CANVIBOSC: Vulnerability of forest species to climate change

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Observed and forecast impacts on the most common tree species in Catalonia

INTRODUCTION:

1.- Objectives

The following fact sheets constitute a metadata extraction that aims to explain and summarise the most recent scientific information published on the observed impacts on the main tree species in the face of the greatest threats foreseen in the context of climate change: **drought, pest outbreaks and forest fires**.

The objective of these fact sheets was to make the most exhaustive extraction of the scientific bibliography available up to the end of 2012 or the middle of 2013 (depending on each individual case). For each species the date of the search has been established, since articles are published in scientific journals at breakneck speed and new ones are constantly appearing. As far as possible a process has been adopted for the digesting scientific information and translating it into a non-scientific, comprehensible language. A second, equally important objective was to identify gaps in our knowledge, areas on which no scientific information is currently available.

This compilation of information is designed to be useful in designing preventive and corrective policies and actions in forest management and for dealing with the threats and vulnerabilities of climate change.

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2.- Methodology

2.1.-Bibliographic metadata extraction and statements

In order to create the bibliography, articles were chosen using the scientific article search website, 'Web of knowledge' (http://wokinfo.com/). This research platform allows for filtered searches with keywords. Three parameters were chosen to filter as keywords: the species, the geographical area studied in the article, and the predicted impact: drought / fire / pest outbreak.

The **species** chosen are the 9 most widespread in Catalonia according to the Mapa de Cobertes del Sòl de Catalunya [Soil Cover Map of Catalonia]:

Table 1: Common name, scientific name and the area occupied for each of the 9 selected species,.

Common name		Scientific name	Area (ha)	% of the total forest
Holm oak		*Quercus ilex*	226,461	17.22
Cork oak		*Quercus suber*	66,542	5.06
European beech		*Fagus sylvatica*	33,514	2.55
Aleppo pine		*Pinus halepensis*	300,912	22.89
European black pine		*Pinus nigra*	119,322	9.07
Mountain pine		*Pinus uncinata*	65,404	4.97
Stone pine		*Pinus pinea*	34,750	2.64
Scots pine		*Pinus sylvestris*	212,227	16.14
Oaks (*)	Downy oak	*Quercus humilis*	145,798	7.30
	Portuguese oak	*Quercus faginea*		3.16
	Sessile oak	*Quercus petraea*		0.39
	Pedunculate oak	*Quercus robur*		0.23

(*) These 4 species have been combined in a single group.

The **study area** was defined within Spain, provided that a reasonable number of studies had been carried out in this area. This area was extended to the entire Iberian Peninsula in the case of the cork oak, given the large number of studies on this species that have been conducted in Portugal. And for the species that are not present in large number in Catalonia and Spain, the area was extended to cover the entire Mediterranean Basin.

The impacts adopted as keywords are: *drought*, *fire* (the term *wild fire* excluded many of the articles) and *pest* or *outbreak*.

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The initial selection for each of the species was made using the combination of these keywords. Once the initial search was completed, articles were eliminated that, judging by the title and the summary, did not deal with vulnerability to drought, fires or pest outbreaks. This pre-selection provided the articles that were then used to compile data. Table 2 specifies the data on each of the searches, the number or articles left after the initial selection and the keywords used.

Table 2: Common name, search date, number of articles read and keywords used in the search for the 9 selected species.

Species	Search date	No. of articles	Keywords used in the search
Holm oak	2 -12-12	77	*Quercus ilex*, Spain, drought / fire / pest/ outbreak
Cork oak	14-1-13	81	*Quercus suber*, Mediterranean, drought / fire / pest / outbreak
European beech	6-2-13	43	*Fagus sylvatica*, Mediterranean, drought / fire / pest / outbreak
Aleppo pine	25-1-13	89	*Pinus halepensis*, Spain, drought / fire / pest / outbreak
European black pine	29-1-13	58	*Pinus nigra*, Mediterranean, drought / fire / pest / outbreak
Mountain pine	7-2-13	30	*Pinus uncinata / Pinus mugo*, Mediterranean, drought / fire / pest / outbreak
Stone pine	28-1-13	31	*Pinus pinea*, Spain, drought / fire / pest / outbreak
Scots pine	14-10-12	35	*Pinus sylvestris*, Mediterranean/ Spain, drought / fire / pest / outbreak
Oaks	5-2-13	84	*Quercus humilis / Quercus petraea / Quercus faginea / Quercus robur* , Mediterranean, drought / fire / pest / outbreak / parasites / infestation / coleopteran / insect / infection / blight

Some of the articles, once read, were rejected because it was impossible to use them to extract useful or relevant information for our purposes. The main ideas and results were extracted from the articles, classifying them in accordance with whether the impacts were on the growth, mortality or regeneration of trees. The statements were composed based on this information, keeping to the original articles as faithfully as possible, but using non-scientific, everyday language, which did not always allow the precision or details of the results to be retained. Thus, this adapted version of the information involved a certain degree of simplification, which led to a loss of precision.

Therefore, the bibliography finally used for each species contains the articles specified in the 'Selected articles' column in Table 3. This is listed separately at the end of each of the fact sheets.

Table 3: Common name, number of articles read and number of articles selected for the 9 species.

Species	Articles read	Articles selected
Holm oak	77	70
Cork oak	81	69
European beech	43	28
Aleppo pine	89	61
European black pine	58	46
Mountain pine	30	28
Stone pine	31	27
Scots pine	35	29
Oaks	84	50
Totals	**528**	**408**

For the articles dealing with very similar subjects, an attempt was made to unify the statements, so that a single sentence may come from several articles. The information contained in these sentences has been reflected and summarised in the infographics.

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2.2.- Infographics

Infographics are graphic representations that aim to summarise and facilitate the understanding of information (see Figure 1). The infographic has three differentiated, intersecting areas (circles): one for drought, one for forest fires and one for pest outbreaks, and in each one there is a table to show the effects on the **growth**, **mortality** and **regeneration** of trees. The numbers of each cell correspond to the sentences referring to the effect of droughts, fires and pest outbreaks reported in the selected bibliography. The lines correspond to additional factors that can worsen (darker colour) or decrease (lighter colour) the negative effect of the impact. Some of these factors refer to climate aspects such as precipitation and temperature. Others refer to the characteristics of the location where the trees are found: altitude, soil depth, erosion and adverse topography, which contain all the variables that determine the availability of water. And others refer to the structure of the forest and the characteristics of the trees: the competition, size and quantity of their reserves. The first line is reserved for statements on the impact without referring to any additional factors. All these elements make up the complex table contained in each circle. (See Figure 1)

In general, each infographic is a pinkish or reddish colour, since droughts, fires and pest outbreaks, due to their individual impacts, all have a negative impact on growth, mortality and regeneration. Thus, the basis already constitutes a negative effect and the colour reflects this. The effect of two of the impacts together, for example fires and pest outbreaks, greatly worsen the situation of the forests. Thus, the colour of the intersection between the two circles is darker.
On the line where there are additional factors, the colours indicate whether the impact is slight (colour lighter than the background colour of the circle), moderate (colour the same as the background), serious (colour darker than the background), or very serious (much darker colour). In this case the colours are determined by the particularities of each species with regard to growth, mortality and regeneration. For example, a species that is highly resistant to drought will have a colour lighter or the same as the background colour of the circle since, although it is affected by drought, it has resources that give it a certain degree of resistance or resilience. A species that finds it hard to regenerate after disturbance will be darker than the background, since the particularities of the species make it more vulnerable to this possible impact.

On the lines with additional factors the colours determine whether the negative effect of the impact decreases or worsens as a result of each of the factors. The lightest colour indicates that the factor mitigates the effect of drought, fires or pest outbreaks on growth, mortality or regeneration. If the colour is the same as the background, the factor does not change the effect of the impact. If the colour is darker, the factor worsens the effect. If the additional effect is very negative, the colour is even darker.

