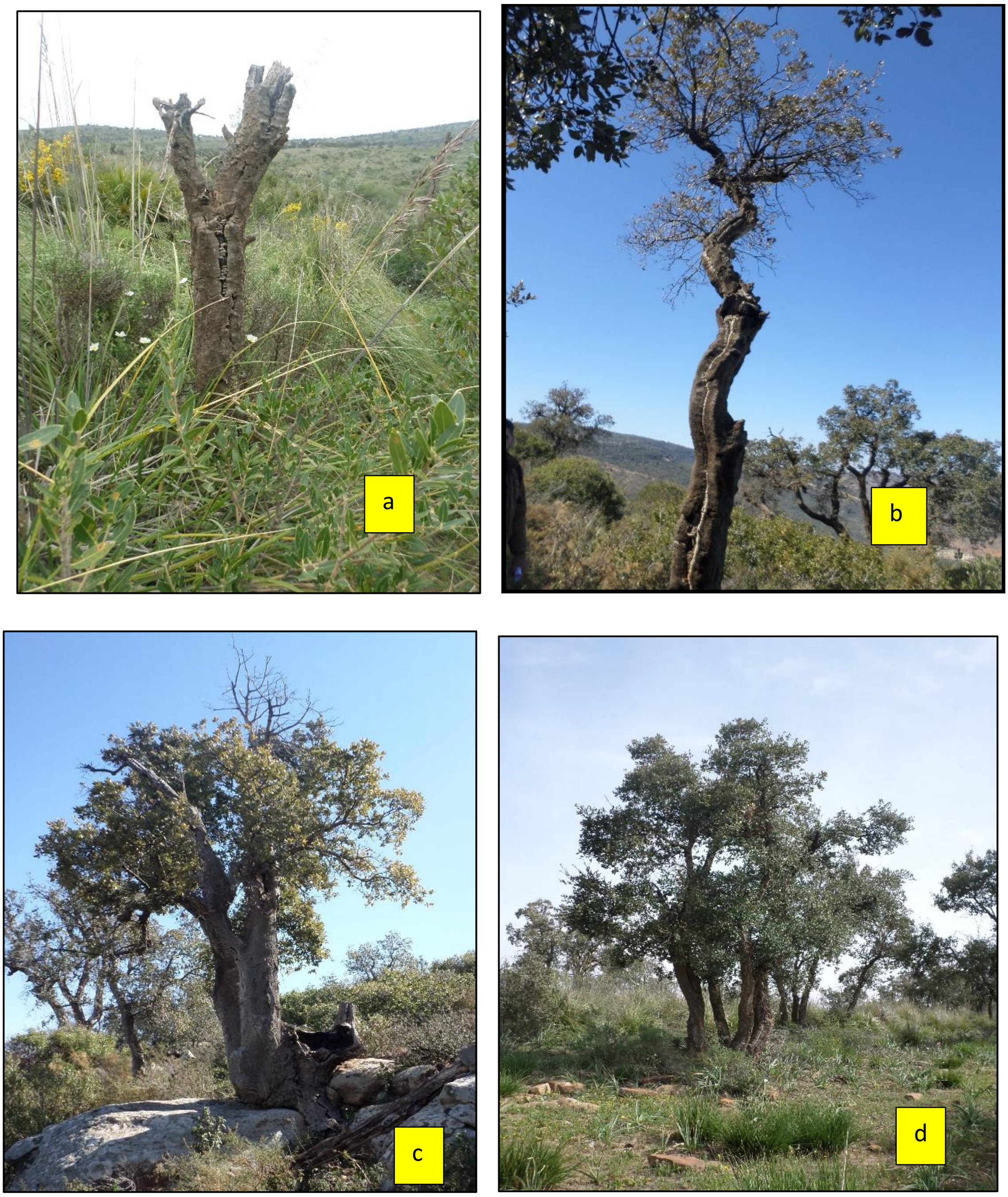


Figure 108. Type of regeneration at the top after fire (a: Total loss of the crown, b: monopodal elongation, C: Partially green crown, d: Total regeneration)

VI.4.1.3- Characterstics of meristematic response

VI.4.1.3.1-Nature of resprouts (NR)

One of the particularities of surviving trees is the resprouting of dormant buds that takes place according to the organ affected. Their distribution is explained graphically in the figures 109 et 110 according to each residual tree category.

Following both figures, we can see that fifteen years after fire ,the recoverable trees stand out with high frequency for the No sprouts (92.25% and 85.45% for the exploited and unexploited trees respectively).on the same category , the crown sprouts doesn’t exceed 7.75% and 14.54%.

Paradoxically, as sunk trees undergo disturbance, the three regeneration classes overlap from top to bottom. Strict regeneration by crown and basal sprouts records 33.61%-34.45% (exploited trees) and 25.61% - 8.26% (unexploited trees).

The combined regeneration 'crown and basal sprouts' also shows a clear frequency of 31.93% and 61.11% respectively for the two types of trees. Very disturbed standing dead subjects seem to invest more in regeneration by basal sprouts only (100%).

VI.4.1.3.2-Number of sprouts down the trunk (NBR)

The number of basal sprouts is considered a signe of a healthy and survived stump.the frequency of sprouts is show in the figures 111 and 112.

The meristematic activity following the disturbance manifest more in the unrecoverable and standing dead trees than the recoverable ones (zero response). The three classes C2: 1-2 sprouts, C3(2-4 sprouts) and C4 (>4 sprouts) register respectively 23.52% ;10.08% and 6.72% (non-recoverable exploited), and 50.01%; 27.21%; 22.78% (standing dead exploited).

With regard to the unrecoverable unexploited , the classe C3(2-4 sprouts) dominate with 66.11% while C4(>4sprouts) register only 8,26%.on the other hand , standing dead unexploited trees occupy the classes 3 and 4 only with 31.48% and 68.52% respectively.

VI.4.1.3.3-Sprouts height(HR)

The primary meristematic growth characterizing the height of basal sprouts after fire is more pronounced in the unrecoverable and standing dead individuals and absent on the recoverable (C1). The results obtained show 11.57% of cases with basal sprouts of class C2 (1-2m), 18.18% of class C3 (2-4m) and 7.43% of C4 (>4m), the rest proves no response (C1). Dead standing subjects accounted for 11.11% and 18.51% (C1 and C2) (Fig.113 and 114).

.

Figure 113. Absolute frequency of post-fire sprouts height according to each exploited residual tree category

For non-exploited subjects, the same trend is observed in unrecoverable subjects, 10.74% of basal sprouts of class C2 (1-2m); 89.26% of class C3 (2-4m). Regarding the standing dead category, 30,03% represented class (C3) while 62,97% represented class (C4).

VI.4.1.3.4-Sprouts diameter (DR)

The basal sprouts radial growth is the result of the secondary meristematic activity, mainly the vascular cambium. Post-stress radial growth reached its optimum in unrecoverable cases with 43.63%; 16.80% and 5.88% respectively for classes C2(1-15cm), C3(5-10cm) and C4(>10cm). It also remains the case for standing dead cases (54.54% (C2); 13.63% (C3) and 31.83% (C3) (Fig.115 and 116).

The figure below mentions 3.31% of cases attributable to class C2 (1-5cm); 28.92% to class C3 (5-10cm) and 67.76% to class C4 (>10cm). In the category of living dead, these two classes account for 49.80% and 50.20% respectively.

Meristematic response traits were found to be strongly related to the degree of post-fire disturbance, when the main stem dies, the stump concedes its reserves only for regeneration from basal sprouts and when the burnt stem is alive, the resources are intended for upwelling and development of the canopy (Catry et al., 2012). For these reasons, this species is probably one of the best adapted to the effects of fire (Pausas 1997, 1998; Silva and Catry 2006).

Several studies mainly confirm the role stump sprouts in the rehabilitation programs of burnt cork oak (Barberis et al., 2003; Pintus and Ruiu, 2004). They highlight the basal sprout regeneration is the most reliable and safe way for the future of the trees by coppicing the dead trunks and exclusively giving optimal conditions for the sprouts for faster growth.

The identification of factors influencing the number of sprouts related to the three trees category was done through multiple linear regression using each type (exploited and unexploited) separately.

Theoretically the number of post-fire future sprouts (NBR) is influenced by two factors :

- The elongation factor (tree height/tree diameter) (EL).
- The health state of the canopy after fire (ES).

A highly significant correlation was found , the model explained 97% of the variable (R^2=0,97) as well as adjusted (Adj-R=0,97) (Tab.36).

Table 37. summarizing the model[b]

Model	R	R^2	Adj-R	SE
1	0.985[a]	0.970	0.970	0.170

a. Predicted variables : (constant), ES, EL

b. Dependent variable : NBR

The model significant is lower than 0,05,

Table 38. Analyse of variance ANOVA[a]

Model		SSq	ddl	MSq	D	Sig.
1	Regression	366.193	2	183.097	6350.106	0.000[b]
	Residue	11.447	397	0.029		

	Total	377.640	399			

a. Dependent variable : NBR
b. Predicted variables : (constantes), ES, EL

The two variables considered shows a high significance only for ES ($p<0,000$) (Tab.38)

Table 39. Analyse of coefficients[a]

Model		Coefficients not standardized		Standardized coefficients	t	Sig.
		A	Standard error	Bêta		
	(Constant)	1.018	0.023		43.963	0.000
1	ES	0.769	0.007	0.983	111.456	0.000
	EL	0.096	0.067	0.013	1.434	0.152

a. Dependent variable : NBR

The model obtained is expressed by the following equation:

Sprouts number (NBR) = 1.018 + 0.769 houppier health state + 0.096 elongation factor

The results of the analysis shows effectively that the good trees vigour of residual trees (high health state) oppose categorically to the basal sprouting regeneration.

The number of future regrowth is strongly dependent on the degree of post-fire disturbance as well as on the morphology of the trees. If the cork oak manages to overcome its wounds and to curb the decline reversibly, the majority of its reserves is intended to restore the crown with a very limited production of stumps sprouts. On the other hand, if the decline increases, the tree enters an irreversible situation close to mortality, it then saves all its resources for a new start, with a marked production of well-developed rejects in its base in number and quality (Fig.117).

Figure 117. Partial regression plot of the dependent variable number of sprouts (NBR) of exploited trees

The figure 118 shows that the post-fire health status decline (ES>2) favors a higher basal resprouts production than the trees with a good health status (ES<2).

Figure 118. Strong basal sprouts remplacing the died trunk

VI.4.2- Characterization of cork carbonization on residual trees

VI.4.2.1-According to the total thickness of cork

The analysis of the carbonization rate according to the total thickness of the cork in each category clearly shows the dominance of the class (Crb1<20%) with 86.43% of cases among the recoverable trees exploited and 96.73% in those not exploited. Similarly,, the unrecoverable category, in turn displays only 17.67% and 19.01% of low carbonization cases, followed by 30% and 29.62% of medium carbonization cases (20%<Crb2<30%). In contrast, in this category, 52.10% and 55.35% of cases have high carbonization (30%<Crb3<40%). On the other hand, in the dead standing trees exploited and unexploited, the totality of the residual subjects shows a very strong carbonization (Crb4>40%) (Fig.119 and 120).

Figure 119. Distribution of cork carbonization classes according to the three categories of exploited residual trees by total thickness

Figure 120. Distribution of cork carbonization classes according to the three categories of unexploited residual trees by total thickness

The non-parametric statistical test indicates a highly significant difference between the total thicknesses of the three categories of trees exploited (Test KW= 55.276; ddl=2; p<0.000) and unexploited (Test KW= 102.669; ddl=2; p<0.000) (Fig.121).

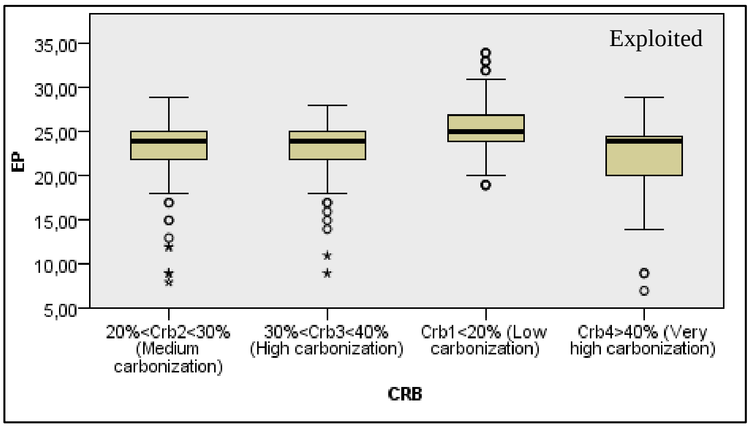


Figure 121. Box plot variation of cork carbonization rate based on the total thickness

Unexploited

VI.4.2.2-According to carbonized thickness

The intensity of the fire and its thermal heat intercepted by the corkback are immediately printed on a certain thickness of the cork commonly called the carbonized thickness. The results of the measurements carried out on the horns are represented in the table 40 according to the three categories of trees exploited and unexploited.

The descriptive statistics of the carbonized thickness inform us that the recoverable residual subjects strongly repressed the heat of the fire compared to the two other categories, which excessively intercepted it. Moreover, the average of 4.06mm-3.17mm seems much lower than that of 9.36mm-8.93mm and 15.78mm-14.03mm. With minimums varying between 1 and 3mm, maximums seem rather significant, reaching respectively global averages ranging from 8-9mm (recoverable) to 17-18mm (unrecoverable) and 24mm (dead standing).

The nonparametric statistical test indicates a highly significant difference between the carbonized thicknesses of the three categories of trees exploited (Test KW= 183.299; ddl=2; $p<0.000$) and not exploited (Test KW= 251.863; ddl=2; $p<0.000$)(Fig.122).

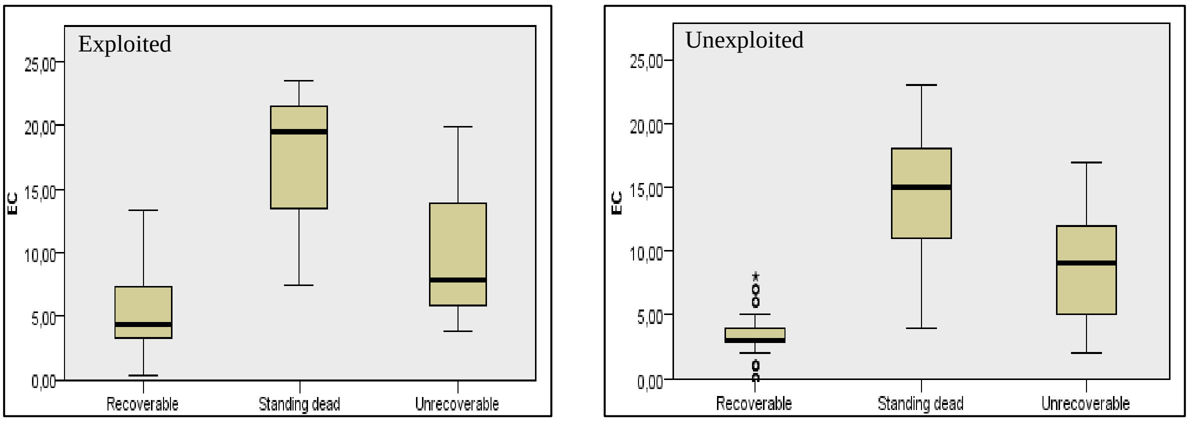


Figure 122. Box plot variation of cork carbonization thickness rate based on three residual tree categories

The figure 122 eloquently supports the results obtained, respectively for exploited and non-operated trees, the low carbonization is effectively correlated with a low carbonized thickness and it is the responsibility of the recoverable subjects (r=0.31; r=0.34). High carbonization is synonymous with a high carbonized thickness affecting more unrecoverable subjects (r=0.45; r=0.48). The observation is the same for the dead standing subjects, a very high carbonization on a great depth (r=0.60; r=0.65) fatally completes the survival of the trees (Fig. 123).

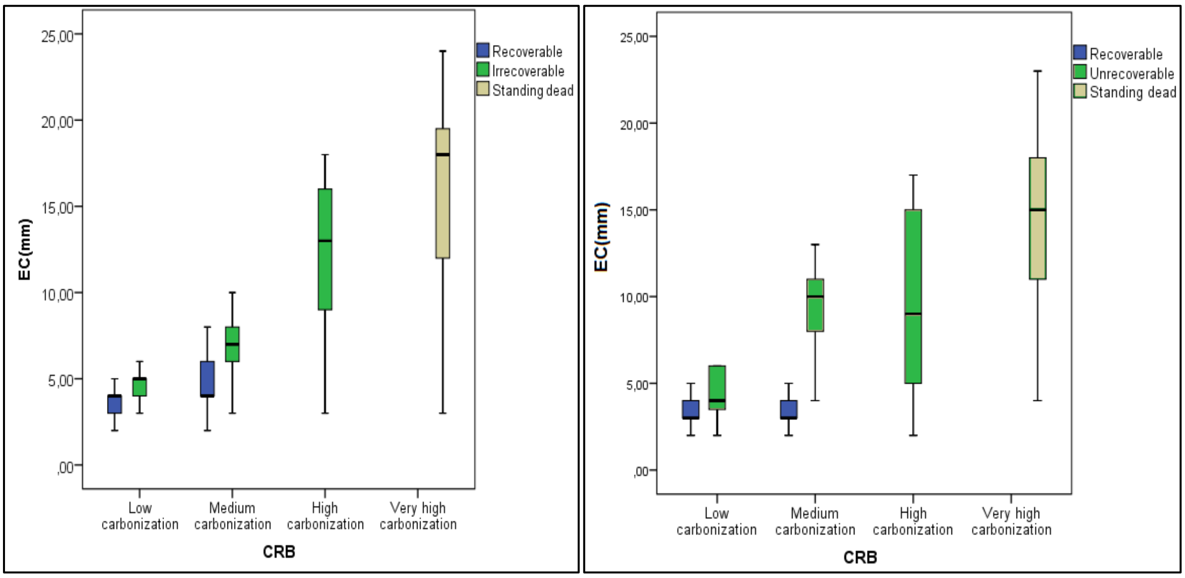


Figure 123. Distribution of carbonized thickness according to the carbonization class for the three categories of trees (left: exploited trees; right: non-exploited trees)

The bibliography is rather discreet on the problem of the carbonized thickness of cork in the forest. In our personal opinion, this bases (phellogen, inner phloem, cambium and sapwood). In the case of non-wood fuel which is cork, the thermal transmission and consumation of the suber is done slowly and gradually because of its structured composition.

This is primarily the thickness of the cork itself (thick or thin), the density of the cell walls (thin or thick), the very low level of oxygen in the suberified cells and mainly the chemical composition based on suberin.

