EFECTES DEL CANVI GLOBAL A LES ROUREDES DE QUERCUS PETRAEA AL NE DE LA PENÍNSULA IBÈRICA

Jordi Bou Manobens

Universitat de Girona

TESI DOCTORAL

Efectes del canvi global a les rouredes de *Quercus petraea* al NE de la Península Ibèrica

Jordi Bou Manobens

2019

Universitat de Girona

Tesi doctoral

Efectes del canvi global a les rouredes de *Quercus petraea* al NE de la Península Ibèrica

Jordi Bou Manobens

2019

PROGRAMA DE DOCTORAT EN MEDI AMBIENT

Dirigida i tutoritzada per:
Dr. Lluís Vilar Sais

Candidat a Doctor:
Jordi Bou Manobens

La present tesi doctoral conté 3 annexos al final del document

Memòria presentada per optar al títol de Doctor per la Universitat de Girona

Universitat de Girona

El Dr. Lluís Vilar Sais, del Departament de Ciències Ambientals i Institut de Medi Ambient de la Universitat de Girona,

Certifica:

Que aquest treball titulat *Efectes del canvi global a les rouredes de Quercus petraea al NE de la Península Ibèrica*, que presenta en Jordi Bou Manobens per a l'obtenció del títol de doctor, ha estat realitzada sota la meva direcció.

I, perquè així consti i tingui els efectes oportuns, signo aquest document.

Dr. Lluís Vilar Sais

Professor Titular

Departament de Ciències Ambientals

Institut de Medi Ambient

Universitat de Girona

Girona, 21 de gener de 2019

Agraïments

Segurament em deixaré a varies persones, ja que durant una tesi doctoral són moltes les que t'acaben acompanyant i donant suport, ja sigui de forma més o menys directe. Per a tots aquells que m'han acompanyat, un sincer gràcies.

En primer lloc agrair al meu director de tesi Lluís Vilar, que en el seu moment em va donar l'oportunitat d'incorporar-me en el seu grup de recerca i introduir-me en l'estudi dels boscos del Montseny, fet que em va portar a iniciar una línia de recerca sobre l'ecologia de les rouredes de roure de fulla gran, tot col·laborant amb la Dra. Antonia Caritat.

Pel que fa als companys de doctorat, sempre recordaré els meus inicis a l'àrea de botànica amb en Miquel i Sergi, els quals em van fer de Mestres Jedi en el camí de la força. També a tots els doctorands i joves investigadors del Departament de Ciències Ambientals, en especial amb qui més moments he compartit aquests anys de tesi, com Maria, Lorena, Jordi, David, Alba, Irene, Giulia, Laures; Marina i tants d'altres. Si parlem de companys de viatge no em puc deixar UdG.doc, on he posat totes les forces i energies que em quedaven després de dies llargs de tesi. Sempre recordaré als companys de junta com la Gemma, la Carol, en Beltran i la Lídia, i els companys de departament que ja he esmentat anteriorment però que també vaig entabanar per sumar forces a l'associació, en David i la Irene. També agrair al PAS de la universitat, en especial a la Sílvia Terradas i la Pilar Eijo, que sense la seva ajuda no podria haver tirat endavant gran part de les coses que he fet en el marc de la tesi, i als investigadors sèniors que s'han apropat en alguns moments determinats de la tesi per donar ànims i força. Alhora un especial record als estudiants en pràctiques de la UdG que van participar en els inventaris forestals del Montseny, en Martí i en Juan.

Agrair també la confiança que em va donar en aquells inicis sobre la recerca de les rouredes de roure de fulla gran en Narcís Vicens, tècnic de la Diputació de Girona i que gràcies al suport logístic i també econòmic s'ha pogut finançar part de la recerca. En aquest mateix sentit agrair la confiança que em van donar l'Institut Ramon Muntaner el 2018, amb la concessió d'una Beca de Recerca Francesc Eixamenis que ha permès finançar part del primer article de la tesi.

Agrair als meus amics la paciència que han tingut tots aquests anys, en que el meu objectiu principal ha estat fer una tesi doctoral i m'he convertit una mica en un disc rallat, tot i que els bons amics sempre aconsegueixen treure't del discurs únic i distreure't una bona estona. Gerard, Sergi i Dr. Pol, quin dia quedem? Ada i Irene, crec que em tocarà fer una tirada llarga amb el cotxe d'aquí poc. També a noves amistats que he trobat en aquests últims temps, com en David i la Giu, que també formen part d'aquests anys de tesi.

Per últim agrair a la meva família el seu suport incondicional, especialment a la meva mare Rosa Maria i al meu pare Josep, que gràcies a la seva manera de veure i transmetre la natura he acabat fent el que aquí presento, una tesi doctoral sobre boscos. Agrair també a ells dos, i al meu germà Francesc en especial, la seva paciència amb les meves disquisicions sobre les rouredes.

Publicacions derivades de la tesi doctoral

Aquesta tesi està redactada per compendi d'articles, els quals són referenciats de la següent forma:

Article 1

Bou, J., & Vilar, L. Sessile oak forest plant community changes on the NE Iberian Peninsula. Enviat a revista. Journal of Plant Ecology. Enviat el 15 d'octubre de 2018.

Journal of Plant Ecology

FI: 1.937, Rang: 80/223 (Plant sciences Q2)

Article 2

Bou, J., & Vilar, L. (2018). Current distribution and recent development of sessile oak forests in Montseny (1956-2015). Landscape Research. http://doi.org/10.1080/01426397.2018.1472751 En premsa.

Landscape Research

FI: 1.198, Rang: 57/84 (Geography Q3)

Article 3

Bou, J., & Vilar, L. (2019). The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula. Natural Areas Journal 39 (2). Acceptat per a publicació.

Natural Areas Journal

FI: 0.980, Rang: 42/66 (Forestry Q3)

Índex

Agraïments ... i

Publicacions derivades de la tesi doctoral ... iv

Índex ... v

Índex de figures ... ix

Índex de taules ... xi

Llista d'abreviatures ... xiii

Resum ... ii

Resumen ... v

Abstract ... ix

1 Introducció general ... 1

1.1 El roure de fulla gran a Catalunya dins el context Europeu ... 1

1.2 Efectes del canvi climàtic sobre les comunitats vegetals de muntanya ... 4

1.3 Canvis en els usos del sòl dels boscos ... 7

1.4 Dinàmica vegetal de les rouredes de roure de fulla gran ... 10

2 Hipòtesis i objectius generals ... 13

3 Àrea d'estudi ... 15

4 Sessile oak forest plant community changes on the NE Iberian Peninsula ... 18

4.1 Abstract ... 18

4.2 Introduction ... 19

4.3 Materials and methods ... 21

4.3.1 Study sites ... 21

4.3.2 Field samplings ... 22

4.3.3 Data analyses ... 23

4.4 Results ... 24

4.4.1 Changes in biodiversity ... 24

4.4.2 Changes in plant traits ... 27

4.5 Discussion ... 29

4.5.1 Biodiversity dynamics ... 29
4.5.2 Forest use and woody plants ... 30
4.5.3 Thermophilization ... 33
4.6 Conclusion ... 35
4.7 Acknowledgments ... 36
4.8 Bibliography ... 36
4.9 Supporting Information ... 40
5 Current distribution and recent development of sessile oak forests in Montseny ... 42
5.1 Abstract ... 42
5.2 Introduction ... 42
5.3 Methodology ... 44
5.3.1 Area of study ... 44
5.3.2 Producing the map of the oak forests of 2015 ... 44
5.3.3 Elaboration of the 1956 map ... 45
5.3.4 Analysis of the cartography ... 45
5.4 Results ... 47
5.4.1 Current situation of the sessile oak forests ... 47
5.4.2 Development of sessile oak forests ... 49
5.5 Discussion ... 49
5.5.1 Current situation ... 49
5.5.2 Evolution of the land cover ... 53
5.6 Conclusions ... 56
5.7 Acknowledgements ... 58
5.8 Disclosure statement ... 58
5.9 ORCID ... 58
5.10 References ... 58
6 The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula ... 64
6.1 Abstract ... 64

6.2 Introduction 64

6.3 Methods 66

6.3.1 Study Area and Sites 66

6.3.2 Stand Structural Attributes 67

6.3.3 Statistical Analysis 68

6.4 Results 69

6.4.1 Characterization of Forest Stands 69

6.4.2 Forest Parameters 70

6.4.3 Environmental factors 71

6.4.4 Approach to Forest Dynamics 73

6.5 Discussion 73

6.6 Conclusions 76

6.7 Acknowledgments 77

6.8 Biographical sketches 77

6.9 Literature cited 77

7 Discussió general 82

7.1 Efectes del canvi global a la comunitat florística de la roureda de roure de fulla gran al NE de la Península Ibèrica 82

7.2 Les rouredes de roure de fulla gran al *xeric limit*, el cas del Montseny 85

7.3 La conservació de les rouredes de roure de fulla gran a Catalunya 88

8 Conclusions 90

9 Referències 93

Annexos 105

Annex A Informació adicional de l'article "Sessile oak forest plant community changes on the NE Iberian Peninsula" 105

A.1 Supplementary information 105

A.2 Inventaris florístics 114

Annex B Còpia de l'article "Current distribution and recent development of sessile oak forests in Montseny (1956-2015)" 124

Annex C Informació adicional de l’article ”The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula” 139

Índex de figures

1 Introducció general

Figura 1.1 Distribució mundial de *Quercus petraea* 2

Figura 1.2 Distribució de les rouredes de roure de fulla gran a Catalunya. Es separen els diferents hàbitats catalans que li corresponen: 41h Rouredes de roure sessiliflor (*Quercus petraea*), de vegades amb altres caducifolis (*Betula pendula*...), acidòfiles i xeromesòfiles, pirinenques i del territori catalanídic septentrional; 41i1 Boscos de roure sessiliflor (*Quercus petraea*), mesohigròfils, dels Pirineus i de les muntanyes catalanídiques septentrionals; 41i2 Boscos de roure sessiliflor (*Quercus petraea*), sovint amb bedolls (*Betula pendula*), acidòfils i higròfils, pirinencs 3

Figura 1.3 Exemple de comunitat de roure de fulla gran a la Vall d'Aran, dominada per espècies adaptades al fred i a la humitat 5

Figura 1.4 Antiga carbonera abandonada al bosc de Marmolers, Montseny 8

Figura 1.5 En primer pla un avet de Douglas (*Pseudotsuga menziesii*) a la roureda dels Graners, Montseny 9

Figura 1.6 Roureda del Puig, al Montseny, on s' observa els efectes de l'explotació forestal 10

2 Hipòtesis i objectius generals

Figura 2.1 Esquema de les hipòtesis plantejades al llarg dels tres articles de tesi doctoral 13

3 Àrea d'estudi

Figura 3.1. Mapa de les localitats estudiades de roureda de roure de fulla gran (representada segons els LHC de Catalunya) 15

4 Sessile oak forest plant community changes on the NE Iberian Peninsula

Figure 1. Sessile oak forests (black) on the NE Iberian Peninsula 20

Figure 2. Richness and diversity values of the sessile oak forests for each subregion and for the two periods studied 25

Figure 3. MDS plots showing forests, according to the abundance for each species, from Pyrenees (A), Pre-Pyrenees (B), Coastal Range (Mn) and Pre-Coastal Range (M) 26

Figure 4. Species classified as being new to the localities or not by comparing the two study period 26

Figure 5. Right, the relative richness of hemicryptophytes (H) and deciduous megaphanerophytes (MPc). Left, the relative abundance of the same plant traits. The results are shown for each subregion and for the two periods studied 31

Figure 6. On the top, the Mediterranean (Med) relative richness and relative abundance, and under them the relative abundance of Atlantic (Atl) and Euro-Siberian (Eur) plants. The results are showed for each subregion on the two studied periods 33

5 Current distribution and recent development of sessile oak forests in Montseny (1956-2015)

Figure 1. Current distribution and recent development of the sessile oak stands in the Natural Park Montseny. Prepared by the authors. Source: Bou et al., 2015; Diputació de Barcelona, 2014; Generalitat de Catalunya, 2017; Institut Cartografic i Geologic de Catalunya, 2015 48

Figure 2. Elevation of sessile oak forests in Montseny 50

Figure 3. Orientation of sessile oak forests in Montseny 50

6 The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula

Figure 1. Sessile oak forests in Montseny Natural Park, NE Iberian Peninsula (Bou et al. 2015b). In black all the sessile oak forest cover, with its locality labels (ref code of Table S1) 67

Figure 2.- Hierarchical cluster of the species composition (BA) of the sessile oak stands studied. Different forest types are indicated in the key 71

Figure 3. Diametric classes distribution for each forest type, defined by the hierarchical cluster. The Y axis shows the tree *Q. petraea* density (stem ha-1) for each diametric class ……………………………..…… 73

Figure 4. The diagram shows the intensity of the forest exploitation during the first half of the 20th century. To order from least to more degree of intensity, the percent of sparse forest for each forest type has been used ………………………………………………………………………………………………… 75

7 Discussió general

Figura 7.1.- Esquema gràfic dels efectes del canvi global a les rouredes de roure de fulla gran al NE de la Península Ibèrica 83

Figura 7.2.- Esquema gràfic de la dinàmica forestal de les rouredes de roure de fulla gran al Montseny…..87

Índex de taules

3 Àrea d'estudi

Taula 3.1 Característiques ambientals de les diferents localitats estudiades 16

4 Sessile oak forest plant community changes on the NE Iberian Peninsula

Table 1. Localities studied classified as subregion and region, with the meteorological characteristics of sessile oak forests. "N" is the number of inventories. [1]Climatic variables were estimated using a georeferenced model (Ninyerola et al., 2000) 21

Table 2. Scales used for Braun-Blanquet plant cover estimates and the corresponding value to the transformations to percentage of cover used in the analyses 23

Table 3. ANOVA results for the biodiversity variables differences over time 24

Table 4. Linear regression between altitude and ecological variables. The first P-value tests the regression model, the second corresponds to the t-test of the intercept (a) whereas the third corresponds to the t-test of whether the regression coefficient or slope (b) is significantly different from 1. The coefficient of determination (r^2) and the residual standard error (SE) of the regression model are also given 27

Table 5. ANOVA results for the plant life-form variables differences over time 28

Table 6. ANOVA result for chorological variables differences over time 29

5 Current distribution and recent development of sessile oak forests in Montseny (1956-2015)

Table 1. Vegetation units considered in the 1956 maps of the oak forests 45

Table 2. Indices used in the cartographical analysis of the fragmentation of sessile oak forests 46

Table 3. Meaning of possible results of the degree of fragmentation index 46

Table 4. Area covered by sessile oak forests in Montseny 48

Table 5. Patton's shape index. Number (Nº) and percentage of sessile oak forest patches 49

Table 6. Calculations of fragmentation and shape indices 49

Table 7. Perimeter of the oak forests according to the units contiguous with them 51

Table 8. The zonification of the park is defined by the Special Plan for Montseny (Diputació de Barcelona, 2008), which defined four different categories (with acronyms in the Catalan language): ZIN, zone of natural interest, which grants basic protection within the terms of the Special Plan; ZRN, nature reserve

zone which only allows management that is directly related to the preservation and improvement of the values protected and ZAINEP, zone of high natural, environmental interest and outstanding beauty. The criteria for intervention for each zone is set out in a specific plan, establishing the management criteria. The Urban Zone is an area subject to existing arrangements, in which the residential and urban centres' own rules and regulations apply 53

Table 9. Surface area of vegetation units in the oak forest under study in 1956 54

Table 10. Surface area covered by different categories of forest (natural and plantations) at Montseny, in order of size. Source: own data combined with data from MCSC [Land Cover Map of Catalonia] 55

6 The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula

Table 1. Species composition variables (the basal area) for each forest type obtained with the cluster analysis. Standard error indicated in parentheses. The number of stands in each type is indicated (n) ….. 69

Table 2. Forest variables for each forest type obtained with the cluster analysis. Standard deviation (SD) indicated in parentheses. The ANOVA results are shown; the significance results are marked in "Sig". The Tukey's HSD in the last column compare differences between pairs of forest types, the letters correspond to pair of types with significant results ……………………………………………………………. 72

Table 3. Percent occurrence of the stands of each forest type to the vegetation units from 1956 (Bou & Vilar, 2018) ………………………………………………………………………………………. 73

Llista d'abreviatures

AG: Alta Garrotxa

Alp: Alpí

Atl: Atlàntic

BA: Àrea basal

BDBC: Banc de dades de biodiversitat de Catalunya

Boreo-subalpine: Bòreo-subalpí i àrtico-alpí

C. sativa: *Castanea sativa*

Ch: Camèfit

CORINE: Coordination of Information on the Environment

DBH: Diàmetre a l'altura del pit

DI: Índex de forma de Patton

Eur: Euro-siberià

F. sylvatica: *Fagus sylvatica*

F: Grau de fragmentació

FCI: Índex de continuïtat del bosc

G: Geòfit

H: Hemicriptòfit

Introd: Introduït

LHC: Llista d'Hàbitats de Catalunya

M/E ratio: relació entre espècies mediterrànies i eurosiberianes

M: Montseny

Med: Mediterrani

Mn: Montnegre

MNN: Distància mitjana fins el fragment més pròxim

MPc: Macrofaneròfit caducifoli

MPp: Macrofaneròfit perennifoli

NPc: Nanofaneròfit caducifoli

NPp: Nanofaneròfit perennifoli

P: Faneròfit

PEIN: Pla d'Espais d'Interès Natural de Catalunya

Plurireg: Pluriregional

Pont: Pòntic

PS: Pallars Sobirà

PSGF: Pla simple de gestió forestal

PTGMF: Pla tècnic de gestió i millora forestal

Q. ilex: *Quercus ilex*

Q. petraea: *Quercus petraea*

SU: la Seu d Urgell

Submed: Submediterrani.

Temp.: Temperatura

Th: Teròfit

VA: Vall d Aran

VR: Vall de Ribes

Resum

El roure de fulla gran, *Quercus petraea*, és un arbre caducifoli de la família de les fagàcies, de distribució eurosiberiana, àmpliament present a centre Europa. Tot i així arriba a tolerar la influència mediterrània, motiu pel qual a la Península Ibèrica no només és present a la Serralada Cantàbrica i als Pirineus, sinó que també el podem trobar a la Serralada Prelitoral catalana o fins i tota la Serralada Litoral. Les poblacions del NE de la Península Ibèrica es trobarien al seu límit meridional de distribució i les de condicions més mediterrànies en el *xeric limit* per aquesta espècie. Estudis de la dinàmica de la vegetació en aquestes condicions extremes són claus per tal de poder millorar el coneixement sobre la resposta de la vegetació al canvi climàtic, a més de ser poblacions adaptades a unes condicions d'estrès hídric, amb un valor genètic molt elevat, sent així un element clau en la conservació de l'espècie. Però no només és el cas de *Q. petraea*, sinó el d'aquelles espècies eurosiberianes que conformen la comunitat vegetal de la roureda, *Lathyro montani-Quercetum petraea*, les quals tenen també el seu *xeric limit* a l'estatge montà humit. En conjunt les rouredes de roure de fulla gran ocupen una reduïda superfície al NE de la Península Ibèrica, però la seva distribució no sempre ha estat com l'actual, i en un futur pot ser que torni a canviar, tot degut al canvi global.

Un dels components del canvi global és el canvi climàtic, amb molts efectes directes sobre les plantes, com ara l'afavoriment d'espècies termòfiles les quals es troben més ben adaptades a les condicions més càlides, en detriment d'espècies adaptades a condicions més fredes, produint-se així la termofilitizació de les comunitats. A més, el NE de la Península Ibèrica es troba en un context de transició entre les regions euro-siberianes i les de clima mediterrani on s'esperen grans canvis. Però els canvis depenen de la vulnerabilitat de cada espècie davant del canvi climàtic, ja que els boscos temperats com la fageda i la roureda de roure de fulla gran es preveu que redueixin el seu rang de distribució, mentre que els arbres mediterranis seran menys afectats. Però tot i que es un tema molt estudiat, existeixen pocs treballs sobre muntanya de baixa i mitjana altitud, on precisament creixen aquests boscos al NE de la Península Ibèrica.

Un segon component del canvi global que ha afectat a les rouredes són els canvis en els usos del sòl dels boscos, ja que des d'antic s'han explotat i transformat, d'aquí la manca d'estructures madures a Europa. Des d'aprofitaments principalment per fusta, fins als de llenya i carboneig en els moments més àlgids d'aquests tipus d'explotacions, arribant a l'actualitat com una de les espècies caducifòlies amb més importància en el sector forestal europeu. Tanmateix els usos del bosc han anat canviant al llarg del temps, especialment a mitjans de segle XX, ja que per una banda el procés d'abandonament rural i la conseqüent reducció de la coberta agrícola, ha permès

la recuperació forestal i, per l'altra, l'aparició de nous combustibles va fer que s'abandonessin moltes pràctiques agroforestals tradicionals. Aquests canvis en els usos van propiciar la substitució d'espais oberts per matollars i boscos tant a Europa com al NE de la Península Ibèrica.

És en aquest marc que es planteja aquesta tesi, amb l'objectiu principal de descriure les dinàmiques ecològiques de les rouredes de roure de fulla gran al NE de la Península Ibèrica des de mitjans de segle XX. Per tal de comprovar les hipòtesis dels efectes del canvi global, s'estudien els canvis corresponents a l'evolució que han tingut les rouredes en els darrers anys. Treballant a nivell de la comunitat florística de la roureda al NE de la Península Ibèrica (Article 1), hem fet especial èmfasi en el cas d'estudi del Montseny on s'aprofundeix en la distribució i l'estructura forestal de les rouredes (Article 2 i 3) ja que es tracta d'una localitat clarament en el *xeric limit*, amb una importància estratègica en la gestió i conservació d'aquests boscos.

Els resultats obtinguts a partir dels inventaris florístics de les rouredes de roure de fulla gran al NE de la Península Ibèrica, mostren que la comunitat ha canviat la seva composició d'espècies des de la segona meitat del s. XX, però de forma sensiblement diferent segons cada regió; així els canvis són força importants a la Serralada Litoral, ja que al Parc Natural del Montnegre s'ha observat una clara pèrdua de biodiversitat. De fet gran part dels canvis en la composició d'espècies de les rouredes del NE de la Península Ibèrica s'expliquen pels canvis en els usos del bosc. Fa 60 anys amb l'abandonament dels aprofitaments agroforestals tradicionals a les rouredes, es va produir un increment dels macrofaneròfits caducifolis el qual ha comportat una disminució de la llum dins del bosc i com a conseqüència una disminució dels hemicriptòfits del sotabosc.

Durant aquest mateix període el canvi climàtic també ha afectat l'espectre corològic de les rouredes, on s'ha evidenciat un procés de termofilització en algunes localitats. El cas més evident és a la Serralada Litoral on les plantes mediterrànies s'han vist afavorides, tot i que també es veuria un estadi menys intens d'aquest procés als Pirineus, on les plantes atlàntiques s'han vist una mica perjudicades; si bé aquestes dinàmiques són observables a les rouredes més orientals, a les més occidentals no hi semblarien ser gaire presents. En aquest darrer cas es tractaria de rouredes més estables davant de totes les dinàmiques derivades del canvi global, segurament degut a que es tracta de localitats situades a la Vall d'Aran i el Pallars Sobirà, amb unes condicions ambientals molt més favorables.

En el cas de les rouredes de roure de fulla gran del Montseny, la cartografia mostra que ocupen molt poca superfície i que són boscos situats en una estreta franja entre l'alzinar i la fageda; i quan comparteix cota altitudinal amb el faig el roure hi queda restringit a vessants sud. Els resultats obtinguts mostren que aproximadament la meitat de les rouredes de fa 60 anys s'han densificat, i que fins i tot la roureda s'ha expandit una mica, tot plegat com a conseqüència de l'abandonament dels aprofitaments agroforestals al massís, des de mitjans de s. XX.

Actualment les rouredes del Montseny, es poden classificar en cinc tipus de bosc diferents. D'una banda les rouredes joves i denses, en les quals hi ha una importat abundància d'espècies arbòries pioneres i de creixement ràpid que acompanyen el roure, que correspondrien a antics rodals dispersos. Un segon tipus correspon a rouredes joves i denses, amb una elevada densitat de roures joves que fa 60 anys eren rodals densos, els quals creiem que haurien tingut una estructura forestal similar al primer tipus descrit, en el que els roures haurien anat substituint a les espècies acompanyants. Un tercer tipus estaria format per rouredes amb estructures intermèdies, amb algun cas de bosc ja més madur, que pensem seria l'estadi clímax d'aquests boscos. Per últim hi ha dos tipus de bosc més, un dels quals es troba en condicions límit per *Q. petraea*, i a on apareixen altres espècies de roures, i l'altre són boscos més de transició a alzinar i fageda. Així doncs al Montseny, s'ha produït una recuperació de la roureda de roure de fulla gran a nivell forestal, però alhora de la comunitat florística, ja que també s'ha observat un augment de la dominància de les plantes eurosiberianes típiques d'aquests boscos. Tot i aquest gran procés de recuperació dels impactes de l'explotació secular, les rouredes mantenen un important grau de fragmentació i hi ha una manca d'estructures madures a causa de l'explotació del passat i l'aparició de noves pràctiques forestals com les plantacions d'avet de Douglas, que estan fent aparèixer noves problemàtiques ambientals per aquests boscos.

La dinàmica de les rouredes de roure de fulla gran al NE de la Península Ibèrica és, doncs, la de recuperació del canvi dels usos del bosc, i el Montseny és el millor exemple d'aquest procés; però, en canvi, per algunes rouredes com les del Montnegre, el canvi climàtic presenta un futur incert. Per aquest motiu és important aprofitar les localitats que es troben en refugis naturals com a reservoris i punts on poder conservar aquest hàbitat. Una gestió sostenible seria necessària per permetre així un desenvolupament natural del bosc, i la tendència a la maduresa en un futur. La gestió adaptada al canvi climàtic no només hauria de ser enfocada a reduir-ne els impactes, sinó també aprofitar la gran capacitat de resiliència d'aquest hàbitat i plantejar una estratègia per a la recuperació de les rouredes de roure de fulla gran en espais que potencialment els hi correspondria i que actualment poden estar ocupats per formacions vegetals seminaturals o artificials. Els nous coneixements sobre aquestes dinàmiques al NE de la Península Ibèrica, especialment en el *xeric limit*, s'haurien de continuar estudiant per continuar aportant informació que ajudi a entendre els futurs canvis d'aquests boscos en aquest territori i a tot Europa.

Resumen

El roble albar, *Quercus petraea,* es un árbol caducifolio de la familia de les Fagáceas, de distribución eurosiberiana, ampliamente presente en centro Europa. Aun así, llega a tolerar la influencia mediterránea, motivo por el que en la Península Ibérica no solo es presente en la Cordillera Cantábrica o los Pirineos, sino que también se puede encontrar en la Cordillera Prelitoral catalana o incluso en la Cordillera Litoral. Las poblaciones del NE de la Península Ibérica se encuentran en su límite meridional de distribución y las de condiciones más mediterráneas ya en el *xeric limit* para esta especie. Estudios de la dinámica de la vegetación en estas condiciones extremas son claves para poder mejorar el conocimiento sobre la respuesta de la vegetación ante el cambio climático, además de ser poblaciones adaptadas a unas condiciones de estrés hídrico con un valor genético muy elevado, siendo así un elemento clave en la conservación de las especies. Pero no solo es el caso de *Q. petraea*, sino también el de aquellas especies eurosiberianas que conforman la comunidad vegetal del robledal, *Lathyro montani-Quercetum petraea*, las que tienen su *xeric limit* en el piso montano húmedo. En conjunto los robledales de roble albar ocupan una reducida superficie al NE de la Península Ibérica, pero su distribución no siempre ha sido como la actual y en un futuro puede que tengan lugar nuevas variaciones debido al cambio global.

Uno de los componentes del cambio global es el cambio climático, con muchos efectos directos sobre las plantas, como el favorecimiento de especies termófilas las cuales se encuentran mejor adaptadas a las condiciones más cálidas, en detrimento de especies adaptadas a condiciones más frías, produciéndose así la termofilitización de las comunidades. Además, el NE de la Península Ibérica se encuentra en un contexto de transición entre les regiones euro-siberianas y las de clima mediterráneo donde se esperen grandes cambios. Pero estos cambios dependen de la vulnerabilidad de cada especie delante del cambio climático, ya que los bosques templados como el hayedo y el robledal de roble albar se prevén que reduzcan su rango de distribución, mientras que los árboles mediterráneos serán menos afectados. Si bien el cambio global está siendo un tema muy estudiado, existen pocos trabajos sobre montaña de baja y media altitud, precisamente donde crecen estos bosques al NE de la Península Ibérica.

Un segundo componente del cambio global que ha afectado a los robledales son los cambios en los usos del suelo de los bosques, ya que se han explotado y transformado des de antiguo para aprovechamientos madereros, y en los momentos más álgidos para leña y carbón, llegando a la actualidad a ser una de las especies caducifolias con más importancia en el sector forestal europeo. Por esta razón actualmente haya escasez de bosques maduros en Europa. Así mismo los usos del

bosque han ido cambiando a lo largo del tiempo, especialmente a mediados del siglo XX, debido por un parte al abandono del mundo rural y la consecuente reducción de la cubierta agrícola, lo que ha permitido la recuperación forestal, y por otra la aparición de nuevos combustibles que promovieron el abandono de prácticas agroforestales tradicionales. Estos cambios en los usos propiciaron la sustitución de espacios abiertos por matorrales y bosques tanto en Europa como al NE de la Península Ibérica.

En este marco es donde se plantea esta tesis, con el objetivo principal de describir las dinámicas ecológicas de los robledales de roble albar al NE de la Península Ibérica des de medidos de siglo XX. Para poder comprobar si las hipótesis de los efectos de cambio global son ciertas, se estudian los cambios correspondientes a la evolución de los robledales en los últimos años. Trabajando a nivel de comunidad florística del robledal en el NE de la Península Ibérica (Articulo 1), y a su vez haciendo especial énfasis en el caso de estudio del Montseny donde se profundiza en la distribución y estructura forestal de los robledales (Articulo 2 y 3), ya que se trata de una localidad claramente en el *xeric limit*, es decir con una importancia estratégica en la gestión y conservación de estos bosques.

Los resultados obtenidos a partir de los inventarios florísticos de los robledales de roble albar al NE de la Península Ibérica, muestran que la comunidad ha cambiado su composición de especies des de la segunda mitad de s. XX, pero de forma diferente según la región; los cambios en la Cordillera Litoral son muy importantes, ya que en el parque natural del Montnegre se ha observado una clara pérdida de biodiversidad. De hecho, gran parte de los cambios en la composición de especies de les robledas del NE de la Península Ibérica se explican por los cambios en los usos del bosque. Hace 60 años se inició el abandonamiento de los aprovechamientos agroforestales tradicionales en los robledales, con lo que se produjo un incremento de los macrofanerófitos caducifolios, lo que ha generado una disminución de la luz dentro del bosque y como consecuencia una disminución de los hemicriptófitos del sotobosque.

A la vez, durante este período el cambio climático también ha afectado al espectro corológico de los robledales, donde se ha evidenciado un proceso de termofilización de algunas localidades. El caso más evidente es en la Cordillera Litoral donde las plantas mediterráneas se han visto favorecidas, aunque también se ve un efecto más suave de este proceso en el Pirineo donde las plantas atlánticas se han visto un poco perjudicadas; estas dinámicas son observables en los robledales más orientales, pero en los más occidentales no parecen ser muy presentes. En este último caso se trataría de robledales más estables delante de todas las dinámicas derivadas del cambio global, seguramente debido a que se trata de localidades situadas a la Vall d'Aran y el Pallars Sobirà, con unas condiciones ambientales mucho más favorables.

En el caso de los robledales de roble albar en el Montseny, la cartografía muestra que ocupan muy poca superficie y que son bosques situados en una estrecha franja entre el encinar y el hayedo; y cuando comparten cota altitudinal con la haya, el roble queda restringido a la vertiente sud. Los resultados obtenidos muestran que aproximadamente la mitad de los robledales se han densificado en estos últimos 60 años, y que incluso se han expandido un poco, todo como consecuencia del abandono de los aprovechamientos agroforestales en el macizo, des de mediados de s. XX.

Actualmente los robledales del Montseny, se pueden clasificar en cinco tipos de bosque diferentes. Por un lado, los robledales jóvenes y densos en los que hay una importante abundancia de especies arbóreas pioneras y de crecimiento rápido que acompañan el roble, que corresponden a antiguos rodales disperso. Un segundo tipo corresponde a robledales jóvenes y densos, con una elevada densidad de robles jóvenes que hace 60 años ya eran bosques densos, que según nuestra hipótesis habrían tenido una estructura forestal similar al primer tipo descrito, en la que los robles habrían ido sustituyendo las especies acompañantes hasta la estructura que se ve actualmente. Un tercer tipo seria el formado por robledales con estructuras intermedias incluyendo también algún rodal más maduro, que pensamos que sería el estadio clímax de estos bosques. Por último, existen dos tipos de bosque más, uno se encuentra en las condiciones límite para *Q. petraea*, donde aparecen otras especies de robles, y el otros son bosques de transición de la encina y el hayedo. Así pues, en el Montseny, se ha producido una recuperación de la robleda de roble albar a nivel forestal, pero a su vez de la comunidad florística, ya que también se ha observado un aumento de la dominancia de las plantas eurosiberianas típicas de estos bosques. A pesar de este gran proceso de recuperación de los impactos de la explotación secular, los robledales mantienen un importante grado de fragmentación y hay una escasez de estructuras maduras a causa de la explotación del pasado y la aparición de nuevas prácticas forestales como las plantaciones de abeto de Douglas, que están generando nuevas problemáticas ambientales para estos bosques.

La dinámica de los robledales de roble albar al NE de la Península Ibérica, pues, es la recuperación de los cambios sufridos en los usos del bosque, y el Montseny es el mejor ejemplo de este proceso; por lo contrario, en algunos robledales como los del Montnegre, el cambio climático presenta un futuro incierto para estos bosques. Por este motivo es importante aprovechar las localidades que se encuentran en refugios naturales como reservorios y puntos donde poder conservar este hábitat. Una gestión sostenible sería necesaria para permitir así un desarrollo natural del bosque y la tendencia a la madurez en un futuro. La gestión adaptada al cambio climático no solo debería de ser enfocada en reducir los impactos, sino también en aprovechar la gran capacidad de resiliencia de estos hábitats y plantear una estrategia para la recuperación de los robledales de roble albar en espacios que potencialmente les corresponda y que actualmente pueden estar ocupados por formaciones vegetales seminaturales o artificiales. Los nuevos conocimientos sobre estas dinámicas al NE de la Península Ibérica, especialmente en el *xeric limit*, deberían continuar estudiándose para seguir aportando información que ayude a entender los futuros cambios de estos bosques en este territorio y en toda Europa.

Abstract

The sessile oak, Q*uercus petraea*, is a deciduous tree in the family Fagaceae, it has a Euro-Siberian distribution and is widespread in Central Europe. Nevertheless, it is able to tolerate the influence of the Mediterranean, which is why on the Iberian Peninsula it is present not just in the Cantabrian Range and Pyrenees, but can also be found in the Catalan Pre-Coastal Range and even the Coastal Range. The populations in the NE Iberian Peninsula are at the southernmost limit of the species range, in the most Mediterranean-type conditions and at the xeric limit. Studies of vegetation dynamics in these extreme conditions are crucial for improving our knowledge of vegetation response to climate change. In addition, these populations are adapted to water-stress conditions and have a very high genetic value, making them a key element in the conservation of the species. However, this applies not only to *Q. petraea*, but all also Euro-Siberian species comprising the oak forest community, *Lathyro montani-Quercetum petraea*, whose xeric limit is in the humid montane ecosystem. Currently, sessile oak forests occupy a small area of the NE Iberian Peninsula, but they have not always presented this distribution pattern and, in the future, their range may be altered as a result of global change.

One component of global change is climate change. This has many direct effects on plants, including favouring thermophilic species, which are better adapted to warmer conditions, to the detriment of species adapted to colder conditions, resulting in the thermophilization of plant communities. Moreover, the NE Iberian Peninsula is in an area of transition between Euro-Siberian regions and those with a Mediterranean climate, where major changes are expected. Nevertheless, these changes depend on the vulnerability of each specie to climate change, as the range of temperate forests, like beech and sessile oak, is expected to decrease, while Mediterranean trees will be less affected. However, despite being a well-studied topic, there is little work on low- and medium-altitude mountains, which is precisely where these forests grow in the NE Iberian Peninsula.

A second component of global change that has affected oak forests involves modifications to forest land use, since woodlands have been exploited and transformed since ancient times, leading to a lack of mature structures in Europe. During its peak exploitation, the sessile oak was used primarily for timber, firewood and charcoal, and still today it is one of the most important deciduous species in the European forestry sector. However, forest use has changed over time, particularly in the mid-20th century, when, on the one hand, rural abandonment and the consequent reduction in agricultural land cover allowed the forest to recover and, on the other, the emergence of new fuels led to many traditional agroforestry practices being abandoned. These changes in

use have led to open spaces being replaced by scrublands and forests in both Europe in general and the NE Iberian Peninsula.

This is the context of this thesis, the main goal of which is to describe the ecological dynamics of sessile oak forests in the NE Iberian Peninsula since the mid-20th century. To verify the hypotheses on the effects of global change, we have studied the modifications of oak forests corresponding to their evolution over recent years. Focusing on the oak forest plant community in the NE Iberian Peninsula (Chapter 1), we put special emphasis on the case study of the Montseny Massif, looking in detail at the distribution and structure of the oak woodland (Chapters 2 and 3), as it is clearly a site at the xeric limit, in other words, strategically important for the management and conservation of these forests.

Floral inventories of the sessile oak groves in the NE Iberian Peninsula show that the community species composition has been altered since the second half of the 20th century, but in slightly different ways in each region; the changes are fairly significant in the Catalan Coastal Range where the Montnegre Natural Park has experienced a clear loss of biodiversity. In fact, many of the changes in the oak forest species composition in the NE Iberian Peninsula can be explained by changes in forest use. Sixty years ago, with the abandonment of traditional oak woodland agroforestry exploitation, there was an increase in deciduous macrophanerophytes, resulting in reduced light levels in the forest and a consequent decrease in hemicryptophytes in the undergrowth. At the same time, climate change during this period has also affected the chorological spectrum of the oak forests, where thermophylisation has been observed in some localities. The most obvious case is the Coastal Range, where Mediterranean plants have been favoured, although this process has been less intense in the Pyrenees, where Atlantic plants have been slightly affected; even though these dynamics are evident in the easternmost oak forests, they appear to be much less discernible in the westernmost woodlands. These western oak forests are more stable in the face of global change-derived dynamics, in all likelihood due to their location in the Aran Valley and the county of Pallars Sobirà, which have far more favourable environmental conditions.

Mapping shows that the sessile oak forests of the Montseny Massif occupy a very small surface area and are located in a narrow strip between holm oak and beech forests; where oaks are found at the same altitude as the beeches, they are restricted to the south-facing slopes. The results show that about half the oak forests from 60 years ago have become denser, and the oak woodland may even have expanded slightly, due to the abandonment of agroforestry land use in the massif beginning in the mid-20th century.

Currently, the Montseny oak forests can be classified into five different types. Firstly, there are young, dense oak forests where there is a great abundance of fast-growing pioneer arboreal species accompanying the oak, corresponding to old scattered stands. A second type involves young, dense oak forests with a high number of young oaks, which 60 years ago were dense stands and which we believe would have had a similar forest structure to the first type described, where the oaks have now replaced the accompanying species. A third type comprises oak forests with intermediate structures, including some cases of more mature woodland, which we think would be the climax stage of these forests. Finally, there are a further two types of forest: one situated in limiting conditions for *Q. petraea*, and where other species of oak appear; the other being forests transitioning to holm oaks and beech woods. Therefore, in the Montseny Massif there has been recovery not only of the sessile oak at forest level, but also of the floral community in general, as there has also been an increase in the dominance of Euro-Siberian plants typical of these forests. Despite this remarkable recovery from the impacts of age-old exploitation, the oak forests are still significantly fragmented and there is a lack of mature structures due to past exploitation and the emergence of new forestry practices, such as Douglas fir plantations, which are causing new environmental problems in these forests.

The sessile oak groves in the NE Iberian Peninsula are, therefore, recovering from the change in forest use, and the Montseny Massif is the best example of this dynamic. For some oak forests, however, such as those in the Montnegre natural park, climate change poses an uncertain future. For this reason, it is important to take advantage of natural refuges of these species as reservoirs and places where the habitat can be preserved. Sustainable management is required to allow the forest to develop naturally, and tend towards maturity in the future. Management adapted to climate change should not only focus on reducing its impacts, but also take advantage of the resilience of this habitat, proposing a strategy for the recovery of sessile oak woodland in areas where they would potentially be found, and which may currently be occupied by semi-natural formations or introduced plant species. These dynamics in the NE Iberian Peninsula, especially at the xeric limit, require further study in order to facilitate an understanding of future changes in these forests across this region and Europe in general.

1 Introducció general

1.1 El roure de fulla gran a Catalunya dins el context Europeu

El roure de fulla gran o roure de fulla grossa, *Quercus petraea* (Matt.) Liebl., és un arbre caducifoli de la família de les fagàcies, i com altres arbres de la família és alt, esvelt i robust, de manera que pot arribar fins uns 30 m d'alçada. Forma part del gènere *Quercus*, el qual es troba en ple procés de diversificació i especiació, i per això els tàxons d'aquest gènere mostren una alta capacitat d'hibridació (Aranda, Ramírez-Valiente, & Rodríguez-Calcerrada, 2014). De fet, arreu d'Europa es troben un elevat nombre d'híbrids (Blanco Castro & Gómez Manzaneque, 1997), i es fa difícil definir amb exactitud la distribució de *Q. petraea* a Europa (Eaton, Caudullo, Oliveira, & de Rigo, 2016). A part dels corresponents híbrids, es troben diferents subespècies del roure de fulla gran, com *Q. petraea* subsp. *huguetiana* que seria exclusiu de la Península Ibèrica (Castroviejo, 2012; Do Amaral Franco & López González, 1987). A la Península Ibèrica hi domina la subespècie tipus, *Q. petraea* subsp. *petraea*, fet que ha donat peu a que alguns autors opinin que degut a que mantenen poblacions diferenciades sobre la base de caràcters estables, s'hauria de considerar en rang específic com a *Q. huguetiana* (Aymerich & Sáez, 2015; Rivas-Martínez & Sáenz, 1991). En tot cas, al nostre estudi no hem trobat aquesta clara diferenciació, i sovint es poden trobar individus amb caràcter de *Q. petraea* subsp. *huguetiana* en una població dominant de *Q. petraea* subsp. *petraea*. Així doncs, per tal de poder dur a terme aquest estudi, s'ha considerat tots els individus d'aquestes dues entitats com a *Q. petraea*, ja que per una banda no s'han trobat prous indicis per ser considerades per separat, ni resultava pràctic a l'hora de dur a terme l'estudi ecològic i geobotànic, ja que ambdues espècies conformen a l'àrea d'estudi la mateixa comunitat, i no seria l'objectiu d'aquest treball entrar en la taxonomia d'aquest grup tan complex.

El roure de fulla gran és àmpliament present a Europa (Figura 1.1) entre la latitud 40º i 60º N, des de localitats a més de 2000 m d'altitud a Turquia, a l'extrem oriental de la seva distribució, fins a Noruega i Suècia pel nord i la Península Ibèrica pel sud (Eaton et al., 2016). És una espècie eurosiberiana montana, que arriba a tolerar la influència mediterrània (Blanco et al., 2005), motiu pel qual a la Península Ibèrica no només és present a la Serralada Cantàbrica, al nord del Sistema Ibèric central o als Pirineus Centrals (Blanco Castro & Gómez Manzaneque, 1997), sinó que també el podem trobar a la Serralada Prelitoral catalana (Bolòs, 1983) o fins i tot la Serralada Litoral per sobre dels 600 m a les parts altes del Montnegre (Montserrat, 2014), on la influència mediterrània és més forta.

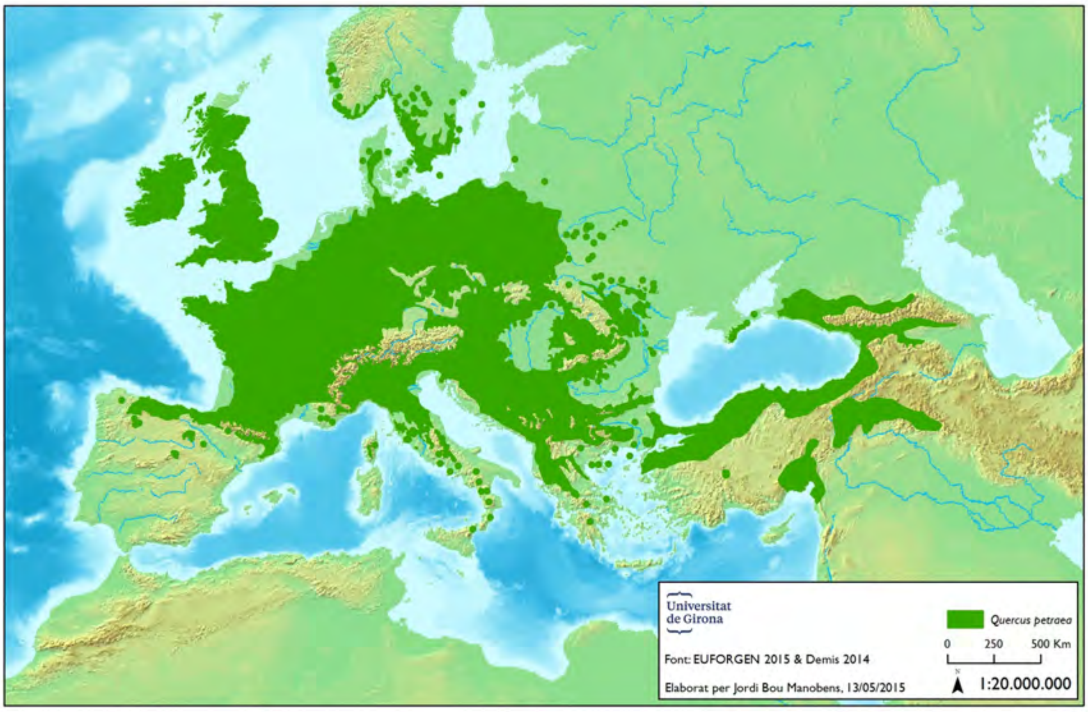

Figura 1.1 Distribució mundial de *Quercus petraea*.

Aquestes poblacions de *Q. petraea* de la Península Ibèrica es trobarien al seu límit meridional de distribució i les de condicions més mediterrànies en el *xeric limit* per aquesta espècie. El *xeric limit* és la línia entre la vida i la mort pels arbres que es troben en el seu rang límit de distribució (Mátyás, 2010). Al NE de la Península Ibèrica es troba la transició entre climes, des dels humits i temperats de la muntanya mitjana humida, fins al mediterrani a la terra baixa i muntanya litoral. Estudis de la dinàmica de la vegetació en aquestes condicions extremes són claus per tal de poder millorar el coneixement sobre la resposta de la vegetació al canvi climàtic, i poder-ne fer una millor gestió i conservació. A més, es tracta de poblacions adaptades a unes condicions d'estrès hídric, sent així el seu valor genètic molt elevat en un context d'escalfament global, ja que poden representar un element clau en la conservació de l'espècie (Mátyás, 2010). Però no només és el cas de *Q. petraea*, sinó el d'aquelles espècies eurosiberianes que conformen la comunitat vegetal de la roureda, les quals tenen també el seu *xeric limit* a l'estatge montà humit.

Les rouredes al NE de la Península Ibèrica pertanyen a la comunitat fitosociològica *Lathyro montani-Quercetum petraeae* (Lapraz) Rivas Mart. 1983, de l'ordre *Quercetalia robori petraeae* R. Tüxen 1932, i a l'aliança *Quercion robori petraeae* Br.-Bl.1932, és a dir boscos acidòfils de llocs humits, dominats per plantes eurosiberianes. Dins l'associació *Lathyro montani-Quercetum petraeae* [*Teucrio scorodonia-Quercetum petraeae* Lapraz 1996, emend. Bolòs 1983, nom. illeg.] hi trobem diferents subassociacions: subass. *stachyetosum*, subass. *castanetosum*, subass. *pinetosum sylvestris* i subass. *vaccino-pinetosum* (Bolòs, 1983; Josep Vigo, 1996).

Pel que fa als hàbitats CORINE, les rouredes de *Q. petraea* s'inclouen fins a 3 hàbitats diferents; l'hàbitat **41.5611** BOSCOS DE ROURE SESSILIFLOR (*QUERCUS PETRAEA*), DE VEGADES AMB ALTRES CADUCIFOLIS (*BETULA PENDULA*...), ACIDÒFILS I XEROMESÒFILS, PIRINENCS I DEL TERRITORI CATALANÍDIC SEPTENTRIONAL, l'hàbitat **41.5612** BOSCOS DE ROURE SESSILIFLOR (*QUERCUS PETRAEA*), SOVINT AMB BEDOLLS (*BETULA PENDULA*), ACIDÒFILS I HIGRÒFILS, PIRINENCS, i l'hàbitat **41.2A⁺** Boscos de DE ROURE SESSILIFLOR (*QUERCUS PETRAEA*), MESOHIGRÒFILS, DELS PIRINEUS I DE LES MUNTANYES CATALANÍDIQUES SEPTENTRIONALS.

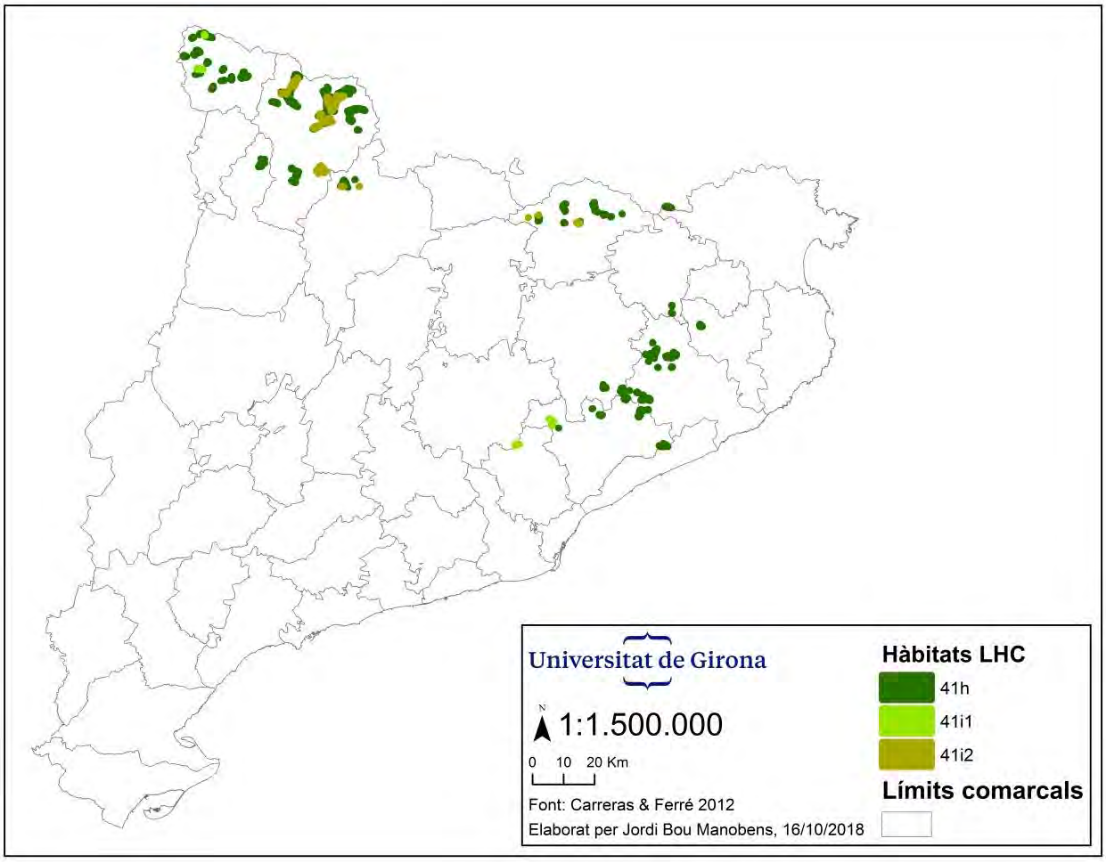

Figura 1.2 Distribució de les rouredes de roure de fulla gran a Catalunya. Es separen els diferents hàbitats catalans que li corresponen: 41h Rouredes de roure sessiliflor (*Quercus petraea*), de vegades amb altres caducifolis (*Betula pendula*...), acidòfiles i xeromesòfiles, pirinenques i del territori catalanídic septentrional; 41i1 Boscos de roure sessiliflor (*Quercus petraea*), mesohigròfils, dels Pirineus i de les muntanyes catalanídiques septentrionals; 41i2 Boscos de roure sessiliflor (*Quercus petraea*), sovint amb bedolls (*Betula pendula*), acidòfils i higròfils, pirinencs.