In some cases there may be several different colours in the same circle. There is no scientific consensus on these issues. Different sources, different experimental designs, different contexts and study areas can give rise to conflicting results.

Some particularities of the statements:

• Each number on the infographic corresponds to a sentence in the bibliographic metadata extraction. There are statements that could not be placed in the infographic. However, because the information was considered relevant, it was decided they should be kept. These sentences that are not displayed in the infographics, have been written in italics in order to indicate this fact.

• Some statements represented in the infographics need to be read indirectly or interpreted in order to understand where they have been placed. The sentence does not discuss one of the

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factors of the infographic directly, but rather refers to another related factor.

For example, statement 5 of the fact sheet on the Aleppo pine says, '*The soil moisture is positively related to photosynthesis levels*'. This statement does not refer directly to any of the additional factors in the infographic. On the other hand, it infers that the soil moisture is related to the following factors: less precipitation, thin and compact soils (lower capacity for water retention), and adverse topography (it is the combination of factors that reduces water availability).

• Some sentences are placed within drought (or fire or pest outbreak) circles although the text does not deal with drought or any additional factor. This is because the context of the original article situates the results within the framework of drought (or fires or pest outbreaks). The article discusses drought, despite the fact that the specific sentence does not mention it, or even gives a result in drought-free conditions.

• Drought can be determined directly by lower precipitation, which means that the trees suffer greater water stress, and they also suffer due to the direct effect of a rise in temperature, since, if it is hotter, the evapotranspiration from the leaves is higher and thus the water requirements also increase. Logically, the interaction of the two variables, lower precipitation and higher temperature, mean that the trees experience even greater water stress.

2.3.- Topo-climatic suitability atlas

This atlas (Ninyerola et al. 2009) is defined as a series of maps that allow us to determine to what extent the main tree species that make up the forests are adapted to the climatic and topographic conditions. With these maps, it is possible to know their suitability in any part of the Iberian Peninsula, with the levels ranging from zero (low suitability) to 1 (maximum suitability). Moreover, these values can be consulted for the current climatic scenario (1950-1998), as well as for future projections, using the scenarios proposed by the Hadley Centre (A1FI and A2 socio-economic storylines).

The report presents the predicted topo-climatic suitability for an A2 storyline. A2 is one of the IPCC's (Intergovernmental Panel on Climate Change) standard scenarios, which presents the effects of high economic and demographic growth on the climate, with an average global temperature rise of 3.5% by the end of the century in comparison with the reference period.

In the Atlas, suitability is considered to be the series of topographic and climatic conditions in which a species currently lives, which are similar to the observed niche.

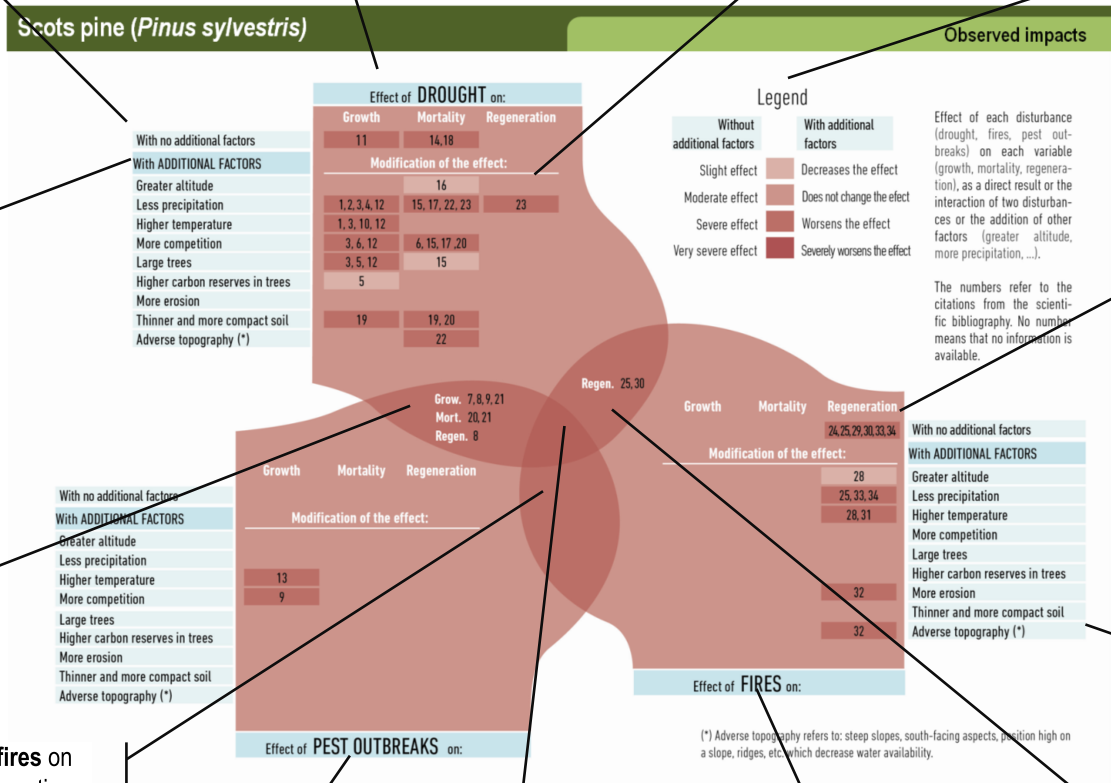
The fact sheets present the current suitability (for the period 1950-1998) and the projected suitability in an A2 storyline for the period 2050-2080, regrouped into 9 categories ranging from 0 (lowest suitability) to 1 (highest suitability).

For more information on the topo-climatic suitability atlas, please consult:

Ninyerola, M., Serra-Diaz, J., Lloret, F. 2009. Atlas de idoneidad topo-climática de leñosas. [Topo-climatic suitability atlas for woody plants] http://www.opengis.uab.cat/IdoneitatPI/ Consulted in May 2013.

Observed and forecast impacts on the most common tree species in Catalonia

Figure 1: **HOW ARE INFOGRAPHICS INTERPRETED?**



Species name

Impact of **DROUGHT** on growth, mortality and regeneration

Cells

Legend for the cells:
Left: With no additional factors the colours range from slight impact (light colour) to a very serious impact (dark colour)
Right: the light colours indicate that the additional factors reduce the effect and the dark colours indicate that they worsen it

With no additional factors: direct impact of drought on the species, with no other factor

With ADDITIONAL FACTORS: factors that reduce or worsen the impact (drought, fires or pest outbreaks). The light colours indicate a reduction, whilst dark colours indicate a worsening

The numbers of the cells refer to the sentences from the scientific bibliography, which are found on the following pages

Impact of **drought** and **pest outbreaks** on growth, mortality and regeneration

Adverse topography: This includes all the factors that decrease the availability of water for trees: gradient, orientation, the slope position, etc.