VI.4.2.3-According to carbonization rate

The cork carbonization rate measured by cork squares scanned images in trasversal section shows a tendency to decrease That is more pronounced for the to 34.95% for the unrecoverable and finally from 75.95% à 71.42% for standing dead trees (Tab.41).

In general, a negative correlation was observed between carbonization rate and the total cork thickness for the trees residual three categories of debarked residual trees (Pearson's r= -0.44 ; Pearson test =0.000) and unexploited (Pearson's r = -0.49 ; Pearson test =0.000)(Tab.42).

The cork carbonization rates measured on the scanned images of the cross sections also show an inclination to increase on thin to very thin thicknesses. These are slices overlapping between 5 and 20 mm, suggesting high carbonization rates ranging from 10.71 to 100% for an overall average of 75.95%. This finding is more visible on dead standing subjects. Paradoxically, on thicknesses (>25mm), the carbonization rates recorded remain low varying between 3.70 and 40% for an overall average of 16.18% characterizing more recoverable subjects (Fig.125).

A negative linear regression was detected between the carbonization rate and the cork thickness classes (Fig. 126).

VI.4.3-The impact of cork carbonization rate on cork oak resilience

The longevity of cork oak post-fire, as a consequence of its good resilience in a disturbed environment cannot be detected individually for each parameter previously elucidated. All these factors act sequentially or synchronously and it is the rate of carbonization of the cork layer at the time of the passage of the fire that will define (at a later date) the ability of each subject to overcome the disturbance or to succumb gradually according to the severity of the damage inflicted on the trees.

To support the results of the various measurements and observations carried out in the field, a multi-variate analysis (MCA) was applied taking into account several quantitative and qualitative variables specific to exploited and non-operated residual trees (Tab. 43).

ACM results are recorded in the figure128 and 129.

Cork oak is a specie with remarkably adapted to forest fires, it possesses two fondamental resillience characteristics: the resistance to fire and regeneration. Fire resistance is strictly related to cork thickness in the time when the fire passes. In fact the cork carbonization rate printed in the thickness can define the type and strategy adapted by the tree: aerial regeneration(crown resprouting) or stump regeneration(basal sprouts) or both.

Two major points are distinguished on the two factor levels (exploited trees and non-exploities):

-In the first ax1 (F1), standing dead trees are opposed to living, recoverable and unrecoverable trees.

-In the second axis 2 (F2), dead and unrecoverable trees are opposed to recoverable trees. The first two categories meet on a significant rate of carbonization on exploited and non-exploited trees

Among the factors contributing significantly on the two axis and constructing on the same time the consequences of carbonization rate on the tree aspect in general, we cite:

-For the exploited recoverable trees, a superficial flaring of the cork crust, reaching at most the first three millimeters of the cork (Crb-1Rate) is not detrimental to the physiology and architecture of the crown. In other words, the temperature of the fire was absorbed by the bark and did not affect the phloem and therefore the cambium. This assumes that the flames have not reached the apex of the stem (FE- Very slender, FE-Slender, HE-Low). These individuals kept after 15 years their leafy green crown (TCM-Houppier1) and their trunks remained free of any injuries or cavities (ET-Trunk1). Physiologically, these trees are healthy, stress-free, undisturbed and have no regeneration strategy (Houppier 1+ DFL1+Trunk1), meaning that the the rise and fall of the sap has never been affected (NR-No sprouts) (Fig.130).

- For unexploited recoverable trees, virgin cork seems to be more resistant to fire than reproductive cork. According to Dehane et al. (2015), crust thickness is generally greater than that of breeding cork (7mm versus 3 mm on average). This characteristic makes that the heat of the fire carbonizes for a long time on the dead phloem then slowly reaches the thickness of the cork without being able to deteriorate the inner phloem and cambium despite the intensity of the fire (Crb-Rate 2 and 3). The temperature thus absorbed at the trunk is very little intercepted in the upper part of the crown (TCM- Houppier1 and DFL1). This stress does not result in breaking the flow of sap (NR-No sprouts).

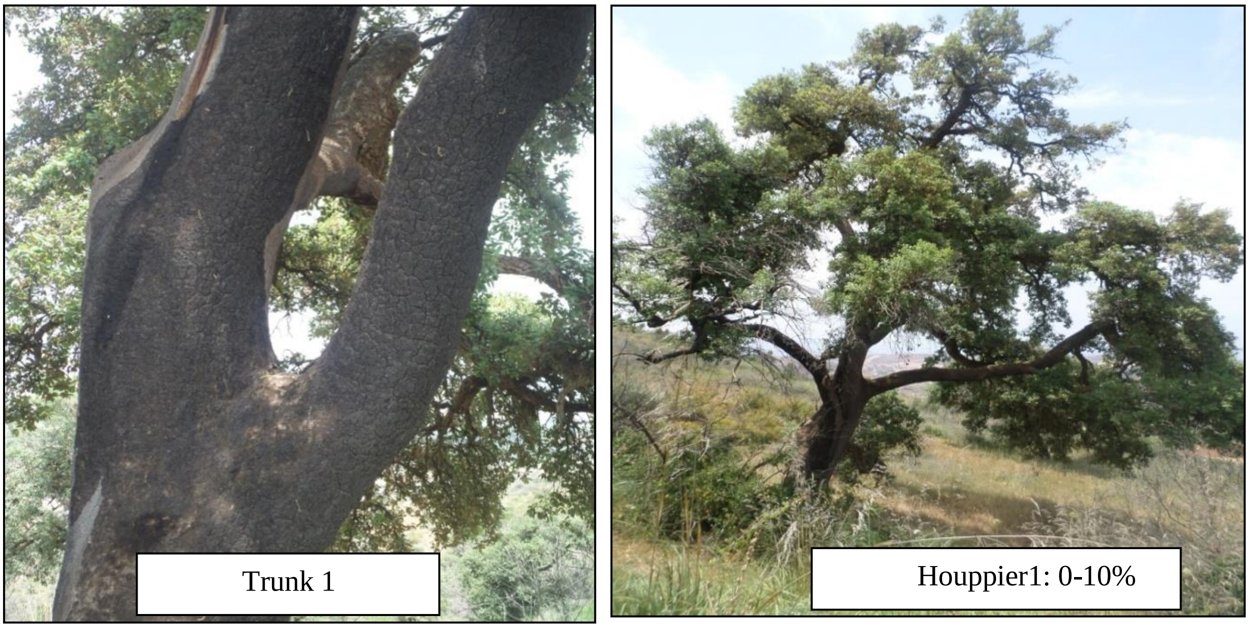


Figure 130. Recoverable tree exploited with low carbonized trunk and green canopy (fifteen years after)

-For the unrecoverable exploited trees**,** where the survival and the resillience arent insured on the long-term (delayed mortality) because of the damage intensity and the stress related to the disturbance (TCM-Houppier 2 or TCM-Houppier 3, ET-Trunk2 or ET-Trunk 3, DFL 2 or DFL 3). Indeed, the black band of carbonization at the time of the fire pierced the entire crust then beyond the first 15 millimeters of the suber. This means that the flammability time was slow in the consumption of cork affecting more or less the cambial tissues.

-The intensity of the flames rose to the apex of the stem by consuming part of the crown but the tree remained alive. The supply of elaborate and raw sap . The supply of elaborate sap and raw sap is more difficult. In the field reality, these trees were more severely affected by fire depending on the intensity and durability of iflmmability, influenced by the climate, topography and surrounding vegetation (Whelan, 1995; Schwik et al., 2006).

-These are trees with reduced morphology, appreciably stripped (FE-Moderately slender, FE- No slender, HE-Midle, HE-Strong) weakened or decayed, colportant wounds at the phloem (Fig.). In this sense, several studies indicate that the time allowed for cambium to reach lethal temperature is a function of both the thickness of the cork and its insulating aspects, namely the chemical composition and its physical structure (Ubeda et al., 2009; Bond and VanWilgen, 1994).

-The tree then evolves towards a regeneration strategy at the level of the crown to restore the organs "photosynthetically active" (Arien or crown rejects) with a tendency to growth in height of monopodal type in burst of light. According to Rosell and Olson (2014), some species, such as cork oak, can accumulate large amounts of water in the stem and, in some cases, in the inner bark (the inner phloem), which partly explains this rapid regeneration after fire. With the disturbance that the fire presents, these performances drop remarkably with measurements of low electrical conductivity (CE-Low). In this sense, Pausas (1997), classifies cork oak as the only Mediterranean species capable of regenerer its entire top calcined in a short time.

-However, the subject generates more stumps sprouts, but weakly developed in the event that dieback occurs as a result of stress caused by environmental factors (dryness, soil erosion, pruning, debarking and pathogenic diseases). According to Iwasa and Kubo (1997), the ability of the tree to regenerate in the crown or in the base depends on the storage organ and the mobilization of reserves and resources in the sprouts and in the main branches particularly carbohydrate reserves (Whelan, 1995). In critical cases, individual mortality sets in (Amo and Chacon, 2003) (Fig.131)..

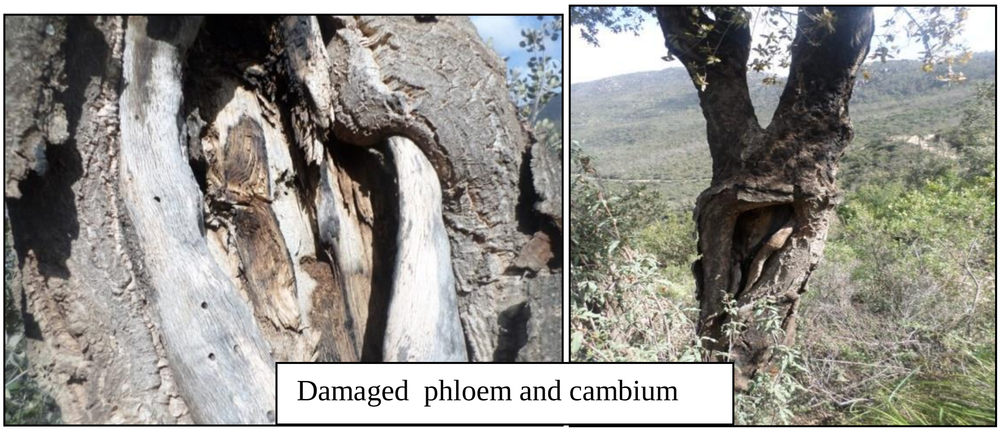


Figure 131 . Unrecoverable tree with a heavily deteriorized trunk (Thirteen years after)

-For the Unrecoverable unexploited trees**,** these are the trees with the big cavities on the cork in the moment when the fire passes that will guide its propagation (Crb Rate 2,3 et 4).The less the cork is damaged the less its susceptibility to be damaged by fire (ET-Trunk2, Crb2 Rate). Contrarily, the more cavities and damages present the more the flames will reach the cambium and take advantage from the exposed internal wood (phloem-sapwood-cambium) to reach higher calorific rates thus inducing a deadly damage to the trunk. This will give a higher chance for fires to reach the crown and start crown fires (Crb Rate 3 and 4, ET-Trunk 3 and 4, DFL2 and 3). Moreover, the sapwood flow is intercepted on the stump, forcing the tree to give a higher regeneration on the basal area (sprouts).the surviving trees present a very weak form and a prominent decline.

-In a study of the impact of fire on European oak cork, Catry et al(2009) state that exploited trees were more likely to be damaged by fire than non-operated trees, regardless of the thickness of the cork, and the interaction between thickness and operating regime showed that the thickness effect is more important on the exploited trees.

-For the debarked standing dead trees**,** the trunk is stand still but with complete absence of the physiological activity (FE- Moderately slender, FE- Not slender). A total sap rupture occured which manifest it self by a destroyed canopy (TCM-Houppier 4 et DEF 4) due to a total cork decarbonization (Crb-4 Rate) and the formation of many cavities on the trunk (ET-Trunk4).

-The two categories unrecoverable and standing dead meet on the same type of management, the removal or debarking is carried out at heights excessive (HE-Strong, HE-Very strong) but never reaching the maximum limit as in Spain and Portugal. This does not prevent irreversible repercussions on crown mortality at the time of fire. Catry et al (2009) highlight a high mortality of crowns after fire when the thickness of cork is less than 1cm and raised at the upper limit of the drum.

-The intensity of the flames has consumed the phloem (secondary phloem) and inhibited the cambium from renewing these tissues, thus deactivating the phellogen in the cork synthesis and the supply of water and sugars (Dejeagere,2005). Wright et Bailey (1982) consider the cambium exposure for one minute to a temperature of 60°C to be deadly(Fig.132).

Figure 132. Models showing the role of bark thickness (in cm) in protecting the cambium against fire heat: (a) maximum cambium temperature (°C) in relation to bark thickness during experimental fires (Uhl & Kauffman 1990; b) Time required to kill the cambium (i.e., reach 60 °C), considering an instantaneous fire temperature of 500 °C, according to Peterson et Ryan (1986)

During the past 13 years of the fire, these individuals regenerated by adopting a survival strategy based on the development of strong releases from the tree stump (Fig.133).

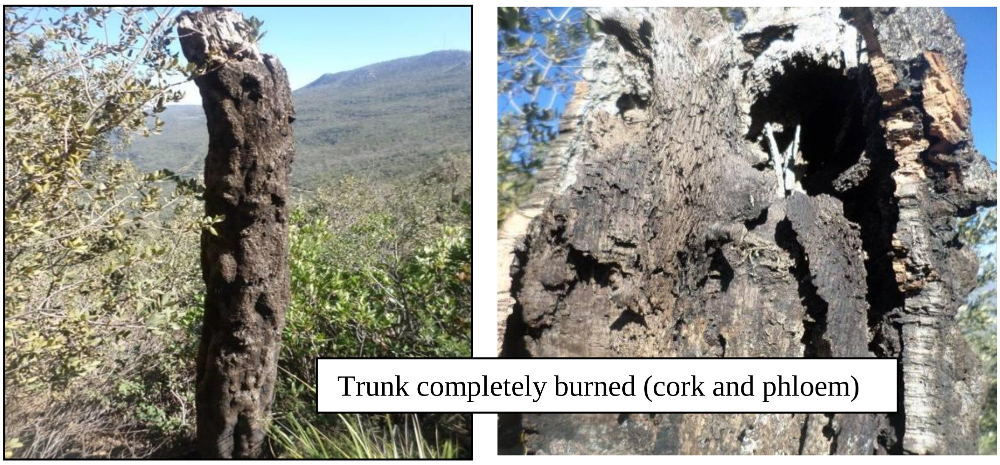


Figure 133. Standing dead tree without any vital sign on the cambium(fifteen years after)

-For unexploited dead standing trees, the burning time was more intense which led to the total carbonization of cork and wood at the time of the fire (Crb4 rate, DFL4, TCM-Houppier 4). It is the direct mortality of the crown and trunk and the cambial bed (reaction of the roots = releases of sprouts). For these subjects, the mortality remained deferred a few years later, following the late reaction of the stump (NR-basal sprouts).

-In order to argue the impact of morphological variables on cork carbonization rate, a multiple linear regression analysis was performed by interfering diameter, height and thickness regardless of tree category. The results of this analysis are entered in the table 44.

Based on the results of the table above , a significant correlation for the two tree types was found ($r=0.73^a$; $r=0.63^a$). R^2 express 54% and 63% of the independent variable variability(TC) validated by the three variables.

The p-value ($p<0,000$) associated to the variance ($F=154,64$; $F=99,42$) is very highly significant. the information added by the explanatory variables is significantly better compared to those explained by the mean of the independent variable solely using the t- student test($p<0,000$) (Tab.45).

cork carbonization rate predictive models are of the following :

- $TC_{exploited}$= 116.212-1.269Thickness -5.708Height +0.152Diameter
- $TC_{unexploited}$ = 95.055-1.373 Thickness -3.493 Height -0.265 Diameter

The three explanatory variables seem very significant for the exploited subjects ($p<0.000$) and less for the unexploited, especially for the variable diameter of the trunk ($p>0.05$). In our opinion, this is due to the physiological effect of debarking, which stimulates radial and subdusty growth during periodic cork exploitation.

VI.5-Discussion

It is therefore clear that an increase in morphology variables decreases the rate of cork carbonization. Well stable slender trees in the stand prove flame and damage resistance more than less slender subjects.

Bertrand (2007) and Pausas (2015), stipulate that the frequency of fires does not sufficiently explain the mortality of the crown and therefore the survival of the species, these are the morphological characters (thickness of the cork, height and circumference) which define the survival of residual trees after fire.

Apart way of its post-fire survival, so that the maximum limit of its delayed mortality was never known. Some studies report the death of disturbed trees even 17 and 20 years after fire (Bertrand, 2007; Dubois, 1990).