Les rouredes de roure de fulla gran a Catalunya (Figura 1.2) ocupen en total 4.825 ha (Carreras & Ferré, 2012). Si considerem que els boscos de Catalunya ocupen aproximadament el 40% del territori, amb 1.350.980 ha (Ibañez & Burriel, 2013), només el 0,38% són rouredes de roure de fulla gran, o sigui que es tracta d'un element de la vegetació realment escàs. Però com veurem a continuació la seva distribució no sempre ha estat com l'actual, i en un futur pot ser que torni a canviar, degut tant a factors ambientals, com directament antròpics.

1.2 Efectes del canvi climàtic sobre les comunitats vegetals de muntanya

El canvi climàtic al NE de la Península Ibèrica ha produït i seguirà produint un augment en la temperatura i un canvi en la intensitat i freqüència de les sequeres (IPCC, 2013), amb un clar avançament de la primavera i retardant-se l'hivern (Peñuelas et al., 2016). Com a conseqüència augmentaran les pertorbacions derivades del clima, que en molts casos poden arribar a superar la resiliència dels ecosistemes naturals (IPCC, 2014), alterant-se així l'estructura i funcionament dels ecosistemes (Peñuelas et al., 2013), com és en el cas de les sequeres extremes que poden generar canvis no lineals i ràpids (Cavin, Mountford, Peterken, & Jump, 2013).

Són molts els efectes directes del canvi climàtic sobre les plantes, des de canvis fisiològics, fenològics i de creixement, fins a canvis en la vegetació (Peñuelas et al., 2016). Per exemple l'augment en la intensitat de les sequeres pot causar el decaïment dels boscos (Allen et al., 2010; Choat et al., 2012; J Vayreda, Martínez-Vilalta, & Banqué, 2013). Alhora l'escalfament global afavoreix les espècies termòfiles, les quals es troben més ben adaptades a les condicions més càlides que preveu el canvi climàtic, en detriment d'espècies adaptades a condicions més fredes, produint-se així la termòfilitizació de les comunitats (De Frenne et al., 2013). Degut a diversos factors del canvi climàtic, doncs, s'espera que la flora europea pugi en altitud (Grabherr, Gottfried, & Pauli, 1994; H Pauli, Gottfried, & Grabherr, 2003; Harald Pauli, Gottfired, & Grabherr, 1996; G.-R. Walther, Beißner, & Burga, 2005) i en latitud (Berger, Söhlke, Walther, & Pott, 2007; Lenoir, 2008; G.-R. Walther, 2003). Cal puntualitzar però, que tot i que molts estudis se centren en la migració de comunitats, les espècies tenen respostes individuals al canvi climàtic, així que és més factible l'aparició de noves comunitats (Bertrand et al., 2011; Harald Pauli, Gottfried, Reiter, Klettner, & Grabherr, 2007; Williams & Jackson, 2007) o canvis en la composició d'espècies de les comunitats (Reif, Xystrakis, Gärtner, & Sayer, 2017).

Aquest context fa que les comunitats vegetals de les muntanyes siguin considerades particularment sensibles als impacte negatius de l'escalfament global, ja que arriba un punt on no poden pujar a localitats més fredes (Fischlin et al., 2007; Loarie et al., 2009), essent així possible la pèrdua d'espècies molt especialitzades en regions muntanyoses (Thuiller, Lavorel, Araújo, Sykes, & Prentice, 2005). Però tot i que hi han molts estudis sobre els efectes del canvi climàtic sobre les comunitats d'alta muntanya, els estudis sobre muntanya de baixa i mitjana altitud son escassos (Kelly & Goulden, 2008; Lenoir, 2008; Peñuelas & Boada, 2003; G.-R. Walther, 2003). Tanmateix, es coneixen diversos casos d'estudis més locals en muntanya mitjana, on els impactes són menys evidents (Nuet, Romo, Montserrat, & Salvador, 2018; Vittoz, Randin, Dutoit, Bonnet, & Hegg, 2009; G. R. Walther & Grundmann, 2001), possiblement com a conseqüència d'un retard en la resposta biològica al canvi climàtic (Bertrand et al., 2011), ja que es tracta d'un procés llarg i les plantes tenen una dispersió limitada (Kelly & Goulden, 2008).

A més s'espera que les espècies tinguin un cert grau d'adaptació al canvi climàtic gràcies a la variabilitat genètica de les poblacions (Peñuelas et al., 2016). Però en el cas d'espècies de vida llarga i de creixement lent, com *Q. petraea*, podria resultar difícil el canvi de composició genètica de la població, limitant així la seva possible adaptació (Sáenz-Romero et al., 2017). En aquest cas, doncs, resulta un gran avantatge la ja esmentada elevada capacitat d'hibridació dels roures; l'augment del flux genètic i la seva variabilitat, podrien permetre a llarg termini salvaguardar les rouredes (Kremer & Petit, 2001). A més el grau d'hibridació dels roures es veu afavorit pel canvi global (Lagache, Klein, Guichoux, & Petit, 2013), essent així un avantatge que altres espècies arbòries no compten.

Figura 1.3 Exemple de comunitat de roure de fulla gran a la Vall d'Aran, dominada per espècies adaptades al fred i a la humitat.

El NE de la Península Ibèrica, es troba en un context de transició entre les regions euro-siberianes i les de clima mediterrani on s'esperen grans canvis (Thuiller et al., 2005); uns canvis definits per l'augment de les espècies termòfiles, produint-se així la migració de taxons de la flora cap a condicions ambientals favorables, el que es coneix com a mediterranització (Peñuelas & Boada, 2003). En aquests espais de transició, doncs, es podria produir un augment de les espècies mediterrànies i una pèrdua d'espècies de llocs temperats o adaptades al fred (Figura 1.3), com les atlàntiques i euro-siberianes (Ruiz-Labourdette, Schmitz, & Pineda, 2013; Thuiller et al., 2005). Aquest fenomen podria propiciar la concentració d'espècies vulnerables al canvi climàtic en els refugis climàtics, com ja s'estudia al NE de la Península Ibèrica (Barbeta et al., 2018).

Així doncs, no totes les espècies són igual de vulnerables davant del canvi climàtic. En el cas de la Península Ibèrica, els boscos temperats com la fageda i la roureda de roure de fulla gran reduiran el seu rang de distribució, mentre que els arbres mediterranis seran menys afectats (Benito-Garzón, Sánchez de Dios, & Sainz Ollero, 2008). De fet en localitats situades en el *xeric limit* d'aquests dos boscos s'ha observat com en un futur, el canvi climàtic provocarà que els boscos quedin majoritàriament fora de l'òptim bioclimàtic (Czúcz, Gálhidy, & Mátyás, 2011).

Per entendre el futur de la roureda de roure de fulla gran, cal conèixer molt bé quines són no només les seves distribucions i dinàmiques, sinó també la de les altres espècies pròximes amb qui comparteix gran part de la distribució, com es el cas de *Q. robur* i *F. sylvatica*, la distribució potencial de les quals a Europa se solapa (Eaton et al., 2016), tot i que a la Península Ibèrica nomes passa amb *F. sylvatica* (García-López & Allué, 2008). La relació entre les fagedes i les rouredes de roure de fulla gran és molt important (García-López & Allué, 2008), ja que la seva distribució a la Península Ibèrica semblaria estar limitada per la competència entre ambdues espècies (Blanco et al., 2005), fet que s'hauria d'incorporar en els models de canvi climàtic per tal de poder predir amb més exactitud el futur d'aquests boscos. A més, cal tenir en compte que estudis paleobiogeogràfics han trobat que els roures (*Q. robur* i *Q. petraea*) haurien estat molt més abundants a la Península Ibèrica, i haurien estat substituïts per *F. sylvatica* en gran part del territori durant el període atlàntic, aprofitant un cicle climàtic més humit i fresc (Costa, García, Morla, & Sainz, 1990). Això ens fa plantejar què pot passar entre aquestes espècies en un escenari de canvi climàtic d'augment de les sequeres precisament al NE de la Península Ibèrica, *Q. petraea* hi semblaria menys sensible que no pas *F. sylvatica* (Jordi Vayreda, Banqué, Anna Grau, & Martínez-Vilalta, 2013) i mostraria una elevada recuperació quan hi ha decaïment estival del bosc (J Vayreda et al., 2013). A més, tot i que els models prediuen una baixada de la idoneïtat de les condicions topo-climàtiques per *Q. petraea* (Jordi Vayreda, Banqué, et al., 2013), no desapareixerien tots els boscos actuals, i encara quedaria superfície potencial amb condicions favorables que actualment no estan colonitzades per aquest roure (Felicísimo, 2011). D'acord amb aquestes prediccions, amb la gestió forestal adequada, es podria preservar aquests elements al NE de la Península Ibèrica, si es reduís la fragmentació i s'obtinguessin noves rouredes.

1.3 Canvis en els usos del sòl dels boscos

Els boscos han constituït sempre un recurs natural bàsic per al desenvolupament humà i per això s'han explotat des de molt antic. A Europa el pas d'una societat nòmada del paleolític a sedentària del neolític significa, ja no només l'explotació, sinó també la transformació del paisatge forestal per tal de poder anar generant nous usos del sòl. Al NE de la Península Ibèrica l'explotació dels bosc com a font de fusta i combustible i la substitució de boscos per conreus, va ser una dinàmica en expansió durant molts segles, tot seguint el ritme en que anava creixent les poblacions humanes (Boada, 2006). L'energia tèrmica només s'obtenia dels combustibles del bosc i per això va ser molt important la recol·lecció de llenya i el carboneig fins l'entrada de nous combustibles (Gordi, 2009). Tot i que preferentment s'utilitzaven els alzinars pel carboneig i es deixaven les rouredes per fusta, es poden trobar diverses carboneres en rouredes del Montseny pròximes a grans ciutats (Figura 1.4). Així doncs, les rouredes de roure de fulla gran, no s'escapen d'aquestes dinàmiques, essent el roure explotat des del neolític quan ja es consumien els aglans (Primavera & Fiorentino, 2013) i de la fusta ja se'n feien refugis de fusta i pous d'aigua (Tegel et al., 2014); i actualment encara són utilitzats per fabricar bótes de vi (Logan, 2005). La seva fusta, doncs, ha tingut molts d'usos durant la història humana, des de la construcció i els mobles, fins a la construcció d'embarcacions, arribant a l'actualitat com una de les espècies caducifòlies amb més importància en el sector forestal europeu (Eaton et al., 2016).

L'explotació forestal, doncs, pot causar grans canvis en la composició d'espècies de les comunitats vegetals (Brunet, Falkengren-Grerup, Rühling, & Tyler, 1997; Lenoir, Gegout, Dupouey, Bert, & Svenning, 2010), però a més també es poden produir canvis estructurals del bosc. És evident que a Europa hi ha una manca de boscos madurs com a conseqüència d'una activitat secular, ja que el 87% dels boscs europeus es consideren semi naturals (Forest Europe, 2015). El mateix succeeix al NE de la Península Ibèrica, on els boscos madurs són molt escassos (Mallarach, Montserrat, & Vila, 2013) i de poca superfície (Comas, Gracia, & Vayreda, 2013). Per exemple al Montseny, un massís principalment forestal, només un 1% del bosc és madur (Salvat, Sàez, Llop, & Guinart, 2018), un valor molt per sota del que podria ser si no fos per una història d'usos molt intensa. Com a conseqüència les rouredes velles i ben conservades són poc comunes a Europa, i en els pocs casos existents són rouredes de *Q. robur* (Korpel, 1995; Parviainen, Little, O'Sullivan, Kettunen, & Korhonen, 1999; Saniga, Balanda, Kucbel, & Pittner, 2014). Aquesta raresa dels boscos madurs, és una important problemàtica, ja que es tracta d'un element forestal amb una elevada biodiversitat (Mallarach et al., 2013).

Tanmateix, a mitjans de segle XX aquesta dinàmica va canviar, ja que per una banda es produí un procés d'abandonament rural, amb una reducció de la coberta agrícola en molts dels països

Figura 1.4 Antiga carbonera abandonada al bosc de Marmolers, Montseny.

desenvolupats (Ramankutty & Foley, 1999), i per l'altra van aparèixer nous combustibles com el butà, fent que s'abandonessin moltes pràctiques agroforestals tradicionals. Aquests canvis en els usos van propiciar la substitució d'espais oberts per matollars i boscos tant a Europa (Ales, Martin, Ortega, & Ales, 1992; Debussche, Lepart, & Dervieux, 1999; Forest Europe, 2015; García-Ruiz et al., 1996; MacDonald et al., 2000; Santos, 2000; UNEP, 1989) com al NE de la Península Ibèrica (Boada, 2002b; Bou Manobens, Àguila, & Gordi, 2015; Gordi, 2009; Pino, 2014; Vila i Subirós, Varga i Linde, Llausàs Pascual, & Ribas i Palom, 2006), on es calcula que en global des del 1990 hi ha un 20% més de bosc (Generalitat de Catalunya, 2015), alhora que clarament s'ha densificant (Lasanta-Martinez et al. 2005; Améztegui et al. 2010).

A més, aquesta història intensiva d'usos també ha alterat la distribució de les espècies, tal com passa a Europa amb el mateix roure de fulla gran (Eaton et al., 2016), però també en trobem exemples a la Península Ibèrica. Així a Galícia, les rouredes (*Q. robur*, *Q. petraea* i *Q. pyrenaica*) han perdut superfície i es troben fragmentades (Amigo et al., 2001) a causa de la creació de pastures, l'extracció de fusta i llenya, els incendis, la silvicultura o les reforestacions amb pi i eucaliptus (Guitián Rivera, 1995). En canvi al Moncayo, també a la Península Ibèrica, s'observa una expansió del roure de fulla gran entre el 1987 i 2010 (Martinez del Castillo, García-martin, Alberto, Aladr, & Luis, 2015). En el cas del Montseny, al NE de la Península Ibèrica, on el roure de fulla gran abans segurament era més abundant, l'acció humana va destruir l'hàbitat de la roureda, en benefici de l'alzinar i les plantacions de castanyer (Llobet, 1947). El cas de les plantacions de castanyer es repeteix en diversos països de la Mediterrània, on pel seu creixement ràpid s'ha plantat i afavorit durant molts d'anys per aprofitar-ne els fruits i la seva fusta (Panadera & Nuet, 1986; Viciani, Gabellini, Gennai, Foggi, & Lastrucci, 2018). En l'àmbit del Montseny-Guilleries, aquestes plantacions estan sent substituïdes actualment per una conífera exòtica (de Ribot Porta, 2016), considerada invasora (Figura 1.5) (Broncano, Vilà, & Boada, 2005). De fet aquest tipus de problemàtica amb espècies invasores, no és tan estranya, ja que el 25% de les plantacions forestals europees utilitzen espècies introduïdes, que representen un risc d'invasió que podria acabar comportant una pèrdua de biodiversitat (Krumm & Vítková, 2016).

Figura 1.5 En primer pla un avet de Douglas (*Pseudotsuga menziesii*) a la roureda dels Graners, Montseny.

Tot i que en els darreres anys s'han reduït els aprofitaments forestals intensius, es continuen produint casos de tallades arreu o tales que malmeten la qualitat estructural dels boscos (Figura 1.6). Per això cal que la superfície forestal estigui ordenada i planificada segons els marcs de cada territori, especialment a Catalunya on majoritàriament el bosc es troba en propietat privada (Terradas et al., 2004); per sort en els darrers anys ha augmentat la superfície ordenada amb

PTGMF i PSGF (Departament Territori i Sostenibiltat, 2016). Pel que fa als marcs territorials, molts d'aquests boscos se situen en l'àmbit dels sistema d'espais naturals protegits, que en el cas de Catalunya representen aproximadament el 30% de la superfície del país (Departament Territori i Sostenibiltat, 2016). Alhora per tal de conservar els boscos de Catalunya, s'han desenvolupat projectes de custodia del territori en propietats privades, on es fa prevaldre l'objectiu de conservació, com és el cas de les reserves forestals de boscos madurs a les comarques de Girona (Diputació de Girona, 2011). A Catalunya, doncs el 49.80% de les rouredes de roure de fulla gran es troben en els espais naturals protegits de Catalunya, com es el cas del Parc Natural Montseny i a les comarques de Girona alguns boscos formen part de reserves forestals (Vicens, Sanitjas, & Barrachina, 2018).

Figura 1.6 Roureda del Puig, al Montseny, on s' observa els efectes de l'explotació forestal.

1.4 Dinàmica vegetal de les rouredes de roure de fulla gran

L'estudi de la dinàmica vegetal de les rouredes de roure de fulla gran no es pot només centrar, com a vegades es fa, en el canvi climàtic, ja que els canvis en els aprofitaments d'aquests boscos clarament poden tenir un efecte directe en la dinàmica forestal. A més a més, el mateix canvi climàtic pot afectar de forma diferent en funció de si un ecosistema es troba alterat o no (Kröel-Dulay et al., 2015). Per aquest motiu doncs és molt important també conèixer la història i l'estat successional dels ecosistemes per poder predir la resposta al canvi climàtic, i analitzar la dinàmica vegetal considerant ambdós components del canvi global.

En aquest marc, les rouredes que es troben al NE de la Península Ibèrica, tenen un interès especial, perquè són boscos en el seu límit de distribució, trobant-se en condicions extremes per a les espècies que les conformen, essent més fàcil en aquests casos observar els possibles efectes del canvi climàtic. En aquest sentit, contrasta la manca de recerca vinculada a la dinàmica específica d'aquestes rouredes en comparació a la fageda o l'alzinar, que han estat àmpliament estudiats (Gutiérrez, 1988; Jump, Hunt, & Peñuelas, 2007; Peñuelas & Boada, 2003; Peñuelas, Hunt, Ogaya, & Jump, 2008; Verdu, Ferrés, Roda, & Terradas, 1980; Verdú, Riba, & Rodà, 1985). No fou fins Gómez (2008) en que s'observa un clar pas per intentar estudiar l'efecte que estava tenint el canvi climàtic en un cas concret del Montseny, a Ridaura, on s'evidencia la mediterranització dels bosc. Tanmateix, un estudi previ a la present tesi (Treball Final de Màster) i d'escala semblant, es va dur a terme en aquest mateix massís, a Marmolers, per tal d'analitzar la mediterranització en la transició de l'alzinar a la roureda, però no si va observar pas la mateixa dinàmica que en l'estudi de Ridaura (Bou Manobens, Vilar, & Caritat, 2015).

L'observació de dinàmiques contradictòries entre ambdós estudis, origina la voluntat d'analitzar quina és la dinàmica general de les rouredes de roure de fulla gran en aquestes localitats al límit de la seva distribució. Per poder abordar aquest repte, cal disposar de dades històriques comparables en el temps que permetin valorar quina dinàmica s'havia produït en els últims anys i també dades actuals, no només per fer aquesta comparació, sinó també per poder realitzar futurs estudis comparatius.

Amb aquesta visió s'inicia aquesta tesi doctoral, que es divideix en dues línies de treball. L'estudi de la totalitat de les rouredes de roure de fulla gran al NE de la Península Ibèrica i un estudi en profunditat del cas del Montseny, on ja s'havia estat treballant prèviament, i que desprenia un especial interès al tractar-se de boscos clarament en el seu *xeric limit*, amb una dimensió mostral important en comparació al Montnegre, i amb un seguit d'estudis molt intensius sobre el seu paisatge i la vegetació (Boada, 2002a; Bolòs, 1983; Llobet, 1947), que permetien poder contextualitzar els resultats que s'obtinguessin.

Per tal de poder determinar quina ha estat la dinàmica vegetal de les rouredes de roure de fulla gran al NE de la Península Ibèrica, s'inicia un estudi focalitzat en la comunitat florística del bosc, que s'exposa en el article 1 de la tesi. Aquesta part del treball té com a objectiu l'anàlisi dels canvis en aquesta comunitat i s'ha basat en dades històriques disponibles gràcies a l'esforç i treball de molts estudis botànics previs, els quals s'han comparat amb un seguit d'inventaris realitzats durant el transcurs d'aquesta tesi i que han permès avaluar els canvis en les rouredes de roure de fulla gran.

A més, en el ja comentat cas especial del Montseny, l'àmplia bibliografia existent permet valorar l'evolució de la distribució del bosc en el parc natural els últims 60 anys. Gràcies als treballs previs, en l'article 2 d'aquesta tesi es genera una cartografia històrica de la roureda de roure de fulla gran que ha estat comparada amb la distribució actual, realitzada en el marc d'aquesta tesi, ja que no existia una cartografia de suficient resolució. Aquest primer article sobre el Montseny dóna com a fruit una primera visió general de l'evolució d'aquests boscos al massís que es completa en l'article 3 de la tesi, al combinar les observacions fetes durant l'article 2 amb un paquet de dades forestals sobre l'estructura de la roureda actual, generada també per aquesta tesi, ja que les dades disponibles no representaven amb prou precisió aquests boscos. El resultat d'aquests dos articles és, doncs, l'anàlisi de les dinàmiques vegetals d'aquests boscos en els últims decennis i alhora l'anàlisi de la situació actual, ja que no es comptava amb cap altra font d'informació actualitzada, permetent així en un futur poder fer valoracions sobre com han evolucionat aquests boscos, a partir de bases de dades completes sobre la seva estructura forestal i distribució.

Previ a l'inici d'aquests tres estudis els companys del grup de recerca havien iniciat al Montseny un altre treball en l'àmbit de la producció de fullaraca i el creixement de *Q. ilex* i *F. sylvatica* i del mateix *Q. petraea*, que culmina en un article que si bé no forma part del cos principal d'aquesta tesi, si del marc conceptual on s'emmarca. Aquest treball es pot trobar als annexos, ja que analitza com afecten els canvis meteorològics al roure de fulla gran i a dues espècies directament competidores per a la supervivència dels seus corresponents hàbitats.

Gràcies doncs a les observacions del passat, i a les noves aportacions, s'intenta al llarg d'aquesta tesi descriure les dinàmiques vegetals que s'han produït a les rouredes de roure de fulla gran al NE de la Península Ibèrica fins a dia d'avui, deixant unes bases per continuar aprofundint en les dinàmiques d'aquests boscos i poder fins i tot preveure els possibles escenaris per aquesta comunitat eurosiberiana en el seu *xeric limit*.

2 Hipòtesis i objectius generals

En el marc d'aquesta tesi es plantegen les següents hipòtesis (Figura 2.1):

- **Hipòtesis 1:** El canvi dels usos del sòl en el bosc ha fet que en l'actualitat no s'exploti tant la roureda de roure de fulla gran, permetent que el bosc adopti noves dinàmiques ecològiques, canviant així l'estructura i composició de les rouredes al NE de la Península Ibèrica.

- **Hipòtesis 2:** El canvi climàtic ha afavorit a espècies termòfiles en els boscos caducifolis de l'estatge montà humit del NE de la Península Ibèrica, motiu pel qual la flora de les rouredes de roure de fulla gran s'haurà mediterranitzat.

- **Hipòtesis 3:** La distribució de la roureda de roure de fulla gran al Montseny haurà canviat en els últims 60 anys a causa de l'impacte del canvi global, entès tant com l'escalfament global i els canvis en els usos del bosc.

- **Hipòtesis 4:** Les rouredes de roure de fulla gran del Montseny no tenen estructures madures a causa de l'acció humana secular; a més l'activitat humana actual comporta un seguit de noves amenaces per a la seva conservació.

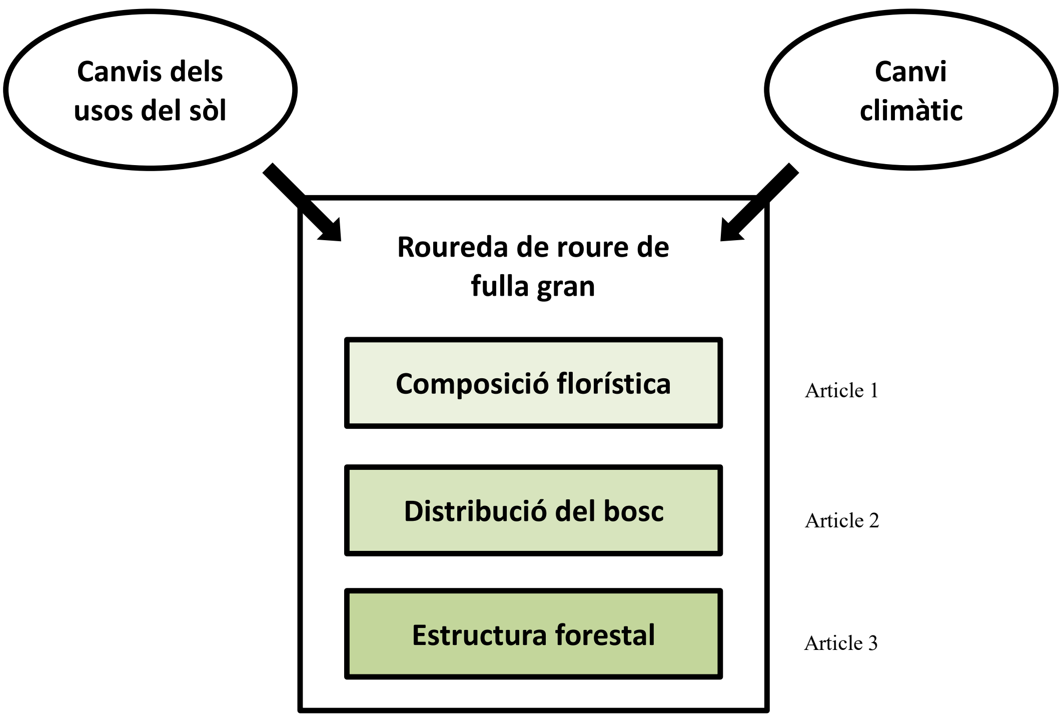

Figura 2.1 Esquema de les hipòtesis plantejades al llarg dels tres articles de tesi doctoral.

Tenint en compte les hipòtesis descrites, la present tesi té com a principal objectiu l'estudi i descripció de les dinàmiques ecològiques de les rouredes de roure de fulla gran al NE de la Península Ibèrica des de mitjans del segle XX. Es fa especial èmfasi en el cas d'estudi del Montseny, un territori estratègic tan per la recerca com per a la seva gestió i conservació, on aquests boscos es troben al *xeric limit*.

De forma més concreta, els objectius específics per els tres articles d'aquesta tesi són els següents:

1. Avaluació de les conseqüències del canvi global en la composició florística a les rouredes de roure de fulla gran al NE de la Península Ibèrica, mitjançant les anàlisis en els canvis de la corologia i formes vitals predominants dins de la comunitat (Article 1).

2. Aportació d'informació acurada sobre la distribució actual de la roureda de roure de fulla gran al massís del Montseny i anàlisi de l'evolució que ha tingut lloc els darrers 60 anys (Article 2).

3. Descripció i caracterització de les estructures forestals actuals de cadascuna de les rouredes de roure de fulla gran al Montseny en base al tipus d'explotació realitzada a mitjans del s. XX (Article 3).

4. Anàlisi de la situació actual i dinàmica de les rouredes de roure de fulla gran al NE de la Península Ibèrica per tal de poder millorar-ne la gestió i la seva conservació, que serveixi de base per a l'estudi i previsió dels futurs canvis en aquests boscos (Article 1, 2 i 3).

3 Àrea d'estudi

Les rouredes de roure de fulla gran estudiades en aquesta tesi se situen al NE de la Península Ibèrica (Figura 3.1), dins de dues unitats fisiogeogràfiques ben diferenciades, la dels Pirineus al nord i la Serralada Litoral al sud. Aquests boscos es troben entre 500 i 1800 m d'altitud, a l'estatge montà humit, és a dir en zones especialment plujoses, però en alguns dels casos situats a baixa altitud, on fins i tot creixen en àrees de clima mediterrani subhumit. Les temperatures mitjanes en les diferents localitats estudiades van de 8 a 13ºC, i la precipitació anual de 812 a 1035 mm (Taula 3.1). Sempre creixen sobre substrat àcid, al sud en granodiorites i leucogranits i en esquistos al nord. Tots aquests boscos es troben dins del límit sud de distribució de *Quercus petraea*, i en el cas de la Serralada Prelitoral i Litoral, es clarament el seu *xeric limit*. Finalment cal tenir en compte que en gran part dels casos es tracta de boscos amb diferents figures de protecció, des de xarxa Natura 2000 i PEIN, fins a parcs naturals i altres espais naturals protegits.

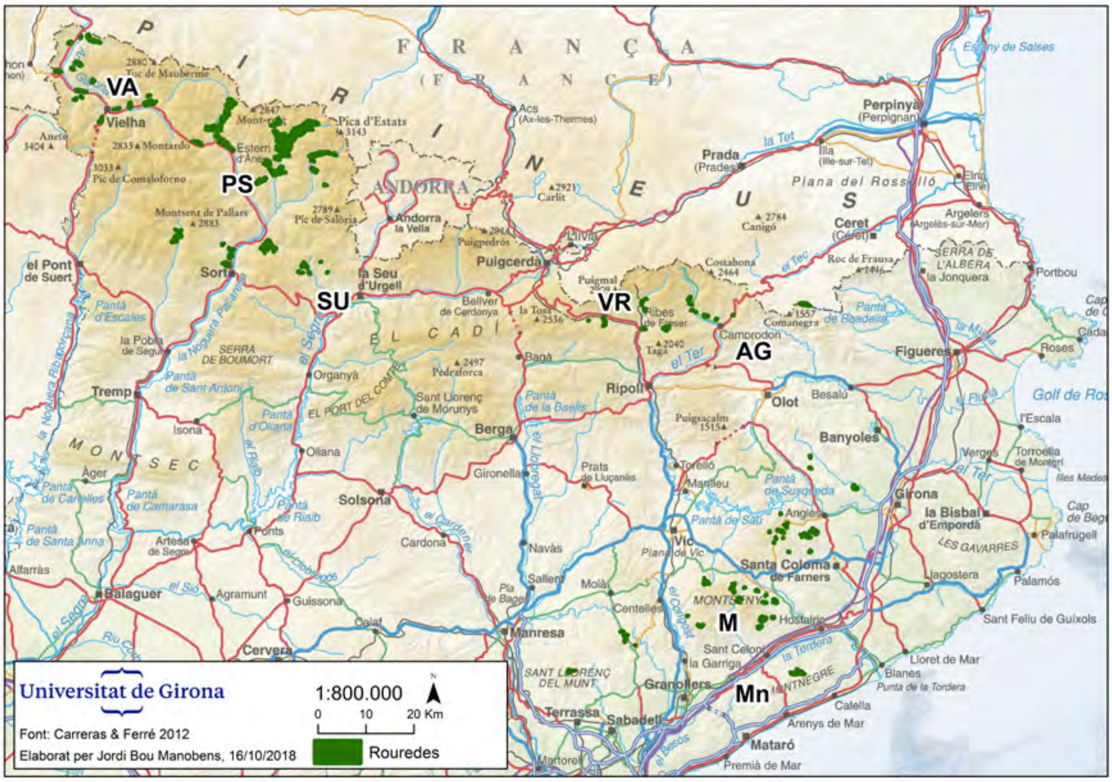

Figura 3.1. Mapa de les localitats estudiades de roureda de roure de fulla gran (representada segons els LHC de Catalunya).

Unitat fisiogeogràfica	**Localitat**		**Altitud mitjana m.s.n.m.**	**Precipitació mitjana[1] mm**	**Temp. mitjana[1] ºC**	**Temp. màxima[1] ºC**	**Temp. mínima[1] ºC**
Pirineus	Pallars Sobirà	(PS)	1439,19	812,56	7,98	13,66	2,38
	Vall de Ribes	(VR)	1063,75	1035,33	9,83	16,25	3,47
	Vall d Aran	(VA)	1127,33	1010,37	8,00	13,50	2,50
Prepirineus	la Seu d'Urgell	(SU)	1325,00	883,25	8,05	14,00	2,15
	Alta Garrotxa	(AG)	1018,83	1095,07	10,03	15,20	4,97
Serralada Prelitoral	Montseny	(M)	930,35	944,63	10,76	15,46	6,11
Serralada Litoral	Montnegre	(Mn)	650,50	945,14	12,56	16,94	8,22

Taula 3.1 Característiques ambientals de les diferents localitats estudiades.

Sessile oak forest plant community changes on the NE Iberian Peninsula

Article 1

Bou, J., & Vilar, L. Sessile oak forest plant community changes on the NE Iberian Peninsula. Enviat a revista. Journal of Plant Ecology. Enviat el 15 d'octubre de 2018.

4 Sessile oak forest plant community changes on the NE Iberian Peninsula

Community changes of sessile oak forest

Jordi Bou[1]* & Lluís Vilar[1]

* Corresponding author; jordi.bou.manobens@gmail.com

[1] LAGP-Flora and Vegetation. Institute of the Environment. University of Girona. Postal address: C/ Ma. Aurèlia Capmany 69, 17003 GIRONA, Catalonia (Spain) Telephone: 699813514

4.1 Abstract

Aims: Has global change altered the composition and structure of the plant community found in the sessile oak forest on the NE Iberian Peninsula over the last decades? Has the decline in forest exploitation activities since the mid-20th century had any effect? Is there any evidence of impact from climate warming?

Methods: We assess changes in the plant community by comparing a current survey of sessile oak forest with an historical dataset obtained from previous regional studies dating from 1962 to 1977. We analyse the regional changes in the community in terms of biodiversity variables, species composition and plant traits. To discern any effects that changes to land use or the impact of climate warming have had on the plant community, we use plant life-forms and their chorological groups as plants traits.

Important Findings: There is a loss of diversity in the community and in the hottest region there is also a loss of species richness. The composition of the community signals that important changes have taken place over the past decades. For instance, while the tree cover canopy in the eastern sessile oak forests is recovering from former exploitation, this has led to a loss of its rich and abundant herbaceous stratum. In fact, this recovery in the Catalan Pre-Coastal Range also brings with it an increase in the plants typical to this community and, while there is evidence of the climate warming impact on the thermophilization of the sessile oak forests on the Coastal Range, there is a lack of such evidence in the western forests which remain more stable.

Keywords: global change, community ecology, Quercus petraea, forest ecology

4.2 Introduction

The sessile oak (*Quercus petraea* (Matt.) Liebl.) is a native to the UK and most of Europe, and its southern-most distribution limit being found on the NE Iberian Peninsula which experiences the dry summer months of a Mediterranean climate. Where only grows in the cooler and moister mountains, (e.g. the Pyrenees or Pre-Coastal Range (Bou et al. 2016) which are sheltered pockets for it in this region (Loidi, 2017; Josep Vigo, 2011). The mountains in southern Europe are particularly interesting because of their enormous biodiversity (Väre, Lampinen, Humphries, & Williams, 2003) and the fact that they constitute the southern-most distribution limit of numerous central European species (e.g., Gómez et al. 2017). As these mountains are wet, cool locations in a warm, dry region, they enable Euro-Siberian and Boreal species to coexist with xerophyllous species (Ruiz-Labourdette et al., 2013). For instance, in the Pyrenees flora like boreo-alpine plants can be found at high altitudes while Mediterranean flora can be found at low and medium altitudes (Loidi, 2017). The sessile oak forest and other similar communities are very sensitive to global change resulting from changes in land use (Boada, 2002b) and/or global warming (Jordi Vayreda, Banqué, et al., 2013).

In the Mediterranean regions in Europe, traditional agroforestry practices were used extensively in the forest, but during the second half of the 20th century these practices were abandoned, resulting in meadows and croplands being replaced by shrub and forest cover (Ales et al., 1992; Debussche et al., 1999; García-Ruiz et al., 1996; MacDonald et al., 2000; Santos, 2000; UNEP, 1989). The NE Iberian Peninsula is a case in point (Boada, 2002b; Bou Manobens, Àguila, et al., 2015; Gordi, 2009) where the forest has grown more dense (Lasanta-Martinez et al. 2005; Améztegui et al. 2010). These anthropogenic factors can cause major changes in the composition of the plant community (Brunet et al., 1997; Lenoir et al., 2010), as has been reported in the oak communities where landscape changes have led to a loss in biodiversity (Amigo et al., 2001). Another consequence of this human factor is the lack of mature forests in Europe (Forest Europe, 2015) and the NE Iberian Peninsula (Mallarach et al., 2013). For centuries the sessile oak forest has formed part of this intensive human activity in Europe which, in turn, has altered its distribution and structure (Eaton et al., 2016). Yet another land use change that can affect forest communities is associated with invasive species. For instance, 25% of European forestry plantations use introduced species, representing an invasion risk that can lead to a loss of biodiversity (Krumm & Vítková, 2016). In the montane zone on the NE Iberian Peninsula an invasive tree, whose source has been identified as coming from forestry plantations, has been reported to have expanded into a natural park (Broncano et al., 2005).

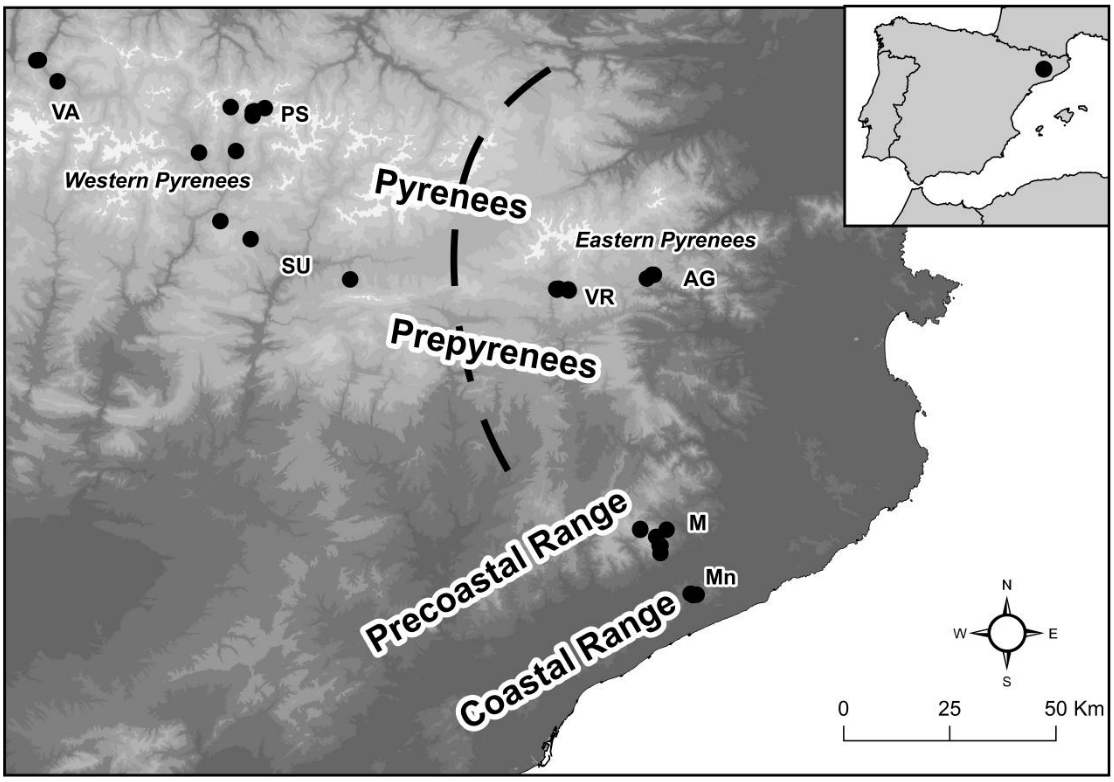

Figure 1. Sessile oak forests (black) on the NE Iberian Peninsula.

Mountain plant communities are considered to be particularly sensitive to the negative impacts of global warming (Fischlin et al., 2007; Loarie et al., 2009; Thuiller et al., 2005) which promote thermophiles species adapted to warmer conditions to the detriment of species adapted to the cold, and which eventually leads to a thermophilization of the communities (De Frenne et al., 2013). In the transition between the Mediterranean and Euro-Siberian regions in particular, huge changes are expected (Thuiller et al., 2005). Climate change in the NE Iberian Peninsula is very present as there has been an increase in both temperature and dry periods (Peñuelas et al., 2016) and this dynamic is expected to continue (IPCC, 2013). The impact of climate change has been reported as northward shifts (Berger et al., 2007; Lenoir, 2008; G.-R. Walther, 2003) or species' ranges shifting to higher elevations (Grabherr et al., 1994; H Pauli et al., 2003; Harald Pauli et al., 1996; G.-R. Walther et al., 2005) as well as changes in species composition (Reif et al., 2017) that can lead to new communities forming (Bertrand et al., 2011; Williams & Jackson, 2007). However, while there are a lot of reported effects of climate change on plant communities in high mountain elevations, studies into the effect on mid- and low-elevation mountain ecosystems are scarce (Kelly & Goulden, 2008; Lenoir, 2008; Peñuelas & Boada, 2003; G.-R. Walther, 2003) and, in some cases in a number of more localized studies the impacts have been much less evident (Vittoz et al., 2009; G. R. Walther & Grundmann, 2001), maybe as a consequence of a lag in the biotic response to climate changes (Bertrand et al., 2011).

We hypothesize that since the mid-20th century global changes have brought about a change in the sessile oak forest community on the NE Iberian Peninsula. As there is evidence of the intensive exploitation of the sessile oak forest in historical times, we would expect to see a change in the plant life-forms of the community along with an increase in tree cover. In addition, we would also expect to find an effect of global warming and, despite there not being a lot of evidence in low-altitude mountain vegetation there is one study on the NE Iberian Peninsula which reports a shift in a similar community: the *Fagus sylvatica* forests (Peñuelas & Boada, 2003). Thus, some level of thermophilization of the sessile oak forest would be expected. To corroborate this hypothesis, the objective of this study is to compare the floristic community of sessile oak forest over two different periods, analyse what changes have occurred and determine what the dynamics have become.

4.3 Materials and methods

4.3.1 Study sites

Our study involves the sessile oak forest found on the NE of the Iberian Peninsula which grows on the physiographic units of the Pyrenees in the north and the Coastal Range bordering the Mediterranean Sea and covers a surface area of 4967.12 ha (Bou et al., 2016) (Figure 1). These forests are at the southern-most distribution limit for this species, and *Quercus petraea* clearly finds its xeric limit on the Pre-Coastal and Coastal ranges. Although the altitude in the NE of the Iberian Peninsula ranges from sea level up to 3,000 m a.s.l., the sessile oak forest spans from 500 to 1700 m a.s.l. Sessile oak is only found in montane zones with high precipitation or, in some cases, with regional microclimates. The mean annual temperature of the regions in this study ranges from 8 to 13ºC, and annual precipitation ranges from 812 to 1035 mm (Table 1). Sessile

Region	**Subregion**		**N**	**Mean altitude m a.s.l.**	**Annual rainfall[1] mm**	**Mean temp[1] ºC**	**Max. temp[1] ºC**	**Min. temp[1] ºC**
Pyrenes	Pallars Sobirà	(PS)	16	1439,19	812,56	7,98	13,66	2,38
	Vall de Ribes	(VR)	12	1063,75	1035,33	9,83	16,25	3,47
	Vall d Aran	(VA)	6	1127,33	1010,37	8,00	13,50	2,50
Prepyrenes	la Seu d Urgell	(SU)	4	1325,00	883,25	8,05	14,00	2,15
	Alta Garrotxa	(AG)	6	1018,83	1095,07	10,03	15,20	4,97
Precoastal Range	Montseny	(M)	21	1029,64	969,09	10,25	14,82	5,78
Coastal Range	Montnegre	(Mn)	10	650,50	945,14	12,56	16,94	8,22

Table 1. Localities studied classified as subregion and region, with the meteorological characteristics of sessile oak forests. "N" is the number of inventories. [1]Climatic variables were estimated using a georeferenced model (Ninyerola et al., 2000).

oak forests always grow on acid lithology (J Vigo, Carreras, & Ferré, 2005). To these environmental conditions the human matrix must be added because a lot of this forest was exploited in historical times, but currently is abandoned and included in different soft protected area figures (Departament de Medi Ambient, 1996).

4.3.2 Field samplings

In the NE Iberian Peninsula, the sessile oak forest has been described as different forest communities, but we focus at the dominated by sessile oak, *Lathyro montani-Quercetum petraea* (Lapraz) Rivas Mart. 1983 (synonymous *Teucrio scorodonia-Quercetum petraeae* Lapraz 1996, em. Bolòs 1983) which includes different subassociations (Bolòs, 1983; Josep Vigo, 1996). To achieve the objectives proposed, the subassociations of mixed stand structures are discarded, so that in this study the concept of sessile oak forest will refer to the typical subassociation *stachyetosum* Lapraz 1966.

To compare how the evolution of the sessile oak has changed, a bibliographic search was carried out to uncover the historical inventories of the forest. The studies available are, for the most part, on a regional scale and not specifically focused on the sessile oak forest. From these studies we discarded one (Mercadé, 2008), because it was so recent, would not have been useful in evaluating the changes that have taken place in the forest since the second half of last century. The historical records selected were studies and inventories from several botanists dating from 1962 to 1997 (Bolòs, 1988; Carreras et al., 1995; Carreras, Carrillo, Josep-Maria, & Vigo, 1997; Lapraz, 1962; Josep Vigo, 1968, 1996; Viñas, 1993) (Table S1). The selected studies and inventories follow the method of Braun-Blanquet (Braun-Blanquet, 1964) and use vegetation censuses over a $100m^2$ plot. Although the plots were described in the papers and related studies (i.e., site description, elevation, surface, slope, and exposition) they did not include the coordinates with which to relocate the plots. Consequently, some very intensive field work has been carried out to (as closely as possible) identify the land, determine the spots and localize the plots where the studies would have been previously carried out. Habitat cartography (Universitat de Barcelona & Generalitat de Catalunya, 2012), along with historical vegetation maps (Bolòs, 1983; Josep Vigo, 1996) were used as support tools which allowed us to determine the community changes in the sessile oak forests. In one case, however, as no area corresponded to the historical description, the inventory had to be discarded. Finally, 38 inventories were selected, and a new inventory of all the vascular plants was compiled between 2014 and 2018 in the same areas as the historical inventories using the same Braun-Blanquet method and marking the plots with a GPS. In one case, the historical inventories had two samples for one specific small forest, but in the new sampling there is only one inventory (on M). At the end of this exhaustive field work, 37 new inventories had been compiled.

4.3.3 Data analyses

This type of study can have problems with mistakes in species identification, changes in nomenclature, overlooked species and observer differences in coverage estimates (Vittoz & Guisan, 2007; Vittoz et al., 2009). We reduced identification mistakes by aggregating all the

confusable subspecies, and the not-sure identifications, in one taxon for each case. The nomenclature of species was scrupulously checked for possible synonymies using the reference nomenclature of the region (Bolòs, Vigo, Masalles, & Ninot, 2005; Castroviejo, 2012). As the overlooked species cannot be avoided, their effect on species richness had to be considered. The historical inventories had been taken by several botanists and the current dataset by others. To avoid differences in coverage estimates, we analysed most of the data in a ‘double way’, i.e., as a presence and absence dataset, and as an abundance dataset. We also transformed this into percentages for each sample to reduce possible errors. To be able to use the inventories in abundances analyses, and to compare the data from different time periods the Braun-Blanquet scale was converted to percentage of cover using Table 2 on all the inventories.Statistical analyses were performed using R environment software (R Core Team, 2015) and, in some cases, Primer version 6.1.11 software (Clarke & Gorley, 2006) and Permanova 1.0.1 software.

The 75 inventories were classified on two location levels: region and subregion (Table 1). On the subregion level, any statistical analysis of SU was discarded because there are only two zones and not enough samples to compare. To be able to see changes in the community over time, we use one-way ANOVA with time as the factor with which to compare the biodiversity variables (richness and diversity) in each subregion.

Braun-Blanquet scale	Values used in analyses
+	0,1
1	5
2	17,5
3	37,5
4	62,5
5	87,5

Table 2. Scales used for Braun-Blanquet plant cover estimates and the corresponding value to the transformations to percentage of cover used in the analyses.

To check differences in species composition between periods, a PERMANOVA analysis and an MDS of the abundance was performed using the Bray-Curtis similarity coefficient (the data were square-root transformed prior to analysis) and for presence the Jaccard coefficient was used. Also, the specific changes in species are calculated for each locality, thus procuring the number of new, extinct or stable species.

Meanwhile, plant traits (plant life-forms and chorological trait) were also analysed using the proportion of species of each type with respect to the total richness for relative richness, and for relative abundance the proportion of abundance of each type with respect to the total abundance. The plant life-forms (Raunkiær plant life-form) fell into nine classes: chamaephytes (Ch), geophytes (G), hemicryptophytes (H), deciduous macrophanerophytes (MPc), evergreen macrophanerophytes (MPp), deciduous nanophanerophytes (NPc), evergreen nanophanerophytes (NPp), phanerophytes (P), and therophytes (Th). The differences in these traits over time were tested with one-way ANOVA, for each subregion. The chorological trait produced nine classes: alpine (Alp), Atlantic (Atl), Boreo-subalpine (Boralp), Euro-Siberian (Eur), Introduced (Introd), Mediterranean (Med), Pluriregional (Plurireg), Pontic (Pont) and Sub-Mediterranean (Submed). The differences in this trait for each subregion were tested with one-way ANOVA. Furthermore, the ratio between Mediterranean and Euro-Siberian species was calculated as M/E ratio= -log(M+1)/(E+1), and tested for correlations with altitude, aspect and slope. This ratio was also analysed for each subregion to determine if there had been any change over time. For these two chorological groups, the differences between periods was also calculated at the municipality level and tested for correlations between altitude, aspect and slope.

4.4 Results

4.4.1 Changes in biodiversity

4.4.1.1 Richness and diversity

While the mean number of species in the sessile oak forest did not change between the first (32.29) and current (35.11) sampling period (ANOVA $F_{1,73}$=1.829, p-value= 0.180), the Shannon diversity index actually decreased (1.75) from the first (2.45) sampling period (ANOVA $F_{1,73}$=40.594, p-value< 0.001). The changes in richness and in the Shannon diversity index over time in each sub-region were tested with one-way

Subregion	Richness		Diversity	
	P	sig	P	sig
Mn	0,021	*	<0,001	***
M	0,690		<0,001	***
AG	0,856		0,177	
PS	0,136		0,166	
VA	0,013	*	0,569	
VR	0,135		0,001	**

Table 3. ANOVA results for the biodiversity variables differences over time.

ANOVA (Table 3 and S2). The richness of the forest community in VA has significantly increased over time, unlike Mn where it has decreased (Figure 2). The diversity has significantly decreased in VR, M and Mn (Figure 2). Of these variables, only diversity has a significant relationship with elevation (Table 4).