Impact of **pest outbreaks** and **fires** on growth, mortality and regeneration

Impact of **PEST OUTBREAKS** on growth, mortality and regeneration

Impact of **fires, pest outbreaks** and **drought** on growth, mortality and regeneration

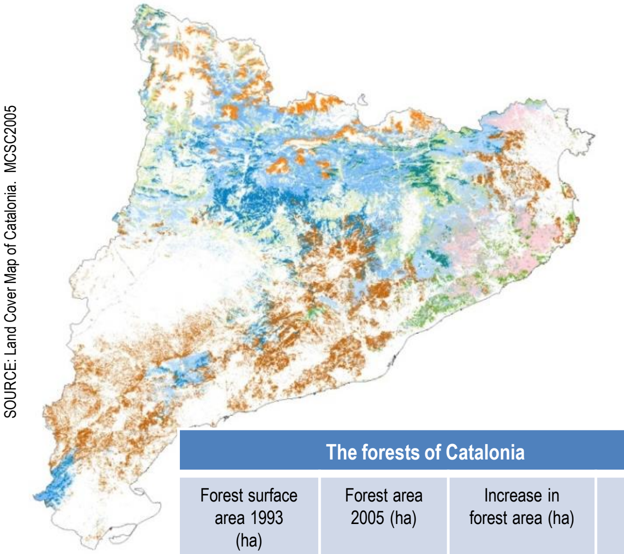
Impact of **FIRES** on growth, mortality and regeneration

Impact of **fires** and **drought** on growth, mortality and regeneration

Forests in Catalonia

Distribution of the forests in Catalonia

Distribution of the 9 species described in the fact sheets: Aleppo pine, European black pine, Scots pine, stone pine, mountain pine, European beech, holm oak, cork oak and four other oaks. And, in grey, the remaining species. (*)



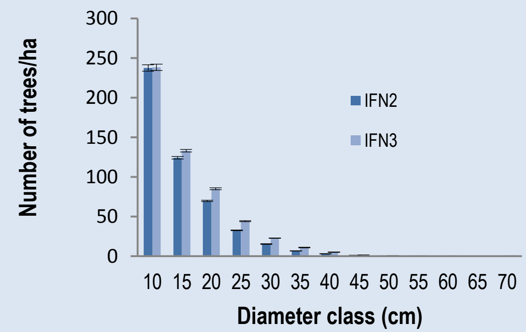
SOURCE: Land Cover Map of Catalonia. MCSC2005

The forests of Catalonia			
Forest surface area 1993 (ha)	Forest area 2005 (ha)	Increase in forest area (ha)	%
1,189,508	1,347,278	157,768	13.2

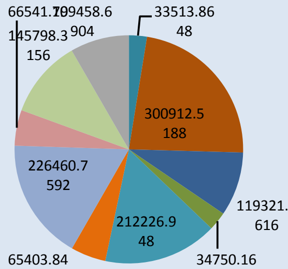
The data come from the 1993 and 2005 editions of the Mapa de Cobertes del Sòl de Catalunya [Map of Soil Cover in Catalonia]: (*) The map legend is the same as in the following sections: 'Distribution and structure' and 'Absolute carbon stocks and sinks'

Structure of the population of forests in Catalonia

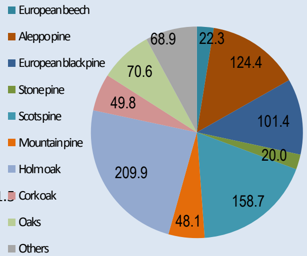
The size structure (diameter classes) of the forests in Catalonia indicates that they are young, with very small trunks and very few over 30 cm in diameter. In 2000 (IFN3) however, there was a slight increase in the number of trees per ha in the larger diameter classes compared with 1990 (IFN2)



Distribution and structure



SOURCE: Land Cover Map of Catalonia. MCSC2005



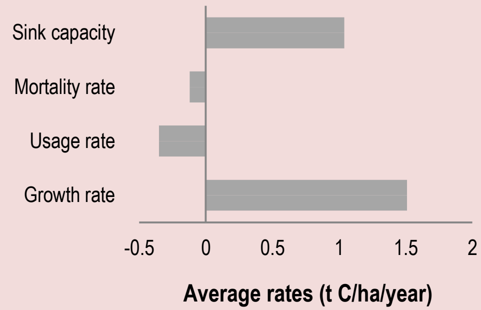
SOURCE: National Forest Inventory 3

The Aleppo pine, the holm oak and the Scots pine account for 56% of the total forest area in Catalonia, and constitute 58% in millions of trees.

Trees with a normal diameter of over 7.5 cm are counted

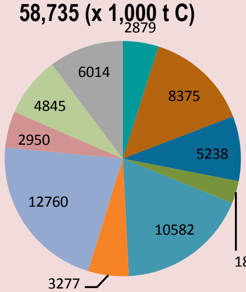
Average carbon (C) rates

The average carbon sink capacity of the forests of Catalonia between 1990 and 2000 is **1.04 t C/ha/year.**

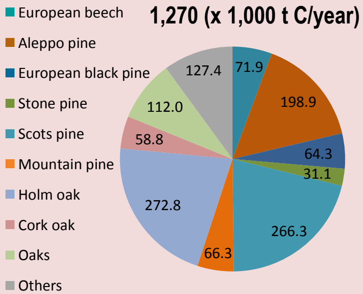


(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks



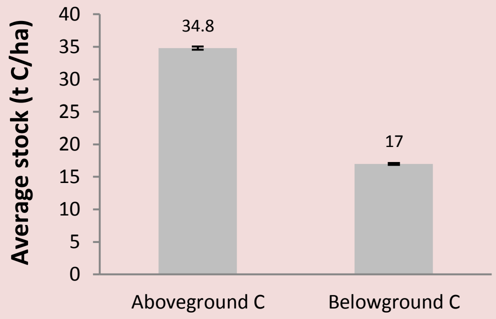
SOURCE: National Forest Inventory 3



Carbon stock and sink

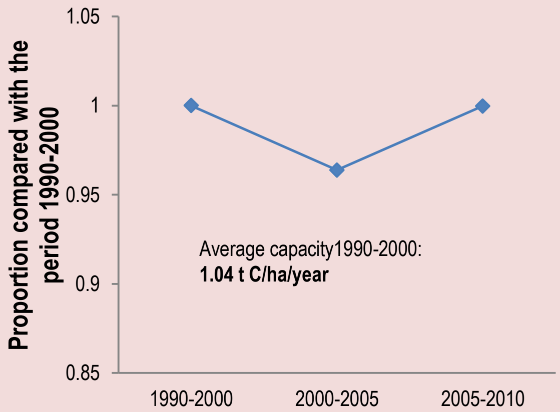
Average carbon (C) stocks

The forests of Catalonia store an average of 34.8 tonnes of carbon/ha in the aboveground fraction and 17 tonnes of carbon/ha in the underground fraction, half of the aboveground fraction.



Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the forests' carbon sink capacity remained very stable during the period 2000-2010



SOURCE: National Forest Inventory 3

Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

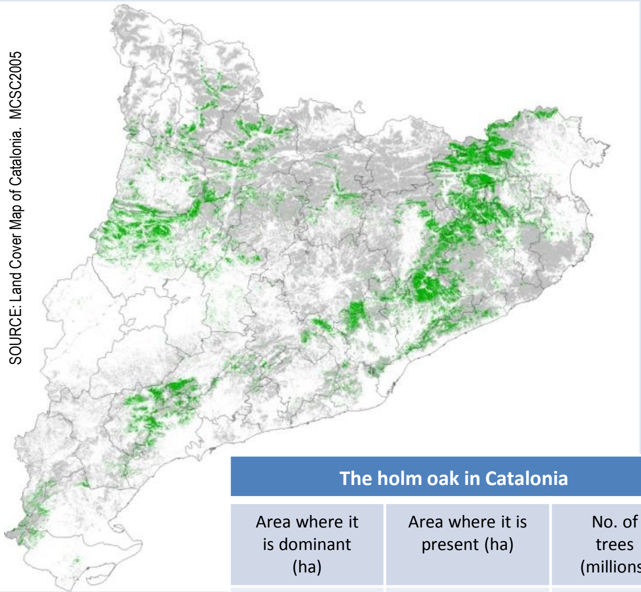
Holm oak (*Quercus ilex*)

Distribution and structure

Carbon stock and sink

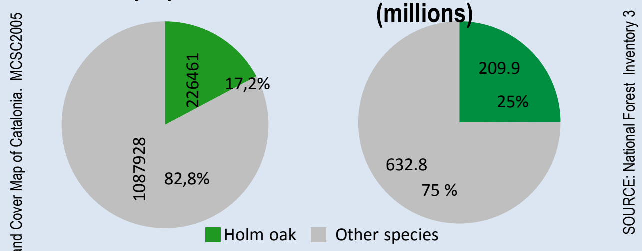
Distribution of the holm oak in Catalonia

In Catalonia, the holm oak is found close to the sea, as well as inland and in continental climate zones.