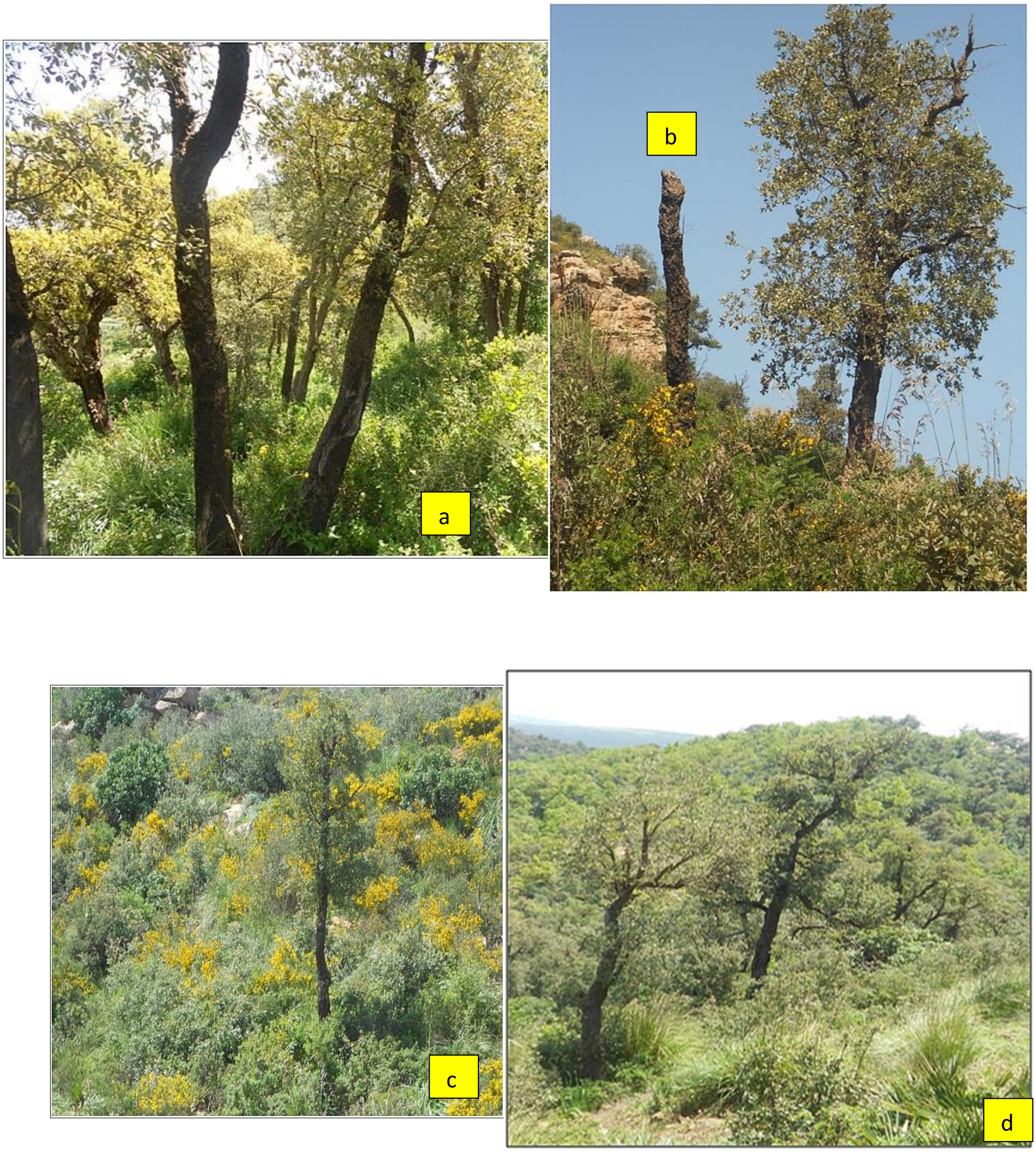


Figure 134. Example of individual resilience of surviving trees (a: Good resilience, b: Poor resilience, s and d: resilience threatened by the maquis and the schrub

Models based mainly on logistic regression have been proposed for the calculation of survival probability (Rigolot, 2002; Moreira et al., 2009). The expected goal was to predict mortality at the individual/ stand level in order to intervene after forest fires by a good management of burned stands: cutting, reclamation, clearing, enrichment or total transformation.

The probability of survival of cork oak can be modelled by logistic regression as a function of carbonized thickness. The ROC method (Receiving Operating Characteristics) (AUC) permits to define three predictive models of post-fire mortality in function of carbonized cork thickness (Fig.135).

The three ROC curves (AUC) indicate a good fit between carbonized thickness (specificity) and sensitivity with an adjusted. The area under the curve varies from 80 to 85% between the predicted probabilities and the observed results. Models for predicting maximum mortality (stem mortality + tree mortality) expressed best performance with high explained variance.
The overall association measure is given by the very significant Chi2 Test ($p<0.000$), which means that the qualitative variables taken into consideration (carbonized thickness, diameter and height) are significantly associated with mortality with increased carbonized thickness regardless of the status of the exploited or unexploited tree (Fig.136).

It is deduced from the figure that the thicker the bark of the cork (characteristics of trees of great morphology), the more is sense variable responses of trees to face the interspecific competition of the post-fire maquis. Cork oak in good resilience quickly emits 80% of its pre-fire architecture when its vascular foundations are not damaged and regenerates only at the level of its crown thanks to the reserves contained in the branches.

Paradoxically, the damage poorly healed as a function of time post-elapsed fire can be fatal for the survival of cork likely to reduce tree vigour, both because of the energy resources trees need to heal, and because the localized death of the active xylem decreases the rate of absorption of nutrients and water that activates regeneration.

In extreme situations of disturbance related to a strong carbonization of cork, the localized destruction of the trunk at the level of living parenchyma cells is accompanied by a total alteration between the crown and the strain. The great compromise is irreversible on the stem, a new start is made from the strain with powerful well-developed rejects adapting to interspecific competition. These findings are consistent with those advanced by Dubois (1990); Ubeda et al.(2006); Silva and Catry (2006).

VI.6-Conclusion

Despite its resistance, its ability to regenerate and its low mortality from fires due to the thermal insulation of the cambium allowed by the properties of the cork, the cork oak in the forest massif Hafir-Zarieffet is in regression because of the recurrence of the fires favored by the drought and the proliferation of the maquis. It is reasonable to say that in the study area, individuals with the most developed morphological characteristics (height, circumference, thickness of cork) are the most able to resist fires. On these recoverable trees, a cork thickness of more than 3cm is sufficient to fix carbonization at rates ranging from 16.18% to 11.52% (exploited and unexploited trees) and therefore inhibit damage by protecting the transfer of sap from the roots to the crown.

When the temperature of the fire intensifies, a strong carbonization of the cork varying from 42.38% to 34.95% will cause various injuries on the trunk and on the top and therefore will affect the development of the cambial seat, responsible for the circulation of the sap. Cork oak said unrecoverable would then opt for a post-fire regeneration strategy (crown and basal sprouts), linked to the resistance of these releases to decline (close to delayed mortality). These trees weakened by fires, die either from their wounds or from pest attacks, unfavourable climatic conditions or inter- and/or intra-specific competitions. Cork oaks whose morphology and growth at the time of the fire are less developed (circumference, height and thickness of the cork) are more severely affected by fire-related disturbances. Carbonization of the cork ranging from 75.95% to 71.42% is likely to completely dislocate the link between the roots of the tree and the crown, causing mortality of the main stem. These trees manage to recover from their stress by producing powerful stump sprouts. The proper development of this regeneration at the base of the tree is initially dependent on the reserves present in the stump.

Chapter VII

Study of the resilience parameters of cork oak after fire

VII.1-Introduction

Forest fires are eternal, very old phenomena (Scott, 2018), and many plant species have accumulated adaptive mechanisms that help them survive and reproduce during recurrent fires (Kelley et al.,2014; Lamont et al., 2019). Nevertheless, some authors consider recurrent fires as a disaster leading to a regression of plant communities (Kazanis et al., 1996 ; De luis et al.,2006) or aggravating soil erosion (De luis et al.,2005). The accidental occurrence of wildfires in an ecosystem requires the confluence of several factors: the ignition of the flame, the continuous fuels, the drought and the appropriate weather conditions (wind, high temperatures and low humidity) (Pausas and Keeley, 2021). Anthropogenic factors may also be a more important driver of fire acceleration than climate change (Williams et al., 2019).

Cork oak (*Quercus suber* L.) is one of the persistent sclerophyllous species. Cork oak ecosystems range from open savannahs to closed forests, along the coastline and inland in the western Mediterranean basin (Pausas et al., 2009). Cork oak bark is produced by the pellogen (cambium-cortical), a secondary meristem which maintains its activity throughout the life of the tree and forms successive annual cork layers, which can reach 30 centimeters in thickness (Natividade, 1956).

Cork stripping is done traditionally and ensures periodic renewal every 9-15 years to obtain commercial quality cork. Cork harvesting is a delicate manual process, requiring skilled workers to remove the cork with an ax without reaching and damaging the vascular cambium below the phellogen (Pereira, 2007).

However, in the Mediterranean region, the cork harvest campaign coincides perfectly with the dry season, linked to a high demand for evaporation from the air and a low availability of soil water. These inappropriate natural conditions are likely to start a fire in a cork oak ecosystem.

The species is the most adapted to the harmful effects of fire thanks to the capacity of its cork which protects it from high temperatures (Barberis et al., 2003 ; U'beda et al., 2006). This protection at the time of the fire offers good regeneration to the dormant buds once the stress has passed. It is for this reason that the cork oak is considered the Mediterranean forest tree with high resilience, with a capacity for regeneration of the stump and the crown by stimulation of the epicormic buds after total consumption of the crown (Silva et Catry, 2006; Paula et al.,2009).

On the other hand, when the fire coincides with the period of debarking and bark renewal, the damage is significant, leading directly to the death of the tree (Pausas,2019). The charred bark is accompanied by a strong loss of water along the barked trunk, with a reduction in nutritional functions and intense consumption of reserves stored in the vascular tissues of the tree (Guedje et al., 2007). Catry et al. (2012) also assume that the wounds caused and poorly healed after debarking are open doors to flames and thermal heat, and therefore considered as the main causes of the vulnerability of cork oak to fire (Rundel , 1973).

Many studies have addressed the impact of fires on the resilience of cork oak as a forest fuel, studying the relationships between fire temperature and the chemical properties of leaves, flammability and humidity, bark role, tree characteristics, abiotic factors and stand management practices (DeBano, 1998 ; Guijarro et al., 2002 ; Liodakis, 2006 ; Dehane et al., 2015).

All these studies assume that the resilience of the cork oak is variable and diverges depending on the morphological characteristics of the trees, the environmental conditions, the type of fire and its behavior during the season. Gaoue and Ticktin (2010) support that early season fires, coinciding with tree flowering or full physiological activity, can have a greater negative impact on resilience than later fires.

In this context, it should be noted that in the context of this chapter, no study has addressed the response of cork oak after fire through the study of its physical aspects of growth and quality, according to a monitoring before and after resilience.

VII.2-Aim of the study

The main aims of the study were to assess the effects of fire on the prameters of resilience: 1) strategie of regeneration after perturbation of surviving trees ; 2) evolution of physical and quality variables of cork . Results are based on the monitoring of two treatments: cork stripped after fire (after resilience) and stripped control trees before fire (before resilience). Main measurements comprised: annual cork growth, cumulative thikness, volumetric density and quality indexes.

VII.3-Materials and methods

VII.3.1-Choice of study site

In the said cork grove, the lifting of the cork is traditionally done every 15 years to obtain commercial quality cork (>27 mm). The time elapsed since the last harvest goes back to the year 2007 (i.e. the age of the bark) and is naturally linked to the thickness of the cork of the harvested trees, because the bark regrows annually after stripping.

This cork oak forest (Zarieffet) well known for its quality cork production, is also becoming very famous for the number of fires that characterize it since years. The forest archives report seven major fires that swept through the cork oak forest of Zarieffet: 1892, 1903, 1964, 1983, 1994, 2005, 2015. In favor of this alarming finding, cork production has also fallen, from 20,000 quintals between 1939 and 1951 to 600 quintals in 2007.

VII.3.2-Data collection

Our research was based on the last fire recorded by the forestry services during the month of March 2015, having ravaged 45 ha of cork oak. The time between the date of the fire and the measurements of the tree was maintained according to two separate follow-ups:

VII.3.2.1-Monitoring during the year 2015

To do this, we followed the natural limits drawn by the fire and we carried out our prospecting on a total area of 10 hectares including both stripping and unstripping surviving cork oaks. Only trees bearing a reproduction cork were considered for sampling. par itinéraries.

On each georeferenced sample tree, we recorded the total height, the diameter at breast height, the health status of the tree and the intensity of the damage. The evaluation of the damage and its intensity was based on the state of the bole and the crown of the trees (intact or burned). Based on these parameters, the trees were classified into three categories:

.

- colored ashes. The soils begin to be affected, hydrophobicity appears on the surface layer up to 2 cm, and they take on a reddish color. The roots are not affected beyond their most superficial layer. The stems of the maquis and the fine fuels are completely carbonized but are not completely consumed. The trees are blackened and leafless, but they are not totally charred, allowing better recovery. For this category, we intercepted 170 trees.

- areas on steep slopes with a large amount of fine fuels or with a large accumulation of debris. These fires produce gray or even white ash, characteristic of total combustion. They do not leave traces of foliage or maquis. The soils are affected and produce crystallizations and blocks of clay, blackening up to 10 centimeters deep and and even sometimes almost the whole foot, especially on the feet affected by cracks or crevices. In this category, we encountered only 40 trees. Totally dead subjects (stem and stump), moreover very few, were discarded in this study.

For each of these three categories, we extracted cork to the method described in the two preceding chapters (Fig.138).

In the laboratory, dried in an ambient environment for one week. The four sides of each cube were sanded and then cleaned with compressed air to quantify the following variables:

- Cork thickness: total thickness was determined for each sample from belly to back with a digital caliper. The age of the cork was estimated by counting the number of full growths (f.g.) plus the (
- rule of 1 mm accuracy and mass was determined with a precision balance of 0.001 g. Thickness value includes also the thickness of the scrape.
- Index of quality: (CICYTEX,2015).

VII.3.2.2-Monitoring during the year 2022

Seven years after the first monitoring, we were interested in the same sample trees, easily identifiable by the shape of the square left on the trunk. The same experimental protocol executed in 2015 was adopted in 2022. On the trunk of each intercepted tree, we took the quantity of cork produced in the last 7 years on the same sample of 2015(Fig. 139).

In front of each operated subject, qualitative and quantitative parameters were recorded to assess the degree of post-fire resilience. The two aspects of the resilience of the cork oak after fire essentially relate to the regeneration strategy adopted by the tree and to the evolution of certain physical variables linked to corky activity from 2015 to 2022 such as the annual growth, cumulative thickness, basal volumetric density, and quality indices.

The state of resilience of each tree is an approximate value noted between 4 and 1, estimated according to the type of regeneration post fire (resprouting from the base (stump) only, resprouting simultaneously from the base and the crown, or resprouting from the crown only):

-Class 1: High resilience tree (HRT) (4): foliar deficit < 25%, small dry and burnt branches, no cavities or
leaf loss, completely charred crown, dried twigs and branches with very apparent stump shoots.

Thus the resilience status after 7 years of follow-up is calculated as follows:

F: frequency of resilience class C from 4 to 1.
N: number of trees sampled by class in the itinrary or in the plot

The post-fire resilience status classes are defined as follows:

-

For each parameter measured, the mean and the standard deviation were alternated by an ANOVA (univariate) (SPSS Statistics 21.0 software).

VII.4-Results

Among the first harmful consequences of a fire in a cork oak or other forest ecosystem is that it reduces the overall density of stands and acts on the structure and morphology of trees and clearly causes the forest to retreat. In this context, the distribution of the residual subjects according to their diameters and their heights gives us an indication of the intensity of the fire.

VII.4.1-Morphology of surviving trees

The distribution of sample trees by estimated mean (diameter and height) and by tree category is shown in figure 140 .

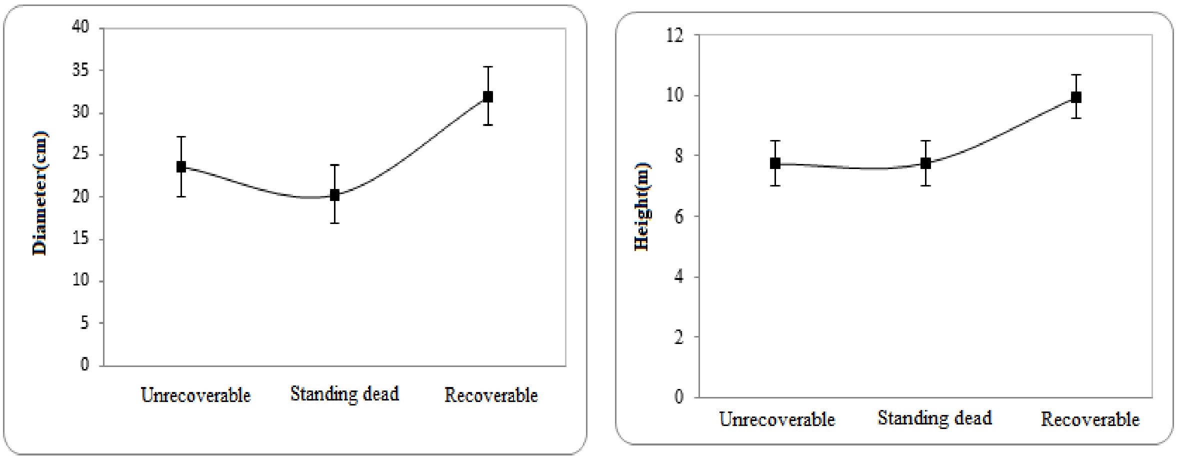


Figure 140. Estimated average diameters and heights of resilied trees

As shown above, from the figure 140, it is clear that the surviving trees have less developed diameters and heights than sunk and dead trees, and have differences in morphology.

As an indication and simultaneously, the average diameters vary between 31.95cm (recoverable trees) and 23.58cm (unrecoverable trees). In addition, standing dead subjects, the average heights are generally below 7m. According to Dubois (1990), after the fire, the tree recognizes the sequelae of the fire at the level of the cambium, the latter acts by slowing down the radial growth in height and in width for years after the fire.

VII.4.2-Evaluation of the resilience variables of the surviving sample trees

VII.4.2.1-The resilience status

The results of post-fire adaptation of the surviving trees after 7 years of monitoring are mentioned in figure 141.

During 7 years of monitoring, the results reveal that the recoverable sample trees appear vigorous, with 83.33% of trees revealing high resilience (HRT) and only 16.67% with medium resilience (ART). In trees classified as unrecoverable, they appear mostly affected, with 40% of ART cases and 46.67% of low resilience (LRT). On the other hand, on the standing dead trees, the fire only perpetuates very altered and erased subjects including 73.33% of very low resilience (VLRT), and 26.67% (LRT). The resilience status show good adaptation for recoverable surviving trees1 (IR=3.80), remain delayed for those unrecoverable (IR=2.67) and seriously fatal for those of standing dead trees (IR=1.23).

VII.4.2.2-Growth

The cork produced annually by the tree is a natural tissue resulting from the growth of the secondary meristems which are the cambium and the phellogen. These two generative layers (vascular and cortical cambium) are commonly called libero-ligneous layer and subero-phellodermal layer.

VII.4.2.2.1-Annual growth

The variations in the annual growth of cork are presented in the complete cycle (7 years) for the three categories of trees before and after resilience (Fig.142).

Recoverable trees**:** Focusing on the figure, recoverbale trees seem less susceptible to fire stress. Moreover, the corky growth resulting from the activity of the cambium and the formation of the traumatic phellogen (when the cork layer is removed) remains stable in the complete cycle (2008-2014) before fire and after stress(2015-2021). Ring width is highest in the first year and decrease steadily in the following years and remains subsequently rather constant with the reduce of age of phellogen. A perfect concordance between the annual increases of cork and the trend curve (R^2=0.99 and R^2=0,98))(Fig.142a, 142b and 142c).

Nevertheless, the passage of the fire in 2015, was not intercepted in the same way by all the recoverable trees. A significant difference was recorded during the 7 years of post-fire resilience (2015-2021) compared to the situation before the fire(2008-2014) ($p<0.0001$)(Fig.134 c). For a cycle of 7 full years, the average annual growth of cork varies from 2.51mm/year (before resilience) to 2.04mm/year (after resilience), i.e. a reduction of 18.72%.