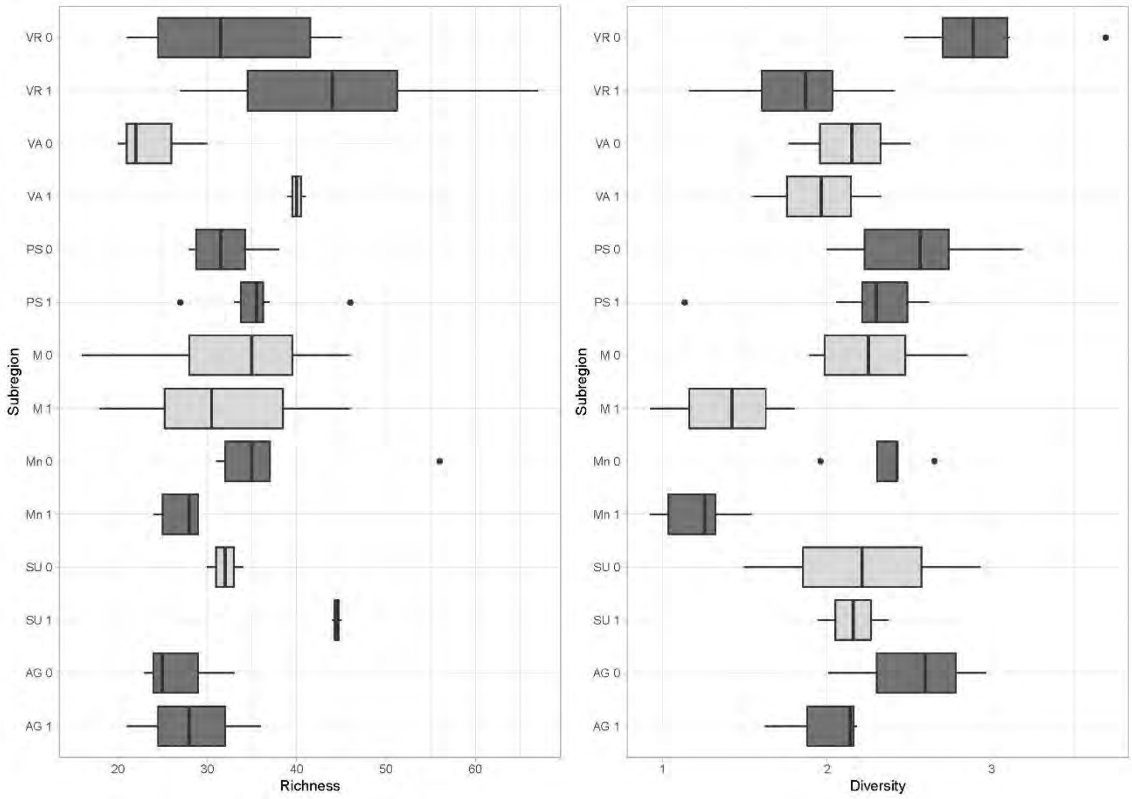

Figure 2. Richness and diversity values of the sessile oak forests for each subregion and for the two periods studied.

4.4.1.2 Species composition

The current species compositions of the sessile oak forest show significant differences between regions for the abundance matrix (PERMANOVA Pseudo-$F_{4,73}$=3.102, p-value= 0,001) and the presence matrix (PERMANOVA Pseudo-$F_{4,73}$=3.521, p-value= 0,001). The composition has changed over time in all the regions except the Pre-Pyrenees (Table S3 and Figure 3). For example, the abundance of *Pteridium aquilinum* has decreased while *Quercus ilex* has increased in the Coastal Range. Meanwhile, in the Pre-Coastal Range *Festuca ovina* has been replaced by *Festuca heterophylla* and in the Pyrenees *Deschampsia flexuosa* has been replaced by *Brachypodium sylvatica*.

When comparing the new and lost species between the two periods on the subregion level studied (Figure 4), a high number of species can be seen to have disappeared in M and Mn (e.g.

Campanula rapunculoides, *Lathyrus pratensis*, *Geranium dissectum*, *Arabis hirsuta* and *Arrhenatherum elatius*) and there is a low number of new species. On the other hand, there are more new species and a low number of losses in the northern subregions like VR and VA (e.g. *Stellaria holostea*, *Vicia sepium*, *Cardamine impatiens*, *Cephalanthera longifolia* and *Hypericum montanum*).

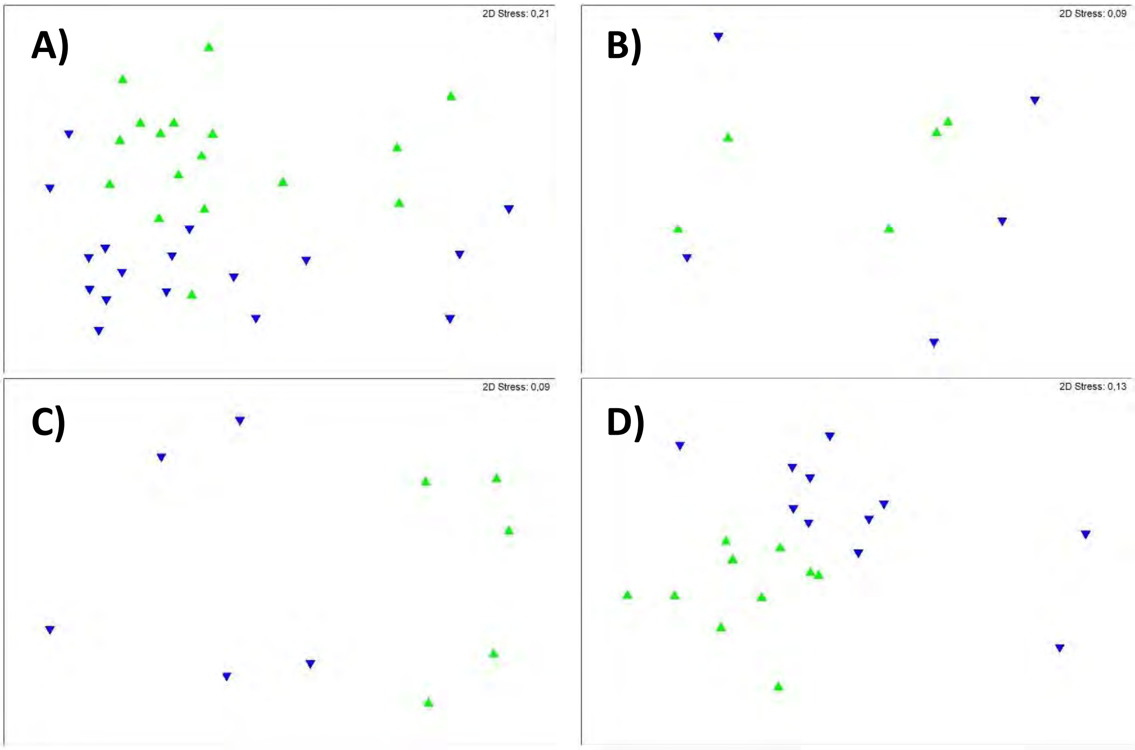

Figure 3. MDS plots showing forests, according to the abundance for each species, from Pyrenees (A), Pre-Pyrenees (B), Coastal Range (Mn) and Pre-Coastal Range (M).

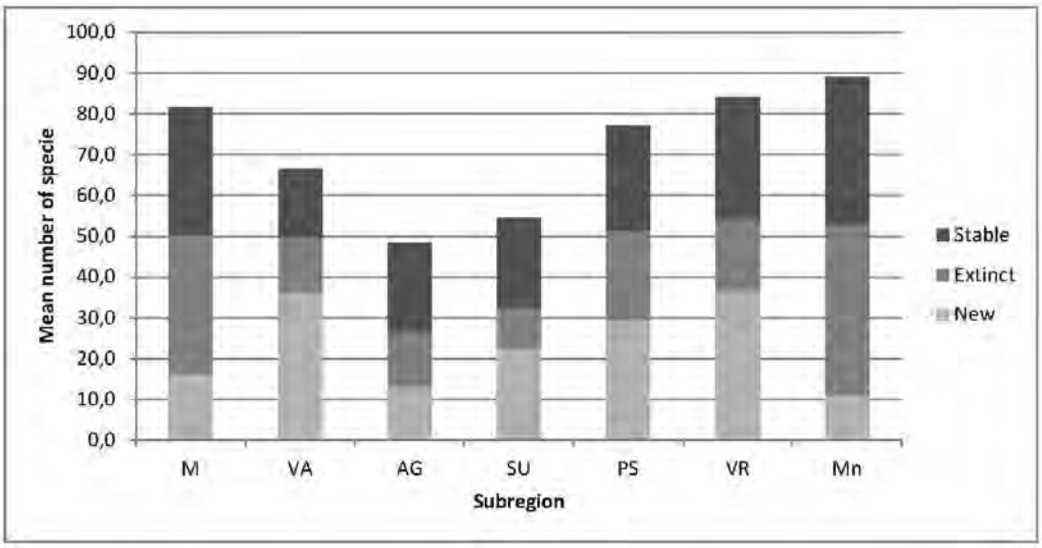

Figure 4. Species classified as being new to the localities or not by comparing the two study periods

Variables		r^2	p	SE	a	p	b	p
Richness increment	Euro-siberian	0,306	0,026	6,431	-17,299	0,063	0,018	0,026
	Mediterranean	0,188	0,094	0,817	2,130	0,071	-0,002	0,094
M/E ratio		0,362	<0,001	0,307	0,187	0,209	0,001	<0,001
Richness		0,011	0,381	0,113	1,480	<0,001	<0,001	0,381
Diversity		0,107	0,004	0,568	1,322	<0,001	0,001	0,004

Table 4. Linear regression between altitude and ecological variables. The first P-value tests the regression model, the second corresponds to the t-test of the intercept (a) whereas the third corresponds to the t-test of whether the regression coefficient or slope (b) is significantly different from 1. The coefficient of determination (r2) and the residual standard error (SE) of the regression model are also given.

4.4.2 **Changes in plant traits**

4.4.2.1 Plant life-forms

Sessile oak forest species are mainly hemicryptophytes (51.88%) and deciduous macrophanerophytes (14.79%). Changes in the species composition in some cases are related to changes in the species relative richness for each plant life-form observed in a community (Table S4 and Figure 5). The relative richness for each life-form shows a great number of significant changes in M and Mn (Table 5). On one hand, the presence of phanerophytes and deciduous macrophanerophytes has increased in M and Mn, but on the other, the presence of hemicryptophytes and evergreen nanophanerophytes has decreased. In Mn the relative richness of geophytes has also increased, while in M the relative richness of evergreen macrophanerophytes has increased. On the other hand, VR, PS and AG only show few marginally significant changes (Table S5).

In terms of relative abundance, the sessile oak forest is dominated by deciduous macrophanerophytes (57.92% abundance), followed by hemicryptophytes (23.18%). These changes can also lead to a change in the relative abundance of the different plant life-forms of the sessile oak forests (Table S4 and Figure 5). The relative abundance for each life-form shows significant changes in VR, PS, M, Mn and AG (Table 5). Chamaephyte abundance has increased in VR, M, AG and decreased in Mn. Also, the relative abundance of deciduous macrophanerophytes has increased in VR, M, Mn and Ag. On the other hand, hemicryptophytes have decreased in VR, M and AG, while geophytes have decreased in VR. At the same time, VR, PS and Mn show some marginally significant changes (Table S5).

	Plant form-life	Mn		M		AG		PS		VA		VR	
		P	Sig	P	Sig	P	Sig	P	Sig	P	Sig	P	Sig
Relative richness	Ch	0,249		0,843		0,671		0,962		0,216		0,217	
	G	<0,001	***	0,281		0,534		0,104		0,709		0,458	
	H	0,002	**	<0,001	***	0,100	.	0,827		0,693		0,284	
	MPc	0,005	**	0,009	**	0,423		0,702		0,220		0,641	
	MPp	0,370		0,008	**	0,714		0,067	.	0,364		0,063	.
	NPc	0,251		0,174		0,835		0,528		0,701		0,896	
	NPp	0,013	*	0,027	*	0,668		0,250		0,161		0,265	
	P	0,010	**	0,008	**	0,065	.	0,860		0,285		0,077	.
	Th	0,981		0,737		0,374		0,223		0,248		0,610	
Relative abundance	Ch	<0,001	***	0,034	*	0,005	**	0,075	.	0,390		0,046	*
	G	0,401		0,274		0,227		0,040	*	0,350		0,619	
	H	0,066	.	0,005	**	0,003	**	0,928		0,409		0,018	*
	MPc	<0,001	***	<0,001	***	0,004	**	0,113		0,717		0,005	**
	MPp	0,861		0,136		0,496		0,140		0,496		0,212	
	NPc	0,137		0,174		0,635		0,343		0,715		0,406	
	NPp	0,294		0,173		0,307		0,127		0,368		0,251	
	P	0,555		0,750		0,382		0,902		0,262		0,054	.
	Th	0,724		0,366		0,374		0,408		0,371		0,371	

Table 5. ANOVA results for the plant life-form variables differences over time.

4.4.2.2 Chorological groups

Most of the species in the sessile oak forest are Euro-Siberian (64.87%) while other chorological groups like the Pluriregional (16.49%) and Atlantic (6.68%) have low presence. In some regions the relative richness for specific chorological groups has changed significantly over time (Table 6). There are increments in pluriregional plants in VR, introduced plants in M and Mediterranean plants in Mn (Table S6; Figure6). In contrast, there are some marginally significantly decreases for Atlantic plants in AG and Euro-Siberian in VR and Mn (Table S7).

If we consider relative abundance, the sessile oak forest is clearly dominated by Euro-Siberian species (84.43%). The relative abundance for each chorological group shows some significant changes in VR and M (Table 6). Atlantic species have decreased in VR and M, but in M the Euro-Siberian species have increased (Table S6; Figure 6). Moreover, in PS the relative abundance of Euro-Siberian plants has marginally significant increased (Table S7).

The M/E ratio shows different values for subregions (Figure S1), and only marginally significant change over time in Mn (ANOVA $F_{1,8}$=4.168, p-value= 0.076). This is because of the increase in Mediterranean plants compared to that of the Euro-Siberian plants. In fact, at low elevations Euro-Siberian increment is negative (Figure S2) and Mediterranean is positive (Table 4). These ratios have a significant relationship with altitude (Table 4; Figure S3) because Mediterranean species are less present in high elevations.

	Chorological groups	**Mn**		**M**		**AG**		**PS**		**VA**		**VR**	
		P	**Sig**	**P**	**Sig**	**P**	**Sig**	**P**	**Sig**	**P**	**Sig**	**P**	**Sig**
Relative richness	Alp	-	-	0,388		-	-	0,121		0,374		0,769	
	Atl	0,911		0,134		0,074	.	0,524		0,593		0,419	
	Boralp	-	-	-	-	-	-	0,950		0,864		0,853	
	Eur	0,069	.	0,722		0,829		0,317		0,607		0,099	.
	Introd	0,744		0,019	*	0,550		-	-	0,374		0,341	
	Med	0,019	*	0,854		0,672		0,510		0,374		-	-
	Plurireg	0,640		0,875		0,910		0,948		0,199		0,007	**
	Pont	-	-	-	-	-	-	-	-	0,374		-	-
	Submed	0,286		0,165		0,415		0,375		0,631		0,263	
Relative abundance	Alp	-	-	0,228		-	-	0,169		0,374		0,180	
	Atl	0,617		0,010	*	0,461		0,324		0,714		0,029	*
	Boralp	-	-	-	-	-	-	0,532		0,718		0,352	
	Eur	0,550		0,031	*	0,457		0,073	.	0,663		0,264	
	Introd	0,707		0,359		0,301		-	-	0,374		0,341	
	Med	0,335		0,410		0,260		0,841		0,374		-	-
	Plurireg	0,249		0,628		0,810		0,404		0,346		0,141	
	Pont	-	-	-	-	-	-	-	-	0,374		-	-
	Submed	0,363		0,822		0,936		0,110		0,385		0,326	

Table 6. ANOVA result for chorological variables differences over time.

4.5 Discussion

4.5.1 Biodiversity dynamics

The sessile oak forest on the NE Iberian Peninsula has lost species diversity since the first study period, as much in the Pyrenees (VR) as in the south in the Pre-Coastal and Coastal ranges (M, Mn). However, this does not necessarily mean a loss in richness because, in general terms this has remained stable and, in fact, only decreased in the Coastal Range (Mn). The loss of diversity is due to a loss of plant abundance, but with some species remaining as dominant, which has its explanation in the changes on the forest structure that we are going to analyse. That said, the species richness has increased in VA, where as we are going to see there are some different patterns. Thus, only the Coastal Range shows a clear process of biodiversity loss, which can probably be explained by the chorological trait changes. Besides these, the Coastal Range forests are in a natural park where they are protected (Diputació de Barcelona, 2018), so the loss of biodiversity could be attributed to a serious conservation problem.

Because there are significant differences in species composition, the different dynamics between regions are understandable, and they to be considered in the analyses of this study. For instance, the southern sessile oak forests have more Mediterranean species like *Erica arborea* and *Arbutus unedo* which, in some cases, do not grow in the northern forests. Instead, the northern forests have some alpine and subalpine plants like *Vaccinium myrtillus* and *Ranunculus montanus*. Most of the regions' species compositions have changed since the historical inventories. This was to be expected as changes in other European oak forests have also been reported (Reczyńska & Świerkosz, 2016). The changes in species composition in the Pyrenees is probably because there are a lot of new species in these forests (VR and VA), unlike in the Pre-Coastal and Coastal ranges where the changes are probably due to the high number of species that have become extinct since the historical inventories (M and Mn). Contrary to these changes, the Pre-Pyrenees seems to be in a stable situation, probably as a consequence of the differences between the two subregions of this landscape element.

4.5.2 Forest use and woody plants

The most abundant plants in the sessile oak forest are deciduous macrophanerophytes, not only because *Quercus petraea* is very abundant, but also as a result of the presence of other deciduous trees like *Corylus avellana*, *Castanea sativa*, *Acer campester* and *Fraxinus excelsior*. Furthermore, as a consequence of the relative luminosity on the low stratums, there is also a great abundance of hemicryptophytes like the gramineae species such as *Brachypodium sylvaticum*, *Festuca ovina* and *F. heterophylla*. In terms of richness, this situation changes and hemicryptophytes are the largest group of plants and there are a lot of different species of the genus *Campanula*, *Carex*, *Festuca* and *Hieracium*.

However, the relative richness and relative abundance of the plant life-forms have changed since the first period of the study and there is a common pattern to these changes with deciduous macrophanerophytes increasing (e.g. *Q. petraea*, but also other deciduous specie like *F. excelsior and F. sylvatica*) and hemicryptophytes plants decreasing (e.g. species of *Festuca* and *Hieracium* genus) in their relative abundance in four of the seven subregions analysed (VR, M, Mn and AG).

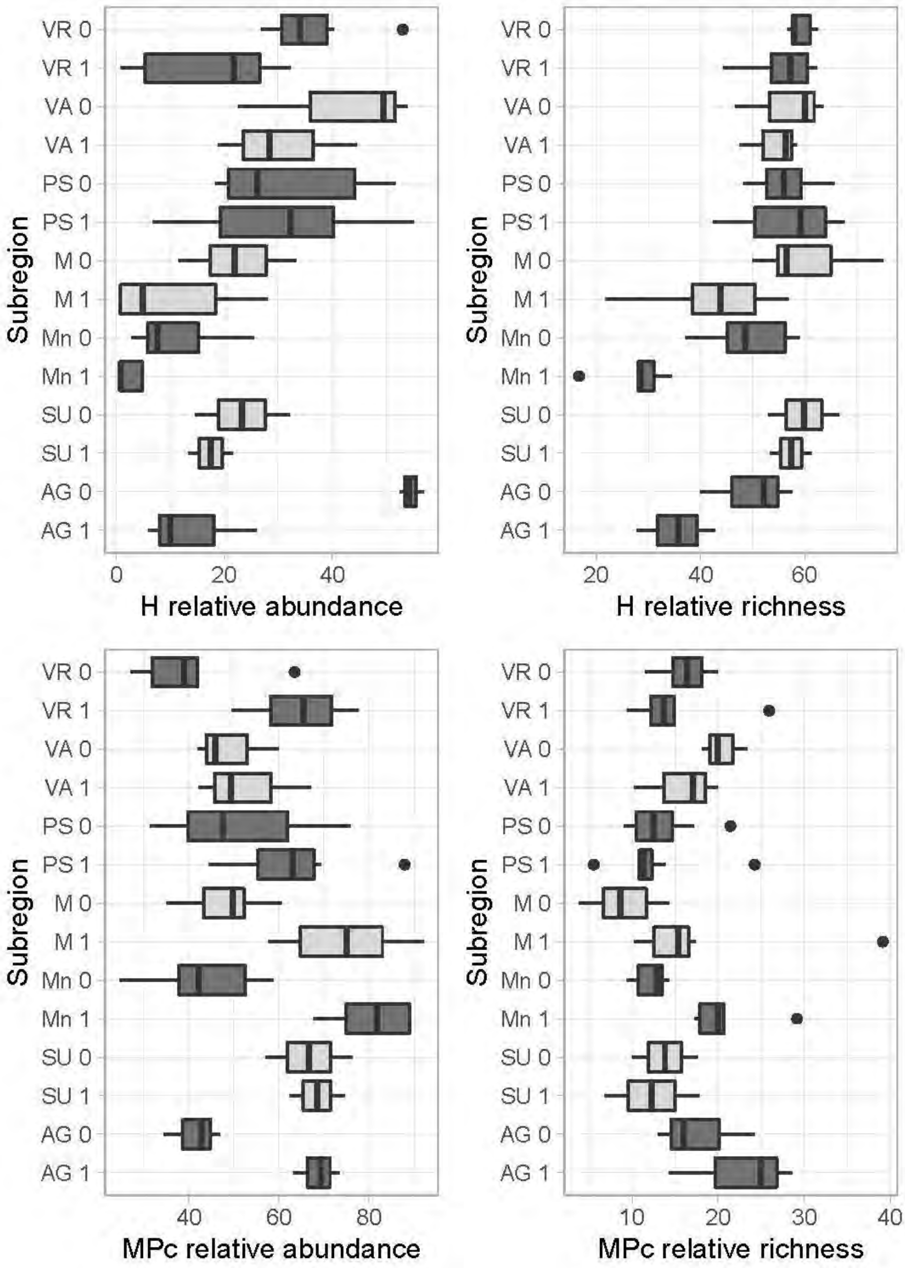

Figure 5. Right, the relative richness of hemicryptophytes (H) and deciduous megaphanerophytes (MPc). Left, the relative abundance of the same plant traits. The results are shown for each subregion and for the two periods studied.

In other words, there is now more tree cover. Besides this, relative richness shows the same dynamics in the Pre-Coastal and Coastal ranges (M and Mn), so this is a strong dynamic. This is probably because of the changes in forest use as historically the forest has been extensively exploited, but this was severely reduced in the half of 20th century (Gordi, 2009). Due to this intensive activity, the sessile oak forest remains more open and dispersed, with a remarkable lightness, as Bolòs (1983) described it in Montseny. These historical factors provide a perfect environment to develop a rich hemicryptophytes cover, but since the falloff of forestry activity the deciduous macrophanerophytes have gained cover and the optimal situation for herbs has been reduced. In fact, the densification of the sessile oak forest has been reported for the Pre-Coastal Range (Bou & Vilar, 2018), where the plant life-forms pattern is very clear, as has the increase in the relative richness of evergreen macrophanerophytes. The Coastal Range also shows an increase in the relative richness of geophytes, because the forest has more ferns than before (e.g. *Asplenium adiantum-nigrum*), probably as a consequence of the shade the current dense forest provides. In PS the situation is the opposite, because the relative abundance of geophytes has been reduced as a consequence of fern and *Lathyrus niger* loss. Only in the north-western forests is this dynamic avoided (VA, PS and SU), as the Pre-Pyrenees and Pyrenees subregions affected are in the east (VR and AG). As there is no change in the relative abundance of deciduous macrophanerophytes, it can be assumed that the light conditions have probably not changed and, as a consequence, a change in hemicryptophytes would not be expected. Thus, the forest remains stable in this sense. Furthermore, there are some changes in woody plants in Pre-Coastal and Coastal ranges, since the relative richness of evergreen nanophanerophytes has decreased and been replaced by phanerophytes that have also increased their abundance. Chamaephytes have also experienced some changes in relative abundance, but as their abundance is still very low this does not have a major impact on the community. Therefore, in general terms, the eastern sessile oak forests have densified and gained woody plants in relative richness and abundance.

Only one introduced species, *Castanea sativa*, appears in the historical inventories. This tree has a long history of substituting sessile oak forests for chestnut plantations in humid montane zones (Llobet, 1947; Panadera & Nuet, 1986). However, new tree species have recently appeared, one of them being *Picea abies,* which is an introduced tree (present in VR) originally from Northern Europe and used for forestry plantations on the NE Iberian Peninsula. The other two species of trees to have appeared have been reported as invasive. In M this is the Douglas fir (*Pseudotsuga menziesii*), which shows an invasive growth in this massif and the surrounding area (Broncano et al., 2005), and has been observed in sessile oak forests not only as tree cover, but also as seedlings (Bou, Vilar, & Caritat, 2018). And in the VA sessile oak forest it is *Buddleja davidii* (MAPAMA, 2018), which is present as a consequence of the proximity to a road where it can easily colonize the margins. Of these three introduced species, the most problematic situation is the Douglas fir because in recent years the sessile oak forest has been increasingly exposed to this invasive plant as a result of the increase in the number of Douglas fir plantations. And landowners have even been advised to replace their chestnut plantations with Douglas fir (Tusell & Beltrán, 2016).

4.5.3 Thermophilization

Although there is some subregional variability, the sessile oak forest is clearly dominated by Euro-Siberian plants, because their relative richness and abundance is always higher than other chorological groups. This is something which is common in humid montane zones on the NE Iberian Peninsula where Euro-Siberian plants are typically present (Andrés & Font, 2011) but unlike the NW Iberian Peninsula where Atlantic plants are more important (Díaz-Maroto & Vila-Lameiro, 2007).

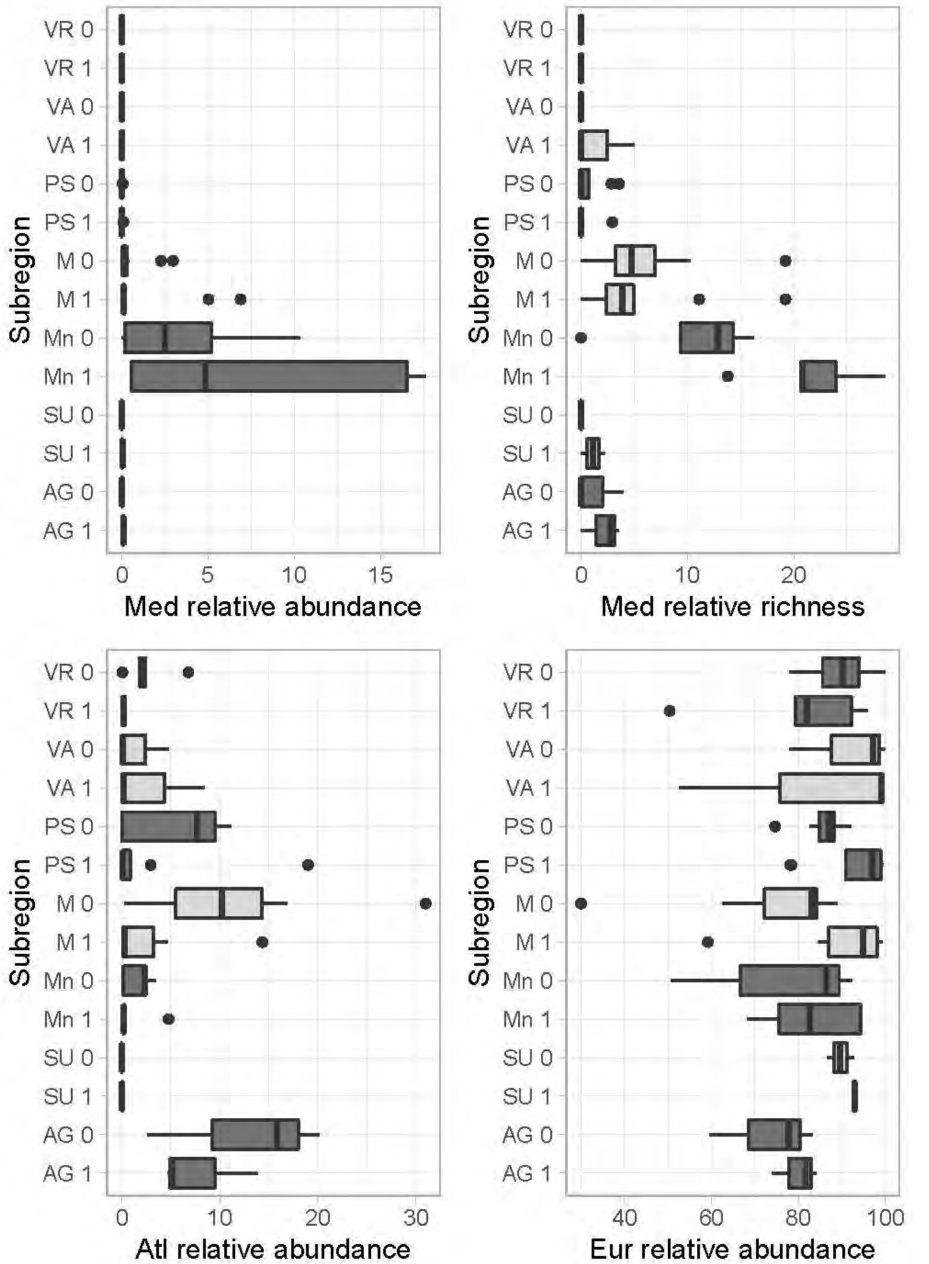

Figure 6. On the top, the Mediterranean (Med) relative richness and relative abundance, and under them the relative abundance of Atlantic (Atl) and Euro-Siberian (Eur) plants. The results are showed for each subregion on the two studied periods.

The sessile oak forests in the Coastal Ranges have experienced an increase in the relative richness for Mediterranean plants, but a decrease trend for Euro-Siberian plants. This is probably due to the warming conditions which promote the thermophilization of the community resulting from an increase in hydric stress which, in turn, promotes plants sensitive to the new conditions being substituted for those more tolerant to them (Reif et al., 2017). On the NE Iberia Peninsula, these tolerant plants are the Mediterranean species which are adapted to the typical summer droughts in these climatic regions. In fact ,the Mediterraneanization of other deciduous forest in the Pre-Coastal Range has already been reported (Peñuelas & Boada, 2003). So, in the hottest locality, at low altitude and close to the sea, one would expect to find this process in a Euro-Siberian community like the sessile oak forest. Also, the ratio between the thermophile species and the typical plant chorology in this forest (M/E ratio), shows a thermophilization of the Coastal Range sessile oak forest.

Next to this region, in the Pre-Coastal Range, this dynamic is not clearly observed because, while there is a decrease in the relative abundance of Atlantic species (a plant group with high hydric requirements), there is also an increase in the relative abundance of Euro-Siberian plants. Therefore, the community in Pre-Coastal Range becomes more typical, i.e., with the vegetation corresponding to a sessile oak forest. This result contradicts one case study in the Montseny Massif where Mediterraneanization was reported in a specific forest (J. F. Gómez et al., 2008), but is, in fact, (according to a larger study of the Massif), where a recovery of the sessile oak forest was reported as taking place in Montseny (Bou & Vilar, 2019). So, the increase in Euro-Siberian plants has to be understood as the recovery of the plant community from the historical forest activity described in Montseny. Because of this recovery from human activity, thermophilization is not observed, however, it could be being masked so monitoring this forest is required in order to evaluate such patterns.

Meanwhile, albeit at a lower intensity than in the Coastal Range forests, thermophilization in the Pyrenees in the VR forests shows a loss of Atlantic relative abundance; another group of plants with high water requirements, and an increase in Pluriregional plants. In other words, less specialized plants are increasing to the detriment of plants typically found in these forests. Also, there is a slight loss trend of Euro-Siberian relative richness. Probably this whole dynamic is a consequence of thermophilization but it has had less impact on these eastern Pyrenees locations than in the Pre-Coastal and Coastal ranges, and only specialization in the flora typical to these areas has been lost i.e., no Mediterranean plants have been gained. In fact, in VR there are not any Mediterranean plants present at all. Meanwhile, in AG there is a loss trend in Atlantic relative richness but it is not followed by all these thermophilization of the community.

Western sessile oak forests in the Pyrenees (VA and PS), show stable chorological compositions, so currently there is no sign of thermophilization there. However, in the past no Mediterranean plants were to be found in VA and SU and currently there are some, like *Quercus ilex* and *Rubia peregrina*, but with a very low cover. So perhaps, over time, Mediterranean plants will expand and these forests will show the thermophilization process in the future. At present, what is observed is that at low altitudes, such as the Coastal Range, there is a marked Mediterraneanization process, while at higher altitudes, like in the west of the Pyrenees, the community appears to be more stable.

It is unusual to find the presence of alpine and boreo-subalpine plants in sessile oak forests, even on the Coastal range, but in the Pre-Pyrenees and Pyrenees they are a little more present in the higher elevation plots because of the proximity to subalpine vegetation, following an altitude gradient, as is to be expected (Grau, Ninot, Font, Ferré, & Grytnes, 2011). There is also one Pontic plant that is only present in VA, albeit with a very low relative abundance.

4.6 Conclusion

There is enough evidence to determine that sessile oak forest on the NE Iberian Peninsula has changed since the second half of the 20th century. That said, there are some regional and subregional differences that must be considered. Most of the forests shows changes in species composition and in the Coastal Range a loss of biodiversity has also been reported. These changes in species composition can be explained by the changes in landscape uses, because the sessile oak forest was heavily exploited in historical times, but such practices have been abandoned. It has been observed that the eastern sessile oak forests are recovering from this impact, showing an increase in tree cover which reduces the optimal conditions for some herbs, thus leading the decay of hemicryptophyte plants. This recovery can also affect the chorological composition of the community, because in the Pre-Coastal Range there is an increase in the typical Euro-Siberian plants. Thus, while many of the changes can be explained by these forests recovering from historical forest activity, there are also other changes that are more closely connected to climate warming. In the Coastal Range sessile oak forests, thermophilization of the community has been reported as an increase in Mediterranean species. This evidence is a warning of climate change and what can happen to this deciduous forest found on the xeric limit populations. In fact, a decrease in the presence of Atlantic plants has also been reported in the Pyrenees and this could be an initial phase of thermophilization. The western sessile oak forest seem to be more stable, probably as a result of being at a higher altitude in better environmental conditions and thus better conserved. To all these dynamics, the emergence of new invasive plants in these forests has to be added, with the case of Douglas fir in the Pre-Coastal Range being of particular concern. More monitoring studies on the effect climate change is having on community composition are needed, especially ones focusing on montane vegetation like sessile oak forests. The evidence of Mediterraneanization on the Coastal Range has to be taken as a warning of the probable future changes that will take place in other sessile oak forests on the NE Iberian Peninsula.

4.7 Acknowledgments

This work has been partially financed by the Francesc Eiximenis 2018 research grant.

4.8 Bibliography

Ales RF, Martin A, Ortega F, Ales EE (1992) Recent changes in landscape structure and function in a Mediterranean region of SW Spain (1950–1984). Landsc Ecol 7:3–18.

Améztegui A, Brotons L, Coll L (2010) Land-use changes as major drivers of mountain pine (Pinus uncinata Ram.) expansion in the Pyrenees. Glob Ecol Biogeogr 19:632–641.

Amigo J, Silva-Pando FJ, González MP, Rozados MJ, Rois M, Díaz-Maroto IJ (2001) Diversidad florística en rob- ledales atlánticos del Noroeste de la Península Ibérica.InIII Congreso Forestal Español.

Andrés M, Font X (2011) Principals patrons de distribució de plantes vasculars a Catalunya.InActes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica. Ordino, 33–44.

Berger S, S??hlke G, Walther GR, Pott R (2007) Bioclimatic limits and range shifts of cold-hardy evergreen broad-leaved species at their northern distributional limit in Europe. Phytocoenologia 37:523–539.

Bertrand R, Lenoir J, Piedallu C, et al. (2011) Changes in plant community composition lag behind climate warming in lowland forests. Nature 479:517–520.

Boada M (2002) Manifestacions del canvi ambiental global al Montseny. Universitat Autònoma de Barcelona.

Bolòs O (1983) La vegetació del Montseny. Barcelona: Diputació de Barcelona.

Bolòs O (1988) La roureda acidòfila (Quercion robori-petraeae) a Catalunya. Monogr Inst Pir Ecol 4:447–453.

Bolòs O, Vigo J, Masalles RM, Ninot JM (2005) Flora manual dels Països Catalans. 3a ed. Barcelona: Pòrtic.

Bou Manobens J, Àguila V, Gordi J (2015) L'evolució del paisatge forestal (1950-2013) a l'Alt Empordà. AIEE 46:343–368 10.2436/20.8010.01.185.

Bou J, Vilar L (2018) Current distribution and recent development of sessile oak forests in Montseny (1956-2015). Landsc Res 10.1080/01426397.2018.1472751.

Bou J, Vilar L (2060) algun dia CAP 2.

Bou J, Vilar L, Caritat A (2016) La roureda de roure de fulla gran. Rev Girona 294:62 – 65.

Bou J, Vilar L, Caritat A (2018) La roureda de roure de fulla gran al Parc Natural del Montseny.InIX Trobada d'Estudiosos del Montseny. Barcelona: Diputació de Barcelona, 152–163.

Braun-Blanquet J (1964) Pflanzensoziologie Grundzüge der Vegetationskunde. Vienna: Springer Vienna.

Broncano MJ, Vilà M, Boada M (2005) Evidence of Pseudotsuga menziesii naturalization in montane Mediterranean forests. For Ecol Manage 211:257–263.

Brunet J, Falkengren-Grerup U, Rühling Å, Tyler G (1997) Regional differences in floristic change in South Swedish oak forests as related to soil chemistry and land use. J Veg Sci 8:329–336.

Carreras J, Carrillo E, Font X, Ninot JM, Soriano I, Vigo J (1995) La vegetación de las sierras prepirenaicas situadas entre los ríos Segre y Llobregat. 1- Comunidades forestales (bosques, mantos marginales y orlas herbáceas). Ecol Mediterr XXI:21–73.

Carreras J, Carrillo E, Josep-Maria N, Vigo J (1997) Contribution to the phytocoenological knowledge of Pyrenean forests. Fragm Florist Geobot 42:95–129.

Castroviejo S (2012) Flora iberica. Madrid: Real Jardín Botánico, CSIC.

Clarke KR, Gorley RN (2006) PRIMER v6: User Manual/Tutorial (PRIMER-E, Ed.). Plymouth.

Debussche M, Lepart J, Dervieux A (1999) Mediterranean landscape changes: evidence from old postcards. Glob Ecol Biogeogr 8:3–15.

Departament de Medi Ambient (1996) Pla d'espais d'interès natural. Barcelona : Generalitat de Catalunya.

Díaz-Maroto IJ, Vila-Lameiro P (2007) Deciduous and semi-deciduous oak forests (Quercus robur, Q. petraea and Q. pyrenaica) floristic composition in the Northwest Iberian Peninsula. Biologia (Bratisl) 62:163–172.

Diputació de Barcelona (2018)https://parcs.diba.cat/web/montnegre (20 August 2018, date last accessed).

Eaton E, Caudullo G, Oliveira S, Rigo D de (2016) Quercus robur and Quercus petraea in Europe: distribution, habitat, usage and threats.In San-Miguel-Ayanz J, Rigo D de, Caudullo G, Houston Durrant T, Mauri A (eds). European Atlas of Forest Tree Species. Luxembourg: Publ. Off. EU., 160–163.

Fischlin A, Midgley GF, Price JT, et al. (2007) Eco- systems, their properties, goods and services.In Parry ML, Canziani OF, Palutikof JP, Linden PJ Van der, Hanson CE (eds). Climate Change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press, 211–272.

Forest Europe (2015) State of Europe's Forests 2015. Madrid: FOREST EUROPE.

Frenne P De, Rodriguez-Sanchez F, Coomes DA, et al. (2013) Microclimate moderates plant responses to macroclimate warming. Proc Natl Acad Sci 110:18561–18565.

García-Ruiz JM, Lasanta T, Ruiz-Flano P, et al. (1996) Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. Landsc Ecol 11:267–277.

Gómez JF, Boada M, Sànchez S (2008) Análisis de los procesos de cambio global: el caso del robledal de Ridaura (Parque Natural del Montseny. barcelona). Boletín la AGE 47:125–142.

Gómez D, Ferrández J, Tejero P, Font X (2017) Distribución espacial y análisis ambiental de la flora alpina en los Pirineos. Pirineos 172 https://doi.org/10.3989/Pirineos.2017.172002.

Gordi J (2009) L'Evolució del paisatge forestal a les terres gironines a la segona meitat del segle XX. Girona: Associació d'Història Rural de les Comarques Gironines.

Grabherr G, Gottfried M, Pauli H (1994) Climate effects on mountain plants. Nature 369:448–448.

Grau O, Ninot J, Font X, Ferré A, Grytnes J (2011) Trends in altitudinal distribution of plant diversity in the Catalan Pyrenees.InActes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica. Ordino, 171–180.

IPCC (2013) Climate change 2013: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (S Solomon, D Qin, M Manning, et al., Eds.). Cambridge: Cambridge University Press.

Kelly AE, Goulden ML (2008) Rapid shifts in plant distribution with recent climate change. Proc Natl Acad Sci 105:11823–11826.

Krumm F, Vítková L (Eds.) (2016) Introduced tree species in European forests: opportunities and challenges. European Forest Institute.

Lapraz G (1962) Recherches phytosociologiques en Catalogne. Collect Bot 6(1-2).

Lasanta-Martinez T, Vicente-Serrano S, Cuadrat-Prats J (2005) Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. Appl Geogr 25:47–65.

Lenoir J (2008) A significant upward shift in plant species. Science (80-) 320:1768–1772.

Lenoir J, Gegout JC, Dupouey JL, Bert D, Svenning JC (2010) Forest plant community changes during 1989-2007 in response to climate warming in the Jura Mountains (France and Switzerland). J Veg Sci 21:949–964.

Llobet S (1947) El Medio y la vida en el Montseny : estudio geográfico. Barcelona: CSIC. Instituto Juan Sebastián Elcano.

Loarie SR, Duffy PB, Hamilton H, Asner GP, Field CB, Ackerly DD (2009) The velocity of climate change. Nature 462:1052–1055.

Loidi J (Ed.) (2017) The Vegetation of the Iberian Peninsula. Cham: Springer International Publishing.

MacDonald D, Crabtree JR, Wiesinger G, et al. (2000) Agriculture abandonment in mountain areas of Europe: environmental consequences and policy response. J Environ Manage 59:47–69.

Mallarach JM, Montserrat J, Vila J (Eds.) (2013) Reptes per preservar els boscos madurs a Catalunya: II Jornades sobre boscos madurs. Santa Coloma de Farners: Institució Catalana d'Històrica Natural.

MAPAMA (2018) Especies exóticas invasoras. https://www.mapama.gob.es (21 August 2018, date last accessed).

Mercadé A (2008) Aportació al coneixement dels boscos mesòfils de la Catalunya Central, I; Fagedes i Rouredes. Acta Bot Barcinonensia 51:93–125.

Ninyerola M, Pons X, Roure JM (2000) A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. Int J Climatol 20:1823–1841.

Panadera JM, Nuet J (1986) Les Castanyedes al Montseny. Ausa 12:65–78.

Pauli H, Gottfired M, Grabherr G (1996) Effects of Climate Change on Mountain Ecosystems - Upward Shifting of Alpine Plants. World Resour Rev 8:382–390.

Pauli H, Gottfried M, Grabherr G (2003) Effects of climate change on the alpine and nival vegetation of the Alps. J Mt Ecol 7:9–12.

Peñuelas J, Boada M (2003) A global change-induced biome shift in the Montseny mountains (NE Spain). Glob Chang Biol 9:131–140.

Peñuelas J, Sardans J, Filella I, et al. (2016) Ecosistemes terrestres.In Institut d'Estudis Catalans, Generalitat de Catalunya (eds). Tercer informe sobre el canvi climàtic a Catalunya. 211–235.

R Core Team (2015) R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Reczyńska K, Świerkosz K (2016) Compositional changes in thermophilous oak forests in Poland over time: do they correspond to European trends? (R Hédl, Ed.). Appl Veg Sci 1–12 10.1111/avsc.12290.

Reif A, Xystrakis F, Gärtner S, Sayer U (2017) Floristic change at the drought limit of European beech (Fagus sylvatica L.) to downy oak (Quercus pubescens) forest in the temperate climate of central Europe. Not Bot Horti Agrobot Cluj-Napoca 45:646–654.

Ruiz-Labourdette D, Schmitz MF, Pineda FD (2013) Changes in tree species composition in Mediterranean mountains under climate change: Indicators for conservation planning. Ecol Indic 24:310–323 10.1016/j.ecolind.2012.06.021.

Santos CCP (2000) Succession of breeding bird communities after the abandonment of agricultural fields in southeast Portugal. Ardeola 47:171–181.

Thuiller W, Lavorel S, Araújo MBMB, Sykes MTMT, Prentice IC (2005) Climate change threats to plant diversity in Europe. Proc Natl Acad Sci 102:8245–8250.

Tusell JM, Beltrán M (Eds.) (2016) XXXIII Jornades Tècniques Silvícoles Emili Garolera. Santa Coloma de Farners: Consorci Forestal de Catalunya.

UNEP (1989) State of the Mediterranean marine environment. Athens.

Universitat de Barcelona, Generalitat de Catalunya (2012)SEMHAVEG.

Väre H, Lampinen R, Humphries C, Williams P (2003) Taxonomic diversity of vascular plants in the european alpine areas.In Nagy L, Grabherr G, Körner C, Thompson DBA (eds). Alpine Biodiversity in Europe. Ecological Studies (Analysis and Synthesis). Berlin: Springer, 133–148.

Vayreda J, Banqué M, Anna Grau, Martínez-Vilalta J (2013) CANVIBOSC: Vulnerabilitat de les espècies forestals al canvi climàtic. Barcelona.

Vigo J (1968) Notas sobre la Vegetación del Valle de Ribes. Collect Bot 8(2) No 66:1171–1185.

Vigo J (1996) El poblament vegetal de la Vall de Ribes. 1st ed. Barcelona: Institut Gartogràfic de Catalunya.

Vigo J (2011) Comparacions entre la flora dels Pirineus i la d'altres muntanyes peninsulars.InActes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica. Ordino, 453–466.

Vigo J, Carreras J, Ferré A (Eds.) (2005) Manual del Hàbitats de Catalunya. 8 volums. Departament de Medi Ambient i Habitatge. Generalitat de Catalunya.

Viñas X (1993) Flora i vegetació de l'Alta Garrotxa. Universitat de Girona.

Vittoz P, Guisan A (2007) How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. J Veg Sci 18:413–422.

Vittoz P, Randin C, Dutoit A, Bonnet F, Hegg O (2009) Low impact of climate change on subalpine grasslands in the Swiss Northern Alps. Glob Chang Biol 15:209–220.

Walther G-R (2003) Plants in warmer world. Perspect Plant Ecol Evol Syst 6:169–185.

Walther G-R, Beißner S, Burga CA (2005) Trends in the upward shift of alpine plants. J Veg Sci 16:541.

Walther GR, Grundmann A (2001) Trend for vegetation change in colline and submontane climax forests in Switzerland. Publ Geobot Inst ETHZ 67:3–12.

Williams JW, Jackson ST (2007) Novel climates, no-analog communities, and ecological surprises. Front Ecol Environ 5:475–482.

4.9 Supporting Information

Additional supporting information may be found in the online version of this article.

Current distribution and recent development of sessile oak forests in Montseny (1956-2015)

Article 2

Bou, J., & Vilar, L. (2018). Current distribution and recent development of sessile oak forests in Montseny (1956-2015). Landscape Research. http://doi.org/10.1080/01426397.2018.1472751 En premsa.

5 Current distribution and recent development of sessile oak forests in Montseny (1956-2015)

Jordi Bou[1]* and Lluís Vilar[1]

* Corresponding author; jordi.bou.manobens@gmail.com

[1] LAGP-Flora and Vegetation. Institute of the Environment. University of Girona. Postal address: C/ Ma. Aurèlia Capmany 69, 17003 GIRONA, Catalonia (Spain) Telephone: 699813514

Landscape Research, 2018 DOI http://doi.org/10.1080/01426397.2018.1472751

5.1 Abstract

There is a distribution limit of sessile oak (*Quercus petraea*) in the northern half of the Iberian Peninsula, with its southernmost populations located at the xeric limit for the species. We present here the current distribution of these populations in the Montseny Massif (N.E. Catalonia) and how the surface area they cover has developed over the last 50 years. Using a new high-resolution map (1:5000) we have calculated that *Q. petraea* currently covers 64.1 ha, and is found between 450 and 1150 m above sea level with a predominantly southern exposure, with the north-facing slopes being dominated by beech forests. With regard to its recent development, 44% of what is now dense forest was, in 1956, much more dispersed while 11% of it consisted of open spaces or shrubs. Such changes clearly show that, in Montseny, *Q. petraea* is well capable of regenerating its forest canopy as well as colonising adjacent environments.

Keywords: Sessile oak; forest dynamics; global change; Montseny.

5.2 Introduction

Sessile oak forests dominated by *Quercus petraea* are abundant in European forested areas, whereas they are somewhat rare at the southern limit of the species' distribution. But this current distribution can change because there has been reported an acute oak decline in Europe (Hartmann, Blank, & Lewark, 1989; Kotroczó, Veres, Fekete, Papp, & Tóth, 2012; Oleksyn & Przybyl, 1987; Saniga, Balanda, Kucbel, & Pittner, 2014; Thomas, Blank, & Hartmann, 2002).

This dynamic is not yet fully understood, probably because it's the consequence of multiple environmental and biotic factors (Eaton, Caudullo, Oliveira, & de Rigo, 2016; Gibbs & Greig, 1997; Siwkcki & Ufnalski, 1998). For this reason, it is very important to study the current distribution and recent development of sessile oak forests along the different regions of Europe, as in the case of the N.E. Iberian Peninsula (Catalonia), where it covers very little surface area. This is probably due to two major factors, the high water requirements of this species and the forestry activity in this region.

In Europe sessile oak forest grows predominantly on slopes and hill tops, with drained and acid soils (Eaton et al., 2016), whereas in the north-east of the Iberian Peninsula it can only be found in humid montane zones, where despite the dry environmental conditions typical of the summer months, there are regular rainy springs and autumns (Bolòs, 1983). In fact, *Q. petraea* has its xeric limit in Catalonia (Bou, Vilar, & Caritat, 2016), in adverse environmental conditions for its biological needs. The xeric limit is considered as the frontier of the distribution of a taxon, beyond which it cannot survive (Mátyás, 2010). In Catalonia, the most important *Q. petraea* forests are concentrated in the areas of *Montseny* and *Les Guilleries*, although they can also be found further north in the Pyrenees. What is relevant about the Montseny massif is that the sessile oak forests, being located further south, are more clearly affected by the aforementioned conditions at the limit of the species' distribution. The study of the climate change effect in them is therefore very interesting.

To understand the current distribution of sessile oak forest, it's very important to consider that the Montseny massif has been exploited since ancient times, through both forestry and agricultural practices (Boada, 2002b). In the second half of the twentieth century, however, such activity changed dramatically with the abandonment of charcoal manufacturing and the increasing spread of conifer plantations (Observatori del Paisatge, 2010). Meanwhile, agricultural and livestock activity has almost completely disappeared and meadows and croplands have been replaced by shrub and forest cover, as has occurred elsewhere along the northern shores of the Mediterranean basin (Ales, Martin, Ortega, & Ales, 1992; Boada, 2002a; Bou Manobens, Àguila, & Gordi, 2015; Debussche, Lepart, & Dervieux, 1999; García-Ruiz et al., 1996; MacDonald et al., 2000; Santos, 2000; UNEP, 1989).

In the context of the acute oak decline it's very important to know the current distribution of sessile oak, to monitor the future dynamics, and at the same time study the recent development of the forest. The Montseny massif is a great case study for this topic, but the existing cartography of the vegetation (Universitat de Barcelona, Generalitat de Catalunya, & Institut d'Estudis Catalans, 2012) and land cover (CREAF, & Generalitat de Catalunya, 2009) as well as earlier efforts (Bolòs, 1983; Llobet, 1947), do not have sufficient resolution to enable us to reliably describe the development of these forests. Hence, in this article, we present a more detailed cartography that allows us, on the one hand, to describe the current distribution of *Q. petraea* in Montseny and, on the other, to carry out a diachronic study of its development by comparing it with aerial images obtained in 1956.