The holm oak in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
226,461	550,956	210

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

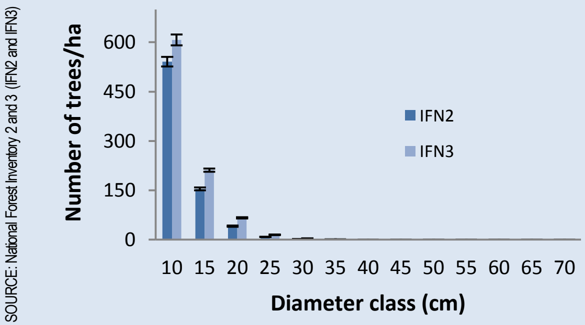


Holm oak forests account for 17% of the total forest area in Catalonia, and 25% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

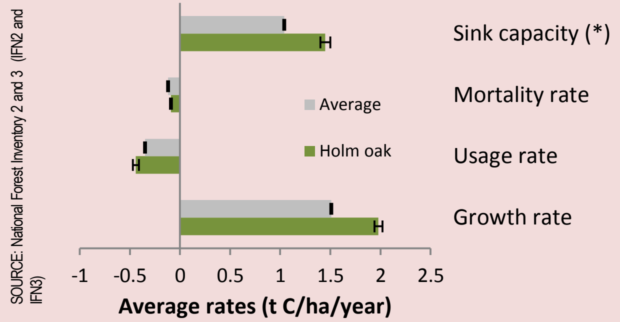
Structure of the holm oak population

In Catalonia the holm oaks are mainly small; very few of the trees have a diameter of over 20 cm.



Average carbon (C) rates

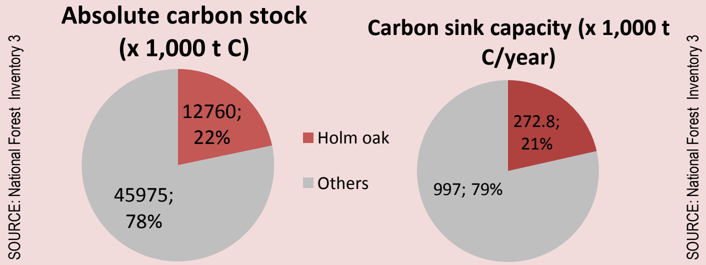
The average carbon sink capacity for the holm oak between the years 1990 and 2000 was **1.45 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

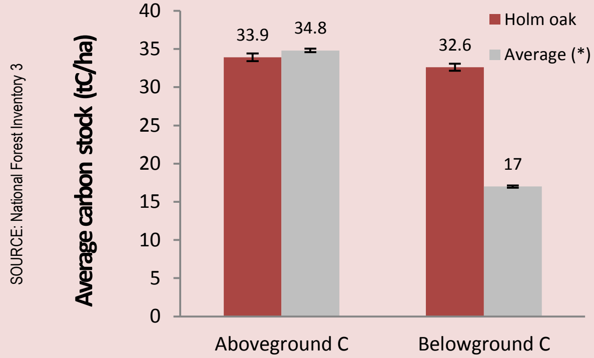
Absolute carbon (C) stocks and sinks

The absolute carbon stock of holm oak forests is **12.7 million t C** (tonnes of carbon). Their carbon sink capacity is **272.8 thousand t C/ha.**



Average carbon (C) stocks

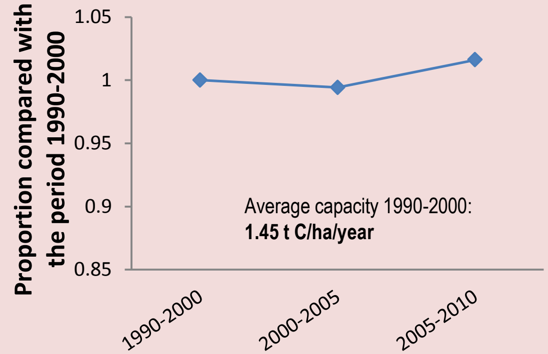
On average, holm oak forests store almost the same amount of carbon in the aboveground part as in the underground fraction.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

The holm oak forests' carbon sink capacity remained very stable during the period 1990-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors	11, 17	17, 19, 20	27, 34, 35
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude	14	25	25
Less precipitation	1, 2, 3, 6, 10	18, 19	28; 1; 29, 30
Higher temperature	3, 4, 14	15, 25	15
More competition	7, 9	16, 18	28
Large trees		21	
Higher carbon reserves in trees		16	34
More erosion			
Thinner and more compact soil		16, 20, 22	8
Adverse topography (*)	5		8, 15

Legend

Without additional factors		With additional factors
Slight effect		Decreases the effect
Moderate effect		Does not change the efect
Severe effect		Worsens the effect
Very severe effect		Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors	12, 13	23	23, 32
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature			
More competition			
Large trees			11; 33
Higher carbon reserves in trees			33
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors			
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation		24	
Higher temperature		24	
More competition			
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Holm oak (*Quercus ilex)*

GROWTH

1. Drought decreases the size of the shoots, the size of the leaves (biomass and leaf area) and the leaf renewal rate and production in order to limit water loss. However, the lack of water does not affect acorn production. (Ref. 31, 11, 43)
2. Growth patterns coincide with warm, humid periods (spring and autumn), thus avoiding low winter temperatures and summer droughts. (Ref. 52)
3. Growth is closely linked to precipitation between the end of spring and the beginning of summer and the temperature of the previous summer (very high temperatures the previous summer are harmful), but varies depending on the zone. Growth can decrease or stop in winter and in summer if there is drought. (Ref. 22, 23, 43, 52).
4. The trees in the warmest places exhibit reduced growth rates due to increased water stress. (Ref. 22)
5. South-facing trees have higher evapotranspiration rates and thus experience greater summer water stress. (Ref. 22)
6. Accumulated precipitation has a positive effect on holm oak root growth in the long term . (Ref. 22)
7. Selective logging increases the growth rate when there is no reduction in precipitation. This positive effect decreases several years later due to the vigorous regrowth of the tree stumps. (Ref. 11)
8. Greater soil water availability favours the development of acorns during summer. (Ref. 9)
9. The areas with greatest tree density have more competition for water, and thus the trees are less able to grow. (Ref. 44)
10. Decreased water availability reduces the growth of the tree in diameter and total biomass. (Ref. 50)
11. Post-fire growth is related to the size of the trees before the fire and the total or partial loss of the tree canopy during the fire. (Ref. 6)
12. The recurrence and the intensity of fire reduce holm oak growth capacity and vitality. (Ref. 6, 33)
13. A high fire recurrence rate has a negative impact on tree carbon sink capacity. (Ref. 33)
14. It is predicated that holm oaks will move uphill to cooler areas and that there will be fewer of them in temperate zones at middle altitudes due to a decrease in water availability. (Ref. 20, 68)

MORTALITY

15. The survival of holm oak seedlings increases in places where solar radiation and temperatures are lower. (Ref. 69)
16. Mortality is related to soil depth, the number of stems per trunk, the exhaustion of carbon reserves and the weakening of canopies. (Ref. 20)
17. Climate change will probably increase mortality and reduce holm oak growth due to an increase in the frequency and intensity of drought. (Ref. 52, 32)
18. Mortality rates were very closely related to the density of stems per trunk, and drought may even double the number of stems. (Ref. 50)
19. In some zones where the 1994 drought was very intense, up to 76% of the holm oaks suffered total crown mortality. (Ref. 38)
20. In response to drought, the most compact lithological substrates give rise to higher mortality rates than cracked substrates, due to the greater penetration of the roots and the use of water at deeper levels. (Ref. 38)
21. Young holm oaks are more vulnerable to drought than older ones. (Ref. 38)
22. Holm oak stands situated on the lower slopes of the mountain (where the soil is deeper) suffered less damage (1994 drought) than those on the upper slopes. (Ref. 38)
23. The holm oak's resistance to fire is very high (99.9%) due to its great resprouting capacity. (6)
24. The black rot fungus Botryosphaeria stevensii is a very common plant pathogen, which kills small and large branches and is favoured by high temperatures and water stress. (Ref. 25)
25. It is predicated that holm oaks will move uphill, to cooler areas and that there will be fewer of them in temperate zones at middle altitudes due to an decrease in the availability of water. (Ref. 20, 68)