Unrecoverable trees**:** The intensity of the disturbance is more visible on unrecoverable trees whose vascular cambium seems to react in a more or less effective way to the stress of the thermal gradient of the flames. In the 7-year cycle (after resilience), the curves of the annual cork growth record a very marked slowdown during 2015 (Fig.143 b).. This sudden stop in the first ring width is clearly linked to the passivity of the phellogen (under stress) whose cells no longer divide under the the effect of lethal heating and consequently the forced blocking of reserves coming from the stump. A weak concordance between the annual cork increments and the trend curve after resilience (R^2=0.53).

For a cycle of 7 full years, the average annual growth of cork varies from 2.42mm/year (before resilience) to 1.13mm/year (after resilience), i.e. a reduction of 61.98% (Fig. 135c).

Standing dead trees**:** The aftermath of the 2015 fire has been firmly rooted in standing dead trees. A very weak corky activity was recorded according to the progressive mortality of the cambium and the phellogen during the 7 years which followed the fire of 2015 (2015-2021). The growth curves remain adjusted to the general trend of the linear regression model for post-fire stress (R2=0.76) (Fig. 144 a and 144b).

For a cycle of 7 full years, the average annual growth of cork varies from 2.48mm/year (before resilience) to 0.26mm/year (after resilience), i.e. a reduction of 89.51% (Fig.144c)..

VII.4.2.2.2-Cumulative thikness

The figure 136 highlights a slight drop of cumulative cork growth for recoverable trees, an average reduction from 18.09±0.93mm (before resilience) to 14.81±0.77mm (after resilience), i.e. by roughly 3.28 mm. This pattern seems dislocated for the unrecoverable trees which record a very slow corky activity of the order of 8.11±0.09mm after resilience against 16,17±0.08mm before resilience (Fig.145).

Moreover, this situation is very deficient for standing dead trees which only produce an average of 2.00±0.10mm in 7 years of reesilience, a significant reduction of 14mm. The Z test of comparison of the means observed before and after resilience indicates a highly significant difference between the measurements of the thicknesses of the cork ($p<0.000$).

The Z-test of comparison of the averages observed before and after resilience indicates a very significant difference between the measurements of the thicknesses of the cork ($p<0,0001$) (Tab.46).

Table 46. Z-test for volumetric density for the three tree categories

Difference	3.28	8.05	14.00
z (Observed value)	28.13	43.80	62.65
|z| (Critical value)	1.96	1.96	1.96
p-value (bilatéral)	<0.0001	<0.0001	<0.0001
alpha	0.05	0.05	0.05

VII.4.2.3-Volumetric density

The results of the measurements of the volumetric density of the cork samples before and after resilience are illustrated in the figures according to the three categories of trees (Fig.147).

Indeed, for the recoverable trees, the cork volumetric density values measured after resiliense turn out to be increased to those recorded before resilience, i.e. an average rise of around 10.72 kg/m^3 (272.88±1.78 kg/m^3 to 283.59±1.89 kg/m^3).

In the other hand, for unrecoverable subjects and standing dead trees, the measurements reveals a trend towards increased of the volumetric density, respectively 62.22kg/m^3 (257,36 ±1.89 kg/m^3 (before resilience) to 319.58 ±2.13 kg/m^3 (after resilience) and 80.30kg/m^3 (267.20 kg/m^3 ±3.25 kg/m^3 (before resilience) to 347.50 ±3.24 kg/m^3 (after resilience).

The Z test of comparison of the means observed before and after resilience indicates a highly significant difference between the measurements of the density of the cork ($p<0.000$)(Tab.47).

Table 47. Z-test for volumetric density for the three tree categories (IR)

Difference	10,72	62,22	80,30
z (Observed value)	6,50	59,80	64,44
|z| (Critical value)	1.960	1.960	1.96
p-value (bilatéral)	**<0.0001**	**<0.0001**	**<0.0001**
alpha	0.05	0.05	0.05

VII.4.2.4-Quality indices

The results of the evolution of the quality indices before and after resilience are recorded in the figure148 .

The figure 140 highlights contrasting fluctuations of the quality indices during the year 2015 and updated in 2022. Statistically, a very significant difference is recorded by comparing the observed averages of the IQ before and after the resilience (p<0.001).

For the samples of recoverable trees, the IQ decreases significantly after 7 years of resilience with an annual average of 0.66. The The values obtained for the main cork features in the three resilience classes classes are summarised in table 48, respectively for growth, thickness, density and IQ variables.

Concerning the IQ of unrecoverable trees, a significant regression was observed (annual IQ =2.46) during the 7 years of resilience. The quality index, recorded in 2015 (IQ=8.29) decreased in 2022 (IQ=5.83). Concerning the IQ of standing dead subjects, a significant regression was reported (annual IQ=7). The quality index, recorded in 2015 (IQ = 8.57), dropped considerably in 2022 (IQ = 1.5), a difference of 7.07(Tab.48).

Table 48. Test Z pour l’indice de qualité pour les trois catégories d’arbres

Différence	0.66	2.46	7.07
z (Observed value	4.99	10.78	10.93
|z| (Critical value)	1.96	1.96	1.96
p-value (bilatéral)	**<0.0001**	**<0.0001**	**<0.0001**
alpha	0.05	0.05	0.05

VII.4.3-Resilience status/cork features

The table 49 summarizes the values obtained for the main characteristics of cork after resilience, respectively for the variables of annual growth, thickness, density and quality index.

The table clearly outlines a good representation of post-fire resilience variables in recoverable trees. The average values of the

The same applies for the cumulative thicknesses, the high resilience recorded during seven years of monitoring is attributable to the trees slightly affected by the flames than those moderately and strongly calcined, (Unrecoverable, IR-2) and 347.02 kg/m^3 (Standing dead tree, IR-3).

The repercussions of the when the trees and samples are grouped according to their Résilience status. The anova test indicates that the average values of these variables show significant differences according to their resilience status ($p < 0.000$).

VII.5-Discussion

The results obtained for the morphology of the surviving trees seem logical because the cork oaks have a very significant on the morphology and growth of small trees. The latter are more likely to be completely affected by the flames than large cork oaks whose upper part has a higher probability of not being burned (>10m).

Indeed, the larger the trees, the thicker the bark, which acts as cambium insulation, resulting in an increase in the resistance of the trees to disturbance by fire (Uhl and Kauffman,1990). The circumference values obtained for the three categories of trees(100,32cm; 74,04cm and 32,27cm) are close to those published by (Pausas, 1997) and Dubois (1990): above a circumference of 37.68 cm, the stem cannot die.

After the fire, the cork oak adopts a very distinct résilience strategy depending on the intensity of the fire:

-Virtually no sprouts when the tree is not disturbed under a low intensity fire. It is clear that this organism, but can only be applied when the vital organs (in particular the cambium) are not seriously affected.

When the fire regime intensifies, the trees show more and more damage, the tree then evolves according to two strategies:

- if the) in case the dieback continues (quoted in this study by low resilience tree (LRT) and average resilience tree(

)), and all the reserves are intended for the production of sprouts at the level of the stump.

Avice et al. (1996) estimate that once the photosynthetic biomass is reconstituted after disturbance by fire, the carbon set by the sprouts is used in the continuous growth of the reiduel tree.

The results show a great reciprocity between the degree of resilience and certain physical parameters of the was recorded between the volumetric density and the cumulative thickness of the planks , with an increase in the samples with low to very low ring-width, with latecork dominance (r=-0.72).

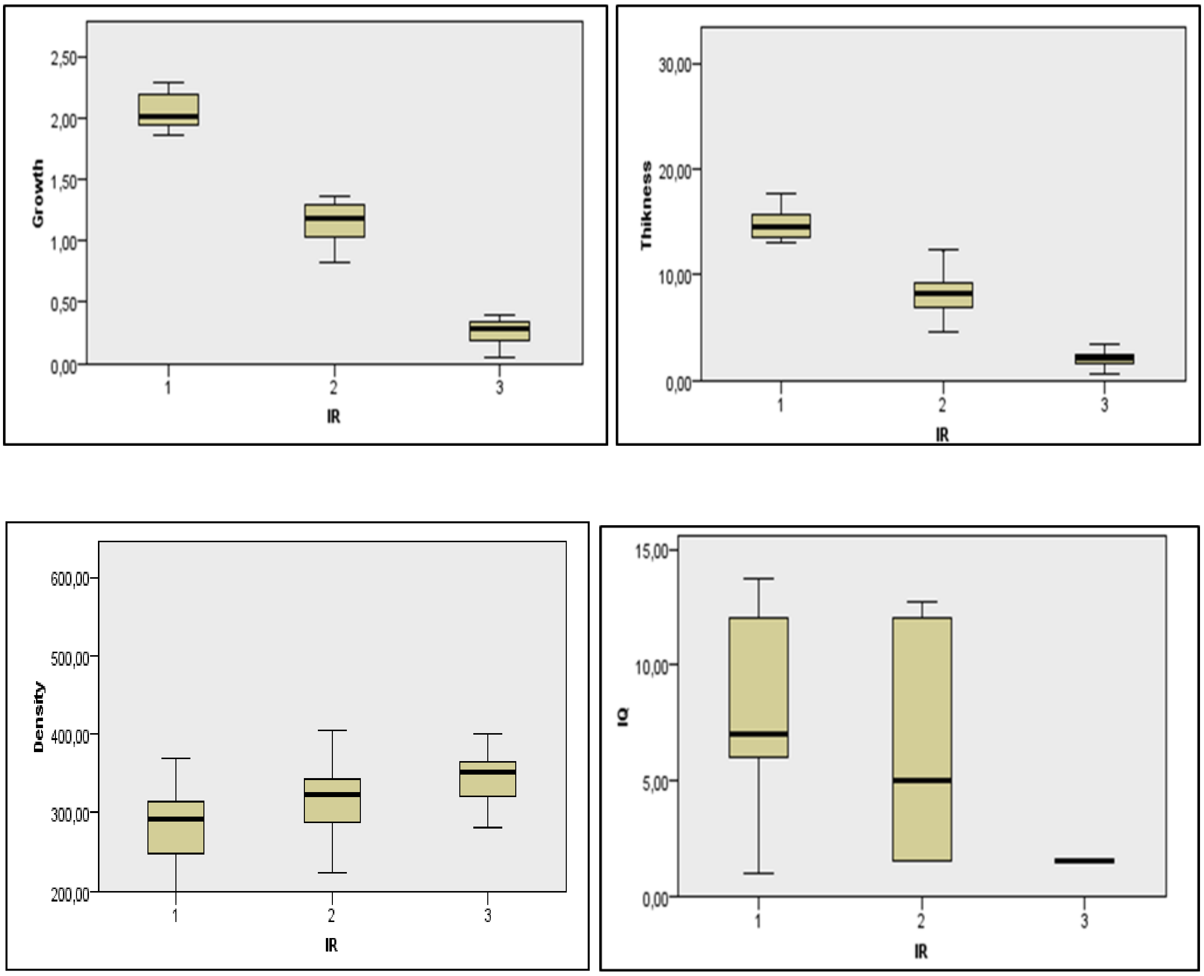


Figure 149 . Distribution of cork features by resilinece status

Bertrand (2007) and Catry et al. (2010) state that fires suspend growth and severely affect vascular tissue. and slows down its subsequent annual growth. This also suggests that resilience is more initiated by the thickness of the cork; which, acting as a thermal insulator and mechanical protector, gives the trees their fire resistance (Hare, 1965; Silva et al., 2006) (Fig.149).

From a physiological point of view, the decrease in the physical parameters of cork in trees disturbed by fire coincides. This is particularly the result of soil disintegration after a fire, leading to deterioration of soil structure, followed by loss of organic matter and mineral elements (Duguy et al., 2007).

Moreover, the forced blocking of the stump during the months preceding the fire remains fatal for the cork thickness and improving its quality by promoting the functioning of the phellogen (Orgeas and Bonin; 1996; Robert,1997 ; Courtois and Masson, 1999).

Indeed, a malfunction of the phloem and the phellogene during the post-fire cork production cycle would have and physical characteristics of cork. Moreover, the quality indices obtained were better on recoverable trees.

These last, slightly affected by fire, the two vital layers of the tree (cambial and cortical assises) are spared the age of the tree and the cork production cycle. As disturbance increases, the funtional phloem of unrecoverable trees may also adapt negatively to the thermal gradient of fire inducing in the still living stump. The cork produced by these trees is very hard without any elasticity.

VII.6-Conclusion

Despite its resistance, its capacity for regeneration and its low mortality in the face of fires due to the thermal insulation of the cambium allowed by the properties of cork, we consider the situation of the cork oak and the cork forest to be worrying at Zarieffet.

gradient at the time of the fire scorches the crown and the trunk, the mortality of the main stem increases (standing dead trees), the strategy of resilience is then dictated by the stump of the tree still active.

From these three configurations, the degree of resilience of the surviving trees seems strictly related to the response of the traumatic phellogen formed after the debarking of the cork. First degree resilience is, making the cork very thin and strongly hard, unsuitable for any use. This situation is completely canceled with the mortality of the cambium and the phellogen under a third degree resilience.

In the context of climate change, it is very likely that the frequency of the fire regime should increase, leading to the disappearance of cork oak stands and their replacement by species of very fire-resistant maquis. The of unrecoverable and dead standing trees remains the siniquanon solution for a better start for the surviving trees facing the maquis.

General conclusion and outlook

General conclusion and outlook

At the end of this work, we can conclude, in view of the results obtained, that the resilience of the cork oak in the Hafir-Zarieffect forest massif is dependent on the rate of carbonization of the cork. We are in the presence of a disturbed community, poorly adapted to the passage of fire, generating three categories of residual trees, recoverable, unrecoverable and standing dead trees.

For each category declared unexploited or exploited, after the inflammation of the corkback (dead phlom) the progressive carbonization of the cork is immediately triggered and not its conflagration.

The flammability slow alteration of the cork (47.10% (virgin cork) and 32.12% (reproduction cork).

The high averages of the flammability parameters of the two corks, namely ignitability, durability and consumability, are the consequence of low combustibility resulting from its low thermal conductivity, allocated mainly to the destruction of its structure and its chemical compounds. identified in the form of gradual carbonization.

The results revealed a % for the reproductive cork. At 450ºC, the combustion process is completed, leaving an ash residue of 2.60 and 2.9% of the initial cork.

The study conducted using remote sensing and GIS took multiple parameters into account such as vegetation,.the results showed that high risk class were present in pure cork oak and mixed cork oak coniferous stands. Medium risk occupied mixed oaks and low risk classes on pastureland and agriculture.

Human factors, particularly proximity to roads, significantly influenced the risk model. Sensitivity analysis highlighted a greater emphasis on the vegetation index over topo-morphology, potentially impacting model accuracy.

Out of all human index parameters, roads were the primary ignition source.the use of vigilance towers, fuel breaks where understory vegetation coupled with weather conditions on the risk model in addition to scenario based effective fuel treatment strategies.

The cork carbonization mechanism in the laboratory was also approved in cork groves, by monitoring the three rate).

On recoverable trees, a thickness of in the short nor in the long term).

The fire intensifies more on subjects with low morphology, with trunks damaged during past harvests. A strong carbonization of the cork varying from 42.38% to 34.95% causes various injuries on the trunk and on the upper subjects, weakened by post-fire stress, therefore suffer delayed mortality, either from their injuries, from attacks by insects and pathogenic fungi, from unfavorable climatic conditions or from inter and/or intra-specific competition.

Very strong carbonization of the cork ranging from 75.95% to 71.42% is capable of causing mortality of the main stem. This results in a complete dislocation between the roots of the tree and the crown. These trees manage to recover from their stress by producing powerful stump shoots. The proper development of this regeneration at the base of the tree is initially dependent on the reserves allowed by the stump.

The impact of the quality indices.

The monitoring carried out (in the Zarieffect cork grove) for seven years, before and after resilience, revealed that the state of resilience of the surviving trees seems strictly linked to the response of the traumatic phellogen formed after the debarking of the cork.

The state of first degree phellogen, under third degree resilience (IR-3) (IQ = 1.5).

This work opens up some perspectives for us to be able to approach the problem of post-fire resilience in a detailed manner:

1-The effect of the recurrence of fires is a very serious social phenomenon, to be considered by the local population, the forest manager and the higher authorities. All means of fighting fire must be put on the ground to anticipate 2-In the context of current climate change, it is very likely that the frequency of the fire regime will increase, leading to the disappearance of cork oak populations and their replacement by very fire-resistant maquis species. The conservation of the Hafir-Zarieffect forest massif must be carried out within a framework of management reducing the biomass from the maquis, through clearing operations, particularly in the very flammable bushy caummunity.

3- The response of the plant to a single fire or to a series of repeated fires is very different. The current protection system and dead standing trees (coppice) remains essential for a better start of the residual trees facing the scrub.

4-The results of this study for crown fires.

5-The appropriate management of debarking and periodic harvesting of cork must anticipate the fire. The most judicious solution is to effectively avoid cork production in a regular system and instead give priority to production operations in an irregular system, but with alternate and extended years for trees forming the same stand. This type of management remains the best solution for maintaining sufficient cork thickness in order to reduce vulnerability to fire and preserve the cork oak ecosystem.