The objectives of this study are, therefore, to analyse the current distribution of sessile oak forests in Montseny and the current surface area they occupy, and analyse if their distribution has changed during the last 60 years and how they have been affected by global change. And as a consequence, provide new knowledge on the dynamics of the sessile oak forests in order to anticipate future changes.

5.3 Methodology

5.3.1 Area of study

The Montseny massif is located in the north-east of the Iberian Peninsula, ranging from 100 to 1700 m of elevation above sea level. It has a marked climate and vegetation gradient, with different forest types, both deciduous and evergreen, depending on elevation, exposure and relief. Consequently, the massif has a wide diversity of landscape (Bou Manobens, Vilar, & Caritat, 2015) consisting mainly of these diverse forested areas, which cover 86% of the massif (CREAF, & Generalitat de Catalunya, 2009). Due to the high value of the natural heritage of the massif (Boada, 1994), in 1977 Montseny massif was declared a Natural Park and a UNESCO Biosphere Reserve in 1978 (Diputació de Barcelona, 2008). In lithological terms, it is a Palaeozoic massif, with predominantly granite rock in the eastern sector, where most of the forests that concern us here are located. In terms of climate, the study area has a typical montane climate, with a mild summer drought and regular and abundant rainfall (Bou, Caritat, & Vilar, 2015).

5.3.2 Producing the map of the oak forests of 2015

In 2015, we produced a high resolution map (1:5000) of the sessile oak forests in the Montseny area. It was based on existing maps (Bolòs, 1983; CREAF, & Generalitat de Catalunya, 2009; Llobet, 1947; Universitat de Barcelona et al., 2012), but the localisation of the main nuclei of oak forests was carried out via fieldwork. The mapping of the different forests was achieved by taking georeference points using GPS devices and, once the information was collected, the data was processed using GIS software, combined with orthophotographs, from which digital maps of the oak forests were created. All the cartographical information was dealt with using the ESRI ArcMap programme. The maps were drawn up with the UTM (Universal Transverse Mercator) map projection system using the coordinate reference system ETRS89 (European Terrestrial Reference System 1989), UTM Zone 31T. Since the forest structure of the studied areas is well known (Bou, Vilar, & Caritat, 2015) and we also have information on the composition of the forest and the current diversity, the map produced allows us to study the dynamics of this oak forest in Montseny in detail.

5.3.3 Elaboration of the 1956 map

To learn more about the dynamics of these forest stands, the vegetation units present in 1956 were measured so that a diachronic analysis could then be carried out. The vegetation units that made up the sessile oak stands about 50 years previously were calculated via photo interpretation (using ArcMap GIS, at an approximate scale of 1: 5000) of aerial photographs taken from aeroplanes in 1956 (which had been rectified previously by the Cartographic Institute of Catalonia). Finally, a map was created made up of polygons with attributes for the vegetation corresponding to 1956, in which we have been able to differentiate up to five vegetation units (shown in Table 1), based on the recognisable physiognomy in the images; consequently, comparisons could be made between the two periods mapped. To produce this 1956 map, we considered the sessile oak forests mapped by Llobet (1947) and Bolòs (1983).

Vegetation units in 1956
Dense forests
Sparse forest
Shrublands
Open spaces
Rocks and screes

Table 1. Vegetation units considered in the 1956 maps of the oak forests.

5.3.4 Analysis of the cartography

We analysed the fragmentation of the oak forests through time by calculating various indices, each of which was measured using the ArcMap GIS and the different formulas that we explain below (Table 2). We used shape indices since the shape of forest fragments may be a crucial factor in the dynamics of the ecosystems that make up the fragments, with compact forms being more resistant to the effects of the matrix, while amorphous or irregular shapes may have considerably longer perimeters and therefore be more sensitive to the effects of the matrix. Hence, Patton’s shape index (Patton, 1975) was calculated which, when equal to 1, indicates a shape that is similar to a circle, while an increasing value indicates a tendency to be irregular in shape.

Name of index	Formula	Variables
Patton's shape index (DI)	$DI = \frac{P}{2 * \sqrt{3.1416} * \sqrt{A}}$	P: perimeter of each fragment (m) A: area of each fragment (m^2)
Forest continuity index (FCI)	$FCI = \ln(\sum A / \sum P)$	∑A= total area of all patches of forest in the study zone (m^2) ∑P= total perimeter of all patches of forest in the study zone (m)
Degree of fragmentation (F)	$F = \sum A / AT$	∑A= total area of all patches of forest in the study zone (m^2) AT= total area of the study zone (m^2)
Mean distance to nearest neighbouring fragment (MNN)	$MNN = dNN / nºfrag$	dNN= sum of the distances between each fragment and its nearest neighbour (m) nºfrag= number of fragments

Table 2. Indices used in the cartographical analysis of the fragmentation of sessile oak forests.

Degree of fragmentation	Range F
No fragmentation	1
Moderate fragmentation	$1>F\geq0.7$
Highly fragmented	$0.7>F\geq0.5$
Isolated	<0.5

Table 3. Meaning of possible results of the degree of fragmentation index.

We also took into account indices based on geographical information systems, such as forest continuity index or the degree of fragmentation. The spatial continuity of the forest was measured using the forest continuity index of Vogelmann (Vogelmann, 1995), FCI, with high values indicating continuity, while low values indicate fragmentation and discontinuity between patches of forest. The degree of fragmentation, F, was calculated by the relationship between the total area of all the patches and the total area of the study zone. Possible values are between 0 and 1 and are interpreted according to Table 3.

The mean distance to the nearest neighbouring fragment (MNN) was calculated by measuring the sum of the distances (in meters) between each fragment with respect to its nearest neighbour, and then dividing the result by the number of fragments. The index is close to 0 when the fragments are close to each other and increases when they are more separated.

Finally, further analyses of the current distribution were carried out with ArcMap GIS, both to calculate which units of the cartography were in contact with the oak forests, as well as to measure which categories of zonification were included, that is, which management category each was under, according to the Special Plan of the Natural Park Montseny (Diputació de Barcelona, 2008). To obtain the perimeter values, the vegetation mapping of Montseny (Bou et al., 2015) was transformed from polygons to lines using ArcToolbox > Data Management Tools > Features > Split Line At Vertices and, having been transformed, the lines in contact with oak forests were selected and the length of these vectors was calculated. Hence, we obtained the perimeter of the oak forests in relation to the unit of the vegetation map that makes contact at each point. To obtain the zonification of the oak forests, we used the park maps (Diputació de Barcelona, 2014) and the ArcToolbox > Analysis tools package.

5.4 Results

5.4.1 Current situation of the sessile oak forests

Our new cartography shows that the sessile oak forests of Montseny (Figure 1) cover an area of 64 ha (Table 4), which is well below the 114 ha of sessile oak forest that can be calculated from the most recent general maps of habitats and vegetation of Catalonia (Universitat de Barcelona et al., 2012), despite the fact that our study included oak forests that are not present in this map. One reason for this large discrepancy is that in the map of habitats, the oak stands are often part of larger masses of mixed forest, whereas in our study we have isolated them. We did not study mixed forests in producing our new detailed mapping, since we focused on pure oak stands; however, we estimate that these mixed forests occupy an area of 384 ha, which is slightly higher than the value calculated from the map of habitats (326 ha). Furthermore, there are the stands with a high degree of hybridization which are yet to be taken into account, in the north-west of Montseny.

The sessile oak forests of Montseny are located between 450 and 1150 m above sea level, with two optimal populations, one at around 550 m, particularly in the *Arbúcies* sector and the other, more preponderant, at around 1000 m (Figure 2). Along the soil catena, the sessile oaks are above the holm oak and below the beech forests. With regard to gradient, there are sessile oak stands in both flat and steep areas, but the majority grow in areas of low incline (mean: 39.1%). Orientation is typically southeast, and sometimes east (Figure 3), since the slopes exposed to the north are dominated by beech. With regard to the substrate, oak forest occurs predominantly on granodiorite (71%), and to a lesser extent, on leucogranite (21%), porphyry (3%) and phyllite and cornubite (5%).

As for fragmentation, three large groups of oak forest were found, divided into 182 fragments, with an average area of 3523 m^2. The Patton's shape index show the predominance of rounded or ovate shapes (Table 5) so indicate compact shapes (Table 6). Regarding fragmentation, the patches are isolated from each other, there is a lack of continuity between them, and the density of the patches is low (Table 6). The distance between the patches is not very large, because it does not take into account the huge distances between the three large groups (Table 6).

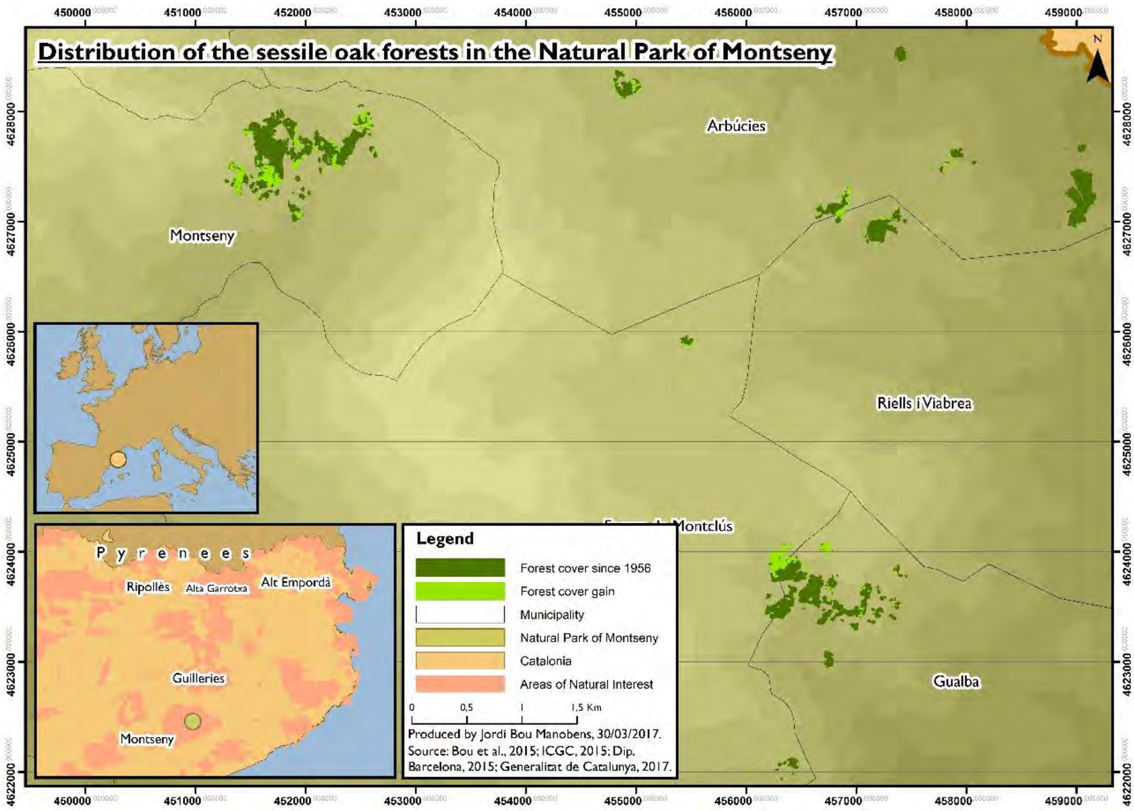

Figure 1. Current distribution and recent development of the sessile oak stands in the Natural Park Montseny. Prepared by the authors. Source: Bou et al., 2015; Diputacio de Barcelona, 2014; Generalitat de Catalunya, 2017; Institut Cartografic i Geologic de Catalunya, 2015.

Oak forests	**Surface (ha)**
Mixed forest of sessile oak	384.0
Sessile oak forest	64.1
Mixed forest of *Q. petraea* ssp. *huguetiana*	2.2

Table 4. Area covered by sessile oak forests in Montseny.

The results obtained from the analysis with GIS neighbouring polygons in contact with the oak forests (Table 7) show that, normally, the oak stands are contiguous with mixed stands of oak with holm oak, beech or sweet chestnut. They are also often contiguous with roads and forest tracks, although to a lesser extent. It is also common to find shrubs alongside or within the oak forests.

Shape	Range	1956		2016	
		Nº	Percentage (%)	Nº	Percentage (%)
Round	<1.25	62	27.6	70	38.5
Oval-round	1.25-1.50	79	35.1	50	27.5
Oval oblong	1.50-1.75	40	17.8	27	14.8
Rectangular	1.76-2	15	6.7	11	6.0
Amorphous/irregular	>2	29	12.9	24	13.2
Total		225	100.0	182	100.0

Table 5. Patton's shape index. Number (Nº) and percentage of sessile oak forest patches.

We also calculated the surface area of the oak forests included in the four categories of zonification defined in the Special Plan for the Natural Park of Montseny (Diputació de Barcelona, 2008), and found that more than half were not within the areas of greatest protection (Table 8).

5.4.2 Development of sessile oak forests

The results show that in 1956, 89% of the current area of oak forest was already established as forest, leaving 11% which can be attributed to expansion of the oak forests over the last 50 years (Table 9). Nevertheless, before assessing the development of these forests, it should be taken into account that, in 1956, 44.3% of the established forest consisted of sparse, low-density forest.

In addition, in 1956 the forest was more fragmented, with 225 patches, and as a consequence there was a higher density of patches and less distance between them (Table 6). The Patton's shape index does not show big differences (Table 5).

Indices of fragmentation and shape	1956	2015
Forest continuity index FCI	2.44	2.54
Degree of fragmentation F	0.001835	0.002063
MNN (m)	11.2	14.1
Density of patches (patches/km^2)	0.7	0.6

Table 6. Calculations of fragmentation and shape indices.

5.5 Discussion

5.5.1 Current situation

The sessile oak stands are mainly located in the eastern part of Montseny, coinciding with granite substrates, which can produce the sandy soils that are optimum for *Q. petraea*. Most of the stands grow in rocky places, most probably places that were less exploited and/or less suitable for plantations and previously not cultivated. Of particular interest are the stands that grow in less sandy soils, upon phyllite and cornubite (hornfel), since the oak stands on this substrate have a very strong Mediterranean character. This is the case at south of the *Fogars de Montclús* municipality, with a high presence of *Quercus ilex*, or one end of the oak stand at Montseny municipality, where *Quercus pubescens* appears (Bou et al., 2015). It seems clear, then, that the metamorphic substrate is not optimal for this forest and we believe that this is a parameter that should be taken into account when modelling potential distributions and population dynamics.

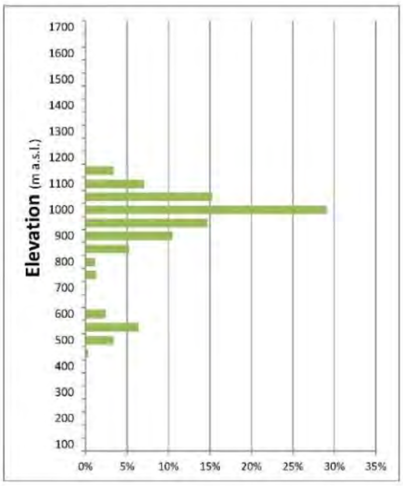

Figure 2. Elevation of sessile oak forests in Montseny.

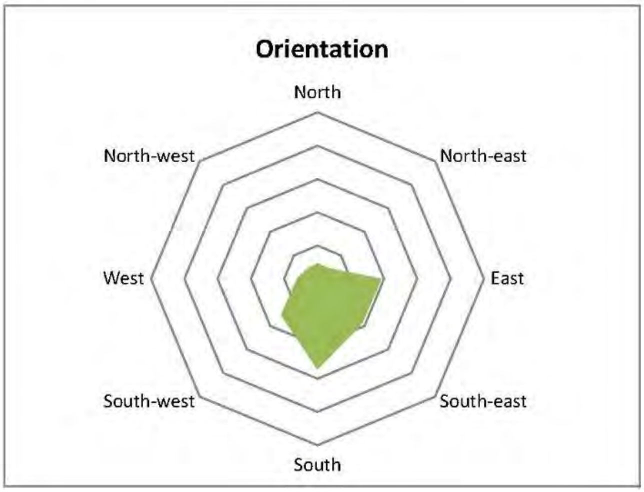

Figure 3. Orientation of sessile oak forests in Montseny

In addition to the substrate, a second determining factor for the sessile oak forests is water availability, since this is a species that does not tolerate summers that go on for too long without rain. Hence, the oaks are found on the montane sector of the eastern massif where climate is more humid, whereas in contrast, they are somewhat rare on the western massif, which is more continental (Bolòs, 1983). At lower elevations, the sessile oaks border with holm oak, while along the higher elevation edge they come into contact with beech, and rarely grow in shady areas even when conditions are highly favourable, because these areas are usually occupied by beech.

The Montseny oak forests have a narrower altitudinal range compared with values for the whole of Catalonia (according to data from the BDBC [Biodivesity Database of Catalonia] for the syntaxa *Teucrio scorodoniae-Quercetum petraeae*, Font, 2013), most likely because they occupy a smaller area, but the most frequent elevations are very similar. As for slope, the range for the whole of Catalonia is similar to that of Montseny, although the average value is slightly higher. The most important difference between Montseny and the rest of Catalonia is the orientation of the oak forests. In Catalonia as a whole, sessile oak is more commonly found on north facing slopes and, in some cases, north-east or north-west. In Montseny, south facing oak forests are more predominant (61%).

The 64.08 ha of sessile oak forest in the Natural Park of Montseny barely make up 0.24% of the total forested area of the Park (Table 10; from our own data combined with data from MCSC [Land Cover Map of Catalonia]) which, along with the fact that there is no continuity between forest fragments, means preserving this forest is problematic.

Units contiguous with sessile oak forests	**Perimeter of oak forest (m)**	**Percentage of oak forest perimeter (%)**
Mixed forest of sessile oak	22400.98	44.51
Paths and roads	11182.02	22.22
Shrublands	4794.76	9.53
Riparian forest	1615.95	3.15
Beech forest	1601.44	3.18
Sweet chestnut forest	1367.60	2.72
Coniferous plantation	1349.37	2.68
Holm oak forest	1243.02	2.47
Aspen stands	972.24	1.93
Mixed deciduous forest	940.59	1.87
Humid forests	915.34	1.82
Hazel formations	554.95	1.10
Rivers and streams	386.38	0.77
Rocks and screes	290.34	0.58
Oriental plane plantations	150.02	0.30
Open spaces	130.69	0.26
Ash forest	125.29	0.25
Clearings	87.75	0.17
Other forest units	70.88	0.14
Mixed forest of holm oak and beech	57.45	0.11
Poplar galleries	45.56	0.09
Douglas fir planted with chestnut tree	40.47	0.08
Anthropogenic area	7.22	0.01
Total	50330.29	100

Table 7. Perimeter of the oak forests according to the units contiguous with them.

As we have said, there are a high number of oak stands very close to each other, but the fact remains that these large forest units are separated from one another and there are various causes for this separation, some more natural than others. One of the natural reasons for this discontinuity

(Table 7) is contact with mixed oak stands (44.51%) which become ecotone areas transitioning to purer stands of other forest species in Montseny, such as beech (3.18%) or holm oak (2.47%), which border with sessile oak; or else, contact with certain habitats that commonly form part of the mosaic of the sessile oak forests, such as riparian forests and the small aspen stands that appear in between.

On the other hand, there is a fragmentation associated with current human impacts as well as impacts from activity carried out decades ago but which have ongoing consequences. Forest tracks and roads, which are contiguous with 22.22% of the oak stands, are good illustrations of this kind of fragmentation. In this case, they give rise to specific problems for some of the oak forests, such as at *Arbúcies*, where half-abandoned forest tracks have been re-established, or at *Fogars de Montclús* where there is a muchfrequented paved road that crosses the forest. In fact, there are new threats in this regard even today such as, for example, the forest track of Montseny municipality that runs through an oak forest and which some want to pave (Coordinadora per a la Salvaguarda del Montseny, 2014; Ecologistes en acció, 2014). Other impacts are more specific, such as the Great Forest Fire of 1994 (Bou et al., 2015), where the oak forest at *Gualba* suffered significant damage in terms of forest structure and composition.

Other processes of fragmentation arise from changes in the landscape and the way that these oak forests have developed over the centuries. If we concentrate on the fragmentation itself, we can see in Table 7 that sweet chestnut plantations account for 2.72% of the perimeter of the oak forests, while conifer plantations take up 2.68% (and .08% of Douglas fir planted with chestnut tree). The latter are more detrimental to the connectedness of the oak forests (Bou & Vilar, 2016), since these consist of plantations of Douglas fir (*Pseudotsuga menziesii*), a tree which is an invasive species in Montseny and the surrounding area (Broncano, Vilà, & Boada, 2005). In recent years, plantations of this tree have increased a great deal, and landowners even advise replacing the chestnut plantations with Douglas fir (Tusell & Beltrán, 2016).

In the context of climate change, the fragmented distribution of these forests may constitute an important vulnerability, since the species could be replaced by others that are more resistant to new climatic conditions (Martínez-Vilalta, Piñol, & Beven, 2002; Peñuelas, Lloret, & Montoya, 2001). In the case of Montseny, the fact that *Q. petraea* is at its xeric limit and is already considered to be a species vulnerable to climate change (Benito Garzón, Sánchez de Dios, & Sainz Ollero, 2008; Czúcz, Gálhidy, & Mátyás, 2011), could facilitate colonisation of the sessile oak forests by better adapted species, such as holm oak. In the long-term, this increased interspecific competition may have negative effects on the sessile oak populations.

We therefore believe that the forestry management of the Natural Park should prioritise conservation of the sessile oak forests over other forest masses that occupy much greater surface area by enhancing the maintenance of the pure stands, and even studying the possibility of converting other forests into sessile oak forests, such as some of the chestnut plantations, currently affected by various diseases and parasites. The actual degree of protection depends on the zoning provisions established in the Special Plan of the Natural Park Montseny (Diputació de Barcelona, 2008), which provides the highest degree of protection that can be designated within the park's zones to the 42% of the sessile oak stands, a figure we consider to be low bearing in mind the uniqueness of the forest. For this reason, it would be advantageous that the sessile oak forests of Montseny were not only designated as zones of natural interest (ZIN) or zone of high natural, environmental interest and outstanding beauty (ZAINEP) but should be considered natural reserve zones (ZRN), and some should even be designated as Integral Natural Reserve.

Zonification	Sessile oak forest	
	ha	%
Zone of natural interest	10.40	16.23
Nature reserve zone	26.68	41.64
Urban	0.00	0.00
Zone of high natural, environmental interest and outstanding beauty	27.01	42.15
Total	64.08	100.00

Table 8. The zonification of the park is defined by the Special Plan for Montseny (Diputació de Barcelona, 2008), which defined four different categories (with acronyms in the Catalan language): ZIN, zone of natural interest, which grants basic protection within the terms of the Special Plan; ZRN, nature reserve zone which only allows management that is directly related to the preservation and improvement of the values protected and ZAINEP, zone of high natural, environmental interest and outstanding beauty. The criteria for intervention for each zone is set out in a specific plan, establishing the management criteria. The Urban Zone is an area subject to existing arrangements, in which the residential and urban centres' own rules and regulations apply.

5.5.2 **Evolution of the land cover**

It is known that Montseny is a massif with a long history of forestry, dating back to the Middle Ages, when oak was used for shipbuilding (Illa, Font, & Arrizabalaga, 2011). This means the forest landscape of the massif is different from what it was in the past, with some species like chestnut being encouraged over others like sessile oak (Panadera & Nuet, 1986), according to the interests and needs of the moment. This continuous alteration of the environment makes it difficult to know with any certainty the extent of the sessile oak forests historically and whether the rather unusual current distribution in such a narrow strip between the holm oak and the beech is natural or the product of human activity.

Regarding the evolution of the oak forests during the last half of the twentieth century, from the results we can say that most (89%) were already areas of forest. It must be pointed out, however, that nearly half of this forested area consisted of scattered trees or low density forest (44.3%). This is because during the first half of the twentieth century, these forests had been exploited, both for timber and charcoal, as evidenced by the charcoal piles found in the area. Also, we must take into account the use of the undergrowth for pasture, which was the case until recently of the oak forests of *Fogars de Montclús*. This whole succession of human activity was reduced in the middle of the last century, as rural areas were abandoned leading to the densification of sessile oak forests in Montseny. This shows that this tree has a capacity for regeneration and growth since, under the right conditions, it has been able to take on a dominant role in the composition of the forest, in the face of competition by other trees that are more resistant to conditions of drought and high temperatures of the Mediterranean. A good example of this process is the sessile oak forest at Montseny municipality, where much of the forest area was once sparse, but is today made up of dense forest. In this area, there are still a large number of pioneer species such as hazel or maple, typical of the intermediate stage in oak forest recovery (Bou et al., 2015). Furthermore, 11% of the current oak forests were once scrub or open spaces and in some cases, even rocky terrain. It is already widely known that sessile oak is well suited to rocky terrain, although we should mention the increase in holm oak also observed in these zones (Bou et al., 2015). The changes in areas that were formerly croplands or scrub and which, over the years, have become sessile oak forests is highly interesting. Such areas are proof of the capacity for expansion these forests have (12.38% increase since 1956), and show that sessile oak forests have followed a pattern similar to other forests in the massif and in neighbouring territories.

As a consequence of this dynamic, the distribution of sessile oak forest has changed since 1956. In the past it was more isolated and fragmented, but the expansion of the forest has joined close patches, making more compact shapes, and as a result a more resistant forest.

Although the existing data on increased forest cover in the neighbouring territories around Montseny is not of the same detail as the data on *Q. petraea*, more global studies also indicate a

Vegetation units in 1956	**Surface**	
	ha	**%**
Dense forests	28.65	44.7%
Sparse forest	28.37	44.3
Open spaces	1.27	2.0
Shrublands	5.65	8.8
Rocks and screes	0.14	0.2
Total	64.08	100.0

Table 9. Surface area of vegetation units in the oak forest under study in 1956.

Forests	**Surface (ha)**	**%**
Holm oak forest	14081.1	52.40%
Beech forest	3585.6	13.34%
Cork oak forest	1660.8	6.18%
Aleppo pine forest	1620.8	6.04%
Sweet chestnut forest	1265.6	4.71%
Stone pine forest	1098.0	4.09%
Coniferous plantation	783.6	2.928%
Riparian forest	731.7	2.72%
White oak forest	483.4	1.80%
Scots pine forest	452.5	1.68%
Mixed forest of sessile oak	384.0	1.43%
Mixed deciduous forest	187.7	0.70%
Ash forest	96.3	0.36%
Oriental plane plantation	81.1	0.30%
Sessile oak forest	64.1	0.24%
Hybrid oak forest	58.2	0.22%
Poplar plantation	49.4	0.18%
Mixed forest of hybrid oak	28.6	0.11%
Other forest units	26.6	0.10%
Maritime pine forest	20.9	0.08%
Deciduous plantation	18.8	0.07%
Fir forests	18.7	0.07%
Humid forests	14.2	0.05%
Evergreen plantation	13.5	0.05%
Hazel formations	9.0	0.03%
Mixed forest of holm oak and hybrid oak	7.7	0.03%
Douglas fir planted with chestnut tree	7.0	0.03%
Mixed forest of alder and black poplar	5.9	0.02%
Mixed forest of holm oak and cork oak	5.0	0.02%
Other mixed forest	4.7	0.02%
Salzmann's pine forests	3.0	0.01%
Mixed forest of *Q. petraea* subsp. *huguetiana*	2.2	0.01%
Aspen stands	1.8	0.01%
Mixed forest of beech and holm oak	0.8	<0.01%
Quercus rubra plantation	0.6	<0.01%
Mixed forest of sweet chestnut and holm oak	0.1	<0.01 %
Poplar galleries	0.1	<0.01 %
TOTAL	**26874.4**	**100%**

Table 10. Surface area covered by different categories of forest (natural and plantations) at Montseny, in order of size. Source: own data combined with data from MCSC [Land Cover Map of Catalonia].

general increase in forest cover. For example, between 1970 and 2007 in the neighbouring province of *Girona*, forest cover has increased by 14% (Gordi, 2009), which is slightly higher than the value calculated for the sessile oak in Montseny, in part because it took into account the whole forest landscape. Studies in north-west of the county of *Alt Empordà* dealing with a period similar to our study, from 1957 to 1989, estimated that forest cover in *Alta Garrotxa* increased by 28.9%, while thickets have decreased in area by 17% (Vila, 1999). Thus the data reflects that, although the Montseny sessile oak forests have increased in surface area in line with other forests in the territory, this increase has not been particularly high or exceptional, as is the case for other forests, such as those of *Alta Garrotxa*.

As for Montseny itself, although the available data (Boada, 2002b) does not cover the same period, they do show very interesting variation of the area of forest cover between 1945 and 1995. In general terms, over that 50-year period, the surface area of beech had decreased quite considerably (−17.94%), while that of holm oak (20.14%) and chestnut (17.9%) increased markedly. From this we can say that, in general, the conditions for the development of sessile oak forests in Montseny appear to have been quite favourable. The increase in the surface area of sessile oak forests in recent years—despite the processes of Mediterranization that Boada (2002b) describes in his thesis—is doubtless due to their adaptability and resilience. While this increase is not as marked as that of the holm oak forests, which are even more resistant to drought (Banqué, Grau, Martínez-vilalta, & Vayreda, 2013), the increase in sessile oak is clear, which is not the case with the beech forests which are less resistant to drought (Banqué et al., 2013). There are also a number of anthropogenic interventions that have favoured monospecific plantations, including sweet chestnut, which has increased greatly, or the more recent plantations of Douglas fir (Bou & Vilar, 2016). Such activities have been altering the Montseny forest landscape for centuries and will certainly have displaced the natural forests, such as those of sessile oak, to such an extent that today, we cannot know with any certainty the past distribution of the forest.

5.6 Conclusions

The sessile oak forest of Montseny only occupies an area of 64.08 ha. Unlike the Pyrenees or other southern European massifs with conditions similar to Montseny, these oak forests not only occupy a small area, but are located in a narrow strip between zones of holm oak and the zones of beech; specifically, at elevations between 450 and 1150 m, coinciding with relatively rainy zones, which allow the development of deciduous forests. In addition, at Montseny, the sessile oak forests are only optimal in granite and, above all, granodiorite.

In order to find out whether this situation is typical of the natural dynamics of this species, further studies are needed focusing on modelling the distribution of *Q. petraea*, to find out what the potential distribution would have been in antiquity. It seems clear that the oak would have dominated more surface area, since during the last 50 years (during which human intervention has decreased) the sessile oak stands have increased in extension. But it seems unlikely that the narrow strip in which sessile oak grows in Montseny could be much greater than it is at present, because the southern situation of the massif, without harsh winters, favours sclerophile trees, especially holm oak, while on the northern slopes, where there is enough moisture for deciduous species, the beech dominates, leaving the sessile oak constricted to a narrow margin between these two types of forest. The combination of these factors are the key to understanding the past and present distribution of sessile oak in Montseny and should therefore be included in future studies modelling this species.

The sessile oak forests observed in this study are divided into three major sectors in the eastern sectors of Montseny and can be subdivided into a total of 182 patches. This very fragmented distribution of rounded and compact stands, with a high degree of discontinuity is probably due to human exploitation of the forest over many centuries. This situation in Montseny means forests are vulnerable to disturbance or other impacts, such as the presence of invasive species and problems driven by climate change which could eventually lead to serious problems for conservation, reducing the extension of sessile oak in the area. We therefore need to increase protection and implement measures to enhance their recovery and conservation.

With regard to their recent development, the sessile oak stands have densified over the past 50 years. The study carried out has revealed that 50% of the forest that already existed has gone from being dispersed to being dense forest. We also detected an expansion in total forest area, with 11% of the current surface being the result of colonisation of adjacent areas. Thus, when human pressure decreases, the oak forests are capable of expanding and densifying. This contrasts with the decline found by Boada in the other deciduous species, namely beech, *Fagus sylvatica*, which indicates that, if the sessile oak stands receive adequate protection, they could well manage to expand in the future. This is a very important finding since, if the beech forests end up being affected negatively by climate change, this may eventually benefit not only the expansion of holm oak, but also the expansion of the neighbouring sessile oak as it makes incursions into areas currently dominated by beech.

5.7 Acknowledgements

We would like to thank the *Parc Natural del Montseny*, for their logistical assistance during the summer of 2015 and the *Diputació de Girona* for their financial assistance in the study of the forests of sessile oak, *Quercus petraea*, in Montseny, which led to the production of the current map of the oak forests used here.

5.8 Disclosure statement

No potential conflict of interest was reported by the authors.

5.9 ORCID

Jordi Bou http://orcid.org/0000-0001-9454-8023

Lluís Vilar http://orcid.org/0000-0002-5035-585X

5.10 References

Ales, R. F., Martin, A., Ortega, F., & Ales, E. E. (1992). Recent changes in landscape structure and function in a mediterranean region of SW Spain (1950–1984). *Landscape Ecology, 7*, 3–18.

Banqué, M., Grau, A., Martínez-vilalta, J., & Vayreda, J. (2013). *CANVIBOSC: Vulnerabilitat de les espècies forestals al canvi climàtic.* Barcelona.

Benito Garzón, M., Sánchez de Dios, R., & Sainz Ollero, H. (2008). Effects of climate change on the distribution of Iberian tree species. *Applied Vegetation Science, 11*(2), 169–178. doi:10.3170/2008-7-18348

Boada, M. (1994). El massís del Montseny. In *Montseny, incerta glòria* (pp. 427–464). Sant Celoni: Plataforma d'Entitats Cíviques del Montseny (PECM).

Boada, M. (2002a). *El Montseny: Cinquanta anys d'evolució dels paisatges*. (CESPA GR, Ed.). Barcelona: Publicacions de l'Abadia de Montserrat.

Boada, M. (2002b, February 26). *Manifestacions del canvi ambiental global al Montseny*. Universitat Autònoma de Barcelona.

Bolòs, O. (1983). *La vegetació del Montseny*. Barcelona: Diputació de Barcelona.

Bou Manobens, J., Àguila, V., & Gordi, J. (2015). L'evolució del paisatge forestal (1950–2013) a l'Alt Empordà. *AIEE, 46*, 343–368. doi:10.2436/20.8010.01.185

Bou Manobens, J., Vilar, L., & Caritat, A. (2015). Estudi de la transició del bosc de Quercus petraea al bosc de Quercus ilex al paratge de Marmolers (Parc Natural del Montseny). *Orsis, 29*, 1–17.

Bou, J., & Vilar, L. (2016). Fitxa InvasIBER de Pseudotsuga menziesii. Retrieved April 13, 2017, from http://invasiber.org

Bou, J., Caritat, A., & Vilar, L. (2015). Litterfall and growth dynamics relationship with the meteorological variability in three forests in the Montseny natural park. *Folia Forestalia Polonica, 57*(3), 146–160. doi:10.1515/ffp-2015-0015

Bou, J., Vilar, L., & Caritat, A. (2015). *Estudi de les rouredes de Quercus petraea al Parc Natural del Montseny*. University of Girona: Girona.

Bou, J., Vilar, L., & Caritat, A. (2016). La roureda de roure de fulla gran. *Revista de Girona, 294*, 62–65.

Broncano, M. J., Vilà, M., & Boada, M. (2005). Evidence of Pseudotsuga menziesii naturalization in montane Mediterranean forests. *Forest Ecology and Management, 211*(3), 257–263. doi:10.1016/j.foreco.2005.02.055

Coordinadora per a la Salvaguarda del Montseny. (2014). Excursió reivindicativa contra la construcció de la carretera Illes - Sant Marça. Retrieved from http://www.salvaguardamontseny.cat

CREAF, & Generalitat de Catalunya. (2009). Mapa de cobertes del sòl de Catalunya. Retrieved from http://www.creaf.uab.es/mcsc/

Czúcz, B., Gálhidy, L., & Mátyás, C. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Annals of Forest Science, 68*(1), 99–108. doi:10.1007/s13595-011-0011-4

Debussche, M., Lepart, J., & Dervieux, A. (1999). Mediterranean landscape changes: Evidence from old postcards. *Global Ecology and Biogeography, 8*(1), 3–15. doi:10.1046/j.1365-2699.1999.00316.x

Diputació de Barcelona. (2008). *Pla especial de protecció del medi natural i del paisatge del Parc Natural de Montseny*. (Oficina Tècnica de Planificació i Anàlisi Territorial de l'Àrea d'Espais Naturals de la Diputació de Barcelona, Ed.). Diputació de Barcelona, Diputació de Girona.

Diputació de Barcelona. (2014). Parc Natural de Montseny. Retrieved from http://parcs.diba.cat/web/montseny

Eaton, E., Caudullo, G., Oliveira, S., & de Rigo, D. (2016). Quercus robur and Quercus petraea in Europe: Distribution, habitat, usage and threats. In J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, & A. Mauri (Eds.), *Quercus robur and Quercus petraea in Europe: Distribution, habitat, usage and threats* (pp. 160–163). Quercus robur and Quercus petraea in Europe: distribution, habitat, usage and threats.

Ecologistes en acció. (2014). Montseny: Concentració contra la construcció de la carretera Illes-Sant Marçal. Retrieved from http://www.ecologistasenaccion.org

Font, X. (2013). Banc de Dades de la Biodiversitat de Catalunya.

García-Ruiz, J. M., Lasanta, T., Ruiz-Flano, P., Ortigosa, L., White, S., González, C., & Martí, C. (1996). Land-use changes and sustainable development in mountain areas: A case study in the Spanish Pyrenees. *Landscape Ecology, 11*(5), 267–277. doi:10.1007/BF02059854

Generalitat de Catalunya. (2017). gencat.cat. Retrieved March 31, 2017, from http://www.gencat.cat/

Gibbs, J. N., & Greig, J. W. (1997). Biotic and abiotic factors affecting the dying back of pedunculate oak Quercus robur L. *Forestry, 70*(4), 399–406. doi:10.1093/forestry/70.4.399

Gordi, J. (2009). *L'Evolució del paisatge forestal a les terres gironines a la segona meitat del segle XX*. Girona: Associació d'Història Rural de les Comarques Gironines.

Hartmann, G., Blank, R., & Lewark, S. (1989). Eichensterben in Norddeutschland—Verbreitung, Schadbilder, mögliche Ursachen. *Forst Und Holz, 44*(18), 475–487.

Illa, J., Font, G., & Arrizabalaga, A. (2011). L'explotació forestal a Arbúcies per la construcció de galeres (s. XVI i XVII). *Monografies Del Montseny, 26*, 74–89.

Institut Cartogràfic i Geològic de Catalunya. (2015). ICGC VISSIR. Retrieved from http://www.icc.cat

Kotroczó, Z., Veres, Z., Fekete, I., Papp, M., & Tóth, J. A. (2012). Effects of Climate Change on Litter Production in a Quercetum petraeae-cerris Forest in Hungary. *Acta Silvatica et Lignaria Hungarica, 8*(1), 31–38. doi:10.2478/v10303-012-0003-6

Llobet, S. (1947). *El Medio y la vida en el Montseny: Estudio geográfico*. Barcelona: CSIC. Instituto Juan Sebastián Elcano.

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., … Gibon, J (2000). Agriculture abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Management, 59*(1), 47–69. doi:10.1006/jema.1999.0335

Martínez-Vilalta, J., Piñol, J., & Beven, K. (2002). A hydraulic model to predict drought-induced mortality in woody plants: An application to climate change in the Mediterranean. *Ecological Modelling, 155*(2–3), 127–147. doi:10.1016/S0304-3800(02)00025-X

Mátyás, C. (2010). Forecasts needed for retreating forests. *Nature, 464*(7293), 1271–1271. doi:10.1038/4641271a

Observatori del Paisatge. (2010). *Comarques Gironines: Catàleg del paisatge*. (J. Nogué i Font, P. Sala i Martí, Departament de Territori i Sostenibilitat, & Observatori del Paisatge, Eds.) (1a ed., Vol. 1). Generalitat de Catalunya.

Oleksyn, J., & Przybyl, K. (1987). Oak decline in the Soviet Union—Scale and hypotheses. *Forest Pathology, 17*(6), 321–336. doi:10.1111/j.1439-0329.1987.tb01325.x

Panadera, J. M., & Nuet, J. (1986). Les Castanyedes al Montseny. *Ausa, 12*(116), 65–78.

Patton, D. R. (1975). A diversity index for quantifying habitat edge. *Wildlife Society Bulletin, 3*, 171–173.

Peñuelas, J., Lloret, F., & Montoya, R. (2001). Severe drought effects on mediterranean woody flora in Spain. *Forest Science, 47*(2), 214–218.

Saniga, M., Balanda, M., Kucbel, S., & Pittner, J. (2014). Four decades of forest succession in the oak-dominated forest reserves in Slovakia. *iForest—Biogeosciences and Forestry, 7*(5), 324–332. doi:10.3832/ifor0996-007

Santos, C. C. P. (2000). Succession of breeding bird communities after the abandonment of agricultural fields in southeast Portugal. *Ardeola, 47*(2), 171–181.

Siwkcki, R., & Ufnalski, K. (1998). Review of oak stand decline with special reference to the role of drought in Poland. *Forest Pathology, 28*(2), 99–112. doi:10.1111/j.1439-0329.1998.tb01171.x

Thomas, F. M., Blank, R., & Hartmann, G. (2002). Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe. *Forest Pathology, 32*(4–5), 277–307. doi:10.1046/j.1439-0329.2002.00291.x

Tusell, J. M. & Beltrán, M. (Eds.). (2016). *XXXIII Jornades Tècniques Silvícoles Emili Garolera*.

Santa Coloma de Farners: Consorci Forestal de Catalunya.

UNEP. (1989). *State of the Mediterranean marine environment*. Athens.

Universitat de Barcelona, Generalitat de Catalunya, & Institut d'Estudis Catalans. (2012). Mapa de vegetació de Catalunya.

Vila, J. (1999). *Anàlisi i valoració dels boscos de les valls d'Hortmoier i Sant Aniol*. Universitat de Barcelona.

Vogelmann, J. (1995). Assessment of Forest Fragmentation in Southern New England Using Remote Sensing and Geographic Information Systems Technology. *Conservation Biology, 9*(2), 439–449.

The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula

Article 3

Bou, J., & Vilar, L. (2019). The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula. Natural Areas Journal 39 (2). Acceptat per a publicació.

6 The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula

Jordi Bou[1]* and Lluís Vilar[1]

* Corresponding author; jordi.bou.manobens@gmail.com

[1] LAGP-Flora and Vegetation. Institute of the Environment. University of Girona. Postal address: C/ Ma. Aurèlia Capmany 69, 17003 GIRONA, Catalonia (Spain) Telephone: 699813514

Natural Areas Journal 39 (2), 2019

6.1 Abstract

While the sessile oak (*Quercus petraea*) may be widely distributed across Europe, it is somewhat rare on the NE Iberian Peninsula, its southern distribution and xeric limit. Understanding the relationship this forest has with not only climate factors but also with past human activity is important. This study aims to analyze the species composition and structure of sessile oak forests that form the xeric limit populations as well as examine the effect environmental factors have on them. The work was focused on the southernmost sessile oak forest, the Montseny Massif populations, which have a marked environmental Mediterranean influence. The sessile oak forest types were defined from field inventories and a cluster analysis classified the inventoried stands into five forest types. The compositional differences among the forest types were the result of past land uses and the intensity of forestry activity 50 y ago. Furthermore, the species composition is influenced by environmental factors, because more hydric stress promotes Mediterranean species. The study concludes that sessile oak are recovering from past forestry activity.

Index terms: community ecology, land use change, Montseny, *Quercus petraea*; xeric limit.

6.2 Introduction

Sessile oak (*Quercus petraea* (Matt.) Liebl.) is widely distributed across Europe and, since ancient times, has been used for many purposes. For instance its wood was used for fuel, the acorns for livestock, the bark for tanning and its timber milled for construction (Eaton et al., 2016). In fact, forest ecosystems are highly exploited (Laurance et al., 2010) and the sessile oak is one of the most economically important deciduous trees in Europe (Praciak et al., 2013). Consequently, such forestry activity in Europe has generated many changes in the forest ecosystems themselves (Parviainen, 2000). For instance, a scarcity of mature forests (Forest Europe, 2015) or the presence of invasive trees coming from plantations (Krumm & Vítková, 2016).

Consequently, the human activity that once took place within these forests and the resulting impact can still influence present-day forest dynamics and structure. In the Mediterranean regions in Europe, the forest was used extensively in traditional agroforestry practices but during the second half of the 20th century these practices were abandoned. As a consequence, meadows and croplands have been replaced by shrub and forest cover (UNEP 1989; Ales et al. 1992; García-Ruiz et al. 1996; Debussche et al. 1999; MacDonald et al. 2000; Santos 2000; Bou Manobens et al. 2015a) and the forest itself has grown much denser (Lasanta-Martinez et al. 2005; Améztegui et al. 2010).

Furthermore, forest dynamics are also susceptible to the effects of climate change which may trigger a loss of genetic diversity (Borovics & Mátyás, 2013), reduce resilience (Huntingford et al., 2013; Tielbörger et al., 2014), cause forest dieback (Allen et al., 2010; Choat et al., 2012) and force species to migrate to higher altitudes (Peñuelas & Boada, 2003) or northward shifts (Lenoir, 2008). Moreover, changes in species composition have also been reported in Europe (Reif et al., 2017). Studies show that vulnerability to climate change is different for each species (Jordi Vayreda, Banqué, et al., 2013). For instance, deciduous forests will experience numerous negative effects, whereas evergreen forests will not suffer quite as much (Aranda and Pardos 2000; Fotelli et al. 2009; Bou et al. 2015a).

An excellent case study of sessile oak forest dynamics can be derived from the xeric limit populations, i.e. the line between life and death for this species. Research should focus on how forest ecosystems respond to extreme environments in order to better understand xeric limit dynamics and shifts (Mátyás, 2010). Sessile oak is at its southernmost xeric limit in the N.E. Iberian Peninsula and grows only in the cooler and moister montane forests in the region: the Pyrenees, the Guilleries, the Montnegre and the Montseny Massif (Bou et al. 2016). With its dry summer months, the Mediterranean climate curtails sessile oak development on the lowlands. The Montseny Massif population lies within this xeric limit area and both human activity and environmental factors have changed the forest over time. The dynamics of the Montseny Massif are quite similar to the remainder of the Mediterranean region, as it too was exploited in earlier centuries. In the Middle Ages timber was milled from the NE Iberian Peninsula oak and used in naval construction (Illa et al. 2011). However, human activity did not stop at simply harvesting the forest, people also converted natural forests into chestnut plantations (Llobet, 1947; Panadera & Nuet, 1986). These and other traditional forest activities were abandoned in the second half of the 20th century (Boada, 2002a). However, in the Guilleries-Montseny region other more modern forest activities saw the abandoned chestnut plantations replaced with stands of Douglas fir (Ribot Porta 2016; Broncano et al. 2005). Against this historical backdrop of human disturbance, and because of concern for the conservation of the natural heritage of the Montseny Massif (Boada, 1994), the Montseny Natural Park was established in 1977 and designated a UNESCO Biosphere Reserve in 1978 (Diputació de Barcelona, 2008). The region's forests are now being affected by climate change in the form of the recent summer droughts, with some species being more vulnerable than others (Jump et al. 2006; Vayreda et al. 2013).

Sessile oak forest dynamics in the xeric limit is an important matter to investigate if the forest is to be conserved. It is to be expected that the forestry activity of the past has had and continues to have a substantial impact on forest dynamics in the N.E. Iberian Peninsula, however, the lack of information about the forest, its dynamics, structure and composition, make it difficult to manage and conserve. Therefore, the aim of the study would be to first characterize the sessile oak forest, and then determine what the current situation in the Montseny Massif (N.E. Iberian Peninsula) really is in order to be able to protect and preserve it.

6.3 Methods

6.3.1 Study Area and Sites

This work focuses on the sessile oak forest of the Montseny Natural Park (Figure 1), which represents the xeric limit of this species on the NE Iberian Peninsula. While there are other populations along the Iberian Peninsula (e.g. the Cantabrian or Pyrenean populations), in Montseny the Mediterranean climate (Panareda, 1979), has a profound influence on the oak population. The sessile oak forests in the Montseny massif cover a mere 64 ha. They are, are dominated by *Q. petraea* distributed into three large groups, and fragmentation of remaining stands is a problem. The sessile oak forest in the Montseny occurs from an altitude of 450 m to 1150 m and is distributed in a narrow strip squeezed between evergreen holm oaks at lower elevations and beech at higher elevations (Bou & Vilar, 2018). Granite substrate is the optimal growing condition for the sessile oak forest (Bolòs, 1983), but it also it can be found growing on porphyric, phyllite and cornubite (Bou & Vilar, 2018).

The climate data from the stands was estimated using specific georeferenced models of the N.E. Iberian Peninsula (Pons 1996; Ninyerola et al. 2000). The mean annual temperature of the study area is 10.76 ºC, with a mean annual minimum temperature of 6.11 ºC and a mean maximum of 15.46 ºC. Annual precipitation ranges from 846.5 to 1022.6 mm.

In the NE Iberian Peninsula there are two controversial subspecies of *Q. petraea*, the more abundant *Q. petraea* subsp. *petraea* and *Q. petraea* subsp. *huguetiana* Franco & G. López. In this study, we consider *Q. petraea* in the broad sense, including both subspecies.

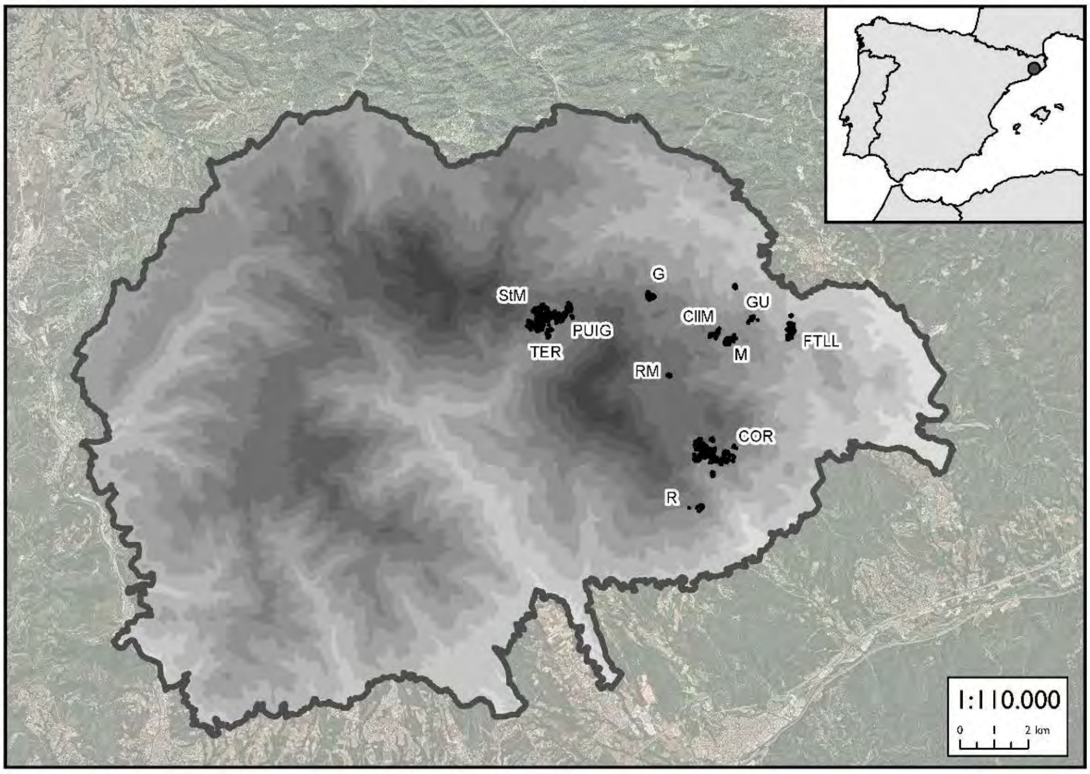

Figure 1. Sessile oak forests in Montseny Natural Park, NE Iberian Peninsula (Bou et al. 2015b). In black all the sessile oak forest cover, with its locality labels (ref code of Table S1).