REGENERATION

26. Fires do not restrict the presence of holm oaks to Mediterranean forests, since these trees readily resprout and thus are equally abundant in burnt areas as in non-burnt areas. (Ref. 57)
27. An increase in drought reduces the number of productive trees, the production of female flowers and acorn size. (Ref. 60, 49)
28. In locations where Scots pine exhibits high defoliation and mortality rates due to episodes of drought, there is an abundant recruitment of holm oaks and other oak species. (Ref. 21)
29. Seedlings survival is closely linked to higher irrigation levels. (Ref. 42)
30. According to the results of experiments, the incorporation of new holm oak saplings was only possible in forests with moist conditions. (Ref. 42).
31. The density of holm oaks before a fire determines the post-fire community. (Ref. 7)
32. Resprouting is the holm oak's main mechanism for natural regeneration after disturbance. (Ref. 33, 26)
33. Post-fire resprouting is not closely related to the pre-fire size of individual trees (Ref. 26). On the other hand, resprouting is related to the size of the base of the trunk and the carbon reserves in underground parts of the tree. (Ref. 32, 18, 16)
34. Recurrent droughts can lead to a progressive loss in tree recovery capacity, due to the exhaustion in the surviving plant's resprouting capacity. (Ref. 38)
35. Drought reduced the emergence and survival of holm oak seedlings and shoots, but increased water use efficiency in existing saplings. (Ref. 37)
36. The holm oak has a limited natural capacity for regeneration by seed. Therefore, several artificial methods have been developed. However, there is no consensus as to which is the best method. (Ref. 24)

Holm oak (*Quercus ilex*)

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below.

DISTRIBUTION

-Climatic limitations and soil properties partially explain the regional distribution of both pines and holm oaks. (Ref. 13)

-Holm oak sensitivity to climate, its extensive distribution and its longevity mean that it can be considered a good candidate for climatic forest restoration in the Mediterranean region. (Ref. 27)

-The decline in the production of reproductive structures can lead to changes in holm oak competitive capacity and, in the long term, changes in the distribution of the species. (Ref. 36)

-*Pinus halepensis* appears to be a good substitute for *Quercus ilex* since it is more resistant to drought, despite the fact that the Aleppo pine is expected to decline in the long term due to continuous droughts. (Ref. 41)

-Mediterranean species will replace Euro-siberian species in the Mediterranean Basin. (Ref. 7)

-Over the course of the last few decades, thousands of hectares of holm oak have burned in Spain due to an increase in the number of large forest fires. (Ref. 56)

-Monospecific Aleppo pine and holm oak forests are very likely to remain intact after a fire. However, most mixed forests become monospecific post-fire. (Ref. 61).

- It is predicted that holm oaks will move uphill, to cooler areas and that there will be fewer of them in temperate zones at middle altitudes due to a decrease in the availability of water. (Ref. 20, 68)

VULNERABILITY

-- Holm oak vulnerability to climate has increased in recent decades, a fact that may be related to the rise in temperatures. (Ref. 22)

-- Holm oaks are very flexible and highly adaptable to the Mediterranean climate, closing their stomata in summer to preserve water. (Ref. 4, 20).

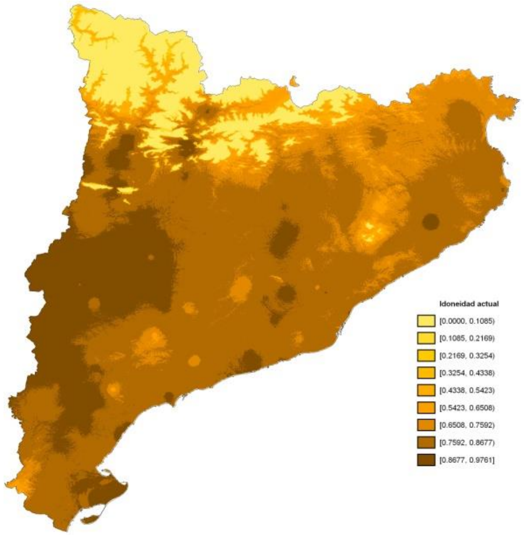
-- The holm oak has good stomatal regulation, which prevents water loss during prolonged periods of drought, especially in summer. (Ref. 27, 29).

-- The holm oak has characteristics that allow it to withstand dry years. (Ref. 41)

Observed impacts

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE HOLM OAK:

CURRENT SUITABILITY: 1950-1998



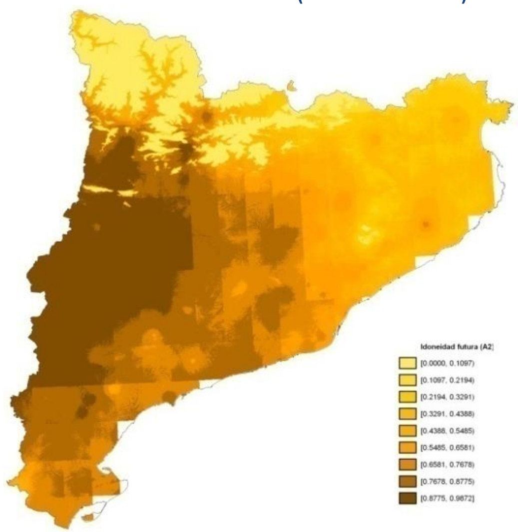
Current suitability map for the holm oak. Source: Ninyerola *et al.* 2009

The extent to which the holm oak was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the holm oak exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	2,798,904	2,050,936
%	86.9	63.6

PROJECTED SUITABILITY (A2 STORYLINE):



Projected suitability map (A2 storyline). Source: Ninyerola *et al.* 2009

At present, the holm oak is found across 87% of the surface area of Catalonia, in accordance with the topo-climatic variables. With the A2 storyline, this percentage would decrease to 63%.

The extent to which the holm oak would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

PREVENTIVE ACTIONS:

NO INFORMATION WAS FOUND

CORRECTIVE ACTIONS:

-The holm oak has been used extensively for reforestation projects in the Mediterranean region. However, it has often shown poor yields in the field, particularly in areas with unfavourable climatic conditions. (Ref. 3)

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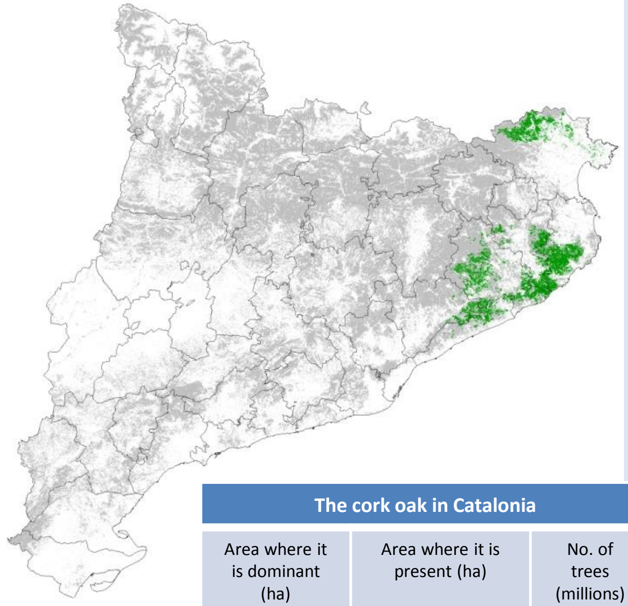
Cork oak (*Quercus suber*)