References

References

1. A.E.F.C.O.,(1914). Fascicule de gestion de la forêt domaniale de M'Sila de 1861 à 1950.Cantonnement d'Oran.
2. Abatzoglou J. T., Williams A. P., & Barbero R., (2019). Global Emergence of Anthropogenic Climate Change in Fire Weather Indices. Geophysical Research Letters, 46(1), 326–336. https://doi.org/10.1029/2018GL080959
3. Abbas M., (2013). Incidence économique des feux de forêts sur les subéraies. Journées d'étude sur la réhabilitation des suberaies incendiées et Reboisement Université de Tlemcen du 16 - 17 janvier 2013
4. Abdendi Z.E.A. (2003). Le dépérissement des forêts au Maroc : Analyse des causes et stratégie de lutte. Science et Changements Planétaires/Sécheresse, 14(4), 209 -218.
5. Acácio, V., Holmgren, M., Rego, F., Moreira, F., & Mohren, G. M. J. (2009). Are drought and wildfires turning Mediterranean cork oak forests into persistent shrublands? Agroforestry Systems, 76(2), 389–400. https://doi.org/10.1007/s10457-008-9165-y
6. Adab H., Kanniah K. D., & Solaimani K., (2013). Modeling forest fire risk in the northeast of Iran using remote sensing and GIS techniques. Natural Hazards, 65(3), 1723–1743. https://doi.org/10.1007/s11069-012-0450-8
7. Aime S., (1976). Contribution à l'étude écologique du chéne liége .Etude de quelques limites.Thése Doct.de spécialité, Université de Nice.France, 180 p.
8. Ait Mouhoub D., 1998 - Contribution à l'étude de la sécheresse sur le littoral algérien par le biais de traitement des données pluviométriques et la simulation. Thèse de Magister, Ecole nationale polytechnique d'Alger, 128 p.
9. Alcaraz C., (1969). Etude géobotanique du pin d'Alep dans le tell Oranais. Th. Doct. 3ème cycle. Fac. Sc. Montpellier. 183 p.
10. Alexandrian D., Esnault F & Calabri G., 1998 - Feux de forêt dans la région méditerranéenne. Unasylva 50 (197) : 35 - 41.
11. Amandier L., Santelli J.,(2004), Typologie des suberaies varoises, ONF, CRPF PACA, IML Vivès, ASL Suberaie varoise, 175 p.
12. Amandier, (2002), Le comportement du Chêne-liège après l'incendie : conséquences sur la régénération naturelle des suberaies. VIVexpo 2002 : Le chêne-liège face au feu. France.13p
13. Anderson HE (1970) Forest fuel ignitability. Fire Tech 6: 312-319.
14. Ammar A., (2001). Etude des plantes médicales localisées dans la région de Ain Ghoraba (wilaya de Tlemcen). Thèse de Magistère. Méd. Pop. Université de Tlemcen. Vol I, 63p.
15. Amo E, Chacón C, (2003). Recomendaciones selvícolas para alcornocales afectados por el fuego. Cuadernos Forestales, IPROCOR, Mérida
16. Angelidis A., (1994), La politique de l'Union Européenne concernant la protection des forêts contre les incendies. CIHEAM, IAM Zaragoza, « La protection contre les incendies de forêt », 9-20 mai 1994, 57 p.
17. Anteur D., Benaradj A., Fekir Y., & Baghdadi D., (2021). Zakour Forest fire risk map assessment in the commune of Mamounia (Mascara, Algeria). Folia Forestalia Polonica, 63(1), 21–35. https://doi.org/10.2478/ffp-2021-0003
18. APCOR (2009). APCOR yearbook 2009. Lisboa: Associaca˜o Portuguesa de Cortica. Available: http://www.realcork.org/userfiles/File/Publicacoes/
19. APCOR, (2012). Cork, 2012.File/Publicacoes/Anuario.pdf.

20. Appiagyei B. D., Belhoucine-Guezouli L., Bessah E., & Morsli B. (2023). Simulating land use and land cover change in a semi-arid region from 1989 to 2039: The case of Hafir-Zariffet forest, Tlemcen, Algeria. GeoJournal. https://doi.org/10.1007/s10708-023-10853-2
21. Appiagyei B. D., Latifa B.-G., Boutkhil M., & Bessah E., (2020). Evolution of Mediterranean Forest Ecosystems and Impact of Natural and Anthropogenic Disturbances: Case of the Cork Oak Forest- Tlemcen- Algeria [Preprint]. In Review. https://doi.org/10.21203/rs.3.rs-31687/v1
22. Arfa A. M. T., Benderradji M. E. H., Gérand T. S., & Alatou D., (2019). Cartographie du risque feu de forêt dans le Nord-est algérien: Cas de la wilaya d'El Tarf. Cybergeo: European Journal of Geography. https://doi.org/10.4000/cybergeo.32304
23. Aronson, J., Pereira,J.S., & Puasas, J.G., (2009). Cork Oak Woodland on the edge. Islandpress. Washington. Covelo. London, 350p.
24. Atmo, (2023). Feux de forêts : quels impacts sur l'air et le climat ? Atmo, publié le : 11 May 2023.
25. Avice, J. C. et al., (1996). Nitrogen and carbon flows estimated by 15N and 13C pulse-chase labelling during regrowth of alfalfa. – Plant Physiol. 112: 281–290.
26. Babrauskas V., (2002). The Cone Calorimeter, In: SFPE Handbook of Fire Protection Engineering, 3rd edn, pp. 3-63–3-81, National Fire Protection Association, Society of Fire Protection Engineering (Ed.), Quincy, MA.
27. Babrauskas V., (2003). Ignition Handbook, pp. 1124, Fire Science Publishers, Issaquah, WA.
28. Bagnouls F. & Gaussen H., (1953). Saison sèche et indice xérothermique. Bull.Soc.Hist.Nat. Toulouse.88 (3-4) :193-239.
29. Balch J.K., Bradley B.A., Abatzoglou J.T., et al., (2017). Human-started wildfires expand the fire niche across the United States. P Natl Acad Sci USA 114: 2946–51.
30. Barber C., Bates L. D., Barron R. W., & Allison H., (1993). Assessment of the relative vulnerability of groundwater to pollution: A review and background paper for the conference workshop on vulnerability assessment.
31. Barberis A, Dettori S, Filigheddu M.R., (2003). Management problems in Mediterranean cork oak forests: post-Wre recovery. Journal of Arid Environment, 54:565–569. doi:10.1006/jare.2002.1079
32. Barbero M., Bonin G., Quezel P., et Loisel R., (1990). Changes and disturbances of forest ecosystems caused by human activities in the Western part of the mediterranean basin. Vegetatio 87 : 151-173.
33. Barlow J, Berenguer E, Carmenta R, et al., (2020). Clarifying Amazonia'sburning crisis. Glob Change Biol 26: 319–21.
34. Batista, A. C., Biondi, D.,(2009). Avaliação da inflamabilidade de Ligustrum lucidum Aiton (Oleaceae) para uso potencial em cortinas de segurança na região sul do Brasil. Revista Brasileira de Ciências Agrárias, Recife,4 (4):435-439.
35. Bauer G., Speck T., Blömer J., Bertling J., Speck O., (2010). Insulation capability of the bark of trees with different fire adaptation. J. Mater. Sci. 45 (21) : 5950–5959.
36. Beaudin I., (2007). Potentiel de la télédétection pour le suivi et la caractérisation des conditions de sécheresse n milieu méditerranéen. Rapport de Maîtrise en Sciences Géomatiques, Université Laval, 233p.
37. Bekdouche F., (2010). Evolution après feu de l'écosystème subéraie de Kabylie. Diplôme de Doctorat d'Etat en sciences Agronomiques.Univ.Tizi-Ouzou.120p.

38. Belahbib N., Pemonge M. H., Ouassou A., Sbay H. Kremer A., and Petit R. J.. (2001). Frequent cytoplasmic exchanges between oak species that are not closely related: *Quercus suber* and *Q. ilex* in Morocco. Molecular Ecology 10:2003–2012.
39. Belgherbi B., Benabdeli K., & Mostefai K., (2018). Mapping the risk forest fires in Algeria: Application of the forest of Guetarnia in Western Algeria. Ekológia (Bratislava), 37(3), 289–300. https://doi.org/10.2478/eko-2018-0022
40. Belhadj-Aissa M., (2003). Application du SIG et de la télédétection dans la gestion des feux de forets en Algerie. Risk Management.
41. Bellarosa R., (2000). Introduction: Brief synthesis of the current knowledge on cork oak. Pp. 11–22 in M. C. Varela, ed. Evaluation of Genetic Resources of Cork Oak for Appropriate Use in Breeding and Gene Conservation Strategies. Handbook of the concerted action FAIR 1 CT 95-0202. INIA-Estação Florestal Nacional, Portugal.
42. Bellingham P.J. and Sparrow A.D., (2000). Resprouting as a life history strategy in woody plant communities. Oikos 89, 409-416.
43. Bellingham P.J. et Sparrow A.D., (2000). Resprouting as a life history strategy in woody plant communities. Oikos 89, 409-416.
44. Benderradji M.H., Alatou D., et Arfa A.M.T., (2004). Bilan des incendies de forêts dans le Nord-Est algérien Cas de Skikda, Annaba et El Tarf période 1990-2000. Forêt méditerranéenne 15(3) : 211-218.
45. Benest M. & Bensalah H., (1995). L'Eocène continental dans l'avant-pays Alpin d'Algérie : environnement et importance de la tectogenèse atlasique polyphasée. Bull. Serv. Géol. L'Agerie. 6(1), 41-59, 8 fig.
46. Benest M., (1971). Importance des mouvements de coulissage et de rotation dans la mise en place de la partie occidentale de la dépression de Sebdou (Monts de Tlemcen, Algérie). Bull. Soc. Hist. Nat. Afr. Nord, 62 (1-2) : 21-38, 5 fig., 3 pl.
47. Benest M., (1985). Evolution de la plateforme de l’Ouest Algerien et du Nord-Est Marocain au cours du Jurassique superieur et au début du Crétacé :Stratigraphie,milieux de dépôts et dynamique sédimentaire.Thèse Doc.Es.Sci.,Fasc.1 et 2,Univ.Lyon,585p.
48. Benguerai A., Benabdeli K., & Harizia A., (2019). Forest Fire Risk Assessment Model Using Remote Sensing and GIS Techniques in Northwest Algeria. Acta Silvatica et Lignaria Hungarica, 15(1), 9–21. https://doi.org/10.2478/aslh-2019-0001
49. Benkirane, H., Benslimane, R, Hachmi, M. et Sesbou, A., (2000). Possibilité de contrôle automatique de la qualité du liège par vision artificielle. Ann. For. Sci. 58 : 455 – 465.
50. Bensaïd S., Gasmi A., Benhafied I., (2005). Les forêts d’Algérie, de Césarée laromaine à ce jour. Rev. Forêt méditerranéenne., 2006, T.XXVIII, n 3, 271p.
51. Bentekhici N., Bellal S.A., & Zegrar A., (2020). Contribution of remote sensing and GIS to mapping the fire risk of Mediterranean forest case of the forest massif of Tlemcen (North-West Algeria). Natural Hazards, 104(1), 811–831. https: // doi.org/10.1007/s11069-020-04191-6
52. Benyacoub,S., (1993). Ecologie de l’avifaune forestière nicheuse d’El Kala (Nord-Est) algérien), Thése Uni.Bourgogne,Dijon,273p.
53. Berdón Berdón J., Bernal Chacón C., Cardillo Amo E., Encinas Barbado M., (2015). Régénération et restauration des suberaies incendiées. Edition: CICYTEX-Centro de Investigaciones Científicas y Tecnológicas de Extremadura.41p.
54. Bernard M. and Nimour N., (1993). Inflammabilité des végétaux Méditerranéens et feux de forêts: role de l’eau sur exothermicité de leur réaction,” Science Technique Technologie,. 26 : 24–30,.

55. Bertrand R. (2007). Etude de l'impact du régime d'incendie sur la végétation et le chêne-liège (Quercus suber) en Provence siliceuse: mortalité, capacité de régénération et morphologie. Mastère spécialisé « Forêt, Nature et Société », 95p.
56. Blanco E., González M. A. C., Tenorio M. C., Bombín R. E., Antón M. G., Fuster M. G., Manzaneque A. G., Manzaneque F. G., Saiz J. C. M., Juaristi C. M., Pajares P. R., and Ollejo H. S.. (1997). Los Bosques Ibéricos. Una Interpretación Geobotánica. Planeta, Barcelona, Spain.
57. BNEDER. (2009). Plan national de développement forestier (PNDF). Rapport de synthèse national, 87p.
58. Boavida L. C., Silva J. P., and Feijó J. A., (2001). Sexual reproduction in the cork oak (Quercus suber L.). III. Crossing intra- and interspecific barriers. Sex Plant Reproduction 14:143–152
59. Bond W.J., van Wilgen B.W. (1994). Fire and plants. Chapman & Hall, London.
60. Bond, W. J. and Midgley, J. J., (2001). Ecology of sprouting in woody plants: the persistence niche. – Trends Ecol. Evol. 16: 45–51.
61. Bouabdallah H., (1991). Dégradation du couvert végétal steppique de la zone Sud-Ouest oranaise (cas d'El-Aricha). Thèse. Magister, Univ. Oran . 207 p + ann.
62. Bouaoune, D., et M. Dahmani-Megrerouche,, (2010)., Reconstitution de données climatiques pour l'Algérie du Nord : application des réseaux neuronaux.» C. R. Geoscience 342: 815–822.
63. Bouazza M., (1995). Etude phyto-écologique des steppes à Stipa tenacissima.L et Lygeum spartum.L au Sud de Sebdou (Oranie-Algérie). Thèse. Doct. Sci.Univ.Tlemcen. 275 p+ Annexes.
64. Boubkeur H., (2016). La foret algérienne face aux feux : proposition d'un dispositif de prévention et de lutte . Journal Algerien des Regions Arides (JARA). Numéro special,13p.
65. Boudy P., (1948). Economie forestière Nord-Africaine. Milieu physique et humain. Ed. Larose, Paris, Tome I, 684 p.
66. Boudy P., (1955a). Economie forestière nord-africaine. Tome IV, Description forestière de l'Algérie et de la Tunisie. 483 p. Ed. Larose, Paris carrée Nîmes, 361 p.
67. Boudy, P., (1955b). Economie forestière Nord-Africaine. Monographie et traitement des essences. Tome III, Fascicule 1, Larousse (Ed.), Paris, France.
68. Bouhraoua R.T, (2003). Situation sanitaire de quelques forêts de chêne –liège de l'ouest algérien.Etude particulière des problèmes posés par les insectes.Thèse. Doct. Dept. Forest. Fac.Sci.,Univ.Tlemcen , 267 p.
69. Bouhraoua R.T., (2013), Effet de la récurrence des feux sur la dégradation paysagère, l'altération sanitaire et la réduction de la production du liège de la suberaie du massif forestier de Hafir-Zarieffet (Tlemcen, Algérie), 2e rencontre méditerranéenne gestionnaires-industriels-chercheurs sur les suberaies et la qualité du liège Université de Jijel (Algérie) – 18 & 19 octobre.
70. Bowen B.J., Pate J.S., (1993). The significance of root starch in postfire shoot recovery of the resprouter Stirlingia latifolia R. Br. (Proteaceae). Ann Bot 72:7–16.
71. Bowman D. M. J. S., Williamson G. J., Abatzoglou J. T., Kolden C. A., Cochrane M. A., & Smith A. M. S., (2017). Human exposure and sensitivity to globally extreme wildfire events. Nature Ecology & Evolution, 1(3), 0058. https://doi.org/10.1038/s41559-016-0058
72. Bugalho, M. N., Caldeira, M. C., Pereira, J. S., Aronson, J., & Pausas, J. G. (2011). Mediterranean cork oak savannas require human use to sustain biodiversity and

ecosystem services. Frontiers in Ecology and the Environment, 9(5), 278–286. https://doi.org/10.1890/100084.

73. Brando P.M., Nepstad D.C., Balch J.K. (2012). Fire-induced tree mortality in a neotropical forest: the roles of bark traits , tree size , wood density and fire behavior. Global Change Biology , 18: 630–641.
74. Brando P.M., Nepstad D.C., Balch J.K., (2012). Fire-induced tree mortality in a neotropical forest: the roles of bark traits, tree size , wood density and fire behavior. Global Change Biology 18: 630–641.
75. Bravo, F., Jandl, R., LeMay, V., & Gadow, K. (2008). Managing forest ecosystems: The challenge of climate change (1st ed.). Springer, pp.338.
76. Breteau P., (2021). Incendies en Grèce, Finlande, Algérie… visualisez l'ampleur des feux en Europe et dans le bassin méditerranéen. Le monde, article publié le 20 août 2021.
77. Bryan G., Bowes J., Mauseth D. (2012). Structure des plantes, Quae, 2012, p. 159.
78. Byun H. R., Wilhite D.A., (1999). Objective quantification of drought severity and duration. Journal of Climate, 12, 2747-2756.
79. C.F.W.T. (1914). Fascicule de gestion de la forêt domaniale de Zarieffet.4p.
80. C.F.W.T., (2007). Bilan exploitation du liège dans la forêt de Zarieffet. Circonscription, de Tlemecen.1p. C.W.F.T., 2008
81. C.F.W.T.,(1996). Répartition des forêts domaniales de la circonscription par district et par commune. Circonscription de Tlemcen, 4 p.
82. Cabezudo B., Pérez-Latorre A., and Nieto J. M., (1995). Regeneración de un alcornocal incendiado en el sur de España (Istán, Málaga). Acta Botanica Malacitana 20:143–151.
83. Calama R., Sánchez-González M., Garchi S., Ammari Y., Cañellas I., & Tahar, S., (2012). Towards the sustainable management of thuya (*Tetraclinis articulata* (Vahl.) Mast.) forests in Tunisia: Models for main tree attributes. Forest Systems, 21(2), Article 2. https://doi.org/10.5424/fs/2012212-02532
84. Calitz W., Potts, A. J.; Cowling, R. M., (2015). Investigating species-level flammability across five biomes in the Eastern Cape, South Africa. South African Journal of Botany, Amsterdam, v. 101, p.32–39,.
85. Campbell D., (1995). The Campbell preditction system|A Wildland Fire Prediction and Communication System (Fourth Edition). Self-Published.
86. Cardillo E.,Bernal C., & Encinas M.,2007-El alcornocal y el fuego.ICMC.ISBN/978-84-612-0002-3.91p.
87. Catry FX, Moreira F, Pausas JG, Fernandes PM, Rego F, et al. (2012). Cork Oak Vulnerability to Fire: The Role of Bark Harvesting, Tree Characteristics and Abiotic Factors. PLoS ONE 7(6): e39810. doi:10.1371/journal.pone.0039810
88. Catry F.X., Rego F, Moreira F., Fernandes P.M., Pausas J.G., (2010). Post-fire tree mortality in mixed forests of central Portugal. Forest Ecology and Management 206: 1184–1192.
89. Catry F.X., Moreira F. Inês Duarte I., Acácio V. (2009). Factors aVecting post-Wre crown regeneration in cork oak (Quercus suber L.) trees. European Jounal of Forest Research, 128:231–240. DOI 10.1007/s10342-009-0259-5
90. Cattau M.E., Wessman C., Mahood A, et al., (2020). Anthropogenic and lightning-started fires are becoming larger and more frequent overa longer season length in the USA. Global Ecol Biogeogr 29:668–81.
91. Certini G., (2005). Effects of fire on properties of forest soils: a revie Oecologia, 143:1-10.