6.3.2 Stand Structural Attributes

The sessile oak forest was inventoried in a total of 67 plots distributed over the 12 sites in the Montseny massif. Sites were systematically selected to include the main areas of the sessile oak forest habitat. The number of plots was proportional to the sample area, and were randomly placed to analyse the structure of the stands. At each sample location, we established a 10 m radius circular plot, in which we recorded the species name and diameter of all adult trees (individuals with a dbh > 5 cm) at breast height (1.37 m). These data were then used to calculate the forest variables: density (adult trees ha^{-1}), basal area (m^2ha^{-1}), mean and maximum diameter (cm) and mortality of *Q. petraea* (%). In each plot, we used 1 m^2 subplots to inventory *Q. petraea* regeneration, counting the number of individuals less than 1.5 m tall. We used 4 subplots when we had a high density of seedlings or 16 suplots when there was a low density of seedlings. We also noted whether or not the stands had been exploited during the first half of the 20th century. To do this we used an earlier study (Bou & Vilar, 2018), in which sessile oak forest was classified in different vegetation units, based on the recognisable physiognomy in the georeferenced aerial photographs taken by aeroplanes in 1956. The exploited forests of this period were mapped and defined as “Sparse forest” and the not exploited forest as “Dense forest”.

We excluded any recently exploited forests from the inventoried stands, as a result their composition had been substantially altered by the activity. For instance, one locality had a very low density of trees (477.7 stem ha^{-1}) because of forest logging 1-2 years earlier. Another example was in a locality, where there was a highly anomalous composition with planted *Pinus pinaster*, the invasive *Robinia pseudoacacia* and a high density of fast-growing trees like *Populus tremula* (Bou et al. 2015b). The 58 selected samples of sessile oak stands (nota bene: from here on, understood as sessile oak stands in the general sense) are mostly located at altitudes ranging from 549 m to 1178 m a.s.l. (mean 930.35m), with gentle slopes ranging from almost flat to a 30% slope. Aspects varied, but most stands (53.72%) were on south-facing slopes.

6.3.3 **Statistical Analysis**

We classified the 58 inventoried stands (Table S1) into five forest types, selecting at the 55% similarity level. Using basal area data and complete linkage hierarchical cluster analysis with the Bray-Curtis similarity coefficient (the data were square-root transformed prior to analysis) for each species. The basal area of the different tree species was used as an abundance parameter to classify the different types of sessile oak forest depending of their species compositions (Table 1). The basal area is the variable that better represent in this case the abundance, because all the species are well represented, and there aren’t problems with its crowns and stature. To avoid the influence of rare species, we excluded those which were only present in one stand (i.e. *Pyrus malus*, *Abies alba* and *Pseudotsuga menziesii*). Statistical analyses were performed using Primer version 6.1.11 software (Clarke & Gorley, 2006) . The rest of statistical analyses were carried out with the R environment software (R Core Team, 2015).

Among the sessile oak groups obtained from the cluster analysis, the differences in the forest variables (DBH, density, BA, diametric classes, cover, regeneration, richness, and other *Q. petraea* parameters) were analysed using one-way ANOVA. Also to determine the specific differences of forest types, a Tukey's HSD was performed. To detect possible association patterns in species composition and environmental data (meteorological and topographic), we fitted the vectors of the environmental variables into a non-parametric multidimensional scaling (NMDS), and statistical significance was evaluated by 999 random permutations, using the 'envfit' function of the 'vegan' package in R (Oksanen et al., 2016). The environmental data used are: precipitation, solar radiation, altitude, slope aspect, slope and temperature (mean, minimum and maximum). We used all the available variables, because there aren't a lot and 'envfit' can deal with all them.

	Type A		**Type B**		**Type C**		**Type D**		**Type E**	
	n=6		**n=12**		**n=22**		**n=3**		**n=15**	
Species	**Mean**	**error**	**Mean**	**error**	**Mean**	**error**	**Mean**	**error**	**Mean**	**error**
Quercus petraea	22,00	4,19	37,75	8,31	51,54	11,86	40,41	8,19	36,63	8,44
Quercus ilex	1,11	1,87	0,19	0,24	0,36	0,58	2,49	0,46	3,06	2,93
Fagus sylvatica	0,33	0,26	0,04	0,09	0,23	0,52	0,50	0,68	0,63	1,12
Castanea sativa	4,96	5,08	1,37	1,70	0,01	0,03	3,39	2,58	0,08	0,22
Crataegus monogyna	0,00	0,00	0,21	0,67	0,01	0,05	0,04	0,04	0,00	0,00
Acer opalus	1,18	1,71	0,08	0,26	0,46	0,95	3,43	4,84	0,00	0,00
Corylus avellana	0,56	0,87	0,15	0,51	0,11	0,39	0,32	0,42	0,07	0,25
Arbutus unedo	0,00	0,00	0,02	0,08	0,08	0,15	0,00	0,00	0,05	0,18
Ilex aquifolium	0,04	0,10	0,01	0,02	0,11	0,25	0,00	0,00	0,10	0,17
Sorbus aria	0,00	0,00	0,02	0,04	0,03	0,10	0,00	0,00	0,10	0,22
Prunus avium	0,04	0,11	0,00	0,00	0,08	0,29	0,00	0,00	0,30	1,12
Juniperus communis	0,03	0,05	0,03	0,09	0,00	0,00	0,00	0,00	0,10	0,21
Erica arborea	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,00	0,36	1,29
Pyrus malus	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,04	0,00	0,00
Quercus pubescens	0,00	0,00	0,00	0,00	0,00	0,00	1,24	0,67	0,00	0,00
Abies alba	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00
Pseudotsuga menziesii	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00
Fraxinus excelsior	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,04	0,00	0,00
Total	30,25	8,52	39,85	8,76	53,04	12,33	51,87	5,00	41,48	10,09

Table 1. Species composition variables (the basal area) for each forest type obtained with the cluster analysis, and standard error. The number of stands in each type is indicated (n).

6.4 Results

6.4.1 Characterization of Forest Stands

The Montseny sessile oak forest density ranges from 382.2 to 2993.6 stems ha^{-1}, while basal area spans 31.8 to 99.8 $m^2\ ha^{-1}$, and the dominant species, occupying 88.02% of the basal area of these forests, is *Q. petraea*. Stands were classified into five forest types (Figure 2). Forest types A, B and D, correspond to forests with a high basal area of *Castanea sativa* . However, because of the presence of *Quercus pubescens,* Type D is very different from Types A and B and all other groups. Type A stands have a complex multi-layered structure with high basal areas of *Acer opalus*, *Coryllus avellana*, and *Quercus ilex*, while in Type B stands the total basal area of companion species is lower and the basal area of *Q. petraea* correspondingly higher. Types C and E had much less *Castanea sativa*. Type E stands had higher basal area of companion species (e.g. *Quercus ilex* or *Fagus sylvatica*) than Type C stands where *Q. petraea* usually has higher total basal area, but Type C shows a greater richness of companion species. Type C is the largest group, encompassing 40% of the inventoried stands, followed by Types E (26%), B (21%) and A (8%). Type D (5%) occurs on few sites, and most of the stands grow on substrate of phyllite and cornubite.

6.4.2 Forest Parameters

The five forest types exhibit important differences not only in species composition, but also in their structure and dynamics (Figure 3). The forest variables are tested with one-way ANOVA (Table 2). The stands of Types C and D have a significantly higher total basal area than do the other groups. In Type D this is the result of a high density of stems, but in Type C it is a result of a larger mean dbh of the trees. In addition, Type C, along with Type B, are characterized by a dominance of *Q. petraea* with the companion species not presenting any substantial density or basal area. On the other hand, in Type A and E stands, the density and the basal area of *Q. petraea* are lower and the richness of companion species higher. Type A forests have a significantly lower total density and, as a consequence, the basal area is lower as well. In many of the stands, *Quercus ilex* is of minor importance, while in Types D and E the density of the species is significantly higher. As with the basal area, there is a significantly higher density of *Castanea sativa* in Type A, B, and D stands.

Type D stands (followed by Type B) have the highest mortality values for *Q. petraea* (Table S2), likely because the substrate is less optimal for this specie. However, the mortality values among the other groups are similar. There are no significant differences between the groups in terms of height, nor are there any differences in shrub or herbaceous cover (Table S2).

The distribution of the diameter classes (Table 2) in Types A, B and D, indicate young stands. The dominance of small diameter stems in Types B and D is due to the significant lower dbh of *Q. petraea*, but in Type A it results from the high density of *C. avellana*. Types C and E, on the other hand, exhibit a broader range of diameters for *Q. petraea*, with the very large trees being found in Type C.

While there are no large differences in the richness of tree species (Table S2) among the other forest types, Type D stands do possess a considerable wealth of tree species, thanks to the presence of deciduous species. There is no significant differences in shrub richness among the forest types.

Q. petraea regeneration (Table S2) shows a high variability within stands, but there aren't significant differences among the types, though regeneration was slightly higher in Type B stands. The regeneration of *Q. petraea* is higher than of companion species, and there are no significant differences among forest types in the regeneration of companion species. That said, Type E stands do generally exhibit less total regeneration, but this is only marginally significant (p-value=0.05).

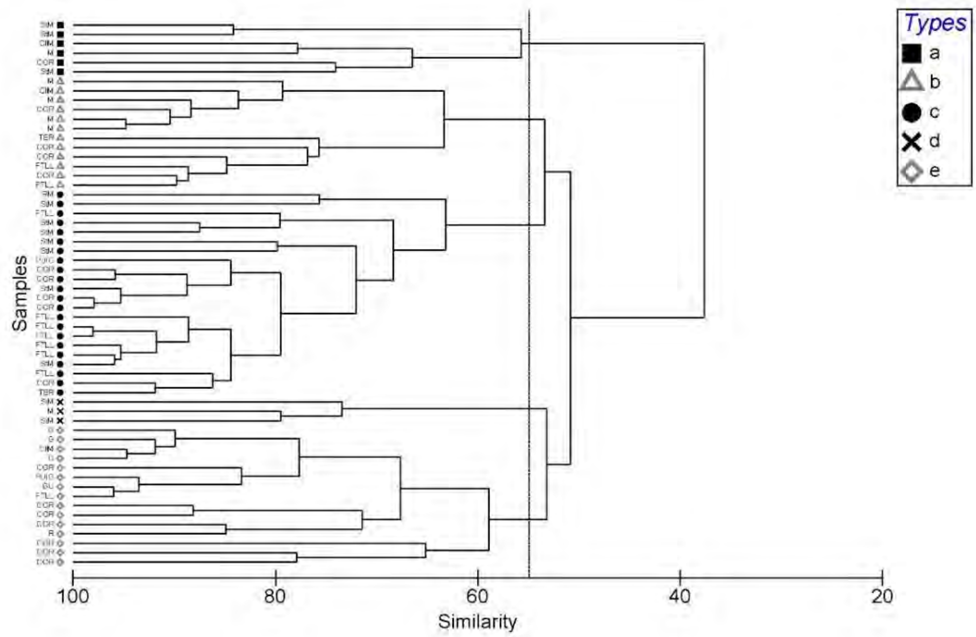

Figure 2.- Hierarchical cluster of the species composition (BA) of the sessile oak stands studied. Different forest types are indicated in the key.

6.4.3 Environmental factors

The species composition shows an environmental gradient (Figure S1), linked to the hydric stress of the plants, since precipitation (p=0.001), solar radiation (p=0.004) and altitude (p=0.001) have the opposite effect to maximum (p=0.001), mean (p=0.001) and minimum (p=0.001) temperatures on the similarities of the compositions. There are not a relationship with slope aspect (p=0.518), and slope (p=0.443). Low hydric stress stands encourage Eurosiberian species such as *Sorbus aria*, *Juniperus communis* and *Corylus avellana*, whereas the Mediterranean species like *Arbustus unedo* and *Quercus ilex* seem to be more commonly found in high hydric stress stands.

Forest variables		DBH (cm)		Density (stem ha^{-1})					BA (m^2 ha^{-1})	Diametric classes (stem ha^{-1})		
		Q. petraea mean	*Q. petraea* max	*Q. petraea*	*Q. ilex*	*C. sativa*	*C. avellana*	Total	BA total	*Q. petraea* 5-25	*Q. petraea* 25 - 45	*Q. petraea* 45 - 105
Type A	mean	26.65	45.74	488.32	63.69	130.04	148.62	942.14	30.25	355.63	122.08	10.62
	SD	(8.0)	(14.9)	(387.3)	(53.3)	(134.5)	(231.1)	(459.8)	(8.5)	(439.6)	(81.6)	(16.4)
Type B	mean	20.57	37.09	1263.27	41.14	72.98	37.15	1491.51	39.85	1052.28	212.31	39.81
	SD	(6.1)	(7.4)	(805.1)	(52.8)	(81.0)	(128.7)	(817.5)	(8.8)	(893.5)	(100.1)	(118.5)
Type C	mean	27.03	51.31	812.70	46.32	6.04	36.19	1034.56	53.04	410.38	357.04	46.68
	SD	(6.9)	(14.7)	(264.8)	(48.9)	(12.5)	(123.7)	(249.9)	(12.3)	(273.6)	(82.1)	(67.8)
Type D	mean	19.12	38.23	1273.89	424.63	116.77	74.31	2186.84	51.87	976.65	297.24	0.00
	SD	(2.6)	(3.2)	(589.8)	(267.1)	(73.5)	(80.1)	(710.2)	(5.0)	(587.5)	(66.3)	(0.0)
Type E	mean	23.15	44.28	911.18	254.78	7.08	27.60	1291.22	41.48	679.76	202.41	29.02
	SD	(8.5)	(11.7)	(447.9)	(200.7)	(24.6)	(90.8)	(422.1)	(10.1)	(526.2)	(115.2)	(33.7)
ANOVA		$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$	$F_{4,53}$
	F	26.89	31.87	41.48	74.63	68.16	1.46	3.97	10.49	21.09	42.96	14.88
	P	<0.05	<0.05	<0.01	<0.001	<0.001	0.23	<0.01	<0.001	0.09	<0.01	0.22
	Sig	*	*	**	***	***		**	***		**	
TukeyHSD		c-b	c-b	a-b, a-c, a-d, a-e	b-d, b-e, c-d, c-e	c-a, e-a, e-b, d-c, d-e		d-a, d-c	c-a, d-a, e-a, c-b, e-c		c-a, e-c	

Table 2. Forest variables for each forest type obtained with the cluster analysis. Standard deviation (SD) indicated in parentheses. The ANOVA results are shown, the significance results are marked in “Sig”. The Tukey’s HSD in the last column compare differences between pairs of forest types, the letters correspond to pair of types with significant results.

6.4.4 Approach to Forest Dynamics

There were clear differences among the forest types in terms of the degree of forestry activity in the first half of the 20th century as mapped by Bou and Vilar (2018) (Table 3). The stands can be classified into those that were sparse forest and those that were dense forest in 1956. The forest types can then be ordered according to their inclusion in these two groups (Figure 4). Type A stands were most heavily exploited followed by Type D. Type E has a similar number of exploited and not exploited stands. Finally, Type C and especially Type B showed little evidence of exploitation.

Vegetation units in 1956	Type A	Type B	Type C	Type D	Type E
Dense forests	0,0%	83,3%	72,7%	33,3%	46,7%
Sparse forests	100,0%	16,7%	27,3%	66,7%	53,3%

Table 3. Percent occurrence of the stands of each forest type to the vegetation units from 1956 (Bou & Vilar, 2018).

6.5 Discussion

Most of the sessile oak forest stands in Montseny show a wide range of diameters for *Q. petraea*, i.e. Types C and E. Thus, there are very a few stands that we can consider as mature forest. This lack of large trees and mature forest in Montseny is a consequence of historical forestry activity (Vicens et al. 2016; Salvat et al. 2016). Type C forests are quite interesting, because in Europe stands tend to lose *Q. petraea* dominance when human activity is abandoned (Eaton et al., 2016; Petritan, Biris, Merce, Turcu, & Petritan, 2012), *Q. petraea* has remained dominant in Montseny for more than 50 years ago. Type E stands, however, have less *Q. petraea*, and show a tendency towards being mixed forests, with *Q. ilex* and *F. sylvatica*.

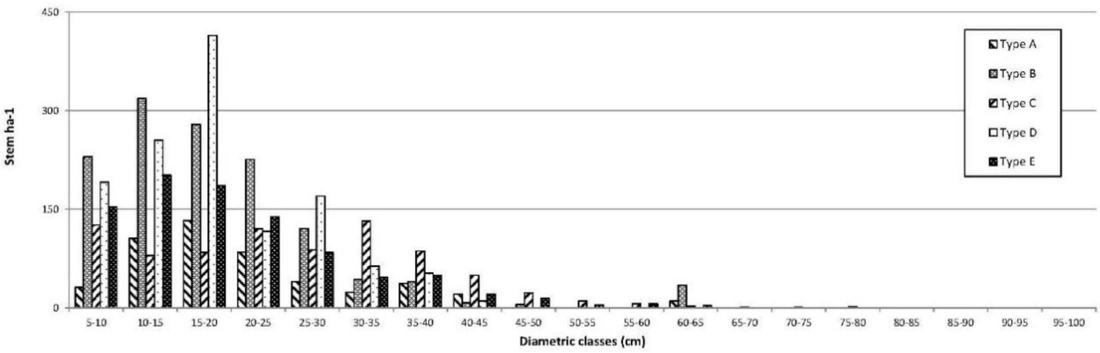

Figure 3. Diametric classes distribution for each forest type, defined by the hierarchical cluster. The Y axis shows the tree *Q. petraea* density (stem ha-1) for each diametric class.

On the other hand, there are some irregular structures (Types A, B and D), where diametric classes tend to be small. In Type A stands, companion species have a high density of low diameter classes, but this is not due to the low-density of *Q. petraea*. This forest type had a lot of agro-forestry activity during the first half of the 20th century, and for this reason has a multi-layered structure with a large abundance of *Corylus avellana*, *A. opalus* and *Q. ile*x. These stands are usually located on old and abandoned agricultural terraces, and have a high density of *C. avellana* in the lower strata and *A. opalus* and *Q. petraea* in the upper strata. Type B stands contain high densities of young trees but in these cases this is due to the high density of *Q. petraea*. The dense structure lead to high levels of competition which can increase the mortality rate (Frelich, 2002), as it happens to *Q. petraea* in some Type B stands.

Understanding forest dynamics is often difficult in places exploited during past eras (Weber, Bugmann, Fonti, & Rigling, 2008) - like the Montseny massif - but our results show that human activity has far-reaching effects on the species composition of several forest groups. Types A and B reveal a great abundance of *C. sativa*, because these areas are former chestnut plantations. For many years, forest management extended this type of plantation at the expense of sessile oak (Llobet, 1947; Panadera & Nuet, 1986). Our results show that the abandoned plantations have been colonized by *Q. petraea* and the sessile oak forest is recovering from this type of human activity.

The density of *Q. petraea* and its companion species in Type A stands has increased over the past 50 years. This process probably began many years ago, when forestry activity in the massif began to be abandoned. Probably abandonment of the forest began earlier in Type B, being dense forests of pioneer species in the 1950s, in that sense, similar to current Type A stands. We assume that the pioneer species of Type A will be replaced by young oaks in the future, converting it to stands similar to Type B today.

Finally, Type D is a prime example of what happens in dry climates like the sub-Mediterranean region. In this case *Q. petraea* tends to mix with *Q. pubescens* and with other drought-tolerant tree species (Eaton et al., 2016). In fact, these two oak species not only compete for water, they sometimes hybridize with each other (Blanco et al., 2005). Most of the stands of Type D were found where the substrate is phyllite and cornubite, being in these cases encountered outside its optimal distribution in Montseny massif (Bou & Vilar, 2018).

There are two contradictory studies of what is happening with the sessile oak forest at Montseny, one of them found a decline of *Q. petraea* (Gómez et al. 2008), but this is probably a consequence of the sample, because they only studied a small area in a Type E forest. On the contrary, there is a similar scale study in Type B forest, that doesn’t shows a sessile oak decline (Bou Manobens et al. 2015). With the current study we analyzed all the sessile oak forest of the Montseny, and we have to conclude that in this population there is not an oak decline, because the forest shows a recovering dynamic from past impacts.

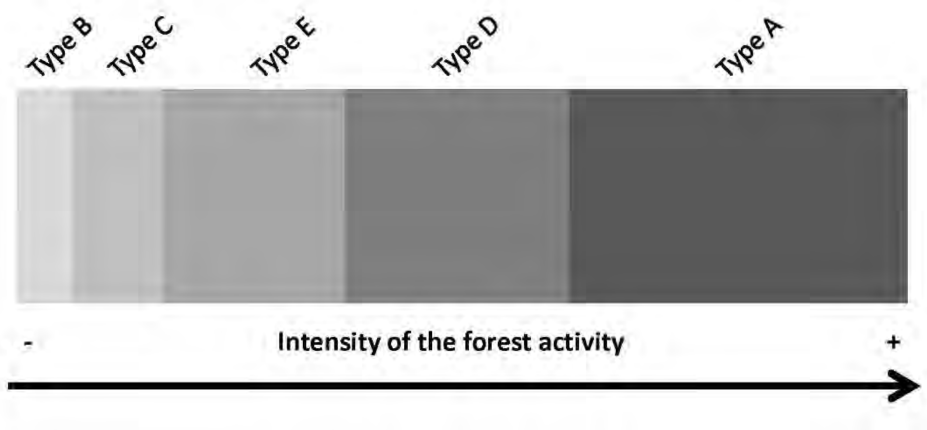

Figure 4. The diagram shows the intensity of the forest exploitation during the first half of the 20th century. To order from least to more degree of intensity, the percent of sparse forest for each forest type has been used.

Generally, the sessile oak forest at Montseny has a similar *Q. petraea* density (921 stems ha^{-1}) to that of the NE Iberian Peninsula (957 stems ha^{-1}), but the basal area is much higher, 41.2 m^2ha^{-1} versus 17.8 m^2ha^{-1} respectively (Terradas et al., 2004), as a result of larger trees in the Montseny forests. Despite a very long history of intensive forestry disturbance, the protection provided by the National Park since 1977, has allowed the forest to recover. It remains important to preserve the Park's sessile oak forest as it acts as a reference for the xeric limit populations. Old-growth sessile oak forests are quite rare in Europe (Saniga et al., 2014), for this reason forest management in Montseny should be focused on conserving mature forests, and promoting diameter-class diversity. Furthermore, some of the logging activities observed should be halted. For example, in el Puig milling was focused only on productivity and not forest sustainability or protection.

Regenerating *Q. petraea* is a problem in some sessile oak forests in Europe (Kotroczó, Krakomperger, Papp, Bowden, & Tóth, 2005; Kotroczó, Veres, Fekete, Papp, & Tóth, 2012), so the high abundance of seedlings found in the xeric limit populations of Montseny are evidence that the forest has a promising future in this extreme locality. Other studies concerning the Iberian Peninsula (Vila-Lameiro & Diaz-Maroto, 2002), note little regeneration in young stands (Types A and B) and a high level of regeneration in older stands (Types C and E). But in our study we did not find these dynamics, because in Montseny the levels of regeneration don not change a function of the forest age.

Sessile oak forest species composition can change as a function of human activity, but environmental factors also influence species abundance. We can separate these factors into climatic and topographic. On the topographic factors, only altitude effected species composition. It is interesting that while slope aspect does not influence forest composition, it is a limiting factor on the distribution of the sessile oak forest in Montseny massif, which predominantly grows on south facing slopes (Bou & Vilar, 2018). In the wetter regions of the Iberian Peninsula the distribution of sessile oak forests is not so distinctly limited by slope aspect (Vila-Lameiro & Diaz-Maroto, 2002). North facing slopes in Montseny are occupied by beech forest. Altitude influences many climatic factors and has direct effect on species composition. Hot, dry stands at low altitude usually include Mediterranean species like *A. unedo* and *Q. ile*x, while cold, wet stands at high altitude have Eurosiberian species such as *S. aria*, *F. sylvatica,* among others. The tolerance of *Q. petraea* for the Mediterranean climate (Blanco et al., 2005), means it is possible to find stands in drier situations in which *Q. ilex* plays an important role in the structure of the forest, and in moister stands where *Q. ilex* is replaced by *F. sylvatica*.

6.6 Conclusions

European countries have reported an extensive decline of their sessile oak forests (Eaton et al., 2016), but the Montseny sessile oak forests depict the opposite dynamic. They are recovering from past human activity and there is an increase of *Q. petraea* dominance in the forest (e.g. Type B). So, land-use changes have had a significant effect on the current dynamics of the sessile oak forest. Interestingly, Type B has more fully recovered from human impact than Type A. In fact we believe that in the future, without forest exploitation, the current Type A stands would be similar to the described Type B stands. This is important to bear in mind because, in the context of climate change and with this population being in the xeric limit, we have to suppose that it will be the first to note the impacts of climate change. However, the effect of land-use change may be masking such impacts. So, if we want to understand the future dynamics of the sessile oak forest, we need to incorporate the effects of land-use changes into future studies. We must not underestimate the physiological adaptations of these xeric limit populations to the drought conditions of the Mediterranean region. More studies are needed to understand these xeric limit populations. For example, work on regeneration dynamics to predict the future seedlings recruitment or Type E forests to study interspecific competition with *Q. ilex* and *F. sylvatica*.

Forest management will be of vital importance if we want to preserve the sessile oak forest. Xeric limit populations should be conserved, as they are better adapted to water stress and are genetically valuable (Mátyás, 2010). We cannot allow the scarce space they currently occupy to be further reduced because there are only 64ha (Bou & Vilar, 2018). This is especially the case for Type C forest, where ceasing all logging activities is recommended, if we want to preserve and protect these big trees and promote mature forests. Type B forests will probably require adaptive management to combat the effects of climate change, as it happens in other forest in Montseny (Sanitjas, 2018), because the high density of these stands is an important vulnerability to summer droughts, which involves the increase of hydric stress and probably mortality.

6.7 Acknowledgments

This work has been partially financed by the Diputació de Girona. We gratefully acknowledge the logistic support from the Montseny Natural Park.

6.8 Biographical sketches

Jordi Bou is a PhD student in the Institute of the Environment, and also an associate professor in the Department of Environmental Science at the University of Girona. <https://orcid.org/0000-0001- 9454-8023>.

Lluís Vilar is a researcher in the Institute of the Environment, and also a senior professor in the Department of Environmental Science at the University of Girona. <https://orcid.org/0000-0002-5035-585X>.

6.9 Literature cited

Ales, R.F., A. Martin, F. Ortega, and E.E. Ales. 1992. Recent changes in landscape structure and function in a mediterranean region of SW Spain (1950–1984). Landscape Ecology 7: 3–18.

Allen, C.D., A.K. Macalady, H. Chenchouni, D. Bachelet, N. McDowell, M. Vennetier, T. Kitzberger, A. Rigling, D. D. Breshears, E.H. Hogg, P. Gonzalez, R. Fensham, Z. Zhang, J. Castro, N. Demidova, J.H. Lim, G. Allard, S.W. Running, A. Semerci, and N. Cobb. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management 259 (4): 660–84. doi:10.1016/j.foreco.2009.09.001.

Améztegui, A., Ll. Brotons, and Ll. Coll. 2010. Land-Use Changes as Major Drivers of Mountain Pine (Pinus Uncinata Ram.) Expansion in the Pyrenees. Global Ecology and Biogeography 19 (5): 632–41. doi:10.1111/j.1466-8238.2010.00550.x.

Aranda, I., L. Gil, and J.A. Pardos. 2000. Water relations and gas exchange in *Fagus sylvatica* L. and *Quercus petraea* (Mattuschka) Liebl. in a mixed stand at their southern limit of distribution in Europe. Trees 14 (6): 344–52. doi:10.1007/s004680050229.

Blanco, E., M. Ángel, M. Costa, R. Ecribano, M. García, M. Génova, Á. Gómez, F. Gómez, J.C. Moreno, C. Morla, P. Regato, H. Sainz. 2005. Los bosques ibéricos : una interpretación geobotánica. Editorial Planeta, Barcelona.

Boada, M. 1994. El massís del Montseny. Pp. 427–640 in Montseny, incerta glòria. Plataforma d'Entitats Cíviques del Montseny (PECM), Sant Celoni.

Boada, M. 2002a. El Montseny: cinquanta anys d'evolució dels paisatges. Publicacions de l'Abadia de Montserrat, Barcelona.

Boada, M. 2002b. Manifestacions del canvi ambiental global al Montseny. Universitat Autònoma de Barcelona, Barcelona.

Bolòs, O. 1983. La vegetació del Montseny. Diputació de Barcelona, Barcelona.

Borovics, A., and C. Mátyás. 2013. Decline of genetic diversity of sessile oak at the retracting (xeric) limits. Annals of Forest Science 70 (8): 835–44. doi:10.1007/s13595-013-0324-6.

Bou, J., A. Caritat, and Ll. Vilar. 2015a. Litterfall and growth dynamics relationship with the meteorological variability in three forests in the Montseny Natural Park. Folia Forestalia Polonica 57 (3): 146–60. doi:10.1515/ffp-2015-0015.

Bou, J., and Ll. Vilar. 2018. Current Distribution and Recent Development of Sessile Oak Forests in Montseny (1956-2015). Landscape Research. doi: 10.1080/01426397.2018.1472751

Bou, J., Ll. Vilar, and A. Caritat. 2015b. Estudi de les rouredes de *Quercus petraea* al Parc Natural del Montseny. Universitat de Girona, Girona.

Bou, J., Ll. Vilar, and A. Caritat. 2016. La roureda de roure de fulla gran. Revista de Girona 294: 62-65.

Bou Manobens, J., V. Àguila, and J. Gordi. 2015a. L'evolució del paisatge forestal (1950-2013) a l'Alt Empordà. AIEE 46: 343–68. doi:10.2436/20.8010.01.185.

Bou Manobens, J., Ll. Vilar, and A. Caritat. 2015b. Estudi de la transició del bosc de *Quercus petraea* al bosc de *Quercus ilex* al paratge de Marmolers (Parc Natural del Montseny). Orsis 29: 1–17. doi:https://doi.org/10.5565/rev/orsis.14.

Broncano, M.J., M. Vilà, and M. Boada. 2005. Evidence of *Pseudotsuga menziesii* Naturalization in Montane Mediterranean Forests. Forest Ecology and Management 211 (3): 257–63. doi:10.1016/j.foreco.2005.02.055.

Choat, B., S. Jansen, T. J. Brodribb, H. Cochard, S. Delzon, R. Bhaskar, S.J Bucci, T.S. Feild, S. Gleason, U.G. Hacke, A.L. Jacobsen, F. Lens, H. Maherali, J. Martínez-Vilalta, S. Mayr, M. Mencuccini, P.J. Mitchell, A. Nardini, J. Pittermann, R.B. Pratt, J.S. Sperry, M. Westoby, I.J. Wright, A.E. Zanne. 2012. Global convergence in the vulnerability of forests to drought. Nature 491 (7426): 752–55. doi:10.1038/nature11688.

Clarke, K.R., and R.N. Gorley. 2006. PRIMER v6: User manual/tutorial. PRIMER-E, Plymouth.

Debussche, M., J. Lepart, and A. Dervieux. 1999. Mediterranean landscape changes: evidence from old postcards. Global Ecology and Biogeography 8 (1): 3–15. doi:10.1046/j.1365-2699.1999.00316.x.

Diputació de Barcelona. 2008. Pla Especial de protecció del medi natural i del paisatge del Parc Natural de Montseny. Oficina Tècnica de Planificació i Anàlisi Territorial de l'Àrea d'Espais Naturals de la Diputació de Barcelona, Barcelona.

Eaton, E., G. Caudullo, S. Oliveira, and D. de Rigo. 2016. *Quercus robur* and *Quercus petraea* in Europe: distribution, habitat, usage and threats. Pp. 160–163 in J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, and A. Mauri, ed., European atlas of forest tree species. Publication Office European Union, Luxembourg.

Forest Europe. 2015. State of Europe's Forests 2015. Forest Europe, Madrid.

Fotelli, M.N., M. Nahm, K. Radoglou, H. Rennenberg, G. Halyvopoulos, and A. Matzarakis. 2009. Seasonal and interannual ecophysiological responses of beech (*Fagus sylvatica*) at its south-eastern distribution limit in Europe. Forest Ecology and Management 257 (3): 1157–64. doi:10.1016/j.foreco.2008.11.026.

Frelich, L. 2002. Forest Dynamics and Disturbance Regimes: Studies from Evergreen-Deciduous Forests. Cambridge University Press, Cambridge.

Gaertig, T., H. Schack-Kirchner, E.E. Hildebrand, and K.V. Wilpert. 2002. The impact of soil aeration on oak decline in southwestern Germany. Forest Ecology and Management 159 (1–2): 15–25. doi:10.1016/S0378-1127(01)00706-X.

García-Ruiz, J.M., T. Lasanta, P. Ruiz-Flano, L. Ortigosa, S. White, C.González, and C. Martí. 1996. Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. Landscape Ecology 11 (5): 267–77. doi:10.1007/BF02059854.

Gómez, J.F., M. Boada, and S. Sànchez. 2008. Análisis de los procesos de cambio global: el caso del robledal de Ridaura (Parque Natural del Montseny. Barcelona). Boletín de la A.G.E. 47: 125–42.

Helama, S., A. Läänelaid, J. Raisio, and H. Tuomenvirta. 2009. Oak decline in Helsinki portrayed by tree-rings, climate and soil data. Plant and Soil 319 (1–2): 163–74. doi:10.1007/s11104-008-9858-z.

Huntingford, C., P. Zelazowski, D. Galbraith, L. M. Mercado, S. Sitch, R. Fisher, M. Lomas, et al. 2013. Simulated resilience of tropical rainforests to CO_2-induced climate Change. Nature Geoscience 6 (4): 268–73. doi:10.1038/ngeo1741.

Illa, J., G. Font, and A. Arrizabalaga. 2011. L'explotació forestal a Arbúcies per la construcció de galeres (S. XVI I XVII). Monografies del Montseny 26: 74–89.

Jump, A.S., J.M. Hunt, and J. Peñuelas. 2006. Rapid climate change-related growth decline at the southern range edge of *Fagus sylvatica*. Global Change Biology 12 (11): 2163–74. doi:10.1111/j.1365-2486.2006.01250.x.

Kotroczó, Z., Z. Krakomperger, M. Papp, R.D. Bowden, and J. Tóth. 2005. Thirty-one years of change in vegetation composition of a central European oak forest at the Sikfokut ILTER. 90th ESA Annual Meeting. Montréal: Ecological Society of America.

Kotroczó, Z., Z. Veres, I. Fekete, M. Papp, and J.A.Tóth. 2012. Effects of climate change on litter production in a *Quercetum petraeae-cerris* forest in Hungary. Acta Silvatica et Lignaria Hungarica 8 (1): 31–38. doi:10.2478/v10303-012-0003-6.

Krum, F., L. Vítková (ed.). 2016. Introduced tree species in European forests: opportunities and challenges. European Forest Institute.

Lasanta-Martinez, T., S.M. Vicente-Serrano, and J.M. Cuadrat-Prats. 2005. Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: A Study of the Spanish central Pyrenees. Applied Geography 25 (1): 47–65. doi:http://dx.doi.org/10.1016/j.apgeog.2004.11.001.

Laurance, W.F., I.G. Warkentin, B.S. Halpern, C.V. Kappel, F. Micheli, K.A. Selkoe, 2010 Habitat destruction: Death by a thousand cutsin N.S. Sodhi and P.R. Ehrlich, ed., Conservation Biology for All. Oxford University Press, Oxford.

Lenoir, J. 2008. A significant upward shift in plant species. Science 320: 1768–1772.

Llobet, S. 1947. El medio y la vida en el Montseny : estudio geográfico. Instituto Juan Sebastián Elcano-CSIC, Barcelona.

MacDonald, D, J.R. Crabtree, G. Wiesinger, T. Dax, N. Stamou, P. Fleury, J. Gutierrex Lazpita, and A. Gibon. 2000. Agriculture Abandonment in mountain areas of Europe: environmental consequences and policy response. Journal of Environmental Management 59 (1): 47–69. doi:http://dx.doi.org/10.1006/jema.1999.0335.

Mátyás, C. 2010. Forecasts needed for retreating forests. Nature 464 (7293): 1271–1271. doi:10.1038/4641271a.

Ninyerola, M., X. Pons, and J.M. Roure. 2000. A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. International Journal of Climatology 20: 1823–41.

Oksanen, J., F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, et al. 2016. Vegan: community ecology package. R Package Version 2.4-1. https://cran.r-project.org/package=vegan.

Panadera, J. M., and J. Nuet. 1986. Les castanyedes Al Montseny. Ausa 12 (116): 65–78.

Panareda, J.M. 1979. Aportació a l'estudi del clima del Montseny. Acta Geológica Hispánica 14: 524–28.

Parviainen, J. 2000. Strict forest reserves in Europe: efforts to enhance biodiversity and research on forests left for free development in Europe (EU-COST-Action E4). Forestry 73 (2):107-118.

Penuelas, J., and M. Boada. 2003. A global change-induced biome shift in the Montseny mountains (NE Spain). Global Change Biology 9 (2): 131–40. doi:10.1046/j.1365-2486.2003.00566.x.

Petritan, A.M., I.A. Biris, O. Merce, D.O. Turcu, and I.C. Petritan. 2012. Structure and diversity of a natural temperate sessile oak (*Quercus petraea* L.) – European beech (*Fagus sylvatica* L.) forest." Forest Ecology and Management 280 (September). Elsevier B.V.: 140–49. doi:10.1016/j.foreco.2012.06.007.

Pons, X. 1996. Estimación de la radiación solar a partir de modelos digitales de elevaciones. propuesta metodológica. In VII Coloquio de Geografía Cuantitativa, Sistemas de Información Geográfica Y Teledetección, edited by J. Juaristi and I. Moro. Vitoria-Gasteiz.

Praciak, A., N. Pasiecznik, D. Sheil, M. Heist, M. Sassen, C. Sousa Correia, C. Dixon, G. Fyson, K. Rushforth and C. Teeling. 2013. The CABI Encyclopedia of Forest Trees. CABI. doi: citeulike-article-id:13496407.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Austria, Vienna. https://www.r-project.org/.

Reif, A., F. Xystrakis, S. Gärtner and U. Sayer. 2017. Floristic change at the drought limit of European beech (*Fagus sylvatica* L.) to downy oak (*Quercus pubescens*) forest in the temperate climate of central Europe. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 45: 646–654.

Ribot Porta, E.. 2016. Les reforestacions amb avet douglas i la seva gestió com alternativa a les masses de castanyer. XXXIII Jornades Tècniques Silvícoles Emili Garolera, Arbúcies.

Salvat, A., L. Sàez, E. Llop, and D. Guinart. 2016. Establiment D'indicadors I Valoració Botànica Dels Boscos Madurs Del Montseny. In IX Trobada d'Estudiosos Del Montseny, edited by Diputació de Barcelona, Diputació de Girona, and Ajuntament de la Garriga. Diputació de Barcelona.

Saniga, M., M. Balanda, S. Kucbel, and J. Pittner. 2014. Four decades of forest succession in the oak-dominated forest reserves in Slovakia. iForest - Biogeosciences and Forestry 7 (5): 324–32. doi:10.3832/ifor0996-007.

Sanitjas, A. 2018. La gestió dels boscos vells al Parc Natural del Montseny. Experiències en els hàbitats forestals madurs mediterranis, Poblet.

Santos, C.P. 2000. Succession of breeding bird communities after the abandonment of agricultural fields in southeast Portugal. Ardeola 47 (2): 171–81.

Terradas, J., J.J. Ibàñez, J. Vayreda, J.M. Espelta, A. Àvila, and C. Gracia. 2004. Els boscos de catalunya estructura, dinàmica i funcionament. Generalitat de Catalunya, Barcelona.

Tielbörger, K., M.C. Bilton, J. Metz, J. Kigel, C. Holzapfel, E. Lebrija-Trejos, I. Konsens, H.A. Parag, and M. Sternberg. 2014. Middle-eastern plant communities tolerate 9 years of drought in a multi-site climate manipulation experiment. Nature Communications 5 (October): 5102. doi:10.1038/ncomms6102.

UNEP. 1989. State of the Mediterranean Marine Environment. Athens.

Vayreda, J., J. Martínez-Vilalta, and M. Banqué. 2013. Els boscos davant del canvi climàtic. CREAF-Oficina Catalana del Canvi Climàtic- Generalitat de Catalunya, Barcelona.

Vicens, N., A. Sanitjas, and M. Barrachina. 2016. Estudi i seguiment de boscos vells al Parc Natural i Reserva de la Biosfera del Montseny." In IX Trobada d'Estudiosos Del Montseny, edited by Diputació de Barcelona, Diputació de Girona, and Ajuntament de la Garriga. Diputació de Barcelona.

Vila-Lameiro, P, and I.J. Diaz-Maroto. 2002. Las masas actuales de *Quercus petraea* en Galicia. Forest Systems 11 (1): 5–28.

Weber, P., H. Bugmann, P. Fonti, and A. Rigling. 2008. Using a retrospective dynamic competition index to reconstruct forest succession. Forest Ecology and Management 254 (1): 96–106. doi:10.1016/j.foreco.2007.07.031.

7 Discussió general

7.1 Efectes del canvi global a la comunitat florística de la roureda de roure de fulla gran al NE de la Península Ibèrica

Les rouredes de roure de fulla gran han perdut diversitat des del segle passat, tant als Pirineus com a la Serralada Litoral i Prelitoral, tret de la Vall d'Aran on la riquesa s'ha incrementat. On s'observa més clarament una dinàmica de pèrdua de biodiversitat és a la Serralada Litoral, ja que no només es perd diversitat d'espècies, sinó que també es perd riquesa. Pel que fa a la composició d'espècies, també s'han detectat molts canvis (Figura 7.1), a l'igual que en altres rouredes a Europa (Reczyńska & Świerkosz, 2016), segurament a causa de la pèrdua d'espècies als territoris meridionals i el guany de noves als septentrionals. Per contra als Prepirineus no s'han vist aquests canvis en la composició d'espècies. Tot aquest seguit de diferències en les dinàmiques vegetals entre les regions, són degudes a que més enllà de ser àrees geogràfiques amb variades condicions meteorològiques, són boscos amb petites diferències en la composició florística. Així, al sud apareixen espècies mediterrànies com *Erica arborea* o *Arbutus unedo*, mentre que al nord no hi són presents. No obstant, en aquest darrer cas hi podem trobar espècies pròpies de localitats més pirinenques, com es el cas de *Vaccinium myrtillus* o *Ranunculus montanus*.

Aquestes rouredes són boscos dominats principalment per macrofaneròfits caducifolis amb la dominància de *Quercus petraea*, i la presència d'altres arbres acompanyants com *Corylus avellana*, *Castanea sativa*, *Acer campester* i *Fraxinus excelsior*. Per altra banda, l'estrat herbaci és molt ric, degut a la seva relativa lluminositat, amb espècies d'hemicriptòfits com *Brachypodium sylvaticum, Campanula persiciflolia*, *Festuca ovina, Festuca heterophylla*, *Hieracium murorum*, etc. Però els canvis en els usos del bosc han fet que en la majoria de subregions analitzades, es produeixi un increment de l'abundància relativa de les formes vitals de macrofaneròfits caducifolis i un descens de de l'abundància relativa de hemicriptòfits. Però no només hem observat que hi hagi més coberta arbòria, si no que en el cas de la Serralada Litoral i Prelitoral, s'observa també un augment de la riquesa d'espècies arbòries caducifòlies. Aquests canvis estan estretament relacionats amb la disminució de l'activitat forestal des de mitjans del s. XX (Gordi, 2009), quan es passa d'un grau d'explotació molt elevada a una explotació baixa. Per això aquests boscos eren descrits abans com masses forestals obertes amb "llur relativa lluminositat" per Bolòs (1983). Actualment, per bé que encara mantenen un gran abundància d'hemicriptòfits, l'abandonament del bosc ha iniciat una densificació que ha acabat reduint les condicions òptimes per les espècies que tenen aquesta forma vital. Seguint aquesta dinàmica a la Serralada Prelitoral també ha augmentat la riquesa relativa de macrofaneròfits perennifolis, i a la

Serralada Litoral l'augment d'ombra ha generat un increment en la riquesa relativa de falgueres. Tanmateix aquestes dinàmiques semblen no haver-se produït al nord-oest, als Pirineus i Prepirineus centrals, on no hi ha canvis en l'estrat arbori, i per això tampoc es produeixen canvis en l'estrat herbaci. Segurament es tracta de boscos més ben conservats, en comparació a les rouredes orientals.

Per altra banda, el canvi en l'activitat forestal ha anat lligat a l'ús de diferents espècies introduïdes i naturalitzades per a finalitats principalment productives. Així els inventaris històrics mostren la presència de *Castanea sativa*, arbre amb una llarga història relacionada amb la substitució de rouredes de roure de fulla gran per plantacions de castanyer a l'estatge montà humit (Llobet, 1947; Panadera & Nuet, 1986). Però actualment han aparegut noves espècies al·lòctones a les rouredes, com es *Picea abies* a la Vall de Ribes o *Buddleja davidii* a la Vall d'Aran. També s'ha observat la presència de l'avet de Douglas (*Pseudotsuga menziesii*) al Montseny, una conífera invasora que creix tant al massís com a àrees pròximes de les Guilleries (Broncano et al., 2005). Sent així les espècies introduïdes una nova problemàtica a considerar a les rouredes de roure de fulla gran.

Però en la interpretació de com ha evolucionat la roureda de fulla gran no només s'ha de considerar el canvi en els usos del bosc, sinó també cal tenir en compte el canvi climàtic i l'escalfament global. En general es tracta de boscos dominats per espècies eurosiberianes, pròpies de la vegetació de l'estatge montà humit al NE de la Península Ibèrica (Andrés & Font, 2011), mentre que les plantes atlàntiques hi tenen una representació menor, just el contrari del que passa al NO de la Península Ibèrica, on aquests tàxons hi guanyen importància (Díaz-Maroto & Vila-

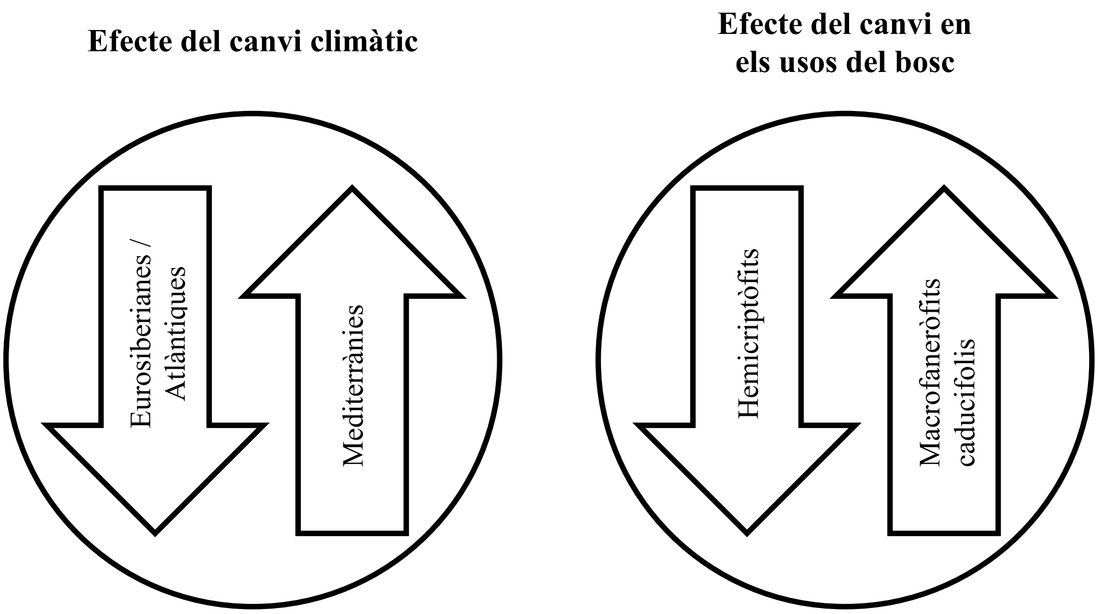

Figura 7.1.- Esquema gràfic dels efectes del canvi global a les rouredes de roure de fulla gran al NE de la Península Ibèrica.

Lameiro, 2007). En el cas de les rouredes de roure de fulla gran de la Serralada Litoral, s'ha detectat un increment de la riquesa relativa de les espècies mediterrànies i una aparent tendència a la disminució de la riquesa relativa d'eurosiberianes. Aquests procés ha estat descrit com la termofilització, ja que l'escalfament global promou unes condicions d'estrès hídric que afavoreixen les espècies més ben adaptades a les noves condicions per davant de les més sensibles (Reif et al., 2017). En el cas del NE de la Península Ibèrica les plantes més tolerants són les mediterrànies, que es troben més ben adaptades als estius secs i desplacen a altres espècies sensibles a la sequera com les eurosiberianes. Aquest procés ja s'ha vist en estudis en boscos caducifolis a la Serralada Prelitoral (Peñuelas & Boada, 2003) i s'ha descrit com a mediterranització. Així doncs a la Serralada Litoral, on la temperatura és més elevada que en les altres localitats, és esperable trobar aquesta dinàmica en una comunitat eurosiberiana com l'estudiada en aquesta tesi.

A la Vall de Ribes, tot i seguir aquesta mateixa dinàmica, el grau d'intensitat és menor i hi ha una pèrdua d'abundància relativa de les espècies atlàntiques mentre que per contra hi ha un increment de la riquesa relativa de plantes pluriregionals. Seria segurament aquesta dinàmica un primer pas cap a l'aparició de plantes mediterrànies, que de moment encara no són presents als Pirineus orientals, a la subregió de la Vall de Ribes. Per contra en la Serralada Prelitoral, ja situada clarament al *xeric limit*, la termofilització no ha estat observada, ja que trobem un increment de l'abundància relativa de les espècies eurosiberianes que es considerarien sensibles a l'escalfament global; tanmateix hi disminueix l'abundància relativa de les espècies atlàntiques que serien considerades sensibles a la termofilització. Així doncs en aquest cas de la Serralada Prelitoral veiem com la comunitat guanya en espècies típiques de la roureda de roure de fulla gran i aquesta evolució indicaria un clar símptoma de recuperació de la roureda un cop cessa l'antiga activitat que hauria alterat la comunitat vegetal. Aquest fet és especialment destacable ja que s'ha produït en el context desfavorable de ser una àrea en el *xeric límit*, d'elevat impacte del canvi climàtic. Aquesta recuperació podria emmascarar l'efecte del canvi climàtic en aquests boscos, i requereix una atenció especial per tal de poder comprendre adequadament les dinàmiques d'aquests boscos a la Serralada Prelitoral. En el cas de les rouredes nord-occidentals dels Pirineus, s'observa una major estabilitat i menys canvis, i destaquem una tendència a l'augment d'abundància relativa d'espècies eurosiberianes al Pallars Sobirà. S'ha de destacar, que les rouredes pirinenques abans no tenien presència de cap espècie mediterrània i actualment n'hi han algunes com *Quercus ilex* o *Rubia peregrina*, tot i que amb escàs recobriment. Aquesta situació fa pensar que en un futur, si l'efecte del canvi climàtic és prou intens, aquestes plantes mediterrànies podrien augmentar la seva abundància i distribució.