Distribution and structure

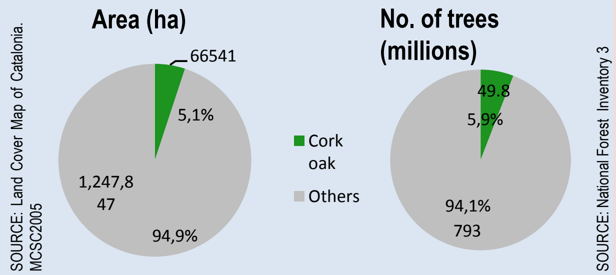
Distribution of the cork oak in Catalonia

Cork oaks are found on the coast of the Province of Girona and in some inland areas L'Alt Empordà



The cork oak in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
66,541	122,767	49.8

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

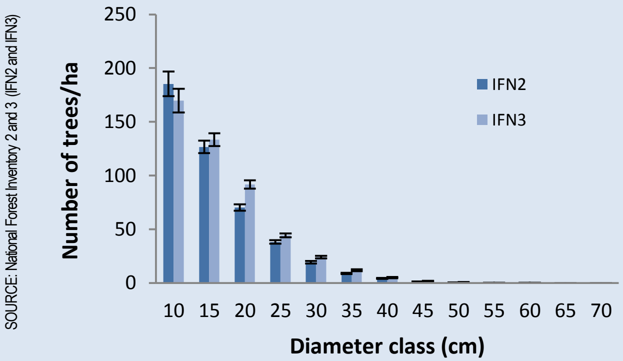


Cork oak forests only account for 5% of the total forest area in Catalonia, and 6% in terms of millions of trees.

Trees with a normal diameter of over 7.5 cm are counted

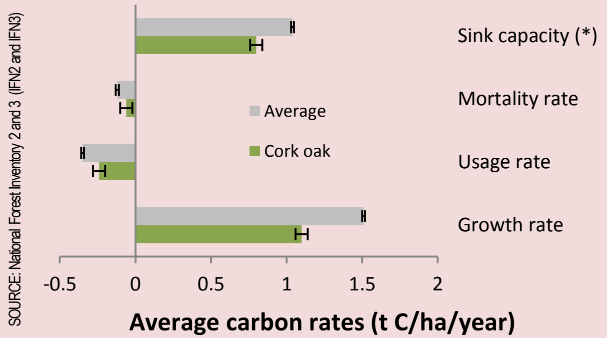
Structure of the cork oak population

In Catalonia the cork oak forests are young with very few trees per hectare. Between 1990 (IFN2) and 2000 (IFN3) there has been an increase in the trees in the highest diameter classes.



Average carbon (C) rates

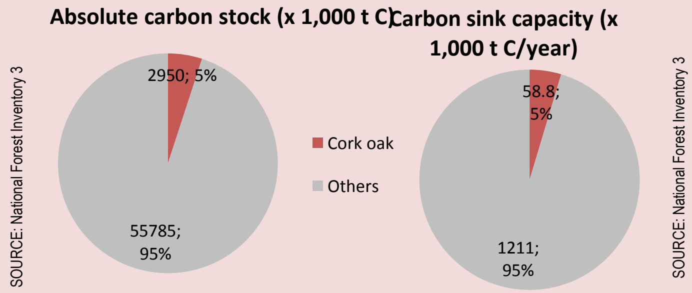
The average carbon sink capacity for the cork oak between the years 1990 and 2000 was **0.8 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

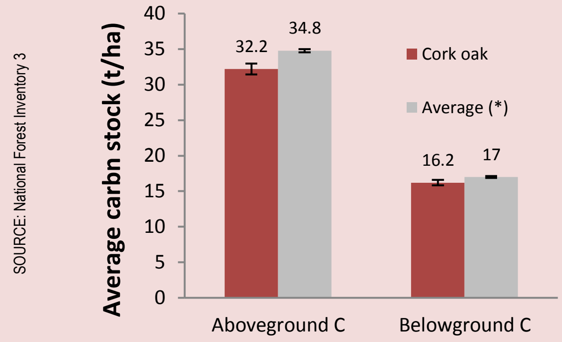
The absolute carbon stock of cork oak forests is **2.9 million t C** (tonnes of carbon). Their carbon sink capacity is **58.8 thousand t C/ha.**



Carbon stock and sink

Average carbon (C) stocks

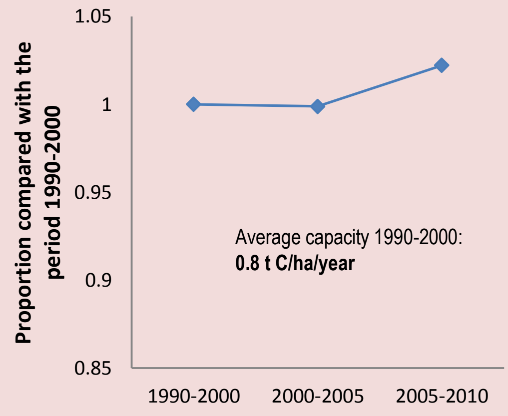
Cork oak forests storage slightly fewer tonnes of C/ha than the average amount stored by other species, with regard to both aboveground and underground carbon.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the cork oak forests' average carbon sink capacity increased during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Legend

Without additional factors	With additional factors
Slight effect	Decreases the effect
Moderate effect	Does not change the efect
Severe effect	Worsens the effect
Very severe effect	Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors	5, 6	7 / 9	26 / 24 / 8, 25
With ADDITIONAL FACTORS (Modification of the effect:)			
Greater altitude			
Less precipitation	1, 2, 5, 6	8	25 / 26 / 28
Higher temperature	5 / 6		26
More competition	3 / 3, 27		27
Large trees			
Higher carbon reserves in trees	3		
More erosion			
Thinner and more compact soil	4		
Adverse topography (*)			

Drought + pest outbreaks: Mort. 9, 21

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors		10, 16	29, 33 / 30
With ADDITIONAL FACTORS (Modification of the effect:)			
Greater altitude			
Less precipitation			
Higher temperature			
More competition			
Large trees		11, 15, 18 / 13	
Higher carbon reserves in trees			30
More erosion			
Thinner and more compact soil			
Adverse topography (*)		13, 17	15, 31

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors		9, 20, 21, 22, 23	9, 35
With ADDITIONAL FACTORS (Modification of the effect:)			
Greater altitude			
Less precipitation		20	
Higher temperature		20	
More competition		9	
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Cork oak (*Quercus suber*)

GROWTH

1. *An increase in CO_2 concentration in the short term (6 months) resulted in an increase in the growth, number and diameter of branches (Ref. 2); however, if the CO_2 exposure was medium to long term (over 9 months) no changes were observed in the height, trunk diameter, number of leaves or the leaf area. On the other hand, the availability of light and water improved these parameters greatly.* (Ref. 5, 49)

2. Cork oak plants that suffer the effects of severe drought have lower levels of aboveground growth and higher levels of belowground growth, as well as folded, shrivelled leaves. (Ref. 35)

3. Seedlings subjected to shade treatment, which is the main limiting factor for growth, are very sensitive to water stress, have lower starch reserves, lower photosynthesis rates, lower water use efficiency and larger leaves. (Ref. 35,25, 4). Other sources indicate that plants grown in the shade are less drought-resistant (Ref. 48).

4. The upper layers of the soil contribute to approximately 33% of the total water requirements between spring and the middle of summer. However, soil layers at greater depths supply most of the water required during periods of drought, during which no growth was recorded. (Ref. 46)

5. A decrease in the annual growth of tree diameter may be related to climatic factors such as drought, since the precipitation accumulated during the growth season (January-June) and the previous autumn and winter (the previous October-November) are decisive (19, 13), on the other hand, temperature has less influence in this aspect (Ref. 20).