92. CFWT ., (2017) . Bilan des opérations d’exploitation du liège à Tlemcen, 2p
93. CFWT, (2004). Rapport sur l'identification des zones de Montagnes.
94. CFWT, (2023). Rapport présenté dans le cadre de la journée nationale sur la forêt, Tlemcen.
95. CFWT., (2022). Bilan des incendies dans la subéraie de Zarieffet,2p.
96. Chorana, A., (2021). Etude et élaboration de la carte de qualité du liège de la région Nord-Ouest d'Algérie [Study and elaboration of the cork quality map of the Northwest region of Algeria]. Doctoral thesis, (Algérie: Département des Ressources Forestières, Université de Tlemcen, 210p.
97. Chuvieco E., & Congalton, R. G., (1989). Application of remote sensing and geographic information systems to forest fire hazard mapping. Remote Sensing of Environment, 29(2), 147–159. https://doi.org/10.1016/0034-4257(89)90023-0
98. CICYTEX (2015). Guide des bonnes pratiques en matière de détermination de la qualité du liège et récolte de liège avec des nouvelles technologies[Guide to good practices in cork quality determination and cork harvesting with new technologies]. [WWW document] URL http://cicytex.juntaex.es/descargas/descargar.php?id=265
99. Claire A., (1973). Notice explicative de la carte lithologique de la région de Tlemcen au 1/100000.
100. Collignon B., (1986). Hydrologie appliqué des aquifères karstiques des Monts de Tlemcen (Algérie), Tome 1. Mémoire de Doctorat nouveau régime, en hydrogéologie, Univ. D'Avignon.
101. Conde, E., Cadahia, E., Garcia-Vallejo, M. C., and Adrados, J. R. G., (1998). “Chemical characterization of reproduction cork from Spanish Quercus suber,” J. Wood Chem. Technol. 18(4), 447-469. DOI: 10.1080/02773819809349592.
102. Correia O., Oliveira G., Martins-Loução M. A., and Catarino F. M., (1992). Effects of barkstripping on the water relations of Quercus suber L. Scientia Gerundensis 18:195–204
103. Costa A., Pereira H., Oliveira A. (2004). The effect of cork-stripping damage on diameter growth of Quercus suber L. Forestry 77:1–8. doi:10.1093/forestry/77.1.1
104. Costa J.J., Oliveira L.A., Viegas D.X., Neto L.P., (1991). On the temperature distribution inside a tree under fire conditions. Int. J. Wildland Fire 1 (2), 87–96.
105. Costa-e-Silva F., Correia A.C., Pinto C.A. , (2012). Effects of cork oak stripping on tree carbon and water fluxes. Forest Ecology and Management. https://doi.org/10.1016/j .foreco.2021.118966.
106. Courtois M. and Masson, P., (1999). Contribution à l'analyse des facteurs de la qualité du liège brut [Contribution to the analysis of the quality factors of raw cork]. Forêt mbtlitermnbenne 2, 95-102
107. CRPF, (2015). Etude de la sensibilite du chene liege au changement climatique en Corse. Centre Régional de la Propriété Forestière de Corse, 109p.
108. Cruz, M.G., Butler, B.W., Alexander, M.E.,(2006). Predicting the ignition of crown fuels above a spreading surface fire. Part II: model evaluation. Int. J. Wildland Fire 15, 61–72.
109. Curt T., Aini A.,et Dupire S.,(2020). Fire Activity in Mediterranean Forests (The Algerian Case). Fire 2020, 3(4), 58; https://doi.org/10.3390/fire3040058
110. Daget P .H. .,(1977). Les bioclimats méditerranéen : caractères généraux, modes de caractérisation vegetacio.34 (1).pp.1-20.

111. Dagorne A., Duché Y., Castex J., Ottavi J., Dalier C., & de Coster A., (1994). Protection des forêts contre l'incendie et systeme d'information géographique: Application à la commune dl Auribeau-sur-Siagne (Alpes-Maritimes). Forêt Méditerranéenne Xv, n 4.
112. Dahmani M., (1984). Contribution à l'étude des groupements à chêne vert des monts de Tlemcen (Ouest algérien). Approche phytosociologique et phyto-écologique. Thèse Doct. 3° Cycle : Univ. H.Boumedien, Alger. 238 p+ ann.
113. Darques R.,(2013). Mythe et réalité des « grands » incendies en Méditerranée. Meditérranée, 11-21 https://doi.org/10.4000/mediterranee.6796,
114. De Luis M., Raventos J. and Gonzales-Hidalgo, J.C., (2006). Post-fire vegetation succession in Mediterranean gorse shrublands. Acta Oecologica 30, 54 – 61.
115. De luis M., Raventos J. and Gonzales-Hidalgo J.C., (2005). Factors controlling seedling germination after fire in Mediterranean gorse shrublands. Implications for fire prescription. Journal of Environmental Management 76, 159 - 166.
116. DE Martonne E., (1926).Une nouvelle fonction climatologique : l'indice d'aridité. La météo. 449-459.
117. De Montgolfier J, 1989. Protection des forêts contre les incendies. Guide technique du forestier méditerraneen français. Dix-huit fiches. Aix-en- Provence : Cemagref.
118. DeBano L.F., Neary D.G., Folliot P.F.,(1998). Fire effects on Ecosystems, John Wiley and Sons, Inc.: New York, NY.
119. Dehane B., 2017, Study of the variability of cork growth in northern Algeria. Agriculture and Forestry 1, 33-41.
120. Dehane B., Hernando C. ,Mercedes Guijarro M. & Madrigal J. (2017). Flammability of some companion species in cork oak (Quercus suber L.) forests. Annals of Forest Science (2017) 74:60 DOI 10.1007/s13595-017-0659-5
121. Dehane B., Madrigal J., Hernando C., Bouhraoua R., & Guijarro M., (2015). New bench-scale protocols for characterizing bark flammability and fire resistance in trees: Application to Algerian cork. Journal of Fire Sciences, 33(3), 202–217. https://doi.org/10.1177/0734904114568858
122. Dehane B., Bouhraoua R. T., Adrados J. R. G., & Belhoucine L., (2012). Caractérisation de la qualité du liège selon l'état sanitaire des arbres par la méthode d'analyse d'image— Cas des forêts de M'Sila et de Zarieffet (Nord-Ouest Algérien) -. Forêt Méditerranéenne, XXXII (1), 39–50.
123. Dehane, B., Benrahou, A., Bouhraoua, R., Hamani, F. Z., and Belhoucine, L. (2014), Chemical composition of Algerian cork according the origin and the quality, Int. J.Res. Envir. Studies 1(2), 17-25.
124. Dehane B., Bouhraoua R.T., Hamani F.Z., Belhoucine L., (2013). La filière liège entre passé et présent. forêt méditerranéenne t. XXXIV, 10p.
125. Dehane B.. (2012). Incidence de l'état sanitaire du chêne liège sur les accroissements annuels et la qualité du liège de deux suberaies oranaises : M'Sila (w.Oran) et Zarieffet (w.Tlemcen). Thèse. Doct. Dept. Forest. Fac.Sci.. Univ.Tlemcen. 293 p.
126. Dehane B., (2012). Incidence de l'état sanitaire du chêne liège sur les accroissements annuels et la qualité du liège de deux suberaies oranaises : M'Sila (w.Oran) et Zarieffet (w.Tlemcen). Thèse. Doct. Dept. Forest. Fac.Sci.,Univ.Tlemcen , 293p.
127. Dehane B., (2006). Incidences des facteurs écologiques sur les accroissements annuels et la qualité du liège de quelques suberaies du nord-ouest algérien. Thèse. Mag. Dept. Forest. Fac.Sci.,Univ.Tlemcen , 129 p.

128. Dejaegere C., (2005). Incidence des incendies répétés sur les suberaies varoises. Rapport de stage de Technicien Supérieur de gestion forestière, 32 p.
129. Delacre J, Tarrier M., (2000). Le Maroc, un royaume de biodiversité. Paris : éditions Ibis Press.
130. Della Rocca G., Hernando C., Madrigal J., Danti R., Moya J., Guijarro M., Pecchioli A., & Moya B., (2015). Possible land management uses of common cypress to reduce wildfire initiation risk: A laboratory study. Journal of Environmental Management, 159, 68–77. https://doi.org/10.1016/j.jenvman.2015.05.020
131. DGF., (2020). Direction générale des forêts., Rapport annuel sur les incendies des forêts, Algerie.
132. DGF., 2020. Estimation de la production du liège pour l'anneé 2020. 2p
133. DGF,, (2013). Le patrimoine forestier Algérien. 15p.
134. DGF., (2014). Direction générale des forêts, Situation des forêts algériennes vis-à-vis les incendies et les feux de forêts, Algerie.
135. Diaz-Delgado R., Lloret F., Pons X., (2004). Spatial pattern of fire occurrence in Catalonia, NE, Spain. Landscape Ecology 19 : 731-745.
136. Dibble A.C., White R.H. and Lebow P.K., (2007). Combustion characteristics of north-eastern USA vegetation tested in the cone calorimeter: invasive versus non-invasive plants. Int J Wildland Fire 16: 426–443
137. Dimitrakopoulos A.P., (2001). Thermogravimetric Analysis of Mediterranean Plant Species, Journal of Analytical Applied Pyrolisis, 60: 123–130.
138. Dimitrakopoulos A. P., Mitsopoulos I. D., & Kaliva A., (2013). Short Communication. Comparing flammability traits among fire-stricken (low elevation) and non fire-stricken (high elevation) conifer forest species of Europe: A test of the Mutch hypothesis. Forest Systems, 22(1), Article 1. https://doi.org/10.5424/fs/2013221-02475
139. Dimitrakopoulos A., (1995). Analyse des causes des feux de forêt en Grèce. Options Méditerranéennes, Série A. Séminaires Méditerranéens, 25: 33-40.
140. Dimitrakopoulos A.P. & Mitsopoulos I.D., (2006). Global forest resources assessment 2005. Report on fires in the Mediterranean Region, (Rome: FAO, Working paper FM/8/E).
141. Djellouli, Y.,(1990). Flore et climat en Algérie septentrionale. Déterminismes climatiques de la répartition des plantes, Thèse de doctorat, université des sciences et de la technologie Houari Boumediene, Alger.
142. Dong X., Li-min D., Guo-fan S., Lei T., & Hui W., (2005). Forest fire risk zone mapping from satellite images and GIS for Baihe Forestry Bureau, Jilin, China. Journal of Forestry Research, 16(3), 169–174. https://doi.org/10.1007/BF02856809
143. Doumergue F., (1910). Carte géologique de l'Algérie au 1/50.000. Feuille n° 271, Lamoricière; Feuille n° 300, Terny ; feuille n° 270, Tlemcen. Publ. Serv. Carte géol. Algérie.
144. Drexhage M., & Colin F., (2001). Estimating root system biomass from breast-height diameters. Forestry: An International Journal of Forest Research, 74(5), 491–497. https://doi.org/10.1093/forestry/74.5.491
145. Dubois C.(1990). Comportement du chêne-liège après incendie, Mémoire E.N.I.T.E.F. Banyuls-sur-Mer, Laboratoire Arago (Université Paris VI), 97p.
146. Duguy B., Rovira P. & Vallejo R., (2007). Land-use history and fire effects on soil fertility in eastern Spain. Eur. J. Soil Sci., 58: 83 – 91.

147. Elena Rosselló M., (2004). Les effets des incendies de l'été 2003 dans les suberaies européennes[The effects of the summer 2003 fires in European cork oak forests]. Actes du colloque international « Le Chêne-liège face au feu », Vivès (France), 18 juin 2004, 7-12.
148. Elmi S.,(1970). Rôles des accidents décrochant de direction SSW-NNE dans la structure des monts de Tlemcen (ouest Algérien).Bull.Soc. Hist.nat.Afr.Nord,Univ.Alger.61 :3-8
149. Emberger L.,(1942).Un projet de classification des climats du point de vue phytogéographique.Bull.Soc.Hist.Nat.Toulouse.77, pp.97-124.
150. Erten E., Kurgun V., & Musaoglu N., (2004). Forest Fire Risk Zone Mapping from Satellite Imagery and GIS Case Study. 20th ISPRS Congress Istanbul, 33–39.
151. ESA .,(2019). « More of Africa scarred by fires than thought » [archive], sur www.esa.int, 4 février 2019 (consulté le 22 septembre 2022).
152. Escudero, A., Arco J. M. D., Sanz I. C., and Ayala J.. (1992). Effects of leaf longevity and retranslocation efficiency on the retention time of nutrients in the leaf biomass of different woody species. Oecologia 90:80–87.
153. Esnault F,. (1995). L'intérêt d'une cartographie des feux de forêt. Forê Mediterraneenne 16 : 159-63. www.foret-mediterraneenne.org/fr/catalogue
154. Fang L., Yang J., Zu J., Li G., & Zhang J., (2015). Quantifying influences and relative importance of fire weather, topography, and vegetation on fire size and fire severity in a Chinese boreal forest landscape. Special Section: The Characteristics, Impacts and Management of Forest Fire in China, 356, 2–12. https://doi.org/10.1016/j.foreco.2015.01.011
155. FAO, (2013). Etat des forêts méditerranéennes 2013. E-ISBN 978-92-5-207538-7 : 58-73
156. Fares S., Bajocco S., Salvati L., Camarretta N., Dupuy J.-L., Xanthopoulos G., Guijarro M., Madrigal J., Hernando C., & Corona P., (2017). Characterizing potential wildland fire fuel in live vegetation in the Mediterranean region. Annals of Forest Science, 74(1), 1. https://doi.org/10.1007/s13595-016-0599-5
157. Forgues, C. (2008). Bilan Carbone des différentes solutions de bouchage des vins tranquilles. Actes Du Colloque VIVEXPO 2008 : « la Guerre Des Bouchons », pp.3.
158. Frejaville T., Curt T., Carcaillet C., (2013). Bark flammability as a fire-response trait for subalpine trees. Front. Plant Sci. 4 (466): 1-8.
159. Fulé P.Z., Ribas M/, Gutiérrez E., Vallejo R., Kaye M.W., (2008). Forest structure and fire history in an old Pinus nigra forest, eastern spain. For Ecol Manag 255(3–4):1234–1242.
160. Galidaki G., Zianis D., Gitas I., Radoglou K., Karathanassi V., Tsakiri–Strati M., Woodhouse I., & Mallinis G., (2017). Vegetation biomass estimation with remote sensing: Focus on forest and other wooded land over the Mediterranean ecosystem. International Journal of Remote Sensing, 38(7), 1940–1966. https://doi.org/10.1080/01431161.2016.1266113
161. Gaouar A., (1980). Hypothèses et réflexions sur la dégradation des écosystèmes forestiers dans la région de Tlemcen. Forêt méd., 3(2) : 131-145.
162. Gaoue O.G., Ticktin T., (2010). Effects of harvest of nontimber forest products and ecological differences between sites on the demography of African mahogany. Conservation Biology 24: 605–614.

163. Garcia-Mozo, H., Hidalgo P. J., Galan C., Gómez-Casero M. T., and Domínguez E.. (2001). Catkin frost damage in Mediterranean cork-oak (Quercus suber L.). Israel Journal of Plant Science 49:41–47.
164. Gibson, L. J., Easterling, K. E., and Ashby, M. F., (1981). “The structure and mechanics of cork,” Proc. Roy. Soc. London A 377(1769), 99-117. DOI: 10.1098/rspa.1981.0117
165. Gignoux, J., Clobert, J., Menaut, J., (1997). Alternative fire resistance strategies in savanna trees. Oecologia 110, 576–583.
166. Gonzáles J.R., Trasobares A., Palahí M., Pukkal T., (2006). Predicting stand damage and tree survival in burned forests in Catalonia (North-East Spain). Annals of Forest. Sciences. 64, 733–742
167. Gonzalez-Pérez J.A., Gonzalez-Vila F.J., Almendros J. & Knicker H., (2004). The effect of fire on soil organic matter - a review. Environ. Int., 30: 855 – 870.
168. Grim S., (1989). Préaménagement et protection des forêts contre l’incendie. In : Le préaménagement forestier. Ministère de l’Hydraulique d’Algérie & Unité des Eaux et Forêts de l’Université catholique de Louvain-la-Neuve, Belgique, 1: 271-289.
169. Groupe formation continue Luminy (2009) Fiche Procédé Constructif. Groupe Coopératif Matériaux Envirobat Méditerranée .6p.
170. Guedje N.M., Zuidema P.A., During H., Foahom B., Lejoly J., (2007). Tree bark as a non-timber forest product: The effect of bark collection on population structure and dynamics of *Garcinia lucida Vesque*. Forest Ecology and Management 240 (1–3), 15: 1-12 ;
171. Guijarro M., Hernando C., Dıez C., Martınez E., Madrigal J., Cabaret C.L., Blanc L., Colin P.Y., Perez-Gorostiaga P., Vega J.A., Fonturbel M.T., (2002). Flammability of some fuel beds common in the South-European ecosystems, In Forest Fire Research and Wildland Fire Safety: Proceedings of IV International Conference on Forest Fire Research, Viegas DX (ed). Wildland Fire Safety Summit, Luso, Coimbra: Portugal: 18-23.
172. Guyette R.P., Muzika R.M., Dey D.C., (2002). Dynamics of an anthropogenic fire regime. Ecosystems 5(5):472–486.
173. Hachmi M., Sesbou A., Benjelloun H., El Handouz N., Bouanane F., (2011). A simple technique to estimate the flammability index of Moroccan forest fuels. J Combust Article ID 263531:11p.
174. Hadjadj-Aoul S., (1995). Les peuplements du Thuya de berbérie (Tetraclinis articulata, Vahl, Master) en Algérie : phytoécologie, syntaxonomie et potentialités sylvicoles. Thèse. Doc. D’Etat : Univ. Aix-Marseille IIII. 159 p. et Annexes
175. Hare R.C., (1965). Contribution of bark to fire resistance of southern trees. Journal of forestry 63,160-161.
176. Harfouche et al. (2004) Quelques résultats a l’états juvénile sur la variation géographique du chêne liège (Quercus suber L.) et stratégies d’amélioration génétique.
177. Harmon, M.E., (1984). Survival of trees after low-intensity surface fires in Great Smoky Mountains National Park. Ecology 65, 796–802.
178. Houcine Sebei, Ali Albouchi, Maurice Rapp, & Mohamed Hédi El Aouni. (2001). Évaluation de La Biomasse Arborée et Arbustive Dans Une Séquence de Dégradation de La Suberaie à Cytise de Kroumirie (Tunisie). Ann. For. Sci., 58(2), 175–191. https://doi.org/10.1051/forest:2001117.
179. INA, (2022). Le lien entre réchauffement climatique et feux de forêt, Publié le 11.07.2022 - Mis à jour le 10.08.2022 in INA.