7.2 Les rouredes de roure de fulla gran al *xeric limit*, el cas del Montseny

Donada la situació geogràfica del massís del Montseny, que se situa clarament al límit de distribució de la roureda de roure de fulla gran, els canvis del bosc són especialment interessants per observar la seva recuperació un cop disminueix, o fins i tot cessa del tot, l'activitat forestal secular. Per entendre com han evolucionat aquests boscos en els últims 50 o 60 anys, primer cal observar com són en l'actualitat. Principalment es localitzen a la part est del Montseny, de clima més humit que l'oest (Bolòs, 1983), en substrats principalment granítics, com la granodiorita, que acaben donant substrats saulonosos i sorrencs. Tot i així la majoria de rouredes creixen en llocs aparentment rocosos, segurament perquè són els únics indrets no conreats mai i a on sempre va quedar alguna resta de bosc, ni tampoc eren molt útils per l'explotació forestal. A nivell altitudinal té un rang molt estret, entre l'estatge de l'alzinar i el de la fageda, tot i que realment algunes rouredes comparteixen el mateix nivell altitudinal que la fageda. La diferència és que les rouredes de roure de fulla gran creixen en vessants sud del massís, mentre que en el vessant nord hi trobem fagedes. Aquesta diferenciació de vessants, és clau per comprendre la distribució d'aquests boscos, ja que el roure aprofita els vessants desfavorables per la fageda al Montseny, tot i que a la resta de Catalunya és més habitual trobar les rouredes amb orientacions de component nord. La superfície que ocupen aquests boscos és només de 64.08 ha en tot el massís, és a dir només un 0.24% de la superfície forestal d'un espai principalment forestal, on a més s'hi afegeix que gran part d'aquesta superfície són fragments de bosc no continus entre ells. En la majoria de casos es tracta de rouredes dominades per *Q. petraea*, amb una densitat de 921 peus ha^{-1} tot i que algunes tenen una mica més d'abundància de *Q. ilex* i *F. sylvatica*, atès que són rodals més pròxims a les zones de transició. De fet les espècies acompanyants van canviant en funció de l'altitud, ja que representa un gradient de precipitacions i temperatura, que fa que a baixa altitud es trobin arbres mediterranis i a elevada altitud arbres eurosiberians.

És conegut que les rouredes de roure de fulla gran del Montseny han estat explotades de molt antic, ja que durant l'edat mitjana s'utilitzava la seva fusta per a la creació d'embarcacions (Illa, Font, & Arrizabalaga, 2011). Com a conseqüència de l'activitat secular, al Montseny només hi ha una única roureda madura, la Roureda de Maçaners. La resta de boscos o són joves o d'estructura intermèdia, i com a molt en aquest segon cas s'hi poden trobar rodals amb característiques de maduresa, com alguns rodals a la zona més alta de Fontdellops. Tot i així l'àrea basal de *Q. petraea* a les rouredes del Montseny (41.2 m^2 ha^{-1}) és més gran que al NE de la Península Ibèrica (17.8 m^2ha^{-1}), tot i tenir densitats similars (Terradas et al., 2004); és a dir que al Montseny els roures serien de classes diamètriques més grans que a la resta de territori. Alhora que hi havia aquesta explotació secular es van anar transformant les cobertes forestals en funció dels interessos productius, com va ser la substitució de moltes rouredes per plantacions de castanyer (Panadera

& Nuet, 1986). Tot això fa que ni la superfície actual ni la de fa 50 anys sigui la que haurien tingut antigament les rouredes en el massís, essent així sempre necessari considerar que aquests boscos d'antic haurien tingut una distribució més amplia que no pas l'estreta franja actual entre l'alzinar i la fageda.

Malgrat que no es poden quantificar aquests canvis, si que podem analitzar amb precisió els que s'han produït més recentment des de l'última meitat de s. XX. Així els resultats obtinguts mostren com la major part de l'actual roureda de roure de fulla gran al Montseny ja era bosc fa 60 anys. Però només la meitat eren boscos densos, i aproximadament l'altra meitat era bosc dispers obert. Aquestes estructures disperses de meitats del s. XX haurien estat conseqüència del seu aprofitament forestal, tant per fusta com per combustible, tal com evidencien algunes carboneres trobades a Marmolers (Riells i Viabrea). Per altra banda també s'havia explotat el sotabosc per a pastura, com es el cas de Can Corbera (Fogars de Montclús), a prop de Can Figueroles, on encara ara hi han les restes del tancat pel bestiar. Però al davallar l'activitat al bosc, l'estructura forestal de les rouredes es va anar densificant fins a l'estat actual. De fet actualment s'ha catalogat un tipus de roureda amb una elevada densitat d'arbres pioners i de creixement ràpid, que en la seva totalitat correspondrien a rodals que antigament eren dispersos, mentre que les rouredes que antigament eren denses, no mostren gaire espècies acompanyants i si una gran densitat de roures joves. Pensem, doncs, que aquests boscos antigament densos, entorn de l'any 1950 haurien presentat una composició i estructura similar al tipus de bosc amb arbres pioners i de creixement ràpid, que hauria passat per un procés de substitució de les espècies acompanyants, que ha donat lloc a una gran densitat de *Q. petraea* (Figura 7.2). Aquesta dinàmica forestal de densificació del bosc durant els últims 60 anys és la prova de que la roureda de roure de fulla gran té una important capacitat de recuperació dels impactes antròpics, ocupant el seu rol en aquests boscos i no cedint davant d'altres espècies amb les que competeix que fins i tot són més resistents a les condicions d'escalfament global en que es troben aquests boscos.

A més un 11% de les rouredes actuals es troben en llocs que fa 60 anys eren espais oberts, matollars o llocs rocosos. En aquesta segona dinàmica, observada en l'anàlisi diacrònic, és molt interessant l'expansió del bosc, ja no només per la seva recuperació de l'impacte sinó també colonitzant espais potencials, el que fa augmentar lleugerament la seva superfície. La expansió del bosc ha fet que la fragmentació que actualment observem sigui menor de la que hi havia el 1956, ja que s'han fusionat diferents fragments de bosc, obtenint formes més compactes i resistents als impactes. Fins i tot semblaria que en algun cas la roureda ha anat colonitzat alguna antiga castanyeda, que hauria estat abandonada abans de meitats de s. XX, ja que en alguns casos es troba *C. sativa* amb força abundància dins de les rouredes. Així, doncs, l'expansió d'aquests boscos segueix la mateixa dinàmica que els d'altres territoris molt forestals com l'Alta Garrotxa

(Vila, 1999). Al Montseny l'alzina també ha tingut un augment de superfície (20.14%) entre el 1945 i el 1995 però, en canvi, el faig hauria reduït la seva superfície en un −17.94% (Boada, 2002b). Vist doncs amb perspectiva, les condicions del Montseny semblarien força favorables pel roure de fulla gran, ja que no estaria en la mateixa situació de l'altre espècie caducifòlia dominant, i no estaria tan allunyat de la dinàmica de l'alzina.

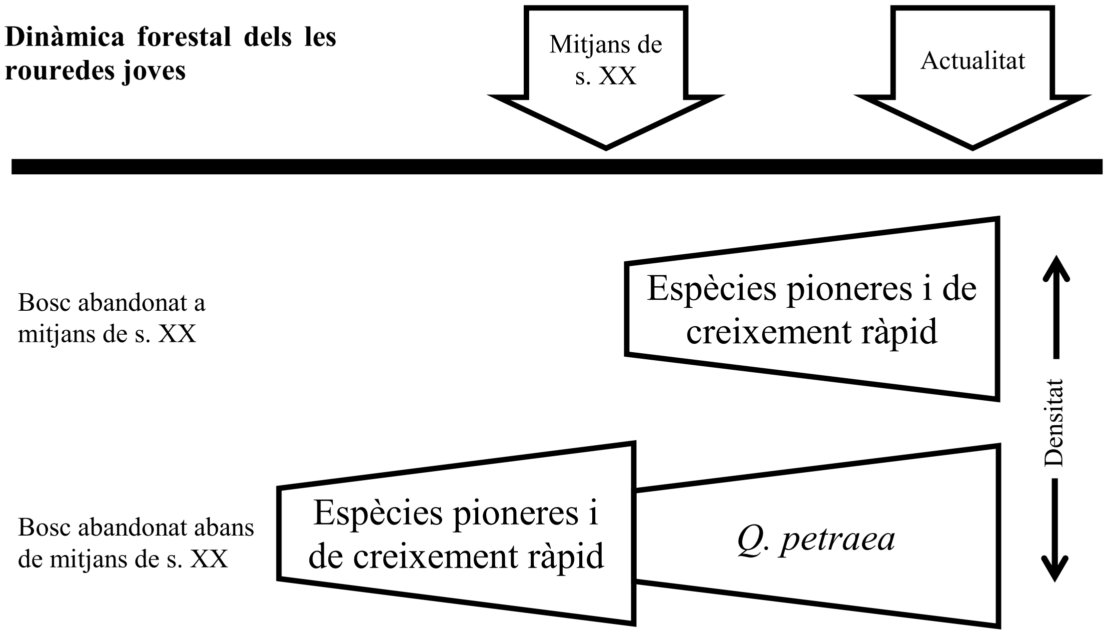

Figura 7.2.- Esquema gràfic de la dinàmica forestal de les rouredes de roure de fulla gran al Montseny.

Aquestes dinàmiques es podrien interpretar com que el roure està en un punt mitjà entre l'alzina i el faig, a causa de la seva gran capacitat d'adaptació i resiliència, que seria molt interessants davant de problemàtiques ambientals com el canvi climàtic. Si al Montseny, doncs, s'ha observat que el roure és una espècie més resistent que el faig al canvi global i la comunitat no mostra signes de mediterranització, en un futur en aquesta regió es podrien mantenir les rouredes en un bon estat de conservació. Només en l'estudi de Gómez et al. (2008), es va detectar la mediterranització del bosc, però es tracta precisament d'un estudi d'un cas molt concret, que només prenia de referència la Roureda de Ridaura, la qual precisament ha estat catalogada dins del grup de rouredes amb estructures més pròximes a la transició vers altres unitats vegetals, tractant-se d'un bosc força aïllat, envoltat principalment per alzinar i que nosaltres pensem que no és del tot representatiu.

Fins i tot es genera una hipòtesi sobre el seu possible futur, i es que a la llarga el roure de fulla gran, podria acabar colonitzant més espais, en contra del faig, segurament en els vessants nord o en altituds elevades, on els alzinars son més llunyans i tardarien un temps considerable en arribar a colonitzar, deixant així prou temps perquè la roureda pogués colonitzar aquests microclimes que actualment permeten la presencia de faig, però que amb l'escalfament global podrien deixar de ser prou òptims pel desenvolupament de la fageda, però si per la roureda. Però aquesta ultima hipòtesi simplement es un possibilitat i caldrien futurs estudis en que es modelitzessin aquests escenaris de canvi climàtic, integrant tota la informació que s'ha exposat en aquesta tesi. Alhora la monitorització d'aquests ambients de transició entre la fageda i el roure serien necessaris per tal de determinar si hi ha un canvi en la composició d'espècies i en especial l'abundància de roure.

7.3 La conservació de les rouredes de roure de fulla gran a Catalunya

Diversos factors poden intervenir en la bona conservació de les rouredes, com ara una gestió forestal enfocada a la conservació de masses forestals madures i a la diversificació de l'estructura de classes diamètriques, especialment en els casos de boscos dins d'espais naturals protegits; cal tenir en compte que no només a Catalunya, sinó que també a Europa els rodals de roure de fulla gran madurs són rars (Saniga et al., 2014).

També creiem necessari controlar el creixement d'espècies arbòries invasores, que com s'ha comentat anteriorment comença a ser una problemàtica a tenir en compte en la conservació de les rouredes de roure de fulla gran. Es preocupant el fet de que hi hagi plantacions de *Pseudotsuga menziesii*, arbre amb un potencial risc d'invasió dins de determinats espais naturals protegits de Catalunya, i que s'hagi detectat com creixen arbres joves d'aquesta espècie en concret dins d'un element tant singular com la roureda de roure de fulla gran. I a més en l'actualitat s'està promovent la substitució de les plantacions de castanyer per plantacions de *Pseudotsuga menziesii* al NE de la Península Ibèrica (Tusell & Beltrán, 2016), fet que augmentaria les fonts d'entrada als hàbitats naturals. Un control de l'ús d'aquest arbre resulta necessari, no només per conservar les rouredes, sinó també per conservar altres boscos del mateix estatge montà humit, que poden ser colonitzats per aquesta espècie, com es en el cas de les fagedes.

A un nivell més específic, al Parc Natural del Montnegre les rouredes estan perdent biodiversitat, essent necessari des de la gestió del parc considerar aquest hàbitat com altament vulnerable i amenaçat en el seu àmbit territorial. Pensem que en la gestió d'aquest espai natural protegit s'ha de tenir una especial atenció en la reducció dels impactes controlables associats a l'activitat humana. En el cas del Parc Natural del Montseny, hi ha una important problemàtica d'escassa superfície de la roureda de roure de fulla gran, afegit a un problema de fragmentació del bosc per manca de continuïtat, la qual cosa en fa difícil la seva conservació. Les raons d'aquest aïllament són barreres naturals en alguns casos, com boscos del propi mosaic de la zona, tot i que la seva presència seria qüestionable d'origen ja que es tracta d'ambients molt alterats per l'activitat humana des d'antic. Però en algun cas l'aïllament es degut directament a l'activitat humana, com les nombrosos pistes forestals o camins de desembosc. En aquest sentit existeixen noves amenaces, com ara la futura pavimentació de la pista que connecta el poble del Montseny amb Sant Marçal (Coordinadora per a la Salvaguarda del Montseny, 2014; Ecologistes en acció, 2014). Tot aquesta problemàtica de fragmentació afegiria una dificultat per a la seva conservació, ja que afectaria a tot l'ecosistema de la roureda, que es trobaria en una situació vulnerable davant d'impactes com els que pot generar el canvi climàtic. Però per altra banda, la capacitat de recuperació de les rouredes que hem observat a la nostra recerca al Montseny, podria resultar molt interessant per a la seva conservació en el context de canvi climàtic. Per això caldria establir un pla de recuperació de la roureda de roure de fulla gran al Montseny amb la finalitat de crear nous boscos i millorar la connectivitat entre els fragments actuals, ja que tenim evidències que es tracta d'un bosc amb capacitat potencial per expandir-se al massís. Aquest pla s'hauria de desenvolupar mitjançant una planificació basada en la seva distribució potencial, prioritzant espais on actualment s'hi troben hàbitats no naturals, com plantacions d'espècies al·lòctones. Es tractaria, doncs, d'una gestió enfocada a reforçar la conservació del roure de fulla gran al parc natural, de tal manera que amb l'escalfament global s'optimitzés el refugi climàtic que sempre ha representat el Montseny per a la biodiversitat, i no pas que el territori potencial de la roureda sigui ocupat per espècies que en alguns casos fins i tot es consideren potencialment invasores.

En termes generals, doncs, la roureda de roure de fulla gran necessita d'un marc normatiu que permeti conservar l'hàbitat que conformen aquests boscos, però alhora requereix d'una bona planificació i estratègia de conservació específica. En el cas d'espais naturals protegits, es podria fer una important tasca en aquest sentit, però també existeixen altres rouredes aïllades que s'haurien de considerar. En resum, es tracta d'un element singular del patrimoni natural al NE de la Península Ibèrica, que com s'ha analitzat al llarg d'aquesta tesi, ha rebut molts impactes al llarg de la història i que actualment es troba amenaçat per noves activitats humanes i pel canvi climàtic. Però també s'ha demostrat la seva resiliència i resistència a aquests impactes i problemàtiques, essent així possible la seva conservació si es porta a terme una gestió adequada d'aquests boscos en els refugis climàtics.

8 Conclusions

- Les rouredes de roure de fulla gran al NE de la Península Ibèrica, han canviat la seva composició d'espècies des de la segona meitat de s. XX, però de forma diferent segons cada regió fisiogeogràfica. En el cas de les rouredes de roure de fulla gran a la Serralada Litoral hi ha hagut una clara pèrdua de biodiversitat.

- Gran part dels canvis observats a les rouredes del NE de la Península Ibèrica, són conseqüència d'un canvi en l'ús del bosc. Fa 60 anys es va produir un abandonament dels aprofitaments que va permetre un increment dels macrofaneròfits caducifolis, amb la conseqüent reducció de la lluminositat dins del bosc que ha portat a la disminució dels hemicriptòfits del sotabosc.

- El canvi climàtic també ha afectat l'espectre corològic de les rouredes de roure de fulla gran al NE de la Península Ibèrica, on s'ha evidenciat un procés de termofilització en algunes localitats, molt clar a la Serralada Litoral, on les plantes mediterrànies s'han vist afavorides. També es veuria un estadi menys intens d'aquest procés als Pirineus, on les plantes atlàntiques s'han vist perjudicades.

- De les rouredes de roure de fulla gran estudiades al NE de la Península Ibèrica, les nord-occidentals són més estables davant de totes les dinàmiques derivades del canvi global; es tracta de localitats amb unes condicions ambientals molt més favorables.

- Les espècies potencialment invasores també s'han de considerar en l'actualitat com una de les problemàtiques de les rouredes, atès que en el cas del Montseny, s'ha vist com *Pseudotsuga menziesii* colonitza fàcilment les rouredes de roure de fulla gran. A més l'augment de plantacions d'aquesta espècie, incrementa el seu risc d'invasió.

- Al Montseny hi han 64.08 ha de roureda de roure de fulla gran, en una estreta franja altitudinal que va dels 450 als 1150 m d'altitud, entre l'alzinar i la fageda. Normalment ocupa vessants suds, ja que el faig ocupa el vessant nord, i creix sobre substrats granítics, principalment granodiorita.

- L'abandonament dels aprofitaments agroforestals al Montseny, a mitjans de s. XX, ha propiciat una densificació i una lleu expansió de la roureda de roure de fulla gran. Tot i això, les rouredes de roure de fulla gran al Montseny, mantenen en general un alt grau de fragmentació.

- En base a la seva estructura forestal les rouredes de roure de fulla gran del Montseny es poden classificar en cinc tipus de bosc diferents. El primer estadi de successió d'aquests boscos seria la roureda jove i densa, en que hi ha una important abundància d'espècies arbòries acompanyants. Seguidament apareixen rouredes també joves i denses, però on ja han anat desapareixent les espècies pioneres i de creixement ràpid i el bosc té l'estructura d'una massa densa de *Q. petraea*. En una fase posterior, la competència entre els mateixos roures fa que al bosc només hi quedin els individus més forts, amb una densitat menor, trobant-se en aquestes estructures intermèdies algun cas de bosc ja més madur. Per últim hi ha dos tipus de bosc més, un correspon a condicions límit per *Q. petraea*, on apareixen altres espècies de roures, i l'altre a boscos de transició cap a l'alzinar o la fageda.

- Donada la poca superfície de les rouredes de roure de fulla gran al Montseny i la discontinuïtat del bosc fruit de l'activitat secular al parc natural, es fa necessari no només conservar les rouredes existents, sinó també recuperar-les en les àrees on potencialment pot créixer, com ara castanyedes abandonades o plantacions de coníferes exòtiques.

- En el Montseny s'ha observat un procés de recuperació de la roureda de roure de fulla gran, amb un augment de la dominància de les plantes eurosiberianes, típiques d'aquests boscos. Alhora s'ha produït un procés de recuperació de l'estructura forestal que tot i que encara es manté jove, amb cobertes compactes i no esclarissades.

- En el cas de les rouredes de roure de fulla gran del Montseny, atesa la situació en el *xeric limit*, seria recomanable reduir els nous impactes sobre aquests boscos, permetent així un desenvolupament natural del bosc, i la tendència a la maduresa en un futur. Tot i així, en boscos especialment densos, degut al context de canvi climàtic, s'hauria de plantejar l'opció de fer tallades selectives per reduir la competència durant els períodes secs que aniran en augment.

- Els nous coneixements sobre les rouredes de roure de fulla gran a Catalunya, generen tot un seguit d'informació que s'hauria de considerar en les hipòtesis i models de futur pels boscos del NE de la Península Ibèrica en el context del canvi climàtic.

- La conservació de les rouredes de roure de fulla gran al NE de la Península Ibèrica, s'ha de basar en una gestió sostenible d'aquests boscos, on es preservin les poques masses forestals existents, que són de vital importància al tractar-se de poblacions en el seu límit de distribució. També s'hauria de considerar la restauració d'aquest hàbitat, en llocs on es va substituir per altres cobertes dels usos del sòl o en espais amb un baix valor ambiental.

9 Referències

Ales, R. F., Martin, A., Ortega, F., & Ales, E. E. (1992). Recent changes in landscape structure and function in a Mediterranean region of SW Spain (1950–1984). *Landscape Ecology*, *7*, 3–18.

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., … Cobb, N. (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management*, *259*(4), 660–684. https://doi.org/10.1016/j.foreco.2009.09.001

Améztegui, A., Brotons, L., & Coll, L. (2010). Land-use changes as major drivers of mountain pine (Pinus uncinata Ram.) expansion in the Pyrenees. *Global Ecology and Biogeography*, *19*(5), 632–641. https://doi.org/10.1111/j.1466-8238.2010.00550.x

Amigo, J., Silva-Pando, F. J., González, M. P., Rozados, M. J., Rois, M., & Díaz-Maroto, I. J. (2001). Diversidad florística en robledales atlánticos del Noroeste de la Península Ibérica. In *III Congreso Forestal Español* (pp. 20–22).

Andrés, M., & Font, X. (2011). Principals patrons de distribució de plantes vasculars a Catalunya. In *Actes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica* (pp. 33–44). Ordino.

Aranda, I., Gil, L., & Pardos, J. A. (2000). Water relations and gas exchange in Fagus sylvatica L. and Quercus petraea (Mattuschka) Liebl. in a mixed stand at their southern limit of distribution in Europe. *Trees*, *14*(6), 344–352. https://doi.org/10.1007/s004680050229

Aranda, I., Ramírez-Valiente, J. A., & Rodríguez-Calcerrada, J. (2014). Características funcionales que influyen en la respuesta a la sequía de las especies del género Quercus: variación inter- e intra-específica. *Ecosistemas*, *23*(2), 27–36. Retrieved from http://www.revistaecosistemas.net/index.php/ecosistemas/article/view/864

Aymerich, P., & Sáez, L. (2015). Comentaris i precisions previs a la checklist de la flora de Catalunya (nord-est de la península Ibèrica). *Orsis*, *29*, 23–90.

Banqué, M., Anna Grau, Jordi Martínez-Vilalta, & Vayreda, J. (2013). *CANVIBOSC: Vulnerabilitat de les espècies forestals al canvi climàtic*. Barcelona.

Barbeta, A., Pujantell, J., Boada, M., Peñuelas, J., Barriocanal, C., & Fuentes, J. (2018). Estudi dendroecològic dels avets (Abies alba L.) del sot dels Avets de Vallfornès. In *IX Trobada d'Estudiosos del Montseny* (pp. 175–185). Diputació de Barcelona.

Benito-Garzón, M., Sánchez de Dios, R., & Sainz Ollero, H. (2008). Effects of climate change on the distribution of Iberian tree species. *Applied Vegetation Science*, *11*(2), 169–178. https://doi.org/10.3170/2008-7-18348

Berger, S., Söhlke, G., Walther, G. R., & Pott, R. (2007). Bioclimatic limits and range shifts of cold-hardy evergreen broad-leaved species at their northern distributional limit in Europe. *Phytocoenologia*, *37*(3–4), 523–539. https://doi.org/10.1127/0340-269X/2007/0037-0523

Bertrand, R., Lenoir, J., Piedallu, C., Dillon, G. R., De Ruffray, P., Vidal, C., … Gégout, J. C. (2011). Changes in plant community composition lag behind climate warming in lowland forests. *Nature*, *479*(7374), 517–520. https://doi.org/10.1038/nature10548

Blanco Castro, E., & Gómez Manzaneque, F. (1997). *Los Bosques ibéricos : una interpretación geobotánica*. Barcelona: Editorial Planeta. Retrieved from http://cataleg.udg.edu/record=b1094564~S10*cat

Blanco, E., Ángel, M., Costa, Ma., Ecribano, R., García, M., Génova, M., … Sainz, H. (2005). *Los Bosques ibéricos : Una interpretación geobotánica*. (Ma. Costa, C. Morla, & H. Sainz, Eds.) (4th ed.). Barcelona: Editorial Planeta.

Boada, M. (1994). El massís del Montseny. In *Montseny, incerta glòria* (pp. 427–464). Sant Celoni: Plataforma d'Entitats Cíviques del Montseny (PECM).

Boada, M. (2002a). *El Montseny: cinquanta anys d'evolució dels paisatges*. (CESPA GR, Ed.). Barcelona: Publicacions de l'Abadia de Montserrat.

Boada, M. (2002b). *Manifestacions del canvi ambiental global al Montseny*. Universitat Autònoma de Barcelona.

Boada, M. (2006). Evolució històrica dels boscos de Catalunya. In L. Vilar, P. Maluquer, X. Mateu, M. Palahí, J. A. Bonet, J. Mogas, … E. de Ribot (Eds.), *Els boscos a Catalunya: Aprofitament i futur* (pp. 89–110). Girona: CEC.

Bolòs, O. (1983). *La vegetació del Montseny*. Barcelona: Diputació de Barcelona.

Bolòs, O. (1988). La roureda acidòfila (Quercion robori-petraeae) a Catalunya. *Monogr. Inst. Pir. Ecol.*, *4*, 447–453.

Bolòs, O., Vigo, J., Masalles, R. M., & Ninot, J. M. (2005). *Flora manual dels Països Catalans* (3a ed.). Barcelona: Pòrtic.

Borovics, A., & Mátyás, C. (2013). Decline of genetic diversity of sessile oak at the retracting (xeric) limits. *Annals of Forest Science*, *70*(8), 835–844. https://doi.org/10.1007/s13595-013-0324-6

Bou, J., Caritat, A., & Vilar, L. (2015). Litterfall and growth dynamics relationship with the meteorological variability in three forests in the Montseny natural park. *Folia Forestalia Polonica*, *57*(3), 146–160. https://doi.org/10.1515/ffp-2015-0015

Bou, J., & Vilar, L. (2016). Fitxa InvasIBER de Pseudotsuga menziesii. Retrieved April 13, 2017, from http://invasiber.org

Bou, J., & Vilar, L. (2018). Current distribution and recent development of sessile oak forests in Montseny (1956-2015). *Landscape Research*. https://doi.org/10.1080/01426397.2018.1472751

Bou, J., & Vilar, L. (2019). The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula. *Natural Areas Journal*.

Bou, J., Vilar, L., & Caritat, A. (2015). *Estudi de les rouredes de Quercus petraea al Parc Natural del Montseny*. Girona.

Bou, J., Vilar, L., & Caritat, A. (2016). La roureda de roure de fulla gran. *Revista de Girona*, *294*, 62 – 65.

Bou, J., Vilar, L., & Caritat, A. (2018). La roureda de roure de fulla gran al Parc Natural del Montseny. In *IX Trobada d'Estudiosos del Montseny* (pp. 152–163). Barcelona: Diputació de Barcelona.

Bou Manobens, J., Àguila, V., & Gordi, J. (2015). L'evolució del paisatge forestal (1950-2013) a l'Alt Empordà. *AIEE*, *46*, 343–368. https://doi.org/10.2436/20.8010.01.185

Bou Manobens, J., Vilar, L., & Caritat, A. (2015). Estudi de la transició del bosc de Quercus petraea al bosc de Quercus ilex al paratge de Marmolers (Parc Natural del Montseny). *Orsis*, *29*, 1–17. https://doi.org/https://doi.org/10.5565/rev/orsis.14

Braun-Blanquet, J. (1964). *Pflanzensoziologie Grundzüge der Vegetationskunde*. Vienna: Springer Vienna. https://doi.org/10.1007/978-3-7091-8110-2

Broncano, M. J., Vilà, M., & Boada, M. (2005). Evidence of Pseudotsuga menziesii naturalization in montane Mediterranean forests. *Forest Ecology and Management*, *211*(3), 257–263. https://doi.org/10.1016/j.foreco.2005.02.055

Brunet, J., Falkengren-Grerup, U., Rühling, Å., & Tyler, G. (1997). Regional differences in floristic change in South Swedish oak forests as related to soil chemistry and land use. *Journal of Vegetation Science*, *8*(3), 329–336. https://doi.org/10.2307/3237321

Carreras, J., Carrillo, E., Font, X., Ninot, J. M., Soriano, I., & Vigo, J. (1995). La vegetación de las sierras prepirenaicas situadas entre los ríos Segre y Llobregat. 1- Comunidades forestales (bosques, mantos marginales y orlas herbáceas). *Ecologia Mediterranea*, *XXI*(3/4), 21–73. Retrieved from http://atzavara.bio.ub.edu/geoveg/docs_Ninot/Carreras_et_al_95.pdf

Carreras, J., Carrillo, E., Josep-Maria, N., & Vigo, J. (1997). Contribution to the phytocoenological knowledge of Pyrenean forests. *Fragmenta Floristica et Geobotanica*, *42*(1), 95-129.

Carreras, J., & Ferré, A. (Eds.). (2012). *Cartografia dels hàbitats a Catalunya versió 2 - Manual d'interpretació*. Departament de Territori i Sostenibilitat. Generalitat de Catalunya.

Castroviejo, S. (2012). *Flora iberica*. Madrid: Real Jardín Botánico, CSIC.

Cavin, L., Mountford, E. P., Peterken, G. F., & Jump, A. S. (2013). Extreme drought alters competitive dominance within and between tree species in a mixed forest stand. *Functional Ecology*, *27*(6), 1424–1435. https://doi.org/10.1111/1365-2435.12126

Choat, B., Jansen, S., Brodribb, T. J., Cochard, H., Delzon, S., Bhaskar, R., … Zanne, A. E. (2012). Global convergence in the vulnerability of forests to drought. *Nature*, *491*(7426), 752–755. https://doi.org/10.1038/nature11688

Clarke, K. R., & Gorley, R. N. (2006). *PRIMER v6: User Manual/Tutorial*. (PRIMER-E, Ed.). Plymouth.

Comas, L., Gracia, M., & Vayreda, J. (2013). Inventari de boscos singulars de Catalunya. *L'Atzavara*, *22*, 29–36. Retrieved from http://www.raco.cat/index.php/Atzavara/article/download/273727/361877

Coordinadora per a la Salvaguarda del Montseny. (2014). Excursió reivindicativa contra la construcció de la carretera Illes-Sant Marça. Retrieved from www.salvaguardamontseny .cat

Costa, M., García, M., Morla, C., & Sainz, H. (1990). La evolucion de los bosques de la Peninsula Iberica: una interpretacion basada en datos paleobiogeograficos. *Ecología*, *1*, 31–58.

CREAF, & Generalitat de Catalunya. (2009). Mapa de cobertes del sòl de Catalunya. Retrieved from http://www.creaf.uab.es/mcsc/

Czúcz, B., Gálhidy, L., & Mátyás, C. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Annals of Forest Science*, *68*(1), 99–108. https://doi.org/10.1007/s13595-011-0011-4

De Frenne, P., Rodriguez-Sanchez, F., Coomes, D. A., Baeten, L., Verstraeten, G., Vellend, M., … Verheyen, K. (2013). Microclimate moderates plant responses to macroclimate warming. *Proceedings of the National Academy of Sciences*, *110* (46), 18561–18565. https://doi.org/10.1073/pnas.1311190110

de Ribot Porta, E. (2016). Les reforestacions amb avet Douglas i la seva gestió com alternativa a les masses de castanyer. In *XXXIII Jornades Tècniques Silvícoles Emili Garolera*.

Debussche, M., Lepart, J., & Dervieux, A. (1999). Mediterranean landscape changes: evidence from old postcards. *Global Ecology and Biogeography*, *8*(1), 3–15. https://doi.org/10.1046/j.1365-2699.1999.00316.x

Departament de Medi Ambient. (1996). *Pla d'espais d'interès natural*. Barcelona : Generalitat de Catalunya. Retrieved from http://cataleg.udg.edu/record=b1097171~S10*cat

Departament Territori i Sostenibiltat. (2016). *Dades del medi ambient a Catalunya 2016*. Generalitat de Catalunya.

Díaz-Maroto, I. J., & Vila-Lameiro, P. (2007). Deciduous and semi-deciduous oak forests (Quercus robur, Q. petraea and Q. pyrenaica) floristic composition in the Northwest Iberian Peninsula. *Biologia*, *62*(2), 163–172. https://doi.org/10.2478/s11756-007-0025-4

Diputació de Barcelona. (2008). *Pla especial de protecció del medi natural i del paisatge del Parc Natural de Montseny*. (Oficina Tècnica de Planificació i Anàlisi Territorial de l'Àrea d'Espais Naturals de la Diputació de Barcelona, Ed.). Diputació de Barcelona, Diputació de Girona.

Diputació de Barcelona. (2014). Parc Natural de Montseny. Retrieved from http://parcs.diba.cat/web/montseny

Diputació de Barcelona. (2018). Parc del Montnegre i el Corredor. Retrieved August 20, 2018, from https://parcs.diba.cat/web/montnegre

Diputació de Girona. (2011). SELVANS. Retrieved October 15, 2017, from http://www.selvans.cat/

Do Amaral Franco, J., & López González, G. (1987). Notas referentes al género "Quercus." *Anales Del Jardín Botánico de Madrid*, *44*(2), 555–558.

Eaton, E., Caudullo, G., Oliveira, S., & de Rigo, D. (2016). Quercus robur and Quercus petraea in Europe: distribution, habitat, usage and threats. In J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, & A. Mauri (Eds.), *European Atlas of Forest Tree Species* (pp. 160–163). Luxembourg: Publications Office of the European Union. https://doi.org/10.2788/4251

Ecologistes en acció. (2014). Montseny: Concentració contra la construcció de la carretera Illes-Sant Marçal. Retrieved from http://www.ecologistasenaccion.org

Felicísimo, A. M. (Ed.). (2011). *Impactos, vulnerabilidad y adaptación al cambio climático de la biodiversidad española. 2. Flora y vegetación*. Madrid: Oficina Española de Cambio Climático, Ministerio de Medio Ambiente y Medio Rural y Marino.

Fischlin, A., Midgley, G. F., Price, J. T., Leemans, R., Gopal, B., Turlay, C., … Velichko, A. A. (2007). Eco- systems, their properties, goods and services. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. Van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 211–272). Cambridge: Cambridge University Press. Retrieved from https://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4_wg2_full_report.pdf

Font, X. (2013). Banc de Dades de la Biodiversitat de Catalunya.

Forest Europe. (2015). *State of Europe's Forests 2015*. Madrid: FOREST EUROPE.

Fotelli, M. N., Nahm, M., Radoglou, K., Rennenberg, H., Halyvopoulos, G., & Matzarakis, A. (2009). Seasonal and interannual ecophysiological responses of beech (Fagus sylvatica) at its south-eastern distribution limit in Europe. *Forest Ecology and Management*, *257*(3), 1157–1164. https://doi.org/10.1016/j.foreco.2008.11.026

Frelich, L. E. (2002). *Forest Dynamics and Disturbance Regimes: Studies from Evergreen-Deciduous Forests*. Cambridge: Cambridge University Press.

García-López, J., & Allué, C. (2008). Characterization and phytoclimatic potentialities of Quercus petraea (Matt.) Liebl. and Quercus robur L. forests in Spain. *Forest Systems*, *15*, 277–295. Retrieved from http://revistas.inia.es/index.php/fs/article/viewArticle/971

García-Ruiz, J. M., Lasanta, T., Ruiz-Flano, P., Ortigosa, L., White, S., González, C., & Martí, C. (1996). Land-use changes and sustainable development in mountain areas: a case study in the Spanish Pyrenees. *Landscape Ecology*, *11*(5), 267–277. https://doi.org/10.1007/BF02059854

Generalitat de Catalunya. (2015). gencat.cat. Retrieved from www.gencat.cat

Gibbs, J. N., & Greig, J. W. (1997). Biotic and abiotic factors affecting the dying back of pedunculate oak Quercus robur L. *Forestry*, *70*(4), 399–406. https://doi.org/10.1093/forestry/70.4.399

Gómez, D., Ferrández, J., Tejero, P., & Font, X. (2017). Distribución espacial y análisis ambiental de la flora alpina en los Pirineos. *Pirineos*, *172*. https://doi.org/https://doi.org/10.3989/Pirineos.2017.172002

Gómez, J. F., Boada, M., & Sànchez, S. (2008). Análisis de los procesos de cambio global: el caso del robledal de Ridaura (Parque Natural del Montseny. barcelona). *Boletín de La A.G.E.*, *47*, 125–142.

Gordi, J. (2009). *L'Evolució del paisatge forestal a les terres gironines a la segona meitat del segle XX*. Girona: Associació d'Història Rural de les Comarques Gironines.

Grabherr, G., Gottfried, M., & Pauli, H. (1994). Climate effects on mountain plants. *Nature*, *369*(6480), 448–448. https://doi.org/10.1038/369448a0

Grau, O., Ninot, J., Font, X., Ferré, A., & Grytnes, J. (2011). Trends in altitudinal distribution of plant diversity in the Catalan Pyrenees. In *Actes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica* (pp. 171–180). Ordino. Retrieved from http://161.116.68.143/website/geoveg/docs/Grau_et_al_2011b.pdf

Guitián Rivera, L. (1995). *Origen y evolución de la cubierta forestal de Galicia*. University of Santiago.

Gutiérrez, E. (1988). Dendroecological study of Fagus sylvatica L. in the Montseny Mountains (Spain). *Acta Oecologica – Oecologia Plantarum*, *9*, 301–309.

Hartmann, G., Blank, R., & Lewark, S. (1989). Eichensterben in Norddeutschland - Verbreitung, Schadbilder, mögliche Ursachen. *Forst Und Holz*, *44 (18)*, 475–487.

Huntingford, C., Zelazowski, P., Galbraith, D., Mercado, L. M., Sitch, S., Fisher, R., … Cox, P. M. (2013). Simulated resilience of tropical rainforests to CO2-induced climate change. *Nature Geoscience*, *6*(4), 268–273. https://doi.org/10.1038/ngeo1741

Ibañez, J. J., & Burriel, J. A. (2013). *MCSC-4:canvis a les cobertes, aplicacions, etc.* Barcelona.

Illa, J., Font, G., & Arrizabalaga, A. (2011). L'explotació forestal a Arbúcies per la construcció de galeres (s. XVI i XVII). *Monografies Del Montseny*, *26*, 74–89.

Institut Cartogràfic i Geològic de Catalunya. (2017). ICGC VISSIR. Retrieved from http://www.icc.cat

IPCC. (2013). *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, … H. L. Miller, Eds.). Cambridge: Cambridge University Press.

IPCC. (2014). *Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral as- pects. Contribution of Working Group II to the Fifth assessment report of the Intergovernmental Panel on Climate Change (AR5)*. (V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. . Bilir, … L. L. White, Eds.). Cambridge. Retrieved from http://www.ipcc.ch/report/ar5/wg2

Jump, A. S., Hunt, J. M., & Peñuelas, J. (2006). Rapid climate change-related growth decline at the southern range edge of Fagus sylvatica. *Global Change Biology*, *12*(11), 2163–2174. https://doi.org/10.1111/j.1365-2486.2006.01250.x

Jump, A. S., Hunt, J. M., & Peñuelas, J. (2007). Climate relationships of growth and establishment across the altitudinal range of Fagus sylvatica in the Montseny Mountains, northeast Spain. *Ecoscience*, *14*(4), 507–518. Retrieved from http://www.bioone.org/doi/abs/10.2980/1195-6860(2007)14%5B507:CROGAE%5D2.0.CO%3B2

Kelly, A. E., & Goulden, M. L. (2008). Rapid shifts in plant distribution with recent climate change. *Proceedings of the National Academy of Sciences*, *105*(33), 11823–11826. https://doi.org/10.1073/pnas.0802891105

Korpel, S. (1995). *Die Urwälder der Westkarpaten. Gustav Fischer Verlag.*

Kotroczó, Z., Krakomperger, Z., Papp, M., Bowden, R. D., & Tóth, J. (2005). Thirty-one years of change in vegetation composition of a Central European oak forest at the Sikfokut ILTER. In *90th ESA Annual Meeting*. Montréal: Ecological Society of America.

Kotroczó, Z., Veres, Z., Fekete, I., Papp, M., & Tóth, J. A. (2012). Effects of Climate Change on Litter Production in a Quercetum petraeae-cerris Forest in Hungary. *Acta Silvatica et Lignaria Hungarica*, *8*(1), 31–38. https://doi.org/10.2478/v10303-012-0003-6

Kremer, A., & Petit, R. (2001). La epopeya de los robles europeos. *Mundo Científico*, *225*, 64–68. Retrieved from http://dialnet.unirioja.es/servlet/articulo?codigo=76441

Kröel-Dulay, G., Ransijn, J., Schmidt, I. K., Beier, C., De Angelis, P., de Dato, G., … Penuelas, J. (2015). Increased sensitivity to climate change in disturbed ecosystems. *Nature Communications*, *6*, 6682. https://doi.org/10.1038/ncomms7682

Krumm, F., & Vítková, L. (Eds.). (2016). *Introduced tree species in European forests: opportunities and challenges*. European Forest Institute. Retrieved from http://www.in-tree.org/uploads/images/book/Introduced_tree_species_EN_HighRes. pdf

Lagache, L., Klein, E. K., Guichoux, E., & Petit, R. J. (2013). Fine-scale environmental control of hybridization in oaks. *Molecular Ecology*, *22*(2), 423–436. https://doi.org/10.1111/mec.12121

Lapraz, G. (1962). Recherches phytosociologiques en Catalogne. *Collect. Bot. (Barcelona)*, *6(1-2)*(2).

Lasanta-Martinez, T., Vicente-Serrano, S., & Cuadrat-Prats, J. (2005). Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. *Applied Geography*, *25*(1), 47–65. https://doi.org/http://dx.doi.org/10.1016/j.apgeog.2004.11.001

Laurance, W. F., Warkentin, I. G., Halpern, B. S., Kappel, C. V., Micheli, F., & Selkoe, K. A. (2010). Habitat destruction: Death by a thousand cuts. In S. S. Navjot & P. R. Ehrlich (Eds.), *Conservation Biology for All*. Oxford: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199554232.003.0005

Lenoir, J. (2008). A significant upward shift in plant species. *Science*, *320*(June), 1768–1772.

Lenoir, J., Gegout, J. C., Dupouey, J. L., Bert, D., & Svenning, J. C. (2010). Forest plant community changes during 1989-2007 in response to climate warming in the Jura Mountains (France and Switzerland). *Journal of Vegetation Science*, *21*(5), 949–964. https://doi.org/10.1111/j.1654-1103.2010.01201.x

Llobet, S. (1947). *El Medio y la vida en el Montseny : estudio geográfico*. Barcelona: CSIC. Instituto Juan Sebastián Elcano.

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B., & Ackerly, D. D. (2009). The velocity of climate change. *Nature*, *462*(7276), 1052–1055. https://doi.org/10.1038/nature08649

Logan, W. (2005). *Oak, the Frame of Civilization*. New York.: Northon & Company.

Loidi, J. (Ed.). (2017). *The Vegetation of the Iberian Peninsula* (Vol. 12). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-54784-8

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., … Gibon, A. (2000). Agriculture abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Management*, *59*(1), 47–69. https://doi.org/http://dx.doi.org/10.1006/jema.1999.0335

Mallarach, J. M., Montserrat, J., & Vila, J. (Eds.). (2013). *Reptes per preservar els boscos madurs a Catalunya: II Jornades sobre boscos madurs*. Santa Coloma de Farners: Institució Catalana d'Històrica Natural.

MAPAMA. (2018). Catálogo Español de Especies Exóticas Invasoras. Retrieved August 21, 2018, from https://www.mapama.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-exoticas-invasoras/default.aspx

Martínez-Vilalta, J., Piñol, J., & Beven, K. (2002). A hydraulic model to predict drought-induced mortality in woody plants: An application to climate change in the Mediterranean. *Ecological Modelling*, *155*(2–3), 127–147. https://doi.org/10.1016/S0304-3800(02)00025-X

Martinez del Castillo, E., García-martin, A., Alberto, L., Aladr, L., & Luis, M. De. (2015). Evaluation of forest cover change using remote sensing techniques and landscape metrics in Moncayo Natural Park (Spain), *62*, 247–255. https://doi.org/10.1016/j.apgeog.2015.05.002

Mátyás, C. (2010). Forecasts needed for retreating forests. *Nature*, *464*(7293), 1271–1271. https://doi.org/10.1038/4641271a

Mercadé, A. (2008). Aportació al coneixement dels boscos mesòfils de la Catalunya Central, I; Fagedes i Rouredes. *Acta Botanica Barcinonensia*, *51*, 93–125. Retrieved from http://www.raco.cat/index.php/ActaBotanica/article/viewArticle/85957/0

Montserrat, P. (2014). Les Muntanyes del Maresme a mitjan segle XX - Una Visio ecobotànica. *L'Atzavara*, *24*, 5–69.

Ninyerola, M., Pons, X., & Roure, J. M. (2000). A methodological approach of climatological modelling of air temperature and precipitation through GIS techniques. *International Journal of Climatology*, *20*, 1823–1841.

Nuet, J., Romo, A., Montserrat, S., & Salvador, F. (2018). les fagedes de Matagalls (Montseny, Catalunya). Descripció, fitodiversitat i caracterització fitosociològica. In *IX Trobada d'Estudiosos del Montseny* (pp. 198–240). Diputació de Barcelona.

Observatori del Paisatge. (2010). *Comarques Gironines: catàleg del paisatge*. (J. Nogué i Font, P. Sala i Martí, Departament de Territori i Sostenibilitat, & Observatori del Paisatge, Eds.) (1a ed., Vol. 1). Generalitat de Catalunya.

Oksanen, J., Guillaume Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., … Wagner, H. (2016). vegan: Community Ecology Package. R package version 2.4-1. Retrieved from https://cran.r-project.org/package=vegan

Oleksyn, J., & Przybyl, K. (1987). Oak decline in the Soviet Union - Scale and hypotheses. *Forest Pathology*, *17*(6), 321–336. https://doi.org/10.1111/j.1439-0329.1987.tb01325.x

Panadera, J. M., & Nuet, J. (1986). Les Castanyedes al Montseny. *Ausa*, *12*(116), 65–78.

Panareda, J. M. (1979). Aportació a l'estudi del clima del Montseny. *Acta Geológica Hispánica*, *14*, 524–528. Retrieved from http://revistes.ub.edu/index.php/ActaGeologica/article/viewFile/4820/6319

Parviainen, J. (2000). Strict forest reserves in Europe: efforts to enhance biodiversity and research on forests left for free development in Europe (EU-COST-Action E4). *Forestry*, *73*(2), 107–118. https://doi.org/10.1093/forestry/73.2.107

Parviainen, J., Little, D., O'Sullivan, A., Kettunen, M., & Korhonen, M. (1999). *Research in forest reserves and natural forests in European countries. EFI Proceedings No 16.* Joensuu, Finland: European Forest Institute.

Patton, D. R. (1975). A diversity index for quantifying habitat edge. *Wildlife Society Bulletin*, *3*, 171–173.

Pauli, H., Gottfired, M., & Grabherr, G. (1996). Effects of Climate Change on Mountain Ecosystems - Upward Shifting of Alpine Plants. *World Resource Review*, *8*(3), 382–390. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=geh&AN=1999-028264

Pauli, H., Gottfried, M., & Grabherr, G. (2003). Effects of climate change on the alpine and nival vegetation of the Alps. *Journal of Mountain Ecology*, *7*(Suppl.), 9–12. https://doi.org/10.1093/conphys/cot001

Pauli, H., Gottfried, M., Reiter, K., Klettner, C., & Grabherr, G. (2007). Signals of range expansions and contractions of vascular plants in the high Alps: Observations (1994-2004) at the GLORIA *master site Schrankogel, Tyrol, Austria. *Global Change Biology*. https://doi.org/10.1111/j.1365-2486.2006.01282.x

Peñuelas, J., & Boada, M. (2003). A global change-induced biome shift in the Montseny mountains (NE Spain). *Global Change Biology*, *9*(2), 131–140. https://doi.org/10.1046/j.1365-2486.2003.00566.x

Peñuelas, J., Hunt, J. M., Ogaya, R., & Jump, A. S. (2008). Twentieth century changes of tree-ring delta C-13 at the southern range-edge of Fagus sylvatica: increasing water-use efficiency does not avoid the growth decline induced by warming at low altitudes. *Global Change Biology*, *14*(5), 1076–1088. https://doi.org/10.1111/j.1365-2486.2008.01563.x

Peñuelas, J., Lloret, F., & Montoya, R. (2001). Severe drought effects on mediterranean woody flora in Spain. *Forest Science*, *47*(2), 214–218.

Peñuelas, J., Sardans, J., Estiarte, M., Ogaya, R., Carnicer, J., Coll, M., … Jump, A. S. (2013). Evidence of current impact of climate change on life: A walk from genes to the biosphere. *Global Change Biology*. https://doi.org/10.1111/gcb.12143

Peñuelas, J., Sardans, J., Filella, I., Estiarte, M., Llusià, J., Ogaya, R., … Terradas, J. (2016). Ecosistemes terrestres. In *Tercer informe sobre el canvi climàtic a Catalunya* (pp. 211–235). Barcelona: Institut d'Estudis Catalans Generalitat de Catalunya.

Petritan, A. M., Biris, I. A., Merce, O., Turcu, D. O., & Petritan, I. C. (2012). Structure and diversity of a natural temperate sessile oak (Quercus petraea L.) – European Beech (Fagus sylvatica L.) forest. *Forest Ecology and Management*, *280*, 140–149. https://doi.org/10.1016/j.foreco.2012.06.007

Pino, J. (2014). Canvi d'usos del sòl. Retrieved April 12, 2015, from http://blog.creaf.cat

Pons, X. (1996). Estimación de la Radiación Solar a partir de modelos digitales de elevaciones. Propuesta metodológica. In J. Juaristi & I. Moro (Eds.), *VII Coloquio de Geografía Cuantitativa, Sistemas de Información Geográfica y Teledetección*. Vitoria-Gasteiz.

Praciak, A., Pasiecznik, N., Sheil, D., Heist, M. van, Sassen, M., Sousa Correia, C., … Teeling, C. (2013). *The CABI Encyclopedia of Forest Trees*. *The CABI encyclopedia of forest trees*. https://doi.org/citeulike-article-id:13496407

Primavera, M., & Fiorentino, G. (2013). Acorn gatherers: fruit storage and processing in south-east Italy during the Bronze Age. In *Origini Prehistory and Protohistory of ancient civilizations* (pp. 211–227).

R Core Team. (2015). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.r-project.org/

Ramankutty, N., & Foley, J. A. (1999). Estimating historical changes in global land cover: croplands from 1700 to 1992. *Global Biochemical Cycles*, *13*(4), 997–1027. https://doi.org/https://doi.org/10.1029/1999GB900046

Reczyńska, K., & Świerkosz, K. (2016). Compositional changes in thermophilous oak forests in Poland over time: do they correspond to European trends? *Applied Vegetation Science*, *20*(2), 293–303. https://doi.org/10.1111/avsc.12290

Reif, A., Xystrakis, F., Gärtner, S., & Sayer, U. (2017). Floristic change at the drought limit of European beech (Fagus sylvatica L.) to downy oak (Quercus pubescens) forest in the temperate climate of central Europe. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *45*(2), 646–654. https://doi.org/10.15835/nbha45210971

Rivas-Martínez, S., & Sáenz, C. (1991). Enumeración de los Quercus de la Península Ibérica. *Rivasgodaya*, *6*, 101–110.

Ruiz-Labourdette, D., Schmitz, M. F., & Pineda, F. D. (2013). Changes in tree species composition in Mediterranean mountains under climate change: Indicators for conservation planning. *Ecological Indicators*, *24*, 310–323. https://doi.org/10.1016/j.ecolind.2012.06.021

Sáenz-Romero, C., Lamy, J.-B., Ducousso, A., Musch, B., Ehrenmann, F., Delzon, S., … Kremer, A. (2017). Adaptive and plastic responses of Quercus petraea populations to climate across Europe. *Global Change Biology*, *23*(7), 1–17. https://doi.org/10.1111/gcb.13576

Salvat, A., Sàez, L., Llop, E., & Guinart, D. (2018). Establiment d'indicadors i valoració botànica dels boscos madurs del Montseny. In *IX Trobada d'Estudiosos del Montseny* (pp. 186–197). Diputació de Barcelona.