6. Drought, temperature or both can limit cork growth. (Ref. 13)

MORTALITY

7. *Quercus ilex* and *Quercus suber* are less susceptible to embolism compared to other deciduous species in temperate zones. (Ref. 54)

8. Saplings originating from locations with dry summers exhibited higher survival rates under drought conditions (58), although the survival of seedlings decreased linearly with increases in light, since this increased the risk of plant desiccation. (Ref. 30)

9. The various causes of cork oak seedling death includes white grubs (Coleoptera: Scarabaeoidea), which attack the roots, summer drought, and the termination of forestry management practices. (Ref. 29, 38)

10. *Quercus suber* has an exceptionally high capacity for survival after fire. (Ref. 59, 51)

11. Bark thickness and bark harvesting/removal are the main factors that affect the resistance of *Quercus suber* to fire. Trees with thin bark (young or recently peeled) are more vulnerable to fire and trees with thicker bark are more resistant. (Ref. 15, 16, 43)

12. *For the same thickness of bark, the trees that were previously harvested were more vulnerable to fire than the non-harvested trees because the cork type is different.* (Ref. 15)

13. Vulnerability to fire increases with severity and was observed to be greater in trees with larger diameters, burnt at the start of the summer or located on south-facing slopes. (Ref. 15)

14. *Survival rates decrease with an increase in tree trunk burn height. This is considered to be an indicator of the extent of fire damage and determines the cork oak post-fire response* (Ref. *16, 43).*

15. Variables that increase the probability of cork oak trunk survival and crown resprouting include cork thickness and tree trunk diameter. *On the other hand, tree trunk burn height and southern or western slope orientation decreases this probability.* (Ref. 14, 43, 51)

16. After a fire, the cork oak's most common response was tree crown resprouting (68.8%), followed by the death of the tree (15.8%), simultaneous tree crown and trunk resprouting (10.1%), and trunk resprouting (5.3%). (Ref. 16, 42, 51)

17. In the event of a fire, cork-harvested trees on south-western slopes have lower survival rates than those that have not been harvested. (Ref. 43).

18. Large trees in dominant positions were more likely to survive in the event of a forest fire. (Ref. 59)

19. The various causes cork oak seedling death include white grubs (*Coleoptera: Scarabaeoidea*), which attack the roots; summer drought and the termination of forestry management practices. (Ref. 29, 38)

20. The fungus *Phytophthora cinnamomi* is a pathogen associated with the mortality and decline of *Quercus suber* and *Quercus ilex* in the Mediterranean region. The fungus requires warm and moist soil conditions (where it reproduces) in order to infect the roots (Ref. 10).

21. *Phytophthora cinnamomi* is an aggressive root pathogen that attacks cork oaks. Its propagation may be an important factor in the decline of cork oaks in the Iberian Peninsula, alongside drought and other factors. (Ref. 11)

22. The ambrosia beetle, *Platypus cylindrus,* is an important pest of the cork oak. It colonises both healthy and decayed stems. It causes serious damage to freshly peeled cork oak trunks and can kill the tree. (Ref. 8)

23. *Botryosphaeria corticola* is a fungus that affects the trunks of holm oaks and cork oaks and contributes to the decline in these forest species, representing a serious disease in the main cork production areas. (Ref. 39)

REGENERATION

24. Acorn production has been shown to not poorly related to climate. (Ref. 55)

25. Cork oaks from locations with drier summers have larger acorns, which suggests a selection of larger acorns in places affected by drought. (Ref. 58)

26. An increase in the intensity and frequency of summer droughts due to climate change could cause a negative impact on the regeneration of *Quercus suber* due to a reduction in the probability of survival and the cancellation of the positive effects of wet years. (Ref. 30)

27. Due to an increase in the leaf area, saplings cultivated under moderate shade (a total of 15% light) accumulated just as much biomass as those cultivated in well-lit environments, and they may experience optimal development even with moderate water stress. However, if the shaded conditions are darker (5% light), development is reduced dramatically. (Ref. 56, 4)

28. Excess soil water moisture during winter reduces seed germination and emergence. (Ref. 67)

29. Cork oak forests that burned 1-2 times over the last 50 years were resistant: they recovered to levels of similar biomass and composition compared to before the fire. However, forests that suffered very frequent fires (3-4 fires over the last 50 years) suffered a loss of recovery capacity, which led to a simplified vertical structure, shrub cover and fewer cork oak trunks. (Ref. 63, 62, 61, 69)

30. Intervals of under 10-15 years between fires are insufficient to allow trees to recover their carbohydrate reserves, and the species richness and diversity are lower compared to control plots. (Ref. 63, 62)

31. Environmental factors such as slope or exposure, in addition to the time elapsed since the last fire, also play a role in determining the structure of the post-fire community. (Ref. 62)

32. Ashes, which can cause a significant rise in pH, constitute, in the short term, an important source of nutrients and improve the fertility of the soil for the recovery of the ecosystem after a fire. (Ref. 52)

33. After a fire, the cork oak's most common response was tree crown resprouting (68.8%), followed by the death of the tree (15.8%), simultaneous tree crown and trunk resprouting (10.1%), and trunk resprouting (5.3%). (Ref. 16, 42, 51)

34. The trees that suffered the most damage died or only resprouted from the trunk. On the other hand, trees protected by thick bark were able to resprout from the crown (Ref. 42).

35. Massive attacks by white grubs *Coleoptera: Scarabaeoidea* on seedling plantation roots meant that only 12% of restoration actions were successful in an experiment in a forest in Morocco. (Ref. 29)

36. The natural regeneration of cork oaks in the forest of Mamora (Morocco) is very difficult due to anthropogenic factors and the introduction of exotic species, mainly pine and eucalyptus. (Ref. 38)

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below. .

DISTRIBUTION

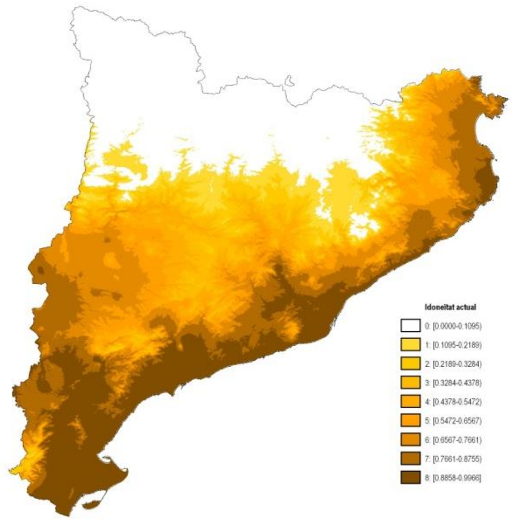
- *Coraebus undatus* is a buprestid beetle that bores galleries within the cork tissue, giving rise to significant financial losses as a result of the reduction in the quantity and quality of the cork. This pathogen's distribution is widespread and a high percentage of cork oak trees are infested (> 70%) in almost all the cork oak forests in southern Spain. (Ref. 34)

VULNERABILITY

- *Botryosphaeria corticola*, is a fungus that affects the trunks of holm oaks and cork oaks and contributes to the decline in this forest species, representing a serious disease in the main cork production areas. (Ref. 39)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE CORK OAK:

CURRENT SUITABILITY : 1950-1998



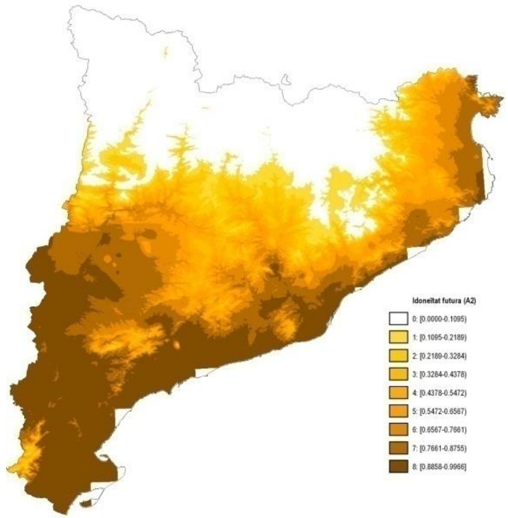
Current suitability map for the cork oak. Source: Ninyerola *et al.* 2009

The extent to which the cork oak was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the cork oak exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,656,552	1,727,844
%	51.4	53.6

PROJECTED SUITABILITY (A2 STORYLINE):



Projected suitability map (A2 storyline) for the cork oak. Source: Ninyerola *et al.* 2009

At present, the cork oak is found across 51% of the surface area of Catalonia, in accordance with the topo-climatic variables. With the A2 storyline, this percentage would increase slightly to 53.6%.