180. Iwasa Y. et Kubo T., (1997). Optimal size of storage for recovery after unpredictable disturbances. Evolutionary Ecology, 11 : 41-65.
181. Jackson J.F., Adams D.C., Jackson U.B., (1999). Allometry of constitutive defense: a model and a comparative test with tree bark and fire regime. American naturalist 153: 614–632.
182. Jarvis, P. G., Rey A., Petsikos C., Wingate L., Rayment M., JPereira. S., J Banza., David J. S., Miglietta F., Borgetti M., Manca G., and Valentini R.. (2007). Drying and wetting of Mediterranean soils stimulates decomposition and carbon dioxide emission: The “birch effect.” Tree Physiology 27:929–940.
183. Jiménez P., López de Heredia U., Collada C., Lorenzo Z., and Gil L.. (2004). High variability of chloroplast DNA in three Mediterranean evergreen oaks indicates complexevolutionary history. Heredity 93:510–515.
184. Jové P., Angels olivella & Cano L., (2011). Study of the variability in chemical composition of bark layers of *Quercus suber* L. from different production area.Biossources.com 6(2): 1806-1815.
185. Kabouya I.L., (2020). Enjeux des feux de forêt en Algérie. Directrice de la Protection de la Faune et de la Flore (DGF). Communication orale dans le séminaire Forest-fires in Algeria, Challenge and Protection.
186. Kadik B., (1987). Contribution à l’étude du pin d’Alep (Pinus halepensis Mill) en Algérie: Ecologie, Dendrométrie, Morphologie. Ed. OPU, Alger 585 p.
187. Kauf Z., Andreas Fangmeier A., Rosavec R., and Španjol C., (2011). Testing Vegetation Flammability: The Problem of Extremely Low Ignition Frequency and Overall Flammability Score. Hindawi Publishing Corporation Journal of Combustion., Article ID 263531, 11 pages, doi:10.1155/2011/263531
188. Kazakis Getghosen D., (2008). Le Pb des incendies de forets en méditerranée. La lettre de veille du ciheam. n°6.page 1.
189. Kazanis D. and Arianoutsou M., (1996). Vegetation composition in a post-fire successional gradient of Pinus halepensis forests in Attica, Greece. Int. J. Wildland Fire, 6, 83 –91.
190. Kazi Aoual N., Rachedi S., (2010). Atelier sur « La génération des forêts par l’utilisation des des eaux usées traitées» expérience Algérienne. Hammamet, pp 34-36.
191. Keeley J.E., (2002). Native American impacts on fire regimes of the California coastal ranges. J Biogeogr 29:303–320.
192. Keeley J.E., Bond W.J., Bradstock R.A., Pausas J.G., Rundel P.W., (2012). Fire in Mediterranean ecosystems: ecology, evolution and management. Cambridge, UK: Cambridge University Press
193. Keeley J.E., Pausas, J.G., Rundel, P.W., (2011). Fire as an evolutionary pressure shaping plant traits. Trends Plant Sciences 16, 406–11.
194. Khabarov N., Krasovskii A., & Obersteiner M., (2016). Forest fires and adaptation options in Europe. Reg Environ Change, 16, 21–30. https://doi.org/10.1007/s10113-014-0621-0
195. Khalip, A., (2017). Le retour en grâce des bouchons en liège Portugais, Reuters, 17 May.
196. Klauber, A., (1920). Die Monographie des Korkes. Berlin.
197. Kunholtz-Lordat, G., (1958). L’écran vert. Ed. du Muséum, Paris, 276 p.
198. Laaribya, S., Alaoui, A., Ayan, S., Benabou, A., Labbaci, A., Ouhaddou, H., & Bijou, M. (2021). Prediction by maximum entropy of potential habitat of the cork oak (Quercus

suber L.) in Maamora Forest, Morocco. Forestist, 71(2), 63–69. https://doi.org/10.5152/forestist.2021.20059.

199. Lamey A. (1893). Le chêne-liège, sa culture et son exploitation. Berger- Levrault et Cie éditeurs, Nancy, Paris.
200. Lamont B.B., He T., & Yan Z., (2019). Evolutionary history of firestimulated resprouting, flowering, seed release and germination. Biology Reviex 94, 903–28.
201. Lamont B.B., He T. & Pausas J.G., (2017). African geoxyles evolved in response to fire; frost came later. Evolutionary Ecology 31(5): 603–617.
202. Larcher W.. (2000). Temperature stress and survival ability of Mediterranean sclerophyllous plants. Plant Biosystems 134:279–295.
203. Lawes M.J., Richards A., Dathe J., Midgley J.J., (2011). Bark thickness determines fire resistance of selected tree species from fire-prone tropical savanna in north Australia. Plant Ecol. 212, 2057–2069.
204. Le Houerou, H.N., (1980). L'impact de l'homme et de ses animaux sur la forêt méditerranéenne». Forêt Méditerranéenne, - 1ère partie: III(1): 31-44-et 2ème partie: (2):155-174.
205. Leblon B., Bourgeau-Chavez L., & San-Miguel-Ayanz, J., (2012). Use of Remote Sensing in Wildfire Management. In S. Curkovic (Ed.), Sustainable Development—Authoritative and Leading Edge Content for Environmental Management. InTech. https://doi.org/10.5772/45829
206. Letreuch Belarouci, A. , (2010). Structural characteristics of the suberaies of the Tlemcen National Park, natural regeneration and sustainable development. (Thesis), University of Tlemcen.).
207. Letreuch-Belarouci, A., Medjahdi, B., Letreuch-Belarouci, N., & Benabdeli, K., (2009). Diversité floristique des suberaies du Parc National de Tlemcen (Algerie). Acta Botanica Malacitana, 34, 77–89. https://doi.org/10.24310/abm.v34i0.6913
208. Liodakis S., Vorisis I.P., Agiovlasitis I.P., (2005). A method for measuring the relative particle fire hazard properties of forest species. Thermochimica Acta 437, 150-157.
209. Lodwick W. A., Monson, W., & Svoboda L., (1990). Attribute error and sensitivity analysis of map operations in geographical informations systems: Suitability analysis. International Journal of Geographical Information Systems, 4(4), 413–428. https://doi.org/10.1080/02693799008941556
210. López de Heredia U. Carrión J. S., Jiménez P., Collada C., and Gil L., (2007). Molecular and palaeobotanical evidence for multiple glacial refugia for evergreen oaks on the Iberian Peninsula. Journal of Biogeography 34:1505–1517.
211. Louni D., (1994). Les forêts algériennes. Forêt méditerranéenne (17) 1 : 59-63.
212. Lucas G., (1952).Bordure nord des Hautes Plaines dans l'Algérie occidentale. 19è congr. Géol. Inter. Alger, Mon. rég. Ser. 1 : Algérie, n° 21, 139 p, 59 fig. Moreira, 2001;
213. Lumaret R. Tryphon-Dionnet M., Michaud H., Sanuy A., Ipotesi E., Born C., and Mir C., (2005). Phylogeographical variation of chloroplast DNA in cork oak (*Quercus suber*). Annals of Botany 96:853–861.
214. Madoui A., 2013. Les incendies de forêts en Algérie. Étude de l'évolution après feu des peuplements de Pinus halepensis Mill dans l'Est algérien. Cas de la forêt de Bou-Taleb, du reboisement de Zenadia et du parc national d'el Kala. Thèse, Doctorat en sciences Université Ferhat Abbas de Sétif ;

215. Madoui, A. & M. Kaabeche., (2010). Régénération post-incendie du pin d'Alep dans les reboisements de la région de Sétif». Séminaire International en Biologie Végétale et Ecologie le 22-25novembre, Constantine.
216. Madoui, A. (2002). Les incendies de forêt en Algérie: Historique, bilan et analyse.» Forêt méditerranéenne 23(1): 23-30.
217. Madrigal, J., Souto-García, J., Calama, R., Guijarro, M., Picos, J., Hernando, C., 2019. Resistance of Pinus pinea L. bark to fire. Int. J. Wildland Fire 28 (5), 342–353.
218. Madrigal J, Hernando C, Guijarro M (2013) A new bench-scale methodology for evaluating flammability of live forest fuels. Journal of Fire Sciences 31(2): 131–142.
219. Madrigal J., Guijarro M., Hernando C., Díez C., & Marino E., (2011). Effective Heat of Combustion for Flaming Combustion of Mediterranean Forest Fuels. Fire Technology, 47(2), 461–474. https://doi.org/10.1007/s10694-010-0165-x
220. Madrigal J, Hernando C, Guijarro M, Díez C, Marino E, De Castro AJ (2009) Evaluation of forest fuel flammability and combustion properties with an adapted mass loss calorimeter device. J Fire Sci 27:323-342.
221. Magri, D., Fineschi S., Bellarosa R., Buonamici A., Sebastiani F., Schirone B., Simeone M. C., and Vendramin G. G.. (2007). The distribution of Quercus suber chloroplast haplotypes matches the palaeogeographical history of the western Mediterranean. Molecular Ecology 16:5259–5266.
222. Maire R., (1926). Note phytogéographique de l'Algérie et de la Tunisie avec une carte/ Alger.
223. Manos P. S., and Stanford A. M., (2001). The historical biogeography of Fagaceae: Tracking the Tertiary history of temperate and subtropical forests of the Northern Hemisphere. International Journal of Plant Sciences 162 (suppl.):S77–S93.
224. Marc, H.,(1930). Notes sur les forêts de l'Algérie. Collection du Centenaire de l'Algérie. Larose , Paris.702p
225. Marc H., (1916). Les incendies de forêts en Algérie.in Notes sur les forêts de l'Algérie. Typographie Adolphe Jourdan. Imprimeur-libraire-Editeur., 1916, Alger.
226. Marques, A. V., Rencoret, J., Gutierres Suarez, A., del Rio, J., and Pereira, H. (2015), Ferulates and lignin structural composition in cork," Holzforschung (ahead of print). DOI: 10.1515/hf-2015-0014
227. Martin, R.E. (1963). Thermal properties of bark. Forest Products Journal, 13, 419–426.
228. Martin, R.E., Gordon, D.A., Gutierrez, M.A., Lee, D.S., Molina, D.M., Schroeder, R.A., ... & Chambers, M., (1994). Assessing the flammability of domestic and wildland vegetation. In: Proceedings of the 12th conference on fire and forest meteorology (pp. 26–28).
229. MATE., (2003). Plan d'action et stratégie national sur la biodiversité. Evaluation des besoins en matière de renforcement des capacités nécessaires à l'évaluation et la réduction des risques menaçant les éléments de la diversité biologique en Algérie.T.VI, Projet Alg /97/G31, 93p.
230. Mayer N. (2020). Réchauffement climatique : des incendies comparables à ceux d'Australie se multiplieront . Futura, publié le le 16 janvier 2020.
231. Meddour SO., (2015). Diagnostic sur les incendies de forêts. Projet TCP/ALG/3501.Assistance Technique en matière de gestion de feux de forêts, (Algérie).
232. Meddour-Sahar, O. & Bouisset C., (2013). Les grands incendies de forêt en Algérie: Problèmes humains et politiques publiques dans la gestion des risques. Méditerranée.

Revue géographique des pays méditerranéens / Journal of Mediterranean geography, 121, Article 121. https://doi.org/10.4000/mediterranee.6827

233. Meddour-Sahar., Arezki Derridj., (2012). Bilan des feux de forêts en Algérie: analyse spatio- temporelle et cartographie du risque (période 1985-2010). Science et changements planétaires / Sécheresse, 133-41.
234. Meddour S.O., Meddour R., Derridj A., (2008). Analyse des feux de forêts en Algérie sur le temps long (1876-2007). Les notes d'analyse du CIHEAM, 39 : 11.
235. Medlyn B. E., Badeck F. W., De Pury D. G. G.,. Barton C. V. M, Broadmeadow M., Ceulemans R., De Angelis P., (1999). Effects of elevated [CO2] on photosynthesis in European forest species: A meta-analysis of model parameters. Plant.Cell.Env. 22 (12) :1475-1495.
236. Mendes A.M.S.C., Graca J.A.R., (2009). Cork bottle stoppers and other cork products. In: Aronson J, Pereira JS, Pausas JG, editors. Cork oak woodlands on the edge: ecology, adaptive management, and restoration. Washington DC.
237. Mesli K., Bouazza M., & Godron M., (2008). Ecological Characterization of the Vegetation and its Facies of Degradation: Mounts of Tlemcen (West-Algeria). Environmental Research Journal, 2, 271–277.
238. Molinas, M. & Campos, M.,(1993).Aplicación del análisis digital de imágenes al estudio de la calidad del corcho[Application of digital image analysis to the study of cork quality]. Actos del 4to Congreso Forestal Espanol, 1-6 Junio, (Espana: Lourizán): 347-353.
239. Moreiera F., Rego F., Ferreira P.G. , (2001). Temporal (1958-1995) pattern of change in a cultural landscape of northwestern Portugal : implications for fire occurrence. Landscape Ecology 16, pp. 557-567.
240. Moreira F., Duarte I., Catry F., Acácio V., (2007). Factors affecting post- fire cork oak survival in southern Portugal. Forest Ecolology Management, 253:30–37.
241. Moro, C, (2004). Inflammabilité, materiels et méthodes," INRA's methodology, Internal report, Version 26/10/94, modified 27/01/04, French Mediterranean Forest Research Institute,INRA, Avignon, France.
242. Napolitano P., & Fabbri A., (1996). Single-Parameter Sensitivity Analysis for Aquifer Vulnerability Assessment Using DRASTIC and SINTACS. In: HydroGIS 96: Application of Geographical Information Systems in Hydrology and Water Resources Management, Proceedings of Vienna Conference, IAHS Pub., Vienna, No. 235, 559–566.
243. Natividade J.V.(1956). Subericulture. Ecole Nationale des Eaux et Forêts. Nancy, 302.
244. Natividade V., (1956). Subericultura. Lisboa: Ministe´rio da Economia, Direcca˜o
245. Natividade, J. V.,(1956). Subericulture. Edition française de l'ouvrage portugais subericultura, 303 pages.
246. Nguyen, T; Zavarin, E.; Barrall II, E. M. (1981), Thermal analysis of lignocellulosic materials. Part I. Unmodified materials. J. Macromol. Sci.-Rev. Macromol. Chem. C 20: 1-65.
247. Odhiambo B., Meincken M., Seifert T., (2014). The protective role of bark against fire damage: a comparative study on selected introduced and indigenous tree species in the Western Cape, South Africa. Trees 28 (2), 555–565.
248. Odhiambo p., B., Meincken, M., Seifert, T., (2014). The protective role of bark against fire damage: a comparative study on selected introduced and indigenous tree species in the Western Cape, South Africa. Trees 28 (2), 555–565.
249. Oliveira G et Costa A., (2012). How resilient is *Quercus suber* L. to cork harvesting? A review and identification of knowledge gaps. For. Ecol. Manage. (270) : 257-272

250. Ordóénez J.L., Retana J., Espelta J.M. (2005). Effects of tree size, crown damage, and tree location on post-fire survival and cone production of Pinus nigra trees. Forest Ecolology Management , 206: 109-117.
251. Orgeas J., Bonin G., (1996). Variabilité des nutriments foliaires de *Quercus suber* L. dans différentes situations écologiques dans le massif des Maures (Var, France) et relations avec la production de liège [Variability of foliar nutrients of *Quercus suber* L. in different ecological situations in the Massif des Maures (Var, France) and relationships with cork production] . Annales des Sciences Forestières 53, 615-624.
252. Paula S., Arianoutsou M., Kazanis D., Tavsanoglu C.¸ Lioret F., (2009). Firerelated traits for plant species of the Mediterranean Basin. Ecology 90, 1420.
253. Pausas J.G. and Keeley J.E., (2021). Wildfires and global change. The Ecological Society of America 19, 387–395, doi:10.1002/fee.2359
254. Pausas J.G. & Keeley J.E., (2017). Epicormic resprouting in fire-prone ecosystems. Trends in Plant Science 22(12): 1008-1015.
255. Pausas J.G., Keeley J.E, Schwilk D.W., (2017). Flammability as an ecological and evolutionary driver. J Ecol 105:289–297 :
256. Pausas J.G.(2015).Review Bark thickness and fire regime. Functional Ecology , 29, 315–327.
257. Pausas J. G., (2015). Alternative fire-driven vegetation states. Journal of Vegetation Science, 26(1), 4–6. https://doi.org/10.1111/jvs.12237
258. Pausas J.G., Belcher C/M., Schwilk D.W., Lamont B.B. (2012). Fire-adapted traits of Pinus arose in the fiery Cretaceous. The New phytologist , 194: 751–759.
259. Pausas JG, Alessio G, Moreira B, et al (2012) Fires enhance flammability in Ulex parviflorus. New Phytol 193: 18–23.
260. Pausas J.G., and Keeley J.E., (2009). A burning story: the role of fire in the history of life. BioScience 59, 593–601.
261. Pausas J.G., Pereira J.S, Aronson, J., (2009). The tree. In: Aronson J, Pereira JS, Pausas JG, editors. Cork oak woodlands on the edge: ecology, adaptive management, and restoration. Washington DC: Island Press. 11–23.
262. Pausas JG. (2006). Simulating Mediterranean landscape pattern and vegetation dynamics under different fire regimes. Plant Ecology 187: 249– 259.
263. Pausas JG et Verdu M (2005) Plant persistence traits in fire –Prone ecosystems of the Mediterranean basin: a phylogenetic approach.Oikos, 109: 196-202.
264. Pausas J G, Ribeiro et Vallejo R., (2004). Post-Fire regeneration variability of Pinus halpensis in the eastern Ibrian peninsula- Forest.Ecol.Manag., 203: 521-259.
265. Pausas J.G., (1998). Modeling fire-prone vegetation dynamics. In Fire and Landscape Ecology, In Trabaud L (ed.). International Association of Wildland Fire: Fairland, Washington, DC; 327–334.
266. Pausas J., (1997). Resprouting of *Quercus suber* in NE Spain after fire. Journal of Vegetation Science 8, 703–706.
267. Pereira H., (2017). Los parámetros-clave para la producción de corcho. 7º CFE, Plasencia 26-30 Junio 2017.
268. Pereira (2015). “Rationale of cork properties,” BioResources 10(3), 6207-6229.
269. Pereira H., (2007). Cork: biology, production and uses. Amsterdam: Elsevier Publishing. 336 p
270. Pereira J. S., Beyschlag G., Lange O. L., Beyschlag W., and Tenhunen J. D.. (1987). Comparative phenology of four Mediterranean shrub species growing in Portugal. Pp.

503– 514 in J. D. Tenhunen, F. M. Catarino, O. L. Lange, and W. C. Oechel, eds. Plant Response to Stress. Springer-Verlag, Berlin, Germany.