Saniga, M., Balanda, M., Kucbel, S., & Pittner, J. (2014). Four decades of forest succession in the oak-dominated forest reserves in Slovakia. *IForest - Biogeosciences and Forestry*, *7*(5), 324–332. https://doi.org/10.3832/ifor0996-007

Sanitjas, A. (2018). La gestió dels boscos vells al Parc Natural del Montseny. In *Experiències en els hàbitats forestals madurs mediterranis*. Poblet: Departament d'Agricultura, Ramaderia, Pesca i Alimetnació. Retrieved from https://ruralcat.gencat.cat/c/document_library/get_file?uuid=49dee285-7fd8-428b-9635-a7a2cd2516cb&groupId=20181

Santos, C. C. P. (2000). Succession of breeding bird communities after the abandonment of agricultural fields in southeast Portugal. *Ardeola*, *47*(2), 171–181.

Siwkcki, R., & Ufnalski, K. (1998). Review of oak stand decline with special reference to the role of drought in Poland. *Forest Pathology*, *28*(2), 99–112. https://doi.org/10.1111/j.1439-0329.1998.tb01171.x

Tegel, W., Seim, A., Hakelberg, D., Hoffmann, S., Panev, M., Westphal, T., & Büntgen, U. (2014). A recent growth increase of European beech (Fagus sylvatica L.) at its Mediterranean distribution limit contradicts drought stress. *European Journal of Forest Research*, *133*(1), 61–71. https://doi.org/10.1007/s10342-013-0737-7

Terradas, J., Ibàñez, J. J., Vayreda, J., Espelta, J. M., Àvila, A., & Gracia, C. (2004). *Els boscos de Catalunya Estructura, dinàmica i funcionament*. (Generalitat de Catalunya, Ed.) (1st ed.). Barcelona: Generalitat de Catalunya.

Thomas, F. M., Blank, R., & Hartmann, G. (2002). Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe. *Forest Pathology*, *32*(4–5), 277–307. https://doi.org/10.1046/j.1439-0329.2002.00291.x

Thuiller, W., Lavorel, S., Araújo, M. B. M. B., Sykes, M. T. M. T., & Prentice, I. C. (2005). Climate change threats to plant diversity in Europe. *Proceedings of the National Academy* *of Sciences*, *102*(23), 8245–8250. https://doi.org/10.1073/pnas.0409902102

Tielbörger, K., Bilton, M. C., Metz, J., Kigel, J., Holzapfel, C., Lebrija-Trejos, E., … Sternberg, M. (2014). Middle-Eastern plant communities tolerate 9 years of drought in a multi-site climate manipulation experiment. *Nature Communications*, *5*, 5102. https://doi.org/10.1038/ncomms6102

Tusell, J. M., & Beltrán, M. (Eds.). (2016). *XXXIII Jornades Tècniques Silvícoles Emili Garolera*. Santa Coloma de Farners: Consorci Forestal de Catalunya.

UNEP. (1989). *State of the Mediterranean marine environment*. Athens. Retrieved from http://web.unep.org/unepmap/mts-028-state-marine-environment-mediterranean-region-0

Universitat de Barcelona, & Generalitat de Catalunya. (2012). Cartografia dels hàbitats de Catalunya 1:50.000 (CHC50), versió 2.

Universitat de Barcelona, Generalitat de Catalunya, & Institut d'Estudis Catalans. (2012). Mapa de vegetació de Catalunya.

Väre, H., Lampinen, R., Humphries, C., & Williams, P. (2003). Taxonomic diversity of vascular plants in the european alpine areas. In L. Nagy, G. Grabherr, C. Körner, & D. B. A. Thompson (Eds.), *Alpine Biodiversity in Europe. Ecological Studies (Analysis and Synthesis)* (pp. 133–148). Berlin: Springer. https://doi.org/10.1007/978-3-642-18967-8_5

Vayreda, J., Banqué, M., Anna Grau, & Martínez-Vilalta, J. (2013). *CANVIBOSC: Vulnerabilitat de les espècies forestals al canvi climàtic*. Barcelona.

Vayreda, J., Jordi Martínez-Vilalta, & Banqué, M. (2013). Els boscos davant del canvi climàtic. In CREAF, Oficina Catalana del Canvi Climàtic, & Generalitat de Catalunya (Eds.) (p. 25). Barcelona: CREAF. Retrieved from http://www.slideshare.net/slideshow/embed_code/27964680#

Vayreda, J., Martínez-Vilalta, J., & Banqué, M. (2013). *Decaïment dels Boscos a Catalunya: DEBOSCAT*. CREAF.

Verdu, A. M. C., Ferrés, L., Roda, F., & Terradas, J. (1980). Estructuta y funcionalismo de un encinar montano en el Montseny. *Mediterranéa*, *4*, 51–67. Retrieved from http://193.145.233.67/dspace/bitstream/10045/28605/1/Mediterranea_04.pdf#page=52

Verdú, A., Riba, M., & Rodà, F. (1985). Retranslocament de nutrients en les fulles senescents de faig (Fagus sylvatica L.). *Orsis: Organismes i Sistemes*, *1*, 91–100. Retrieved from http://www.raco.cat/index.php/Orsis/article/viewArticle/24076/0

Vicens, N., Sanitjas, A., & Barrachina, M. (2018). Estudi i seguiment de boscos vells al Parc Natural i Reserva de la Biosfera del Montseny. In *IX Trobada d'Estudiosos del Montseny* (pp. 49–61). Diputació de Barcelona.

Viciani, D., Gabellini, A., Gennai, M., Foggi, B., & Lastrucci, L. (2018). Woods with Quercus petraea (Matt .) Liebl . in Tuscany (Italy): a vegetation classification approach, *39*(1), 3–16. https://doi.org/http://dx.doi.org/10.5209/MBOT.59040

Vigo, J. (1968). Notas sobre la Vegetación del Valle de Ribes. *Collect. Bot. (Barcelona)*, *8(2) Nº 66*, 1171–1185.

Vigo, J. (1996). *El poblament vegetal de la Vall de Ribes* (1st ed.). Barcelona: Institut Gartogràfic de Catalunya.

Vigo, J. (2011). Comparacions entre la flora dels Pirineus i la d'altres muntanyes peninsulars. In *Actes del IX Col·loqui Internacional de Botànica Pirenaico-Cantàbrica* (pp. 453–466). Ordino.

Vigo, J., Carreras, J., & Ferré, A. (Eds.). (2005). *Manual del Hàbitats de Catalunya. 8 volums.* Departament de Medi Ambient i Habitatge. Generalitat de Catalunya.

Vila-Lameiro, P., & Diaz-Maroto, I. J. (2002). Las masas actuales de Quercus petraea en Galicia. *Forest Systems*, *11*(1), 5–28. Retrieved from http://recyt.fecyt.es/index.php/IA/article/viewArticle/2517

Vila i Subirós, J., Varga i Linde, D., Llausàs Pascual, A., & Ribas i Palom, A. (2006). Conceptes i mètodes fonamentals en ecologia del paisatge («landscape ecology»): una interpretació des de la geografia. *Documents d'anàlisi Geogràfica*, *48*, 151–166. Retrieved from http://dialnet.unirioja.es/servlet/articulo?codigo=2328164&info=resumen&idioma=ENG

Vila, J. (1999). *Anàlisi i valoració dels boscos de les valls d'Hortmoier i Sant Aniol*. Universitat de Barcelona.

Viñas, X. (1993). *Flora i vegetació de l'Alta Garrotxa*. Universitat de Girona.

Vittoz, P., & Guisan, A. (2007). How reliable is the monitoring of permanent vegetation plots? A test with multiple observers. *Journal of Vegetation Science*, *18*(3), 413–422. https://doi.org/10.1111/j.1654-1103.2007.tb02553.x

Vittoz, P., Randin, C., Dutoit, A., Bonnet, F., & Hegg, O. (2009). Low impact of climate change on subalpine grasslands in the Swiss Northern Alps. *Global Change Biology*, *15*(1), 209–220. https://doi.org/10.1111/j.1365-2486.2008.01707.x

Vogelmann, J. (1995). Assessment of forest fragmentation in southern New England using remote sensing and geographic information systems technology. *Conservation Biology*, *9*(2), 439–449.

Walther, G.-R. (2003). Plants in warmer world. *Perspectives in Plant Ecology, Evolution and Systematics*, *6*(3), 169–185. https://doi.org/https://doi.org/10.1078/1433-8319-00076

Walther, G.-R., Beißner, S., & Burga, C. A. (2005). Trends in the upward shift of alpine plants. *Journal of Vegetation Science*, *16*(5), 541. https://doi.org/10.1658/1100-9233(2005)16[541:TITUSO]2.0.CO;2

Walther, G. R., & Grundmann, A. (2001). Trend for vegetation change in colline and submontane climax forests in Switzerland. *Publications of the Geobotanical Institute ETHZ*, *67*, 3–12.

Weber, P., Bugmann, H., Fonti, P., & Rigling, A. (2008). Using a retrospective dynamic competition index to reconstruct forest succession. *Forest Ecology and Management*, *254*(1), 96–106. https://doi.org/10.1016/j.foreco.2007.07.031

Williams, J. W., & Jackson, S. T. (2007). Novel climates, no-analog communities, and ecological surprises. *Frontiers in Ecology and the Environment*. https://doi.org/10.1890/070037

Annexos

Annex A Informació adicional de l'article "Sessile oak forest plant community changes on the NE Iberian Peninsula"

A.1 Supplementary information

Supporting Information for

Sessile oak forest plant community changes on the NE Iberian Peninsula

Jordi Bou & Lluís Vilar

LAGP-Flora and Vegetation. Institute of the Environment. University of Girona.

Postal address: C/ Ma. Aurèlia Capmany 69, 17003 GIRONA, Catalonia (Spain)

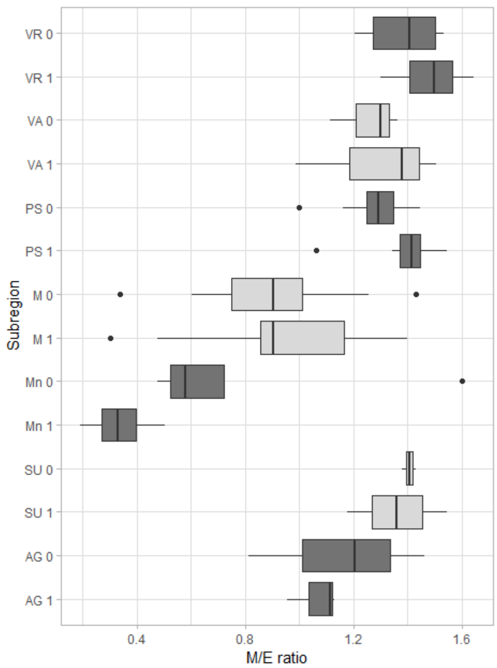

Figure S1. M/E ratio values for each subregion in the two study periods.

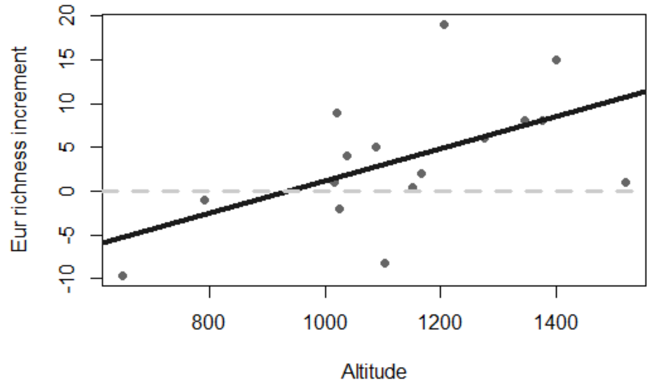

Figure S2. Euro-Siberian species increment over time, in n function of the altitude of the plot. A non-continuous line marks the zero changes.

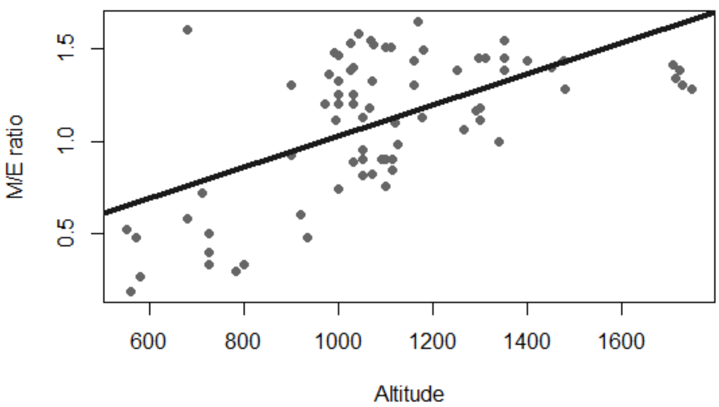

Figure S3. M/E ratio value in function of altitude.

Bibliographic reference	**Publication**	**Authors**	**Subregion**
Vigo 1996	El poblament vegetal de la vall de Ribes.	Vigo, J.	VR
Carreras et al. 1997	Contribution to the phytocenological knowledge of Pyrenean forest	Carreras, J. Carrillo, E.; Ninot, J.M. & Vigo, J.	SU, PS
Viñas 1993	Flora i vegetació de l'Alta Garrotxa.	Viñas, X.	AG
Carreras et al. 1995	La vegetación de las sierras prepirenaicas situadas entre los ríos Segre y Llobregat. 1- Comunidades forestales (bosques, mantos marginales y orlas herbáceas).	Carreras, J.; Carrillo, E.; Font, X.; Ninot, J. M.; Soriano, I. & Vigo, J.	SU
Lapraz 1962	Recherches phytosociologiques en Catalogne.	Lapraz, G.	M, Mn
Bolòs 1988	La roureda acidòfila (Quercion robori-petraeae) a Catalunya	Bolòs, O. de	M
Vigo 1968	Notas sobre la vegetación del valle de Ribes'.	Vigo, J.	VR

Table S1. Historical inventories used in the study to describe the early periods.

Subregion	Richness								Diversity							
	Historical		Current		ANOVA				Historical		Current		ANOVA			
	mean	SD	mean	SD		F	P	sig	mean	SD	mean	SD		F	P	sig
Mn	38,20	10,23	27,00	2,35	$F_{1,8}$	8,13	0,02	*	2,35	0,25	1,22	0,24	$F_{1,8}$	52,19	0,00	***
M	33,45	8,63	31,90	9,55	$F_{1,19}$	0,16	0,69		2,27	0,31	1,38	0,31	$F_{1,19}$	43,70	0,00	***
AG	27,00	5,29	28,33	7,51	$F_{1,4}$	0,04	0,86		2,52	0,48	1,98	0,31	$F_{1,4}$	2,68	0,18	
SU	32,00	2,83	44,50	0,71					2,21	1,01	2,16	0,31				
PS	31,88	3,68	35,50	5,26	$F_{1,14}$	2,51	0,14		2,54	0,42	2,22	0,47	$F_{1,14}$	2,14	0,17	
VA	24,00	5,29	40,00	1,00	$F_{1,4}$	18,44	0,01	*	2,14	0,37	1,95	0,39	$F_{1,4}$	0,38	0,57	
VR	32,67	10,33	44,50	14,49	$F_{1,10}$	2,64	0,14		2,96	0,43	1,82	0,43	$F_{1,10}$	20,85	0,00	**

Table S2. Biodiversity variables for each subregion and period, with the mean value and standard deviation. ANOVA results for differences over time.

Region	Presence/abscence		Abundance	
	P	sig	P	sig
Pyrenees	0,00	**	0,00	**
Prepyrinees	0,74		0,40	
Precoastal Range	0,00	***	0,00	***
Coastal Range	0,00	**	0,01	**

Table S3. P-value of the PERMANOVA analysis, testing the differences over time in each region.

	Plnta life-forms	Mn				M				AG				SU				PS				VA				VR			
		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Relative richness	Ch	2,47	1,42	4,45	3,27	8,19	5,09	7,81	3,11	4,23	4,35	5,56	2,48	4,61	1,80	10,13	1,75	10,62	2,30	10,73	5,74	5,81	2,96	10,82	5,12	7,64	2,33	5,83	2,41
	G	4,67	1,66	9,55	1,27	7,81	2,82	9,59	4,43	5,81	2,84	4,63	1,00	6,27	0,55	3,38	1,64	5,01	2,48	7,92	4,03	3,33	5,77	5,00	4,33	7,96	2,20	9,70	5,07
	H	49,23	8,75	27,75	6,70	60,37	7,93	42,42	11,21	49,92	9,00	35,45	7,54	59,80	9,71	57,35	5,68	56,12	5,68	56,98	9,42	56,77	8,93	54,15	5,86	59,13	2,43	55,86	6,63
	MPc	12,16	2,05	20,99	4,79	9,06	3,34	16,81	8,20	17,76	5,80	22,62	7,43	13,82	5,41	12,30	7,75	13,39	4,12	12,46	5,31	20,51	2,61	15,78	5,00	16,22	3,03	14,94	5,74
	MPp	10,81	4,23	13,27	3,93	3,18	3,96	8,47	4,23	5,45	6,08	7,01	3,23	4,61	1,80	4,49	0,07	3,65	3,33	1,08	1,50	3,89	3,47	1,67	1,45	1,40	1,64	4,17	2,80
	NPc	1,74	1,59	3,04	1,72	0,43	0,96	0,00	0,00	2,34	2,09	1,85	3,21	4,61	1,80	2,25	0,04	2,89	2,92	2,07	2,04	1,11	1,92	1,69	1,46	1,97	2,26	2,16	2,73
	NPp	7,60	2,69	3,04	1,72	3,78	2,14	1,53	2,16	6,58	3,09	5,29	3,69	0,00	0,00	0,00	0,00	2,45	1,54	1,50	1,63	0,00	0,00	2,54	2,56	3,14	3,00	1,57	1,27
	P	10,60	3,01	17,23	3,21	5,80	4,73	12,25	5,23	7,91	4,54	15,74	2,87	6,27	0,55	6,74	0,11	4,35	1,66	4,50	1,63	2,63	2,35	5,81	3,81	1,21	1,33	3,76	2,87
	Th	0,71	1,60	0,69	1,54	1,38	1,99	1,11	1,51	0,00	0,00	1,85	3,21	0,00	0,00	3,36	1,54	1,53	2,43	2,76	1,26	5,96	3,55	2,54	2,56	1,34	2,07	2,00	2,30
Relative abundance	Ch	0,52	1,03	0,11	0,08	0,16	0,14	0,22	0,11	0,05	0,05	0,15	0,11	3,94	0,58	10,58	6,76	5,31	5,14	1,01	1,53	0,08	0,03	2,07	3,26	1,56	2,71	2,70	4,70
	G	26,02	10,83	1,12	1,98	22,33	11,14	9,70	14,17	0,68	1,08	4,57	0,55	3,98	0,65	0,12	0,02	6,43	8,33	0,69	1,37	0,10	0,16	1,31	2,18	19,69	16,31	3,42	6,27
	H	11,41	9,16	2,43	2,31	22,33	7,49	9,57	10,77	54,60	2,18	14,01	10,66	23,30	12,40	17,49	5,86	31,60	13,12	30,93	15,85	41,96	16,95	30,58	13,01	36,36	9,41	17,44	13,50
	MPc	43,18	13,22	80,48	9,32	48,45	8,02	74,21	12,43	41,42	6,30	68,63	5,12	66,71	13,61	68,45	8,56	51,23	15,24	63,14	12,81	49,33	9,48	52,92	12,86	40,16	12,87	64,62	10,56
	MPp	11,32	15,76	9,73	11,74	0,31	0,87	2,39	4,34	0,89	1,49	3,47	5,78	0,11	0,04	2,86	3,85	0,07	0,06	0,03	0,04	0,08	0,10	0,03	0,03	0,89	2,14	11,47	19,32
	NPc	0,03	0,03	1,90	2,53	0,01	0,03	0,00	0,00	0,03	0,03	0,06	0,11	1,81	2,43	0,09	0,03	0,05	0,06	0,64	1,69	5,55	9,61	10,04	17,32	0,38	0,89	0,07	0,06
	NPp	0,72	1,28	0,07	0,04	3,50	7,70	0,05	0,07	0,08	0,04	0,12	0,04	0,00	0,00	0,00	0,00	1,81	3,10	0,03	0,04	0,00	0,00	2,84	4,86	0,03	0,03	0,07	0,06
	P	6,79	7,25	4,13	6,36	2,61	5,39	3,82	11,04	2,25	3,68	7,41	8,33	0,16	0,03	0,27	0,09	3,08	6,49	3,46	5,51	0,05	0,05	0,15	0,12	0,02	0,02	0,15	0,15
	Th	0,03	0,06	0,02	0,03	0,28	0,85	0,03	0,04	0,00	0,00	1,58	2,73	0,00	0,00	0,14	0,11	0,42	1,14	0,07	0,05	2,86	4,82	0,06	0,05	0,91	2,20	0,07	0,07

Table S4. Plant life-form variables for each subregion and period, with the mean value and standard deviation.

	Plnta form-life	Mn				M				AG				PS				VA				VR			
			F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig
Relative richness	Ch	$F_{1,8}$	1,54	0,25		$F_{1,19}$	0,04	0,84		$F_{1,4}$	0,21	0,67		$F_{1,14}$	0,00	0,96		$F_{1,4}$	2,15	0,22		$F_{1,10}$	1,74	0,22	
	G	$F_{1,8}$	27,19	0,00	***	$F_{1,19}$	1,23	0,28		$F_{1,4}$	0,46	0,53		$F_{1,14}$	3,03	0,10		$F_{1,4}$	0,16	0,71		$F_{1,10}$	0,59	0,46	
	H	$F_{1,8}$	18,98	0,00	**	$F_{1,19}$	18,23	0,00	***	$F_{1,4}$	4,55	0,10	.	$F_{1,14}$	0,05	0,83		$F_{1,4}$	0,18	0,69		$F_{1,10}$	1,28	0,28	
	MPc	$F_{1,8}$	14,38	0,01	**	$F_{1,19}$	8,33	0,01	**	$F_{1,4}$	0,80	0,42		$F_{1,14}$	0,15	0,70		$F_{1,4}$	2,11	0,22		$F_{1,10}$	0,23	0,64	
	MPp	$F_{1,8}$	0,90	0,37		$F_{1,19}$	8,77	0,01	**	$F_{1,4}$	0,15	0,71		$F_{1,14}$	3,95	0,07	.	$F_{1,4}$	1,05	0,36		$F_{1,10}$	4,37	0,06	.
	NPc	$F_{1,8}$	1,54	0,25		$F_{1,19}$	1,99	0,17		$F_{1,4}$	0,05	0,83		$F_{1,14}$	0,42	0,53		$F_{1,4}$	0,17	0,70		$F_{1,10}$	0,02	0,90	
	NPp	$F_{1,8}$	10,21	0,01	*	$F_{1,19}$	5,75	0,03	*	$F_{1,4}$	0,21	0,67		$F_{1,14}$	1,44	0,25		$F_{1,4}$	2,95	0,16		$F_{1,10}$	1,39	0,27	
	P	$F_{1,8}$	11,35	0,01	**	$F_{1,19}$	8,81	0,01	**	$F_{1,4}$	6,39	0,06	.	$F_{1,14}$	0,03	0,86		$F_{1,4}$	1,52	0,28		$F_{1,10}$	3,90	0,08	.
	Th	$F_{1,8}$	0,00	0,98		$F_{1,19}$	0,12	0,74		$F_{1,4}$	1,00	0,37		$F_{1,14}$	1,63	0,22		$F_{1,4}$	1,83	0,25		$F_{1,10}$	0,28	0,61	
Relative abundance	Ch	$F_{1,8}$	25,57	0,00	***	$F_{1,19}$	5,21	0,03	*	$F_{1,4}$	30,62	0,01	**	$F_{1,14}$	3,69	0,08	.	$F_{1,4}$	0,93	0,39		$F_{1,10}$	5,21	0,05	*
	G	$F_{1,8}$	0,79	0,40		$F_{1,19}$	1,27	0,27		$F_{1,4}$	2,03	0,23		$F_{1,14}$	5,15	0,04	*	$F_{1,4}$	1,12	0,35		$F_{1,10}$	0,26	0,62	
	H	$F_{1,8}$	4,51	0,07	.	$F_{1,19}$	10,10	0,00	**	$F_{1,4}$	41,78	0,00	**	$F_{1,14}$	0,01	0,93		$F_{1,4}$	0,85	0,41		$F_{1,10}$	7,93	0,02	*
	MPc	$F_{1,8}$	26,58	0,00	***	$F_{1,19}$	32,50	0,00	***	$F_{1,4}$	33,74	0,00	**	$F_{1,14}$	2,86	0,11		$F_{1,4}$	0,15	0,72		$F_{1,10}$	12,95	0,00	**
	MPp	$F_{1,8}$	0,03	0,86		$F_{1,19}$	2,43	0,14		$F_{1,4}$	0,56	0,50		$F_{1,14}$	2,45	0,14		$F_{1,4}$	0,56	0,50		$F_{1,10}$	1,78	0,21	
	NPc	$F_{1,8}$	2,73	0,14		$F_{1,19}$	1,99	0,17		$F_{1,4}$	0,26	0,63		$F_{1,14}$	0,96	0,34		$F_{1,4}$	0,15	0,71		$F_{1,10}$	0,75	0,41	
	NPp	$F_{1,8}$	1,26	0,29		$F_{1,19}$	2,00	0,17		$F_{1,4}$	1,37	0,31		$F_{1,14}$	2,64	0,13		$F_{1,4}$	1,03	0,37		$F_{1,10}$	1,49	0,25	
	P	$F_{1,8}$	0,38	0,55		$F_{1,19}$	0,10	0,75		$F_{1,4}$	0,96	0,38		$F_{1,14}$	0,02	0,90		$F_{1,4}$	1,70	0,26		$F_{1,10}$	4,75	0,05	.
	Th	$F_{1,8}$	0,13	0,72		$F_{1,19}$	0,86	0,37		$F_{1,4}$	1,00	0,37		$F_{1,14}$	0,73	0,41		$F_{1,4}$	1,01	0,37		$F_{1,10}$	0,88	0,37	

Table S5. Complete ANOVA results for differences over time in the plant life-form variables.

	Chorological groups	Mn				M				AG				SU				PS				VA				VR			
		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current		Historical		Current	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Relative richness	Alp	0,00	0,00	0,00	0,00	0,26	0,86	0,78	1,75	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,91	3,30	0,80	1,51	1,67	2,89	0,00	0,00	1,85	1,54	2,10	1,31
	Atl	7,03	1,85	7,22	3,23	10,79	3,42	8,53	3,15	11,38	2,05	7,41	2,00	0,00	0,00	1,14	1,61	2,98	2,13	3,64	1,93	5,96	3,55	4,21	3,83	7,88	4,43	6,10	2,69
	Boralp	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,14	1,61	1,73	3,20	1,64	1,99	2,22	3,85	1,71	2,96	0,82	1,28	0,98	1,59
	Eur	59,71	6,53	50,77	6,94	57,61	7,74	59,02	10,13	66,02	18,44	63,36	7,88	76,57	0,14	70,73	6,82	68,05	8,50	72,03	6,74	73,23	13,18	68,19	8,46	74,44	6,65	69,14	2,62
	Introd	2,74	0,57	3,01	1,71	0,20	0,66	2,14	2,43	1,45	2,51	2,78	2,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,83	1,44	0,00	0,00	0,40	0,97
	Med	10,56	6,41	21,58	5,40	5,93	5,36	5,48	5,64	1,33	2,31	2,12	1,88	0,00	0,00	1,14	1,61	0,80	1,50	0,37	1,04	0,00	0,00	1,67	2,89	0,00	0,00	0,00	0,00
	Plurireg	18,08	3,15	16,72	5,40	20,13	6,52	20,68	9,01	13,36	10,49	14,29	8,33	14,41	7,90	18,01	3,46	17,06	9,26	16,78	7,64	10,96	5,62	18,43	6,25	6,13	4,03	15,16	5,11
	Pont	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,85	1,48	0,00	0,00	0,00	0,00
	Submed	1,88	1,74	0,69	1,54	5,08	2,97	3,36	2,42	6,46	4,84	10,05	4,85	9,02	8,04	7,85	1,46	6,46	3,90	4,74	3,62	5,96	3,55	4,11	5,06	8,88	4,86	6,13	2,94
Relative abundance	Alp	0,00	0,00	0,00	0,00	0,00	0,01	0,03	0,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,05	0,02	0,03	0,02	0,03	0,00	0,00	0,62	0,94	0,06	0,03
	Atl	1,70	1,50	1,11	2,06	11,04	8,48	2,49	4,52	12,87	9,15	7,92	5,19	0,00	0,00	0,03	0,05	5,79	4,93	2,81	6,62	1,64	2,70	2,89	4,82	2,56	2,24	0,23	0,14
	Boralp	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,05	0,03	0,05	0,05	0,06	5,58	9,67	10,03	17,37	0,88	2,14	0,03	0,05
	Eur	77,08	17,86	83,03	11,59	75,21	16,86	90,27	12,12	73,47	12,39	79,88	5,35	89,64	4,30	92,91	0,74	85,67	5,23	92,86	9,11	91,71	11,93	83,70	27,00	89,57	7,73	80,75	16,53
	Introd	1,69	3,67	0,97	2,01	5,34	17,71	0,07	0,08	0,02	0,03	0,06	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,04	0,00	0,00	0,01	0,03
	Med	3,64	4,30	8,00	8,47	0,57	1,04	1,26	2,52	0,02	0,03	0,06	0,06	0,00	0,00	0,03	0,05	0,02	0,03	0,01	0,03	0,00	0,00	0,05	0,08	0,00	0,00	0,00	0,00
	Plurireg	15,84	13,31	6,88	9,11	6,80	4,24	5,05	10,94	11,91	7,28	10,15	9,36	4,63	6,25	5,02	1,57	6,89	6,90	3,83	7,32	0,19	0,17	3,20	4,88	1,75	2,70	6,88	7,37
	Pont	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,03	0,00	0,00	0,00	0,00
	Submed	0,05	0,05	0,02	0,04	1,04	1,83	0,83	2,34	1,72	2,90	1,93	2,95	5,73	1,96	1,97	2,17	1,56	1,67	0,43	0,85	0,86	1,37	0,09	0,12	4,61	3,63	12,04	17,24

Table S6. Chorological variables for each subregion and period, with the mean value and standard deviation.

	Chorological groups	Mn				M				AG				PS				VA				VR			
			F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig		F	P	Sig
Relative richness	Alp	-	-	-	-	$F_{1,19}$	0,78	0,39		-	-	-	-	$F_{1,14}$	2,72	0,12		$F_{1,4}$	1,00	0,37		$F_{1,10}$	0,09	0,77	
	Atl	$F_{1,8}$	0,01	0,91		$F_{1,19}$	2,45	0,13		$F_{1,4}$	5,78	0,07	.	$F_{1,14}$	0,43	0,52		$F_{1,4}$	0,34	0,59		$F_{1,10}$	0,71	0,42	
	Boralp	-	-	-	-	-	-	-	-	-	-	-	-	$F_{1,14}$	0,00	0,95		$F_{1,4}$	0,03	0,86		$F_{1,10}$	0,04	0,85	
	Eur	$F_{1,8}$	4,40	0,07	.	$F_{1,19}$	0,13	0,72		$F_{1,4}$	0,05	0,83		$F_{1,14}$	1,08	0,32		$F_{1,4}$	0,31	0,61		$F_{1,10}$	3,30	0,10	.
	Introd	$F_{1,8}$	0,11	0,74		$F_{1,19}$	6,57	0,02	*	$F_{1,4}$	0,43	0,55		-	-	-	-	$F_{1,4}$	1,00	0,37		$F_{1,10}$	1,00	0,34	
	Med	$F_{1,8}$	8,65	0,02	*	$F_{1,19}$	0,03	0,85		$F_{1,4}$	0,21	0,67		$F_{1,14}$	0,46	0,51		$F_{1,4}$	1,00	0,37		-	-	-	-
	Plurireg	$F_{1,8}$	0,24	0,64		$F_{1,19}$	0,03	0,88		$F_{1,4}$	0,01	0,91		$F_{1,14}$	0,00	0,95		$F_{1,4}$	2,37	0,20		$F_{1,10}$	11,56	0,01	**
	Pont	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	$F_{1,4}$	1,00	0,37		-	-	-	-
	Submed	$F_{1,8}$	1,31	0,29		$F_{1,19}$	2,08	0,17		$F_{1,4}$	0,82	0,42		$F_{1,14}$	0,84	0,38		$F_{1,4}$	0,27	0,63		$F_{1,10}$	1,41	0,26	
Relative abundance	Alp	-	-	-	-	$F_{1,19}$	1,55	0,23		-	-	-	-	$F_{1,14}$	2,10	0,17		$F_{1,4}$	1,00	0,37		$F_{1,10}$	2,08	0,18	
	Atl	$F_{1,8}$	0,27	0,62		$F_{1,19}$	8,06	0,01	*	$F_{1,4}$	0,66	0,46		$F_{1,14}$	1,04	0,32		$F_{1,4}$	0,15	0,71		$F_{1,10}$	6,47	0,03	*
	Boralp	-	-	-	-	-	-	-	-	-	-	-	-	$F_{1,14}$	0,41	0,53		$F_{1,4}$	0,15	0,72		$F_{1,10}$	0,95	0,35	
	Eur	$F_{1,8}$	0,39	0,55		$F_{1,19}$	5,42	0,03	*	$F_{1,4}$	0,68	0,46		$F_{1,14}$	3,75	0,07	.	$F_{1,4}$	0,22	0,66		$F_{1,10}$	1,40	0,26	
	Introd	$F_{1,8}$	0,15	0,71		$F_{1,19}$	0,88	0,36		$F_{1,4}$	1,41	0,30		-	-	-	-	$F_{1,4}$	1,00	0,37		$F_{1,10}$	1,00	0,34	
	Med	$F_{1,8}$	1,05	0,33		$F_{1,19}$	0,71	0,41		$F_{1,4}$	1,72	0,26		$F_{1,14}$	0,04	0,84		$F_{1,4}$	1,00	0,37		-	-	-	-
	Plurireg	$F_{1,8}$	1,54	0,25		$F_{1,19}$	0,24	0,63		$F_{1,4}$	0,07	0,81		$F_{1,14}$	0,74	0,40		$F_{1,4}$	1,14	0,35		$F_{1,10}$	2,56	0,14	
	Pont	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	$F_{1,4}$	1,00	0,37		-	-	-	-
	Submed	$F_{1,8}$	0,93	0,36		$F_{1,19}$	0,05	0,82		$F_{1,4}$	0,01	0,94		$F_{1,14}$	2,92	0,11		$F_{1,4}$	0,95	0,38		$F_{1,10}$	1,07	0,33	

Table S7. complete ANOVA results for differences over time in the chorological variables

A.2 Inventaris florístics

A continuació es presenta una taula amb els inventaris florístics utilitzats en el article 1 d'aquesta tesi.

1: AG_1; Coll de la Boixeda; Ripollès; DG 5386 ;21/05/17. **2:** AG_2; Bosc de Can Sibat, a Rocabruna; Ripollès; DG 5487 ;21/05/17. **3:** AG_3; Bosc de la Masó, a Rocabruna; Ripollès; DG 5487 ;21/05/17 **4:** M_06; Roureda de Maçaners, al Montseny; Vallès Oriental; DG 5725; 1/10/14. **5:** M_07; Can Corberars, al Montseny; Vallès Oriental; DG 5623; 12/05/18. **6:** M_08; Can Corberars, al Montseny; Vallès Oriental; DG 5623; 12/05/18. **7:** M_09; Can Corberars, al Montseny; Vallès Oriental; DG 5623; 12/05/18. **8:** M_10; Can Corberars, al Montseny; Vallès Oriental; DG 5623; 12/05/18. **9:** M_11; Ridarua, al Montseny; Vallès Oriental; DG 5622; 12/05/18. **10:** M_14; els Guacs, al Montseny; Selva; DG 5727; 28/5/18. **11:** M_15; Sant Marçal, al Montseny; Vallès Oriental; DG 5127; 8/06/18. **12:** M_16; Sant Marçal, al Montseny; Vallès Oriental; DG 5127; 8/06/18. **13:** M_17; Sant Marçal, al Montseny; Vallès Oriental; DG 5127; 8/06/18. **14:** Mn_1; Sot d'en Cases, al Montnegre; Vallès Oriental; DG 6312; 30/04/18. **15:** Mn_2; Sot d'en Cases, al Montnegre; Vallès Oriental; DG 6312; 30/04/18. **16:** Mn_3; Coll de Basses, al Montnegre; Vallès Oriental; DG 6412; 30/04/18. **17:** Mn_4; Coll de Basses, al Montnegre; Vallès Oriental; DG 6412; 30/04/18. **18:** Mn_5; Turó Gros, al Montnegre; Vallès Oriental; DG 6412; 30/04/18. **19:** PS_1; Vall d'Aneu, a la Guingueta d'Àneu; Pallars Sobirà; CH 4716; 18/05/16. **20:** PS_2; Pla de Boavi; Pallars Sobirà; CH 6326; 19/05/16. **21:** PS_3; prop del barranc del Closell, a la Noguera de Cardós; Pallars Sobirà; CH 6026; 19/05/16. **22:** PS_4; collada d'Estallo, a la Noguera de Cardós; Pallars Sobirà; CH 6026; 19/05/16. **23:** PS_5; el pont de Morieto i Artamon, a la Noguera de Cardós; Pallars Sobirà; CH 6025; 19/05/16. **24:** PS_6; Noarre, a Lladorre; Pallars Sobirà; CH 5527; 20/05/16. **25:** PS_7; Arrós, a Esterri de Cardós; Pallars Sobirà; CH 5616; 20/05/16. **26:** PS_8; sota Planell del Roi, a Rialp; Pallars Sobirà; CH 5200; 20/05/16. **27:** SU_1; entre Sant Andreu i Santa Creu, a la vall de Castellbò; Alt Urgell; CG 6094; 28/05/17. **28:** SU_2; Ansovell, a Cava; Alt Urgell; CG 8386; 28/05/17. **29:** VA_1; Vall de l'Artiga Lin, a Es Bòrdes; Vall d'Aran; CH 1433; 18/05/16. **30:** VA_2; Eth Portilhon, a Bossòst; Vall d'Aran; CH 0933; 18/05/16. **31:** VA_3; pujada a Eth Portilhon, a Bossòst; Vall d'Aran; CH 1038; 18/05/16. **32:** VR_01; Santa Caterina, a Ribes de Freser; Ripollès; DG 3184; 10/06/18. **33:** VR_03; Santa Caterina, a Ribes de Freser; Ripollès; DG 3184; 10/06/18. **34:** VR_04; el Mas, a Ribes de Freser; Ripollès; DG 3284; 17/06/18. **35:** VR_05; Can Barratort, a Pardines; Ripollès; DG 3484; 17/06/18. **36:** VR_06; Can Barratort, a Pardines; Ripollès; DG 3484; 17/06/18. **37:** VR_07; Can Perpinyà, a Pardines; Ripollès; DG 3384; 17/06/18.

Classe *Querco-Fagetea* Br.-Bl. (1931) 1932

Ordre *Quercetalia robori petraeae* R. Tüxen 1932

Aliança *Quercion robori petraeae* Br.-Bl.1932

Associació *Lathyro montani-Quercetum petraeae* (Lapraz) Rivas Mart. 1983

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Característiques i diferencials de l'associació i l'aliança																																					
Quercus petraea	5	5	5	5	5	5	5	5	5	5	4	4	5	5	3	5	4	5	+	4	2	5	5	+	3	5	5	5	4	5	4	5	5	4	5	4	4
Teucrium scorodonia	+	+	1	+	+	+	1	2	1	+	+	+	+	+		+				1	+	3	+				2	+	1	2	1	+	+	+			
Pteridium aquilinum	+		+	1	+	1	2	+	+	+	+		4	3	1	+				+	1	+						1	1	1	1	1	2	+	+		
Stachys officinalis					+	+	1	+	+	+							1		+	1		2	+				1	+	+			+	+	+	+	1	+
Deschampsia flexuosa	+	+		+	+														3		+	+			+	1	+		1	1	+	3	+	+	+		
Lathyrus linifolius var. montanus				+		+	+	+	+							+				+			1	+	1	1	1	+			+	1	+	+			
Holcus mollis						+	+					+	+	1	+	+		+	+	+	1	+					1										
Melampyrum pratense							+		+	+										+		+	+				+					+	+				
Serratula tinctoria																																+	+	+		+	
Quercus canariensis	+	+	+	+	+																																
Tanacetum corymbosum								+								1	+									+										+	
Acer opalus										+			+	+	1																						
Potentilla erecta																											+					+					
Symphytum tuberosum														+	+																						
Carex depressa						+																						+									
Hieracium sabaudum																+																					
Hieracium lachenalii																																		+			
Sorbus torminalis																										+											

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Característiques de la classe																																					
Brachypodium sylvaticum	+	+	+	+	+	+	+	1	+	2	+					1	1	1	3	2		3	2	1		4	+	3	+	1	+	+	+	1	+	2	+
Stellaria holostea			+		+	+	+	+	+	+	+	+	+	+	+	2	1		1	+	+	+	+	+	+	1	+	+		+		1		+	2	+	
Corylus avellana	+		+		+			+		+		+	+		2		+		2	3		+			2		+	+	1		1	1		+	2	1	+
Viola sylvestris	+	+					+	+		+						+	+		+	+	+	1	+	+	+	+			+			+	+		+	+	+
Fraxinus excelsior						+				+		+			+		+	+	1			+		1	1			+	+	+	+	+	+	+	+	+	+
Prunus avium	+	+	1	+	+	+	+		+	+		+					1							+			+	+	+		+	+		+	+	+	
Crataegus monogyna	+	+	+		+			+	+	+					+	1	+	+					+	+	+	+		1	+					+	+	+	
Rubus ulmifolius			+	+	+		+	+	+	+	+		+	+	+	+	+							+		+				+	+		+			+	
Rosa canina							+	+		+				+	+	+	+	+					+	+	+	+		+	+				+	+	+	+	
Hedera helix	2	+	+	+	+		+	+			+	3	+	+	+													+	2	+	1	+				+	
Fagus sylvatica			+	1		1	1		+	+	+		+		+											+	+		+			+				+	1
Ilex aquifolium	+	+	+	+	+	+	+	+	+	1	+				+														+		1						
Euphorbia amygdaloides	+	+	+		+	+	+	+	+	+																+	+	+	+		+						
Primula veris					+	+										+	+	+					+		+				+					+	+	+	+
Sorbus aria						+	+	1	+	+				+	+							+	1		+	+											+
Festuca heterophylla						+	+	1	2	2	+	+	+	+	+							+	1														
Lonicera xylosteum	+	+	1	1																		+		+	+									+	+	+	+
Helleborus foetidus						+										1	+	+	+	+	+	+		+		+			+								
Lonicera periclymenum				+	+	+		+		+	+	+															+		+	+	+						
Buxus sempervirens																	+												+	+	1	+	1	+		2	4
Campanula trachelium						+	+		+						+	1	+		+															+	+		
Polygonatum odoratum							+		+	+			+												+			+					+		+		+
Hypericum montanum																					+			+		+	+						+	+	+	+	
Alliaria petiolata					+		+			+							+							+		+							+		+		
Hepatica nobilis																	+	+	+	+				+	+												+
Aquilegia vulgaris			+	+			+	+	+																											+	
Melica uniflora		+	+	+	+							+							+									+									
Tamus communis	+	+			+											+												+					+				
Cardamine impatiens																		+						+		+		+				+			+		
Doronicum pardalianches					+	+						+						+							+										+		

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Característiques de la classe																																					
Poa nemoralis																1								+										2	2	+	
Campanula persicifolia																										+						+		+			+
Acer campestre																						+			+			+							+	+	
Luzula sylvatica		+					+		+	+																							+				
Polystichum setiferum	+	+																	+															+	+		
Prunus spinosa																+	+	+											+								
Hieracium glaucinum																				1			+		+							+					
Luzula forsteri														+																		+				+	
Luzula nivea																	+		+					+	3												
Phyteuma spicatum																	+					+					+	+									
Myosotis arvensis																																		+	+	+	
Pyrus malus															+	+	+																				
Dryopteris filix-mas																		+									+	+									
Astragalus glycyphyllos																+		+						+													
Cephalanthera longifolia																							+		+	+											
Helleborus viridis																			+																+	+	
Anemone nemorosa				+																													+				
Luzula campestris																					1	+															
Poa compressa																																			+		
Poa trivialis																																	+			+	
Pulmonaria affinis																						+						+									
Prunella vulgaris																1	+																				
Carex sylvatica		+			+																																
Cephalanthera rubra																							+		+												
Quercus pubescens																															+						
Viola alba																																	+				
Frangula alnus																													+								
Rosa rubiginosa																		1																			
Viburnum lantana																													+								
Acer monspessulanum																										+											

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Característiques de la classe																																					
Acer platanoides																										+											
Actaea spicata																									+												
Rubus hirtus																												+									
Lamium album																										+											
Lamium flexuosum												+																									
Mercurialis perennis																												+									
Ribes uva-crispa																												+									
Primula acaulis																+																					
Sorbus aucuparia																							+														
Ulmus minor																	+																				
Tilia cordata																												+									
Campanula latifolia																										+											
Daphne mezereum																													+								
Digitalis lutea																															+						
Epilobium montanum																												+									

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Companyes																																					
Cruciata glabra						+	+		+	+				+				+	+	+	+	1	+		+	+	+		+		+	1		+	1	+	+
Conopodium majus		+	+		+		+	+	+		+	+	+	+	+			+	+	+	+	+	+	+			+							+			
Fragaria vesca						+											+	+	+		+			+	+	+	+	+	+		+	+	+	+	+	+	+
Juniperus communis						+	+	+	+				+	+		+	+			2	2	+	+	+	+				+	+	+	+					
Silene nutans							+	+	+	+			+			+	+		+			+	1			+				+	+	+	+	+	+	+	
Hieracium murorum						+				+				+			+	+	+		+	1		+		+	+					+	+	+	+	+	+
Quercus ilex	1	+	+	+	2		+			+	1	1	+	+	+	+															+						
Vicia cracca						+	+			+				+		1	+	+					1	1		1		+						+		+	+
Prunella grandiflora subsp. pyrenaica	+	+				+	+	+	+	+	+																					+		+	+	+	+
Sarothamnus scoparius						+		+	+	+																	+	+	+	+	+	+		+	+	+	
Galium pumilum							+	+	+	+			+							+	+		+		+									+	+	+	
Betula pendula																		1	5	2	4			4	+				+		1	+		1	+		+
Asplenium adiantum-nigrum	1	+						+		+		+			+				+					+		+	+	+							+		
Ranunculus bulbosus							+			+			+	+		+	+	+	+		+	+		+												+	
Laserpitium latifolium						+	+	+	+	+				+	+	+							+				+							+			
Veronica chamaedrys													+	+		+	+		+													+		+	+	+	
Veronica officinalis																			+	+	+	+	+	+	+		+		+						+		
Castanea sativa		+	+	1	+	+	+				+				+															+	+						
Erica arborea	+	2		+	+		+	+	+	+	1		+																								
Vicia sepium						+										+	+					+			1	+	1							+	+	+	
Dactylis glomerata												+	+	1		+	+	+														+			+	1	
Polypodium vulgare subsp. vulgare	+	+						+				+													+							+	+	+			+
Rubia peregrina	+	+	+	+				+			+	+						+										+									
Silene vulgaris							+	+	+	+		+										+				+	+								+		
Anthoxanthum odoratum							+		+	+									+	+	+			1												+	
Festuca ovina												+	+									+					+							+	+		+
Festuca rubra																		+	+	+	+			2			+			1		+					
Pinus sylvestris																+	1								+							+		+		+	1
Stellaria media		+														+	+										+		1				+		+	+	
Achillea millefolium							+	+												+	1	+	+													+	

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Companyes																																					
Vincetoxicum hirundinaria subsp. intermedium													+	+								+	+			+						+			+		
Asplenium trichomanes																		+								+	+	+						+	+	+	
Ruscus aculeatus	+	+	+	+	+							+																	+								
Abies alba						+						+							+		+					+	+										
Populus tremula																	+								1						+		+		+		+
Succisa pratensis						+																										+	+			+	
Dianthus hyssopifolius						+		+																											+	+	+
Valeriana officinalis						+											+												+						+	+	
Asphodelus albus								+												+			+									+					
Hieracium pilosella							+	+	+		+										+																
Rumex acetosa							+		+								+											+								+	
Galium verum																+					+					+										+	
Solidago virgaurea	+																												+		+	+					
Calluna vulgaris									+														+				2			+							
Sedum rupestre										+									+															+		+	
Daphne laureola			+		+					+																										+	
Lotus corniculatus							+														+						+									+	
Lathyrus pratensis																+	+							+	1												
Linaria repens																			+		+	+								+							
Galium aparine												+					+							+					+								
Geranium robertianum																		+	+					+				+									
Potentilla montana						+	+		+	+																											
Saponaria ocymoides																+				+			+			+											
Silene rupestris																					+	+		+			+										
Smilax aspera	+	1	+		+																																
Urtica dioica																					+												+		+	+	
Trifolium pratense																+	+				1			1													
Genista balansae subsp. europaea																				+	+	+															
Arbutus unedo	+	2		+																																	
Biscutella laevigata							+	+		+																											

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Companyes																																					
Campanula rapunculoides																																		+	+	+	
Chamaespartium sagittale																	+						+													+	
Geum urbanum																	+																		+	+	
Euphorbia cyparissias																		+						+	+												
Platanthera chlorantha																	+							+					+								
Polygala vulgaris																				+		+		+													
Origanum vulgare													+													+									+		
Sanguisorba minor																								+		+										+	
Satureja vulgaris																								+											+	+	
Vaccinium myrtillus																							+				4										+
Taraxacum officinale																					+			+				+									
Thymus serpyllum																					+		1			1											
Hypericum perforatum																		+					+														
Campanula patula																		+										+									
Chelidonium majus				+						+																											
Clematis vitalba										+																										+	
Erica scoparia	+			+																																	
Lapsana communis																		+																		+	
Genista triflora	+											+																									
Helianthemum nummularium																+							+														
Hieracium cordifolium																														+	+						
Poa pratensis																					+			+													
Orchis maculata																																				+	+
Ornithogalum ortophyllum subsp. monticolum													+	+																							
Pseudotsuga menziesii						+						+																									
Rubus idaeus																			1																	+	
Saxifraga granulata																								+										+			
Sedum hirsutum																							+				+										
Silene latifolia																																		+		+	
Trifolium ochroleucon																										+										+	

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Companyes																																					
Gentiana lutea																																		+			
Galium maritimum								+																													
Alchemilla alpina																+																					
Antirrhinum asarina																														+							
Arabis hirsuta																																				+	
Arabis turrita																																			+		
Artemisia chamaemelifolia																											+										
Centaurea nigra																							+														
Centaurea pectinata								+																													
Avenula pratensis										+																											
Bryonia cretica L. subsp. dioica L.																																+					
Buddleja davidii																												+									
Bupleurum falcatum																		+																			
Campanula rapunculus																								+													
Carex praecox													+																								
Carex caryophyllea																+																					
Coeloglossum viride																								+													
Cruciata laevipes																								+													
Festuca nigrescens																	+																				
Galium rotundifolium																			+																		
Holcus lanatus																												+									
Peucedanum oreoselinum																+																					
Picea abies																																+					
Plantago lanceolata																																				+	
Plantago media																		+																			
Myrrhis odorata																																	+				
Potentilla rupestris																+																					
Rorippa pyrenaica																			+																		
Ranunculus acris																																+					
Rumex acetosella																					+																

Codi inventari	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Companyes																																					
Salix caprea																																				+	
Sedum telephium																														+							
Veronica arvensis																					+																
Veronica austriaca																																	+				
Veronica spicata																		+																			
Viola bubanii										+																											
Trifolium repens																																				+	

Annex B Còpia de l’article “Current distribution and recent development of sessile oak forests in Montseny (1956-2015)”

LANDSCAPE RESEARCH, 2018
https://doi.org/10.1080/01426397.2018.1472751

Current distribution and recent development of sessile oak forests in Montseny (1956–2015)

Jordi Bou and Lluís Vilar

Institute of the Environment, University of Girona, Girona, Spain

ABSTRACT

There is a distribution limit of sessile oak (*Quercus petraea*) in the northern half of the Iberian Peninsula, with its southernmost populations located at the xeric limit for the species. We present here the current distribution of these populations in the Montseny Massif (N.E. Catalonia) and how the surface area they cover has developed over the last 50 years. Using a new high-resolution map (1:5000) we have calculated that *Q. petraea* currently covers 64.1 ha, and is found between 450 and 1150 m above sea level with a predominantly southern exposure, with the north-facing slopes being dominated by beech forests. With regard to its recent development, 44% of what is now dense forest was, in 1956, much more dispersed while 11% of it consisted of open spaces or shrubs. Such changes clearly show that, in Montseny, *Q. petraea* is well capable of regenerating its forest canopy as well as colonising adjacent environments.