271. Pereira J. S., Chaves M. M., Caldeira M., and Correia A. V.. (2006). Water availability and productivity. Pp. 118–145 in J. I. L. Morison and M. D Morecroft, eds. Plant Growth and Climate Change. Blackwell, London, UK.
272. Pereira, H. 1988: Chemical composition and variability of cork from Quercus suber L. Wood Sci. Technol. 22: 211- 218.
273. Pereira, H., and Marques, A. V. (1988). "The effect of chemical treatments on the cellular structure of cork," IAWA Bull. 9(4), 337-345. DOI: 10.1163/22941932-90001093.
274. Pereira, H., Rosa, M. E., and Fortes, M. A. (1987). "The cellular structure of cork from
275. Pereira, H.; Ferreira, E. 1989: Scanning electron microscopy observations of insulation cork agglomerates. Mater. Sci. Eng. A 111: 217-225
276. Pereira, H.; Fortes, M. A. 1991: Effects of hot water treatments on the structure and properties of cork. Wood Fiber Sci. 22: 149-164
277. Peterson, D. & Ryan, K. (1986). Modeling postfire conifer mortality for long-range planning. Environmental Management, 10, 797–808.
278. Peyerimhoff, P.,(1941). Notice sur la carte forestière de l'Algérie et de la Tunisie. Bacconnier, Alger, 71 p. 1 Vol. Imp. Pape Baconnier Frères : 70 p., 1 carte.
279. Peyre S., (2001). L'incendie, désastre ou opportunite ? L'exemple des Pyrenees Orientales.
280. Piazetta R ., (2011). La gestion des suberaies après incendie. Institut Méditerranéen du liège. Vives, 16p.
281. Pinard M.A and Huffman J., (1997). Fire resistance and bark properties of trees in a seasonally dry forest in eastern Bolivia. J. Trop.Ecol. 13, 727–740.doi:10.1017/S0266467400010890.
282. Pinard M.A., Huffman J., (1997). Fire resistance and bark properties of trees in a seasonally dry forest in eastern Bolivia. J. Trop. Ecol. 13, 727–740.
283. Pintus A, Ruiu P. (2004). La réhabilitation des suberaies incendiées. Colloques Internationaux Vivexpo 2004: Le chêne-liège face au feu.
284. PNT, (2015). Parc National de Tlemcen . brochure. 4p.
285. PNT. (2009), Plan de gestion (2006-2010) rapport de ministère de l'Agriculture et du Développement rural, Parc National de Tlemcen.
286. Pouget M., (1980). Les relations sol-végétation dans les steppes Sud-algéroises. Ed. O.R.S.T.O.M., Paris, 555 p. texte+annexes. Quezel P.et Barbero M., (1990). Les forêts Méditerranéennes, problèmes posés par leur signification historiques, écologique et leur conservation. Acta. Botanica Malacitana 15 pp :145-178.
287. Pourkhosravani M., Jamshidi F., & Sayari N., (2021). Evaluation of groundwater vulnerability to pollution using DRASTIC, composite DRASTIC, and nitrate vulnerability models. Ehemj, 8(2), 129–140. https://doi.org/10.34172/EHEM.2021.16
288. Quezel P., (2000). Réflexions sur l'évolution de la flore et de la végétation au Maghreb méditerranéen. Ibis Press, Paris, 117 p.
289. Quezel, P. et Barbero, M., (1985). Carte de la végétation potentielle de la région méditerranéenne I: Méditerranée Orientale Ed. C.N.R.S., Paris: 69 p + carte.
290. Quintano C. et al., (2011), Estimation of area burned by forest fires in Mediterranean countries: a remote sensing data mining perspective, Forest Ecology and Management, 262, 1597-1607. DOI : 10.1016/j.foreco.2011.07.010

291. Rahmani S., & Benmassoud H., (2020). Modeling and mapping forest fire risk in the region of Aures (Algeria). Geoadria, 24(2), 79–91. https://doi.org/10.15291/geoadria.2846
292. Ray C.E.,(2018). Réchauffement: de plus en plus de risques d'incendies dans l'Europe méditerranéenne, Article paru 08/10/2018 In FUTURA.
293. Rebai, A. (1986). Les incendies de forêts dans la wilaya de Mostaganem (Algérie). Etude écologique et proposition d'aménagement.» Thèse de Docteur de Spécialité écologie méditerranéenne, option : Phytoécologie. Fac. Sci. Tech. St Jérôme,130 p.
294. Rego F. C., Morgan P., Fernandes P., & Hoffman C., (2021). Fire Science: From Chemistry to Landscape Management. Springer. https://link.springer.com/book/10.1007/978-3-030-69815-7
295. Rigolot E.,(2004). Predicting postfire mortality of Pinus halepensis Mill. And Pinus pinea L. Pant Ecol. 171: 139-151.
296. Robert B.,(1997). Contribution to the study of the cork-oak (Quercus suber L.) mineraI nutrition in the natural medium. Doctoral thesis (France: ENSA Toulouse-Université de Gérone).
297. Rosa, M. E., Pereira, H., and Fortes, M. A., (1990). "Effects of water treatment on the structure and properties of cork," Wood Fiber Sci. 22(2), 149-164
298. Rosell J.A., (2016). Bark thickness across the angiosperms: more than just fire. New Phytologist 211: 90–102
299. Rosell J.A., Olson M.E., (2014). The evolution of bark mechanics and storage across habitats in a clade of tropical trees. Am. J. Bot. 101, 764–777 .
300. Hare R.C., (1965). The contribution of bark to fire resistance of southern trees. J. Forest. 4 (248–554), 251.
301. Roteta E., Bastarrika A., Franquesa M., & Chuvieco E., (2021). Landsat and Sentinel-2 Based Burned Area Mapping Tools in Google Earth Engine. Remote Sensing, 13(4). https://doi.org/10.3390/rs13040816
302. Ruffault J., Curt T., Moron V., Trigo R. M., Mouillot F., Koutsias N., Pimont F., Martin-StPaul N., Barbero R., Dupuy J.-L., Russo A., & Belhadj-Khedher C., (2020). Increased likelihood of heat-induced large wildfires in the Mediterranean Basin. Scientific Reports, 10(1), 13790. https://doi.org/10.1038/s41598-020-70069-z
303. Ruiz-Peinado R., Rio M. del & Montero G., (2011). New models for estimating the carbon sink capacity of Spanish softwood species. Forest Systems, 20(1), Article 1. https://doi.org/10.5424/fs/2011201-11643
304. Ryan K.C., Reinhardt E.D., (1988). Predicting postfire mortality of seven western conifers. Canadian, Journal of Forest Research, 18: 1291–1297.
305. Saccardy L., (1937). Notes sur le liège et le liège en Algérie. Bull.Stat.Rech.for.Afr. nord. Tome III (2).pp.271-374.7
306. Saccardy L.,(1937).Notes sur le liège et le liège en Algérie .Bull.Stat.Rech.for. Afr.nord. Tome III(2).pp.271-374.
307. Saidi S., Younes A. B., & Anselme B., (2021). A GIS-remote sensing approach for forest fire risk assessment: Case of Bizerte region, Tunisia. Applied Geomatics, 13(4), 587–603. https://doi.org/10.1007/s12518-021-00369-0
308. Salis M. Laconi M., Ager A. A., Alcasena F. J., Arca B., Lozano O., Fernandes de Oliveira A., & Spano D., (2016). Evaluating alternative fuel treatment strategies to reduce wildfire losses in a Mediterranean area. Forest Ecology and Management, 368, 207–221. https://doi.org/10.1016/j.foreco.2016.03.009

309. Salleo, S., and Nardini A., (2000). Sclerophylly: Evolutionary advantage or mere epiphenomenon .Plant Biosystems 134:247–259.
310. Santos Pereira, J., Burgalho, M.N. & Caldeira M.C., (2008).From the cork oak to cork. A sutainable systeme. APCOR(Portugal). 44p.
311. Sari D., 1976. L'homme et l'érosion dans l'Ouarsenis, (Algérie). Ed. SNED, 224 p.
312. Schumacher S. et Bugmann H., (2006). The relative importance of climatic effects, wildfires and management for future forest landscape dynamics in the Swiss Alps. Global Change Biol., 12 : 1435-1450.
313. Schwilk D.W., Knapp E.E., Ferrenberg S.M., Keeley J.E., Caprio A.C., (2006). Tree mortality from Wre and bark beetles following early and late season prescribed fres in a Sierra Nevada mixed-conifer forest. Forest Ecology Management, 232:36–45
314. Scott A.C., (2018). Burning planet: the story of fire through time. Oxford, UK: Oxford University Press.
315. Scott J. H., & Burgan R. E., (2005). Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/rmrs-gtr-153
316. Seifert, T., Meincken, M., Odhiambo, B.O., (2017). The effect of surface fire on tree ring growth of Pinus radiata trees. Ann. Forest Sci. 74 (2), 34.
317. Seigue, A., (1987). La forêt méditerranéenne française. Aménagement et protection contre les incendies. EDISUD, Aix en Provence, 159p.
318. Sekkoum S., & Maachou H. M., (2018). Le parc national de Tlemcen (Algérie): Un potentiel touristique sous-exploité. Études caribéennes, 39–40, Article 39–40. https://doi.org/10.4000/etudescaribeennes.12450
319. Seltzer P. (1946). Le climat de l'Algérie. La Typo-Litho,Alger,249p.
320. Sen A., Miranda I, Sara Santos S., Graca J, Pereira H. (2010). The chemical composition of cork and phloem in the rhytidome of quercus cerris bark. Industrial Crops and Products.6p
321. Shaffhauser A., (2009). Impact de la répétition des incendies sur la végétation, in Info DFCI no 63, Cemagref. Aix-en-Provence.
322. Shakesby R.A. & Doerr S.H., (2006). Wildfire as a hydrological and geomorphological agent. Earth Sci. Rev., 74: 269 - 307.
323. Silva J., S, Catry F., (2006). Forest Fires in cork oak (Quercus suber L.) stands in Portugal, International Journal of Environmental Studies 63(3): 235–257.
324. Silva J.S., Catry F., (2006). Forest fires in cork oak (Quercus suber) stands in Portugal. International Journal of Environmental Studies 63, 235–257.
325. Silva J.S., Catry F., (2006). Forest fires in cork oak (Quercus suber) stands in Portugal. International Journal of Environmental Studies 63: 235–257.
326. Silva SP, Sabino MA, Fernandes EM, Correlo VM, Boesel LF, Reis RL (2005) Cork: properties, capabilities and applications. International Materials Reviews 50: 345–365.
327. Smith J. E., Heath L. S., & Woodbury P. B., (2004). How to Estimate Forest Carbon for Large Areas from Inventory Data. Journal of Forestry, 102(5), 25–31. https://doi.org/10.1093/jof/102.5.25
328. Szpakowski D. M., & Jensen J. L. R., (2019). A Review of the Applications of Remote Sensing in Fire Ecology. 31.
329. Spampinato, G., Massimo, D. E., Musarella, C. M., De Paola, P., Malerba, A., & Musolino, M. (2019). Carbon Sequestration by Cork Oak Forests and Raw Material to Built up Post Carbon City. In F. Calabrò, L. Della Spina, & C. Bevilacqua (Eds.), New

Metropolitan Perspectives (Vol. 101, pp. 663–671). Springer International Publishing. https://doi.org/10.1007/978-3-319-92102-0_72.

330. Talbi O., Benabdeli K., Benhanifia, K., & Haddouche D., (2018). Cartographie des zones de risque de feux de forêt dans la commune de Doui Thabet, Saïda, Algérie. International Journal of Environmental Studies, 75(4), 543–552. https://doi.org/10.1080/00207233.2017.1386434
331. Taylor G.,(1918). Geographical factors controlling the settlements of Tropical Australia. Queensland Geographical Journal. Vol. 32, pp. 1-67.
332. Thonicke K., Venevsky S. et Sitch S., (2001). The role of fire disturbance for global vegetation dynamics: coupling fire into a dynamic global vegetation model. Global Ecology and Biogeography 10, pp. 661-677.
333. Tinthoin R. ,(1948). Les aspects physiques du tell oranais.L. Fouquet,Oran,639 p.
334. Titah A.,(2011). Adaptation au changement climatique des conditions cadres de la politique forestier dans la région Mena. 2ème Semaine forestière méditerranéenne, Avignon, 5p.
335. Trabaud L., & Galité J-F.,(1996). Effects of fire frequency on plant communities and landscape pattern in the massif des aspres (South France). Landscape Ecology,11 (4): 215-224.
336. Trabaud L., (1990). Influence du feu sur les propriétés chimiques des couches superficielles d'un sol de garrique. Rev. Ecol. Biol. Sols 27 (4): 383 - 394.
337. Trabaud L., (1991). Le feu est-il un facteur de changement pour les systèmes écologiques du bassin méditerranéen ? Sécheresse, 3 (2): 163 - 174.
338. Trabaud, L., (1980). Impact biologique et écologique des feux de végétation sur l'organisation, la structure et l'évolution de la végétation des garrigues du Bas Languedoc.» Thèse Doctorat Etat Sciences, Univ. Sci. Tech. du Languedoc, Montpellier, 288 P.
339. Trabaud, L., (1983). «Risques d'incendie et accroissement de la végétation dans la région méditerranéenne française.» Rev. Gén. Sécurité, 25: 41-46.
340. U´beda X., Outeiro L.R., Sala M., (2006). Vegetation regrowth after a differential intensity forest fire in a Mediterranean environment, Northeast Spain. Land Degradation & Development 17: 429–440.
341. U ´beda X., Pereira P., Martin D.A., (2009). Fire temperature effects on Total Carbon, Total Nitrogen, C/N and release of water soluble phosphorous on litter from two Quercus suber trees located in different plots of Iberian Peninsula. Second International Meeting of Fire Effects on Soil Properties. Marmaris, Turkey.
342. Úbeda X, Outeiro LR, Sala M. (2006). Vegetation regrowth after a differential intensity forest fire in a Mediterranean environment, Northeast Spain. Land Degradation & Development 17: 429–440.
343. ÚBeda X. Pereira P. Outeiro L.. Martin D. A. (2009). Effects of Fire Temperature On The Physical And Chemical Characteristics Of The Ash From Two Plots of Cork Oak (*Quercus Suber*). Land Degradation & Development. 20: 589–608.
344. Uhl C. & Kauffman J.B.(1990) . Deforestation, fire susceptibility, and potential trees responses to fire in the Eastern Amazon, Ecology 71: 437-449.
345. Unfccc., (2023). « Les incendies incontrôlés vont augmenter de 50% d'ici à 2100 et les gouvernements n'y sont pas préparés. » [archive], sur unfccc.int, 23 février 2022 (consulté le 4 Juillet 2023).

346. Vallette J.C., (1997). Inflammabilities of mediterranean species. In Forest fore risk and management. (Eds) P Balabanis, G Eftichidis, R Fantechi, 51–64.
347. Vallete JC (1990) Inflammabilités des espèces forestières méditerranéennes, conséquences sur la combustibilitédes formations forestières. Revue Forestiere Française, 42: 76–92.
348. Van Lierop P., Lindquist E., Sathyapala S., & Franceschini G., (2015). Global forest area disturbance from fire, insect pests, diseases and severe weather events. Changes in Global Forest Resources from 1990 to 2015, 352, 78–88. https://doi.org/10.1016/j.foreco.2015.06.010
349. Varela MC., (2004). Le chêne-liège et les incendies de forêts : le cas portugais 2004. Colloque Vivexpo : le chêne liège face au feu. Perpignan, 2004.
350. Veille J,F., (2004). Régénération et sylviculture des suberaies incendiées. Forêt Méditerranéenne, 27(4): 357-362.
351. Velez R. (1994). La protection contre les incendies de forêt [(Forest fire control], (CIHEAM-IAMZ, ICONA, FAO).
352. Velez R.,(1991). Silvicultura preventiva de incendios forestales, Unasylva 162. Available at: http://www.fao.org/docrep/t9500s/t9500s03.htm [verified in 15 of July of 2008].
353. Velez, R., (1990). Protection contre les incendies de forêts : principes et méthodes d'action.» Options méditerranéennes, Série B : Etudes et recherches, Numéro 26, CIHEAM, 118 p.
354. Vennetier M., (2008). Impact de la répétition des incendies sur l'environnement » in Info DFCI no 61, novembre 2008. Cemagref. Aix-enProvence.
355. Vesk, P. A., (2006). Plant size and resprouting ability: trading tolerance and avoidance of damage? – J. Ecol. 94: 1027–1034.
356. Vignes E., (1990). Le traitement du taillis du chêne dans le var.O.N.F.Arboréscence. n°26.pp 21-23.
357. Vines R.G., (1981). Physics and chemistry of rural fires. In 'Fire and the Australia Biota. (Eds AM Gill, RH Groves, IR Noble) : 129–149. (Australian Academy of Science: Canberra).
358. Wagner C. E. V., (1988). Effect of slope on fires spreading downhill. Canadian Journal of Forest Research, 18(6), 820–822. https://doi.org/10.1139/x88-125
359. Warburg,O. & Warburg,E.,(1933). Oaks in cultivation in the British Isles.Jour.Royal Hort.,Soc,LVIIII,part I,pp.176-189.
360. Whelan R.J. (1995). The ecology of fire. New York: Cambridge University Press. 346 p
361. White, R. H.; Zipperer, W. C., (2010).Testing and classification of individual plants for fire behaviour: plant selection for the wildland–urban interface. International Journal of Wildland Fire, Clayton South, v. 19, p. 213–227.
362. Wildland Fire Behavior., (2022). [National Park Service. Wildland Fire Behaviour Series. Wildland Fire-Learning in Depth. US. Department of the Interior.]. Wildland Fire Behavior (U.S. National Park Service). https://www.nps.gov/articles/wildland-fire-behavior.htm
363. Wright H.A. & Bailey A.W.(1982), Fire Ecology: United States and Southern Canada, Ed.Wiley, 528p.
364. WWF, (2007). Beyond cork—a wealth of resources for people and nature. World Wide Fund for Nature, Madrid.
365. WWF., (2004). Les PFNL et le paiement des Services Environnementaux: Conservation des subéraies à travers la maximisation de leurs valeurs économiques et sociales.

366. Zhan, Z.; Zhang, Z.; Zhou, D. (2011). Flammability characterization of grassland species of Songhua Jiang-Nen Jian Plain (China) using thermal analysis. Fire safety Journal, Amsterdam, v. 46, n.5, p. 283-288.
367. Zouaidia H., (2006). Bilan des incendies de forêts dans l'Est algérien. Cas de Mila, Constantine, Guelma et Souk-Ahras.» Mémoire de magister en écologie végétale, université de Constantine. 155 p.