KEYWORDS

Sessile oak; forest dynamics; global change; Montseny

Introduction

Sessile oak forests dominated by *Quercus petraea* are abundant in European forested areas, whereas they are somewhat rare at the southern limit of the species' distribution. But this current distribution can change because there has been reported an acute oak decline in Europe (Hartmann, Blank, & Lewark, 1989; Kotroczó, Veres, Fekete, Papp, & Tóth, 2012; Oleksyn & Przybyl, 1987; Saniga, Balanda, Kucbel, & Pittner, 2014; Thomas, Blank, & Hartmann, 2002). This dynamic is not yet fully understood, probably because it's the consequence of multiple environmental and biotic factors (Eaton, Caudullo, Oliveira, & de Rigo, 2016; Gibbs & Greig, 1997; Siwkcki & Ufnalski, 1998). For this reason, it is very important to study the current distribution and recent development of sessile oak forests along the different regions of Europe, as in the case of the N.E. Iberian Peninsula (Catalonia), where it covers very little surface area. This is probably due to two major factors, the high water requirements of this species and the forestry activity in this region.

In Europe sessile oak forest grows predominantly on slopes and hill tops, with drained and acid soils (Eaton et al., 2016), whereas in the north-east of the Iberian Peninsula it can only be found in humid montane zones, where despite the dry environmental conditions typical of the summer months, there are regular rainy springs and autumns (Bolòs, 1983). In fact, *Q. petraea* has its xeric limit in Catalonia (Bou, Vilar, & Caritat, 2016), in adverse environmental conditions for its biological needs. The xeric limit is considered as the frontier of the distribution of a taxon, beyond which it cannot survive (Mátyás, 2010). In Catalonia, the most important *Q. petraea* forests are concentrated in the areas of *Montseny* and *Les*

CONTACT Jordi Bou jordi.bou.manobens@gmail.com

Guilleries, although they can also be found further north in the Pyrenees. What is relevant about the Montseny massif is that the sessile oak forests, being located further south, are more clearly affected by the aforementioned conditions at the limit of the species' distribution. The study of the climate change effect in them is therefore very interesting.

To understand the current distribution of sessile oak forest, it's very important to consider that the Montseny massif has been exploited since ancient times, through both forestry and agricultural practices (Boada, 2002b). In the second half of the twentieth century, however, such activity changed dramatically with the abandonment of charcoal manufacturing and the increasing spread of conifer plantations (Observatori del Paisatge, 2010). Meanwhile, agricultural and livestock activity has almost completely disappeared and meadows and croplands have been replaced by shrub and forest cover, as has occurred elsewhere along the northern shores of the Mediterranean basin (Ales, Martin, Ortega, & Ales, 1992; Boada, 2002a; Bou Manobens, Àguila, & Gordi, 2015; Debussche, Lepart, & Dervieux, 1999; García-Ruiz et al., 1996; MacDonald et al., 2000; Santos, 2000; UNEP, 1989).

In the context of the acute oak decline it's very important to know the current distribution of sessile oak, to monitor the future dynamics, and at the same time study the recent development of the forest. The Montseny massif is a great case study for this topic, but the existing cartography of the vegetation (Universitat de Barcelona, Generalitat de Catalunya, & Institut d'Estudis Catalans, 2012) and land cover (CREAF, & Generalitat de Catalunya, 2009) as well as earlier efforts (Bolòs, 1983; Llobet, 1947), do not have sufficient resolution to enable us to reliably describe the development of these forests. Hence, in this article, we present a more detailed cartography that allows us, on the one hand, to describe the current distribution of *Q. petraea* in Montseny and, on the other, to carry out a diachronic study of its development by comparing it with aerial images obtained in 1956.

The objectives of this study are, therefore, to analyse the current distribution of sessile oak forests in Montseny and the current surface area they occupy, and analyse if their distribution has changed during the last 60 years and how they have been affected by global change. And as a consequence provide new knowledge on the dynamics of the sessile oak forests in order to anticipate future changes.

Methodology

Area of study

The Montseny massif is located in the north-east of the Iberian Peninsula, ranging from 100 to 1700 m of elevation above sea level. It has a marked climate and vegetation gradient, with different forest types, both deciduous and evergreen, depending on elevation, exposure and relief. Consequently, the massif has a wide diversity of landscape (Bou Manobens, Vilar, & Caritat, 2015) consisting mainly of these diverse forested areas, which cover 86% of the massif (CREAF, & Generalitat de Catalunya, 2009). Due to the high value of the natural heritage of the massif (Boada, 1994), in 1977 Montseny massif was declared a Natural Park and a UNESCO Biosphere Reserve in 1978 (Diputació de Barcelona, 2008). In lithological terms, it is a Palaeozoic massif, with predominantly granite rock in the eastern sector, where most of the forests that concern us here are located. In terms of climate, the study area has a typical montane climate, with a mild summer drought and regular and abundant rainfall (Bou, Caritat, & Vilar, 2015).

Producing the map of the oak forests of 2015

In 2015, we produced a high resolution map (1:5000) of the sessile oak forests in the Montseny area. It was based on existing maps (Bolòs, 1983; CREAF, & Generalitat de Catalunya, 2009; Llobet, 1947; Universitat de Barcelona et al., 2012), but the localisation of the main nuclei of oak forests was carried out via fieldwork. The mapping of the different forests was achieved by taking georeference points using GPS devices and, once the information was collected, the data was processed using GIS software, combined with orthophotographs, from which digital maps of the oak forests were created. All the cartographical information was dealt with using the ESRI ArcMap programme. The maps were drawn

Table 1. Vegetation units considered in the 1956 maps of the oak forests.

Vegetation units in 1956
Dense forests
Sparse forest
Shrublands
Open spaces
Rocks and screes

Table 2. Indices used in the cartographical analysis of the fragmentation of sessile oak forests.

Name of index	Formula	Variables
Patton's shape index (DI)	$DI = \frac{P}{2 * \sqrt{3.1416} * \sqrt{A}}$	*P*: perimeter of each fragment A: area of each fragment
Forest continuity index (FCI)	$FCI = \ln(\sum A / \sum P)$	$\sum A$ = total area of all patches of forest in the study zone (m^2) $\sum P$ = total perimeter of all patches of forest in the study zone (m)
Degree of fragmentation (F)	$F = \sum A / AT$	$\sum A$ = total area of all patches of forest in the study zone (m^2) AT = total area of the study zone (m^2)
Mean distance to nearest neighbouring fragment (MNN)	$MNN = dNN / n^o frag$	dNN = sum of the distances between each fragment and its nearest neighbour (m) n^ofrag = number of fragments

up with the UTM (Universal Transverse Mercator) map projection system using the coordinate reference system ETRS89 (European Terrestrial Reference System 1989), UTM Zone 31T. Since the forest structure of the studied areas is well known (Bou, Vilar, & Caritat, 2015) and we also have information on the composition of the forest and the current diversity, the map produced allows us to study the dynamics of this oak forest in Montseny in detail.

Elaboration of the 1956 map

To learn more about the dynamics of these forest stands, the vegetation units present in 1956 were measured so that a diachronic analysis could then be carried out. The vegetation units that made up the sessile oak stands about 50 years previously were calculated via photo interpretation (using ArcMap GIS, at an approximate scale of 1: 5000) of aerial photographs taken from aeroplanes in 1956 (which had been rectified previously by the Cartographic Institute of Catalonia). Finally, a map was created made up of polygons with attributes for the vegetation corresponding to 1956, in which we have been able to differentiate up to five vegetation units (shown in Table 1), based on the recognisable physiognomy in the images; consequently, comparisons could be made between the two periods mapped. To produce this 1956 map, we considered the sessile oak forests mapped by Llobet (1947) and Bolòs (1983).

Analysis of the cartography

We analysed the fragmentation of the oak forests through time by calculating various indices, each of which was measured using the ArcMap GIS and the different formulas that we explain below (Table 2). We used shape indices since the shape of forest fragments may be a crucial factor in the dynamics of the ecosystems that make up the fragments, with compact forms being more resistant to the effects of the matrix, while amorphous or irregular shapes may have considerably longer perimeters and therefore be more sensitive to the effects of the matrix. Hence, Patton's shape index (Patton, 1975) was calculated which, when equal to 1, indicates a shape that is similar to a circle, while an increasing value indicates a tendency to be irregular in shape.

Table 3. Meaning of possible results of the degree of fragmentation index.

Range F	Degree of fragmentation
1	No fragmentation
1>F≥.7	Moderate fragmentation
.7>F≥.5	Highly fragmented
<.5	Isolated

We also took into account indices based on geographical information systems, such as forest continuity index or the degree of fragmentation. The spatial continuity of the forest was measured using the forest continuity index of Vogelmann (Vogelmann, 1995), FCI, with high values indicating continuity, while low values indicate fragmentation and discontinuity between patches of forest. The degree of fragmentation, F, was calculated by the relationship between the total area of all the patches and the total area of the study zone. Possible values are between 0 and 1 and are interpreted according to Table 3.

The mean distance to the nearest neighbouring fragment (MNN) was calculated by measuring the sum of the distances (in metres) between each fragment with respect to its nearest neighbour, and then dividing the result by the number of fragments. The index is close to 0 when the fragments are close to each other and increases when they are more separated.

Finally, further analyses of the current distribution were carried out with ArcMap GIS, both to calculate which units of the cartography were in contact with the oak forests, as well as to measure which categories of zonification were included, that is, which management category each was under, according to the Special Plan of the Natural Park Montseny (Diputació de Barcelona, 2008). To obtain the perimeter values, the vegetation mapping of Montseny (Bou et al., 2015) was transformed from polygons to lines using ArcToolbox > Data Management Tools > Features > Split Line At Vertices and, having been transformed, the lines in contact with oak forests were selected and the length of these vectors was calculated. Hence, we obtained the perimeter of the oak forests in relation to the unit of the vegetation map that makes contact at each point. To obtain the zonification of the oak forests, we used the park maps (Diputació de Barcelona, 2014) and the ArcToolbox > Analysis tools package.

Results

Current situation of the sessile oak forests

Our new cartography shows that the sessile oak forests of Montseny (Figure 1) cover an area of 64 ha (Table 4), which is well below the 114 ha of sessile oak forest that can be calculated from the most recent general maps of habitats and vegetation of Catalonia (Universitat de Barcelona et al., 2012), despite the fact that our study included oak forests that are not present in this map. One reason for this large discrepancy is that in the map of habitats, the oak stands are often part of larger masses of mixed forest, whereas in our study we have isolated them. We did not study mixed forests in producing our new detailed mapping, since we focused on pure oak stands; however, we estimate that these mixed forests occupy an area of 384 ha, which is slightly higher than the value calculated from the map of habitats (326 ha). Furthermore, there are the stands with a high degree of hybridisation which are yet to be taken into account, in the north-west of Montseny.

The sessile oak forests of Montseny are located between 450 and 1150 m above sea level, with two optimal populations, one at around 550 m, particularly in the *Arbúcies* sector and the other, more preponderant, at around 1000 m (Figure 2). Along the soil catena, the sessile oaks are above the holm oak and below the beech forests. With regard to gradient, there are sessile oak stands in both flat and steep areas, but the majority grow in areas of low incline (mean: 39.1%). Orientation is typically south-east, and sometimes east (Figure 3), since the slopes exposed to the north are dominated by beech. With regard to the substrate, oak forest occurs predominantly on granodiorite (71%), and to a lesser extent, on leucogranite (21%), porphyry (3%) and phyllite and cornubite (5%).

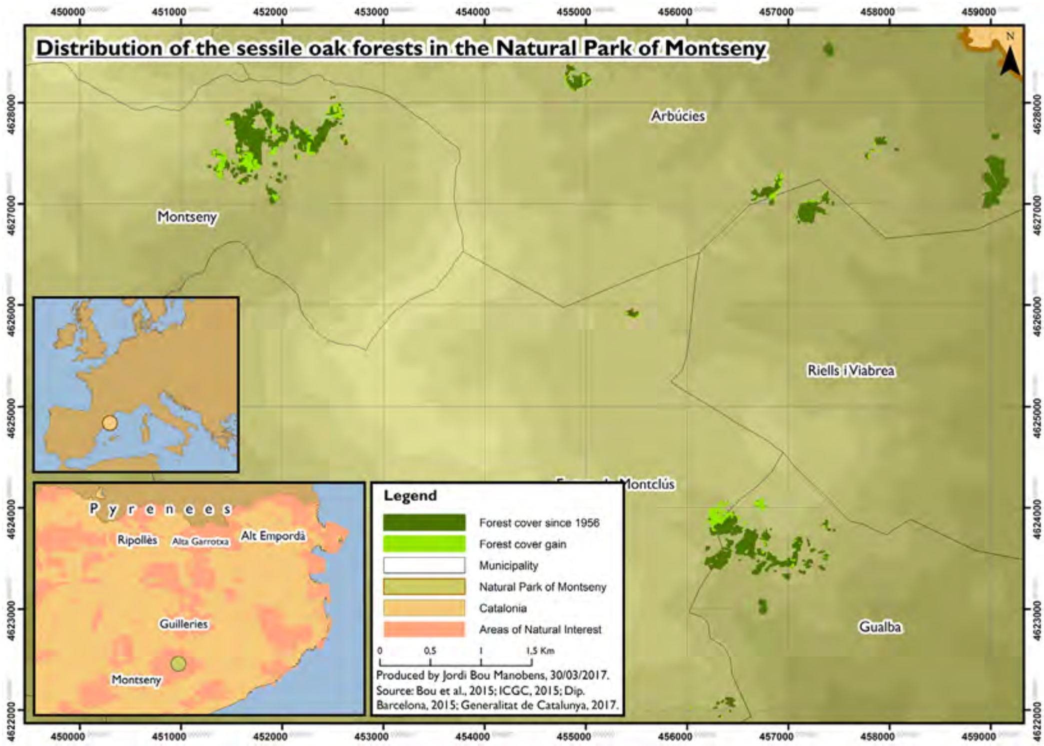

Figure 1. Current distribution and recent development of the sessile oak stands in the Natural Park Montseny. Prepared by the authors. Source: Bou et al., 2015; Diputació de Barcelona, 2014; Generalitat de Catalunya, 2017; Institut Cartogràfic i Geològic de Catalunya, 2015.

Table 4. Area covered by sessile oak forests in Montseny.

Oak forests	Surface (ha)
Mixed forest of sessile oak	384.0
Sessile oak forest	64.1
Mixed forest of *Q. petraea* ssp. *huguetiana*	2.2

As for fragmentation, three large groups of oak forest were found, divided into 182 fragments, with an average area of 3523 m^2. The Patton's shape index show the predominance of rounded or ovate shapes (Table 5) so indicate compact shapes (Table 6). Regarding fragmentation, the patches are isolated from each other, there is a lack of continuity between them, and the density of the patches is low (Table 6). The distance between the patches is not very large, because it does not take into account the huge distances between the three large groups (Table 6).

The results obtained from the analysis with GIS neighbouring polygons in contact with the oak forests (Table 7) show that, normally, the oak stands are contiguous with mixed stands of oak with holm oak, beech or sweet chestnut. They are also often contiguous with roads and forest tracks, although to a lesser extent. It is also common to find shrubs alongside or within the oak forests.

We also calculated the surface area of the oak forests included in the four categories of zonification defined in the Special Plan for the Natural Park of Montseny (Diputació de Barcelona, 2008), and found that more than half were not within the areas of greatest protection (Table 8).

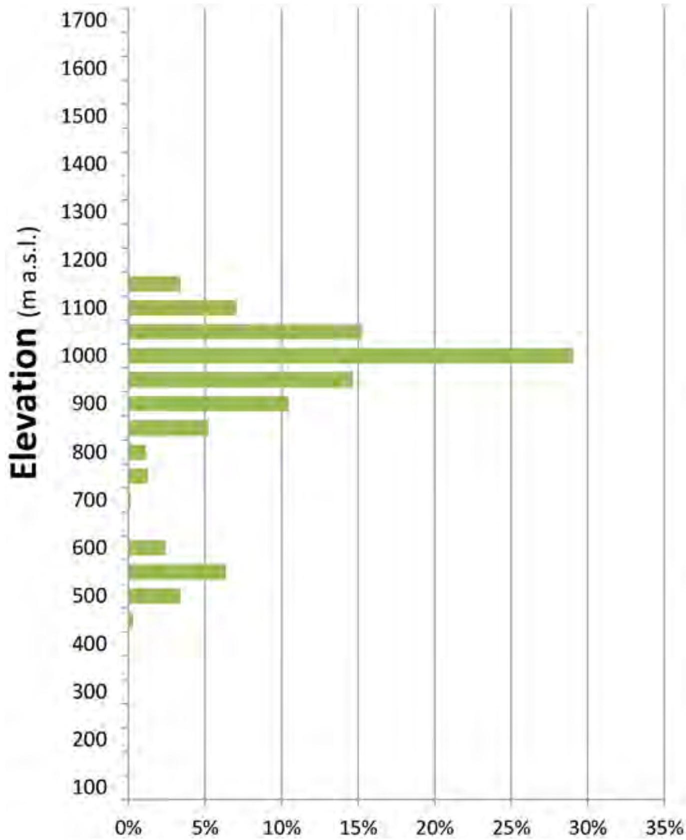

Figure 2. Elevation of sessile oak forests in Montseny.

Development of sessile oak forests

The results show that in 1956, 89% of the current area of oak forest was already established as forest, leaving 11% which can be attributed to expansion of the oak forests over the last 50 years (Table 9). Nevertheless, before assessing the development of these forests, it should be taken into account that, in 1956, 44.3% of the established forest consisted of sparse, low-density forest.

In addition, in 1956 the forest was more fragmented, with 225 patches, and as a consequence there was a higher density of patches and less distance between them (Table 6). The Patton's shape index does not show big differences (Table 5).

Discussion

Current situation

The sessile oak stands are mainly located in the eastern part of Montseny, coinciding with granite substrates, which can produce the sandy soils that are optimum for *Q. petraea*. Most of the stands grow in rocky places, most probably places that were less exploited and/or less suitable for plantations and previously not cultivated. Of particular interest are the stands that grow in less sandy soils, upon phyllite and cornubite (hornfel), since the oak stands on this substrate have a very strong Mediterranean character. This is the case at south of the *Fogars de Montclús* municipality, with a high presence of *Quercus ilex*, or one end of the oak stand at Montseny municipality, where *Quercus pubescens* appears

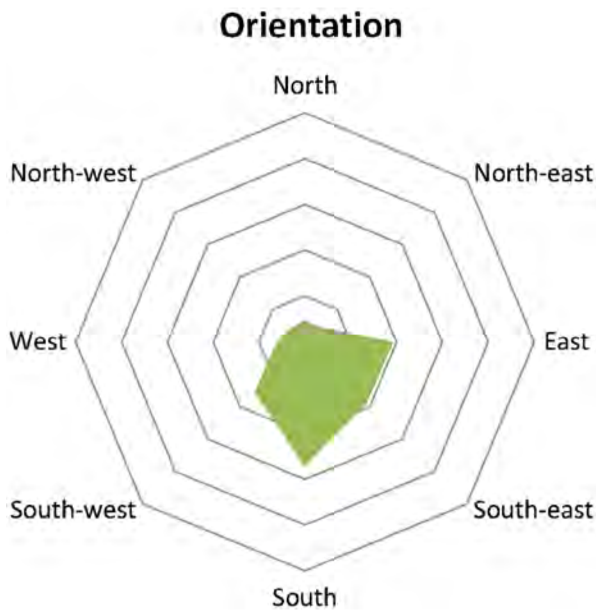

Figure 3. Orientation of sessile oak forests in Montseny.

Table 5. Patton's shape index.

Forma	Range	1956		2016	
		*N*º	Percentage (%)	*N*º	Percentage (%)
Round	<1.25	62	27.6	70	38.5
Oval-round	1.25–1.50	79	35.1	50	27.5
Oval oblong	1.50–1.75	40	17.8	27	14.8
Rectangular	1.76–2	15	6.7	11	6.0
Amorphous/irregular	>2	29	12.9	24	13.2
Total		225	100.0	182	100.0

Note:
Number (*N*º) and percentage of sessile oak forest patches.

Table 6. Calculations of fragmentation and shape indices.

Indices of fragmentation and shape	1956	2015
Forest continuity index FCI	2.44	2.54
Degree of fragmentation F	.001835	.002063
MNN (m)	11.2	14.1
Density of patches (patches/km^2)	.7	.6

(Bou et al., 2015). It seems clear, then, that the metamorphic substrate is not optimal for this forest and we believe that this is a parameter that should be taken into account when modelling potential distributions and population dynamics.

In addition to the substrate, a second determining factor for the sessile oak forests is water availability, since this is a species that does not tolerate summers that go on for too long without rain. Hence, the oaks are found on the montane sector of the eastern massif where climate is more humid, whereas in contrast, they are somewhat rare on the western massif, which is more continental (Bolòs, 1983). At lower elevations, the sessile oaks border with holm oak, while along the higher elevation edge they come into contact with beech, and rarely grow in shady areas even when conditions are highly favourable, because these areas are usually occupied by beech.

Table 7. Perimeter of the oak forests according to the units contiguous with them.

Units contiguous with sessile oak forests	Perimeter of oak forest (m)	Percentage of oak forest perimeter (%)
Mixed forest of sessile oak	22 400.98	44.51
Paths and roads	11 182.02	22.22
Shrublands	4794.76	9.53
Riparian forest	1615.95	3.15
Beech forest	1601.44	3.18
Sweet chestnut forest	1367.60	2.72
Coniferous plantation	1349.37	2.68
Holm oak forest	1243.02	2.47
Aspen stands	972.24	1.93
Mixed deciduous forest	940.59	1.87
Humid forests	915.34	1.82
Hazel formations	554.95	1.10
Rivers and streams	386.38	.77
Rocks and screes	290.34	.58
Oriental plane plantations	150.02	.30
Open spaces	130.69	.26
Ash forest	125.29	.25
Clearings	87.75	.17
Other forest units	70.88	.14
Mixed forest of holm oak and beech	57.45	.11
Poplar galleries	45.56	.09
Douglas fir planted with chestnut tree	40.47	.08
Anthropogenic area	7.22	.01
Total	50 330.29	100

Table 8. The zonification of the park is defined by the Special Plan for Montseny (Diputació de Barcelona, 2008), which defined four different categories (with acronyms in the Catalan language): ZIN, zone of natural interest, which grants basic protection within the terms of the Special Plan; ZRN, nature reserve zone which only allows management that is directly related to the preservation and improvement of the values protected and ZAINEP, zone of high natural, environmental interest and outstanding beauty. The criteria for intervention for each zone is set out in a specific plan, establishing the management criteria. The Urban Zone is an area subject to existing arrangements, in which the residential and urban centres' own rules and regulations apply.

	Sessile oak forest	
Zonification	ha	%
Zone of natural interest	10.40	16.23
Nature reserve zone	26.68	41.64
Urban	.00	.00
Zone of high natural, environmental interest and outstanding beauty	27.01	42.15
Total	64.08	100.00

Table 9. Surface area of vegetation units in the oak forest under study in 1956.

	Surface	
Vegetation units in 1956	ha	%
Dense forests	28.65	44.7
Sparse forest	28.37	44.3
Open spaces	1.27	2.0
Shrublands	5.65	8.8
Rocks and screes	.14	.2
Total	64.08	100.0

The Montseny oak forests have a narrower altitudinal range compared with values for the whole of Catalonia (according to data from the BDBC [Biodivesity Database of Catalonia] for the syntaxa *Teucrio scorodoniae-Quercetum petraeae,* Font, 2013), most likely because they occupy a smaller area, but the most frequent elevations are very similar. As for slope, the range for the whole of Catalonia is similar to that of Montseny, although the average value is slightly higher. The most important difference between

Montseny and the rest of Catalonia is the orientation of the oak forests. In Catalonia as a whole, sessile oak is more commonly found on north facing slopes and, in some cases, north-east or north-west. In Montseny, south facing oak forests are more predominant (61%).

The 64.08 ha of sessile oak forest in the Natural Park of Montseny barely make up .24% of the total forested area of the Park (Table 10; from our own data combined with data from MCSC [Land Cover Map of Catalonia]) which, along with the fact that there is no continuity between forest fragments, means preserving this forest is problematic.

As we have said, there are a high number of oak stands very close to each other, but the fact remains that these large forest units are separated from one another and there are various causes for this separation, some more natural than others. One of the natural reasons for this discontinuity (Table 7) is contact with mixed oak stands (44.51%) which become ecotone areas transitioning to purer stands of other forest species in Montseny, such as beech (3.18%) or holm oak (2.47%), which border with sessile oak; or else, contact with certain habitats that commonly form part of the mosaic of the sessile oak forests, such as riparian forests and the small aspen stands that appear in between.

On the other hand, there is a fragmentation associated with current human impacts as well as impacts from activity carried out decades ago but which have ongoing consequences. Forest tracks and roads, which are contiguous with 22.22% of the oak stands, are good illustrations of this kind of fragmentation. In this case, they give rise to specific problems for some of the oak forests, such as at *Arbúcies*, where half-abandoned forest tracks have been re-established, or at *Fogars de Montclús* where there is a much-frequented paved road that crosses the forest. In fact, there are new threats in this regard even today such as, for example, the forest track of Montseny municipality that runs through an oak forest and which some want to pave (Coordinadora per a la Salvaguarda del Montseny, 2014; Ecologistes en acció, 2014). Other impacts are more specific, such as the Great Forest Fire of 1994 (Bou et al., 2015), where the oak forest at *Gualba* suffered significant damage in terms of forest structure and composition.

Other processes of fragmentation arise from changes in the landscape and the way that these oak forests have developed over the centuries. If we concentrate on the fragmentation itself, we can see in Table 7 that sweet chestnut plantations account for 2.72% of the perimeter of the oak forests, while conifer plantations take up 2.68% (and .08% of Douglas fir planted with chestnut tree). The latter are more detrimental to the connectedness of the oak forests (Bou & Vilar, 2016), since these consist of plantations of Douglas fir (*Pseudotsuga menziesii*), a tree which is an invasive species in Montseny and the surrounding area (Broncano, Vilà, & Boada, 2005). In recent years, plantations of this tree have increased a great deal, and landowners even advise replacing the chestnut plantations with Douglas fir (Tusell & Beltrán, 2016).

In the context of climate change, the fragmented distribution of these forests may constitute an important vulnerability, since the species could be replaced by others that are more resistant to new climatic conditions (Martínez-Vilalta, Piñol, & Beven, 2002; Peñuelas, Lloret, & Montoya, 2001). In the case of Montseny, the fact that *Q. petraea* is at its xeric limit and is already considered to be a species vulnerable to climate change (Benito Garzón, Sánchez de Dios, & Sainz Ollero, 2008; Czúcz, Gálhidy, & Mátyás, 2011), could facilitate colonisation of the sessile oak forests by better adapted species, such as holm oak. In the long-term, this increased interspecific competition may have negative effects on the sessile oak populations.

We therefore believe that the forestry management of the Natural Park should prioritise conservation of the sessile oak forests over other forest masses that occupy much greater surface area by enhancing the maintenance of the pure stands, and even studying the possibility of converting other forests into sessile oak forests, such as some of the chestnut plantations, currently affected by various diseases and parasites. The actual degree of protection depends on the zoning provisions established in the Special Plan of the Natural Park Montseny (Diputació de Barcelona, 2008), which provides the highest degree of protection that can be designated within the park's zones to the 42% of the sessile oak stands, a figure we consider to be low bearing in mind the uniqueness of the forest. For this reason, it would be advantageous that the sessile oak forests of Montseny were not only designated as zones of natural interest (ZIN) or zone of high natural, environmental interest and outstanding beauty (ZAINEP) but

Table 10. Surface area covered by different categories of forest (natural and plantations) at Montseny, in order of size.

Forests	Surface (ha)	%
Holm oak forest	14 081.1	52.40
Beech forest	3585.6	13.34
Cork oak forest	1660.8	6.18
Aleppo pine forest	1620.8	6.04
Sweet chestnut forest	1265.6	4.71
Stone pine forest	1098.0	4.09
Coniferous plantation	783.6	2.928
Riparian forest	731.7	2.72
White oak forest	483.4	1.80
Scots pine forest	452.5	1.68
Mixed forest of sessile oak	384.0	1.43
Mixed deciduous forest	187.7	.70
Ash forest	96.3	.36
Oriental plane plantation	81.1	.30
Sessile oak forest	64.1	.24
Hybrid oak forest	58.2	.22
Poplar plantation	49.4	.18
Mixed forest of hybrid oak	28.6	.11
Other forest units	26.6	.10
Maritime pine forest	20.9	.08
Deciduous plantation	18.8	.07
Fir forests	18.7	.07
Humid forests	14.2	.05
Evergreen plantation	13.5	.05
Hazel formations	9.0	.03
Mixed forest of holm oak and hybrid oak	7.7	.03
Douglas fir planted with chestnut tree	7.0	.03
Mixed forest of alder and black poplar	5.9	.02
Mixed forest of holm oak and cork oak	5.0	.02
Other mixed forest	4.7	.02
Salzmann's pine forests	3.0	.01
Mixed forest of *Q. petraea* subsp. *huguetiana*	2.2	.01
Aspen stands	1.8	.01
Mixed forest of beech and holm oak	.8	<.01
Quercus rubra plantation	.6	<.01
Mixed forest of sweet chestnut and holm oak	.1	<.01
Poplar galleries	.1	<.01
TOTAL	26 874.4	100

Source: own data combined with data from MCSC [*Land Cover Map of Catalonia*].

should be considered natural reserve zones (ZRN), and some should even be designated as Integral Natural Reserve.

Evolution of the land cover

It is known that Montseny is a massif with a long history of forestry, dating back to the Middle Ages, when oak was used for shipbuilding (Illa, Font, & Arrizabalaga, 2011). This means the forest landscape of the massif is different from what it was in the past, with some species like chestnut being encouraged over others like sessile oak (Panadera & Nuet, 1986), according to the interests and needs of the moment. This continuous alteration of the environment makes it difficult to know with any certainty the extent of the sessile oak forests historically and whether the rather unusual current distribution in such a narrow strip between the holm oak and the beech is natural or the product of human activity.

Regarding the evolution of the oak forests during the last half of the twentieth century, from the results we can say that most (89%) were already areas of forest. It must be pointed out, however, that nearly half of this forested area consisted of scattered trees or low density forest (44.3%). This is because during the first half of the twentieth century, these forests had been exploited, both for timber and charcoal, as evidenced by the charcoal piles found in the area. Also, we must take into account the use of the undergrowth for pasture, which was the case until recently of the oak forests of *Fogars de Montclús*. This whole succession of human activity was reduced in the middle of the last century, as rural areas were abandoned leading to the densification of sessile oak forests in Montseny. This shows that this tree has a capacity for regeneration and growth since, under the right conditions, it has been able to take on a dominant role in the composition of the forest, in the face of competition by other trees that are more resistant to conditions of drought and high temperatures of the Mediterranean. A good example of this process is the sessile oak forest at Montseny municipality, where much of the forest area was once sparse, but is today made up of dense forest. In this area, there are still a large number of pioneer species such as hazel or maple, typical of the intermediate stage in oak forest recovery (Bou et al., 2015). Furthermore, 11% of the current oak forests were once scrub or open spaces and in some cases, even rocky terrain. It is already widely known that sessile oak is well suited to rocky terrain, although we should mention the increase in holm oak also observed in these zones (Bou et al., 2015). The changes in areas that were formerly croplands or scrub and which, over the years, have become sessile oak forests is highly interesting. Such areas are proof of the capacity for expansion these forests have (12.38% increase since 1956), and show that sessile oak forests have followed a pattern similar to other forests in the massif and in neighbouring territories.

As a consequence of this dynamic, the distribution of sessile oak forest has changed since 1956. In the past it was more isolated and fragmented, but the expansion of the forest has joined close patches, making more compact shapes, and as a result a more resistant forest.

Although the existing data on increased forest cover in the neighbouring territories around Montseny is not of the same detail as the data on *Q. petraea*, more global studies also indicate a general increase in forest cover. For example, between 1970 and 2007 in the neighbouring province of *Girona*, forest cover has increased by 14% (Gordi, 2009), which is slightly higher than the value calculated for the sessile oak in Montseny, in part because it took into account the whole forest landscape. Studies in north-west of the county of *Alt Empordà* dealing with a period similar to our study, from 1957 to 1989, estimated that forest cover in *Alta Garrotxa* increased by 28.9%, while thickets have decreased in area by 17% (Vila, 1999). Thus the data reflects that, although the Montseny sessile oak forests have increased in surface area in line with other forests in the territory, this increase has not been particularly high or exceptional, as is the case for other forests, such as those of *Alta Garrotxa*.

As for Montseny itself, although the available data (Boada, 2002b) does not cover the same period, they do show very interesting variation of the area of forest cover between 1945 and 1995. In general terms, over that 50-year period, the surface area of beech had decreased quite considerably (−17.94%), while that of holm oak (20.14%) and chestnut (17.9%) increased markedly. From this we can say that, in general, the conditions for the development of sessile oak forests in Montseny appear to have been quite favourable. The increase in the surface area of sessile oak forests in recent years—despite the processes of Mediterranization that Boada (2002b) describes in his thesis—is doubtless due to their adaptability and resilience. While this increase is not as marked as that of the holm oak forests, which are even more resistant to drought (Banqué, Grau, Martínez-vilalta, & Vayreda, 2013), the increase in sessile oak is clear, which is not the case with the beech forests which are less resistant to drought (Banqué et al., 2013). There are also a number of anthropogenic interventions that have favoured monospecific plantations, including sweet chestnut, which has increased greatly, or the more recent plantations of Douglas fir (Bou & Vilar, 2016). Such activities have been altering the Montseny forest landscape for centuries and will certainly have displaced the natural forests, such as those of sessile oak, to such an extent that today, we cannot know with any certainty the past distribution of the forest.

Conclusions

The sessile oak forest of Montseny only occupies an area of 64.08 ha. Unlike the Pyrenees or other southern European massifs with conditions similar to Montseny, these oak forests not only occupy a small area, but are located in a narrow strip between zones of holm oak and the zones of beech; specifically, at elevations between 450 and 1150 m, coinciding with relatively rainy zones, which allow the development of deciduous forests. In addition, at Montseny, the sessile oak forests are only optimal in granite and, above all, granodiorite.

In order to find out whether this situation is typical of the natural dynamics of this species, further studies are needed focusing on modelling the distribution of *Q. petraea*, to find out what the potential distribution would have been in antiquity. It seems clear that the oak would have dominated more surface area, since during the last 50 years (during which human intervention has decreased) the sessile oak stands have increased in extension. But it seems unlikely that the narrow strip in which sessile oak grows in Montseny could be much greater than it is at present, because the southern situation of the massif, without harsh winters, favours sclerophile trees, especially holm oak, while on the northern slopes, where there is enough moisture for deciduous species, the beech dominates, leaving the sessile oak constricted to a narrow margin between these two types of forest. The combination of these factors are the key to understanding the past and present distribution of sessile oak in Montseny and should therefore be included in future studies modelling this species.

The sessile oak forests observed in this study are divided into three major sectors in the eastern sectors of Montseny and can be subdivided into a total of 182 patches. This very fragmented distribution of rounded and compact stands, with a high degree of discontinuity is probably due to human exploitation of the forest over many centuries. This situation in Montseny means forests are vulnerable to disturbance or other impacts, such as the presence of invasive species and problems driven by climate change which could eventually lead to serious problems for conservation, reducing the extension of sessile oak in the area. We therefore need to increase protection and implement measures to enhance their recovery and conservation.

With regard to their recent development, the sessile oak stands have densified over the past 50 years. The study carried out has revealed that 50% of the forest that already existed has gone from being dispersed to being dense forest. We also detected an expansion in total forest area, with 11% of the current surface being the result of colonisation of adjacent areas. Thus, when human pressure decreases, the oak forests are capable of expanding and densifying. This contrasts with the decline found by Boada in the other deciduous species, namely beech, *Fagus sylvatica*, which indicates that, if the sessile oak stands receive adequate protection, they could well manage to expand in the future. This is a very important finding since, if the beech forests end up being affected negatively by climate change, this may eventually benefit not only the expansion of holm oak, but also the expansion of the neighbouring sessile oak as it makes incursions into areas currently dominated by beech.

Acknowledgements

We would like to thank the *Parc Natural del Montseny*, for their logistical assistance during the summer of 2015 and the *Diputació de Girona* for their financial assistance in the study of the forests of sessile oak, *Quercus petraea*, in Montseny, which led to the production of the current map of the oak forests used here.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Jordi Bou http://orcid.org/0000-0001-9454-8023
Lluís Vilar http://orcid.org/0000-0002-5035-585X

References

Ales, R. F., Martin, A., Ortega, F., & Ales, E. E. (1992). Recent changes in landscape structure and function in a mediterranean region of SW Spain (1950–1984). *Landscape Ecology, 7*, 3–18.

Banqué, M., Grau, A., Martínez-vilalta, J., & Vayreda, J. (2013). *CANVIBOSC: Vulnerabilitat de les espècies forestals al canvi climàtic*. Barcelona.

Benito Garzón, M., Sánchez de Dios, R., & Sainz Ollero, H. (2008). Effects of climate change on the distribution of Iberian tree species. *Applied Vegetation Science, 11*(2), 169–178. doi:10.3170/2008-7-18348

Boada, M. (1994). El massís del Montseny. In *Montseny, incerta glòria* (pp. 427–464). Sant Celoni: Plataforma d'Entitats Cíviques del Montseny (PECM).

Boada, M. (2002a). *El Montseny: Cinquanta anys d'evolució dels paisatges*. (CESPA GR, Ed.). Barcelona: Publicacions de l'Abadia de Montserrat.

Boada, M. (2002b, February 26). *Manifestacions del canvi ambiental global al Montseny*. Universitat Autònoma de Barcelona.

Bolòs, O. (1983). *La vegetació del Montseny*. Barcelona: Diputació de Barcelona.

Bou Manobens, J., Àguila, V., & Gordi, J. (2015). L'evolució del paisatge forestal (1950–2013) a l'Alt Empordà. *AIEE, 46*, 343–368. doi:10.2436/20.8010.01.185

Bou Manobens, J., Vilar, L., & Caritat, A. (2015). Estudi de la transició del bosc de Quercus petraea al bosc de Quercus ilex al paratge de Marmolers (Parc Natural del Montseny). *Orsis, 29*, 1–17.

Bou, J., & Vilar, L. (2016). Fitxa InvasIBER de Pseudotsuga menziesii. Retrieved April 13, 2017, from http://invasiber.org

Bou, J., Caritat, A., & Vilar, L. (2015). Litterfall and growth dynamics relationship with the meteorological variability in three forests in the Montseny natural park. *Folia Forestalia Polonica, 57*(3), 146–160. doi:10.1515/ffp-2015-0015

Bou, J., Vilar, L., & Caritat, A. (2015). *Estudi de les rouredes de Quercus petraea al Parc Natural del Montseny*. University of Girona: Girona.

Bou, J., Vilar, L., & Caritat, A. (2016). La roureda de roure de fulla gran. *Revista de Girona, 294*, 62–65.

Broncano, M. J., Vilà, M., & Boada, M. (2005). Evidence of Pseudotsuga menziesii naturalization in montane Mediterranean forests. *Forest Ecology and Management, 211*(3), 257–263. doi:10.1016/j.foreco.2005.02.055

Coordinadora per a la Salvaguarda del Montseny. (2014). Excursió reivindicativa contra la construcció de la carretera Illes-Sant Marça. Retrieved from http://www.salvaguardamontseny.cat

CREAF, & Generalitat de Catalunya. (2009). Mapa de cobertes del sòl de Catalunya. Retrieved from http://www.creaf.uab.es/mcsc/

Czúcz, B., Gálhidy, L., & Mátyás, C. (2011). Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. *Annals of Forest Science, 68*(1), 99–108. doi:10.1007/s13595-011-0011-4

Debussche, M., Lepart, J., & Dervieux, A. (1999). Mediterranean landscape changes: Evidence from old postcards. *Global Ecology and Biogeography, 8*(1), 3–15. doi:10.1046/j.1365-2699.1999.00316.x

Diputació de Barcelona. (2008). *Pla especial de protecció del medi natural i del paisatge del Parc Natural de Montseny*. (Oficina Tècnica de Planificació i Anàlisi Territorial de l'Àrea d'Espais Naturals de la Diputació de Barcelona, Ed.). Diputació de Barcelona, Diputació de Girona.

Diputació de Barcelona. (2014). Parc Natural de Montseny. Retrieved from http://parcs.diba.cat/web/montseny

Eaton, E., Caudullo, G., Oliveira, S., & de Rigo, D. (2016). Quercus robur and Quercus petraea in Europe: Distribution, habitat, usage and threats. In J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, & A. Mauri (Eds.), *Quercus robur and Quercus petraea in Europe: Distribution, habitat, usage and threats* (pp. 160–163). Quercus robur and Quercus petraea in Europe: distribution, habitat, usage and threats.

Ecologistes en acció. (2014). Montseny: Concentració contra la construcció de la carretera Illes-Sant Marçal. Retrieved from http://www.ecologistasenaccion.org

Font, X. (2013). Banc de Dades de la Biodiversitat de Catalunya.

García-Ruiz, J. M., Lasanta, T., Ruiz-Flano, P., Ortigosa, L., White, S., González, C., & Martí, C. (1996). Land-use changes and sustainable development in mountain areas: A case study in the Spanish Pyrenees. *Landscape Ecology, 11*(5), 267–277. doi:10.1007/BF02059854

Generalitat de Catalunya. (2017). gencat.cat. Retrieved March 31, 2017, from http://www.gencat.cat/

Gibbs, J. N., & Greig, J. W. (1997). Biotic and abiotic factors affecting the dying back of pedunculate oak Quercus robur L. *Forestry, 70*(4), 399–406. doi:10.1093/forestry/70.4.399

Gordi, J. (2009). *L'Evolució del paisatge forestal a les terres gironines a la segona meitat del segle XX*. Girona: Associació d'Història Rural de les Comarques Gironines.

Hartmann, G., Blank, R., & Lewark, S. (1989). Eichensterben in Norddeutschland—Verbreitung, Schadbilder, mögliche Ursachen. *Forst Und Holz, 44*(18), 475–487.

Illa, J., Font, G., & Arrizabalaga, A. (2011). L'explotació forestal a Arbúcies per la construcció de galeres (s. XVI i XVII). *Monografies Del Montseny, 26*, 74–89.

Institut Cartogràfic i Geològic de Catalunya. (2015). ICGC VISSIR. Retrieved from http://www.icc.cat

Kotroczó, Z., Veres, Z., Fekete, I., Papp, M., & Tóth, J. A. (2012). Effects of Climate Change on Litter Production in a Quercetum petraeae-cerris Forest in Hungary. *Acta Silvatica et Lignaria Hungarica, 8*(1), 31–38. doi:10.2478/v10303-012-0003-6

Llobet, S. (1947). *El Medio y la vida en el Montseny: Estudio geográfico*. Barcelona: CSIC. Instituto Juan Sebastián Elcano.

MacDonald, D., Crabtree, J. R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., … Gibon, J (2000). Agriculture abandonment in mountain areas of Europe: environmental consequences and policy response. *Journal of Environmental Management, 59*(1), 47–69. doi:10.1006/jema.1999.0335

Martínez-Vilalta, J., Piñol, J., & Beven, K. (2002). A hydraulic model to predict drought-induced mortality in woody plants: An application to climate change in the Mediterranean. *Ecological Modelling, 155*(2–3), 127–147. doi:10.1016/S0304-3800(02)00025-X

Mátyás, C. (2010). Forecasts needed for retreating forests. *Nature, 464*(7293), 1271–1271. doi:10.1038/4641271a

Observatori del Paisatge. (2010). *Comarques Gironines: Catàleg del paisatge*. (J. Nogué i Font, P. Sala i Martí, Departament de Territori i Sostenibilitat, & Observatori del Paisatge, Eds.) (1a ed., Vol. 1). Generalitat de Catalunya.

Oleksyn, J., & Przybyl, K. (1987). Oak decline in the Soviet Union—Scale and hypotheses. *Forest Pathology, 17*(6), 321–336. doi:10.1111/j.1439-0329.1987.tb01325.x

Panadera, J. M., & Nuet, J. (1986). Les Castanyedes al Montseny. *Ausa, 12*(116), 65–78.

Patton, D. R. (1975). A diversity index for quantifying habitat edge. *Wildlife Society Bulletin, 3*, 171–173.

Peñuelas, J., Lloret, F., & Montoya, R. (2001). Severe drought effects on mediterranean woody flora in Spain. *Forest Science, 47*(2), 214–218.

Saniga, M., Balanda, M., Kucbel, S., & Pittner, J. (2014). Four decades of forest succession in the oak-dominated forest reserves in Slovakia. *iForest—Biogeosciences and Forestry, 7*(5), 324–332. doi:10.3832/ifor0996-007

Santos, C. C. P. (2000). Succession of breeding bird communities after the abandonment of agricultural fields in southeast Portugal. *Ardeola, 47*(2), 171–181.

Siwkcki, R., & Ufnalski, K. (1998). Review of oak stand decline with special reference to the role of drought in Poland. *Forest Pathology, 28*(2), 99–112. doi:10.1111/j.1439-0329.1998.tb01171.x

Thomas, F. M., Blank, R., & Hartmann, G. (2002). Abiotic and biotic factors and their interactions as causes of oak decline in Central Europe. *Forest Pathology, 32*(4–5), 277–307. doi:10.1046/j.1439-0329.2002.00291.x

Tusell, J. M. & Beltrán, M. (Eds.). (2016). *XXXIII Jornades Tècniques Silvícoles Emili Garolera*. Santa Coloma de Farners: Consorci Forestal de Catalunya.

UNEP. (1989). *State of the Mediterranean marine environment*. Athens.

Universitat de Barcelona, Generalitat de Catalunya, & Institut d'Estudis Catalans. (2012). Mapa de vegetació de Catalunya.

Vila, J. (1999). *Anàlisi i valoració dels boscos de les valls d'Hortmoier i Sant Aniol*. Universitat de Barcelona.

Vogelmann, J. (1995). Assessment of Forest Fragmentation in Southern New England Using Remote Sensing and Geographic Information Systems Technology. *Conservation Biology, 9*(2), 439–449.

Annex C Informació adicional de l'article "The effect of past forestry activity on Mediterranean sessile oak forests on the NE Iberian Peninsula"

Ref	Locality	UTM 31N	n	Annual rainfall[1] mm	Mean temp[1] ºC	Min. temp[1] ºC	Max. temp[1] ºC	Solar radiation 10 kJ/ (m^2*dia* micrometer)[2]	Dominant aspect	Mean altitude m a.s.l.	Mean slope
COR	Can Corbera	DG 6723	17	955.3	15.6	5.9	10.7	1536	South	992.7	13.9%
ClIM	Collet de Malcompàs	DG 6827	3	953.3	15.2	6.0	10.5	1357	East	940.5	3.7%
GU	el Guacs	DG 7927	1	913.0	16.4	6.6	11.5	1297	Southeast	785.0	15.0%
PUIG	el Puig	DG 2127	2	979.7	14.0	5.6	9.8	1519	South	1049.5	15.0%
TER	el Terrers	DG 1927	2	950.4	14.4	5.9	10.2	1477	Southeast	992.5	20.2%
FTLL	Fontdellops	DG 9027	10	855.8	17.9	7.3	12.6	1178	Northeast	579.5	6.6%
G	Graners	DG 4828	3	969.7	14.7	5.9	10.3	1251	Northeast	1001.2	2.2%
M	Marmolers	DG 7226	6	934.8	15.6	6.2	10.9	1471	Southwest	898.5	1.7%
R	Ridaura	DG 6322	1	955.9	16.4	6.1	11.2	1490	South	933.3	15.0%
RM	Roureda del Maçaners	DG 5425	1	993.3	13.4	5.3	9.3	1444	South	1178.0	0.5%
StM	Sant Marçal	DG 1727	12	990.8	13.9	5.5	9.7	1469	East	1091.1	10.6%

Table S1. Geographic characteristics of sessile oak forests localities studied in Montseny massif. The number of stands in each locality is indicated "n". 1Climatic variables were estimated using a georeferenced model (Ninyerola et al., 2000). 2Solar radiation was estimated using a georeferenced model (Pons, 1996).

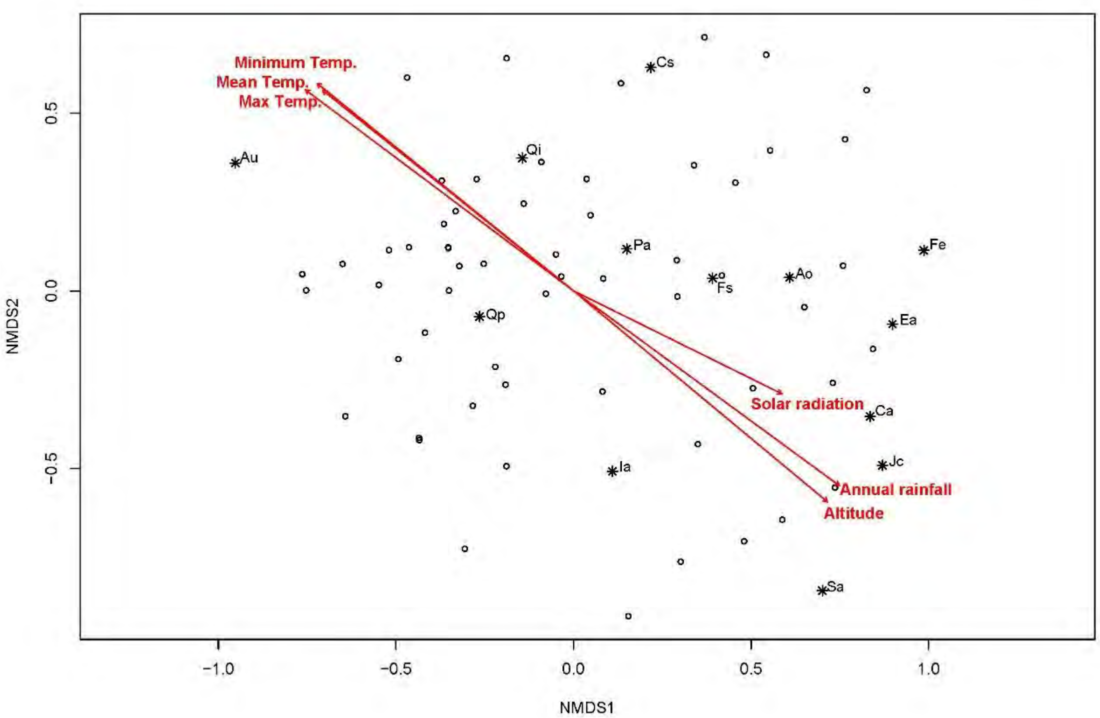

Figure S1. NMDS plot showing stands according to their basal area for each species. The environmental factors with a significant effect (p≤0.05) are represented by arrows: minimum temperature, mean temperature, max temperature, solar radiation, annual rainfall, and altitude. Acronyms for tree species: **Cs** (*C. sativa*), **Au** (*A. unedo*), **Qi** (*Q. ilex*), **Qp** (*Q. petraea*), **Pa** (*P. avium*), **Fs** (*F. sylvatica*), **Ao** (*A. opalus*), **Fe** (*F. excelsior*), **Ea** (*E. arborea*), **Ca** (*C. avellana*), **Ia** (*I. aquifolium*), **Jc** (*J. communis*) and **Sa** (*S. aria*).