The extent to which the cork oak would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

PREVENTIVE ACTIONS:

NO INFORMATION WAS FOUND

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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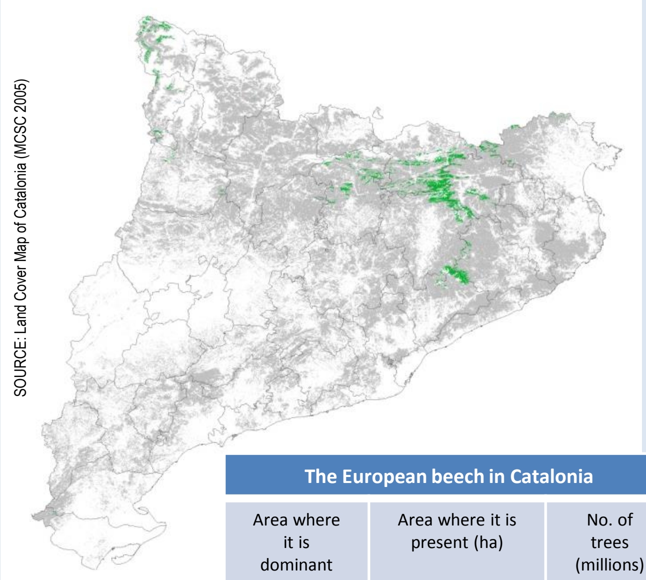
European beech (*Fagus sylvatica*)

Distribution and structure

Carbon stock and sink

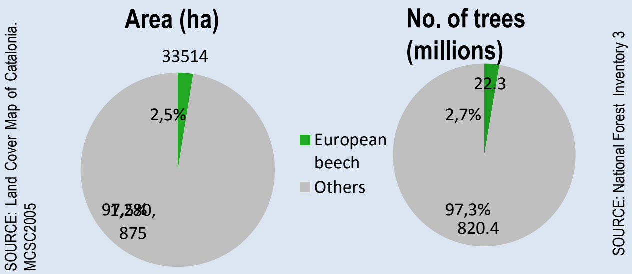
Distribution of the European beech in Catalonia

In Catalonia, European beech forests are found in parts of the pre-Pyrenees at altitudes of between 500 and 2,000 m, as well as in parts of El Montseny and in La Garrotxa.



The European beech in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
33,513	71,341	22.3

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform: SOURCES: IFN3 and MCSC2005

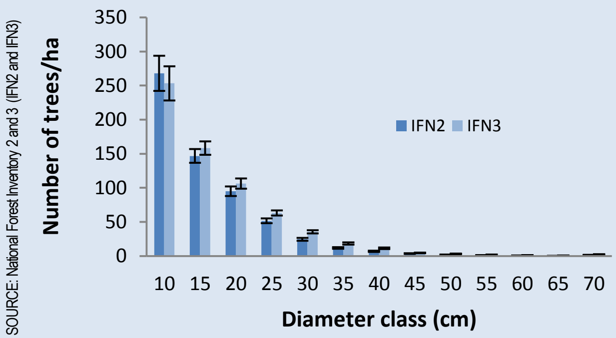


European beech forests account for 2.5% of the total forest area in Catalonia, and 2.6% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are shown.

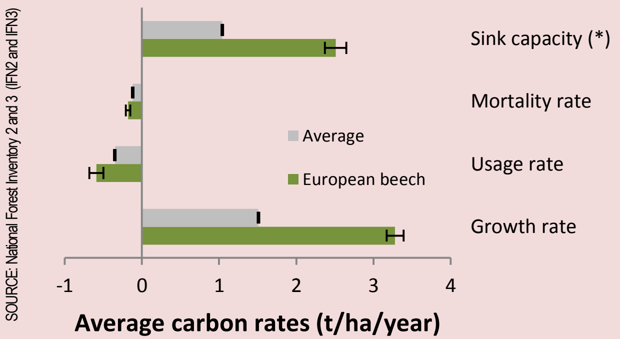
Structure of the European beech population

In Catalonia the European beech forests are young, with most trees being below the 25 cm diameter class.



Average carbon (C) rates

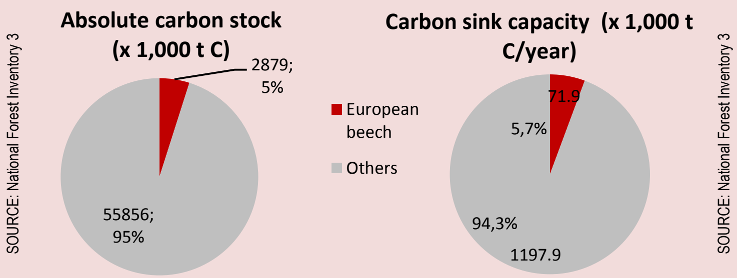
The annual carbon stock change rate is **2.51 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

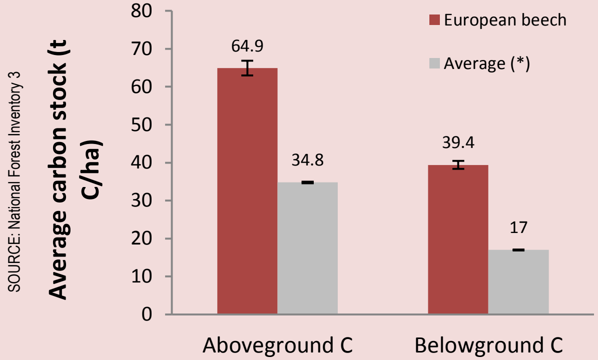
Absolute carbon (C) stocks and sinks

The absolute carbon stock of European beech forests is **2.8 million t C** (tonnes of carbon). Their carbon sink capacity is **71.9 thousand t C/ha.**



Average carbon (C) stocks

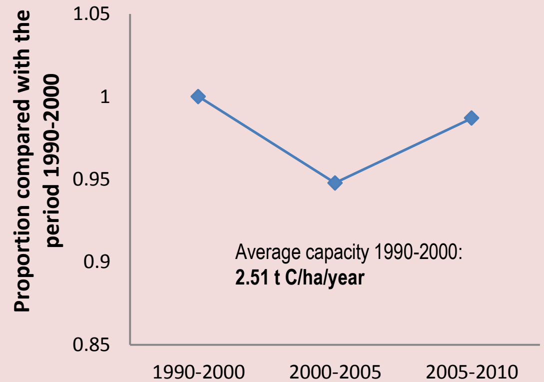
European beech forests store much more carbon than the average in both the aboveground and underground parts.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the European beech forests' carbon sink capacity remained stable in 2010 after a slight decrease during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

(**) 1,3,4,6,7,8,9,10,11, 12

	Growth	Mortality	Regeneration
With no additional factors	3, 11	13	
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude	3, 5		19, 20
Less precipitation	(**)	14,15	22, 25
Higher temperature	2,3,4,6,9,12		22
More competition			24, 25
Large trees	4		
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil	8	14,15	
Adverse topography (*)		14,15	

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors			16, 21
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature			
More competition			
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors			
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature			
More competition		17	
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Legend

Without additional factors	With additional factors
Slight effect	Decreases the effect
Moderate effect	Does not change the efect
Severe effect	Worsens the effect
Very severe effect	Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

European beech (*Fagus sylvatica)*

GROWTH

1. Leaf respiration decreases as the plant water deficit increases. (Ref. 24)
2. Although there is an increase in the water use efficiency in the lower limits of beech forests, this does not prevent growth reduction in as a result of global warming. (Ref. 19)
3. There is a significantly lower growth in mature trees at the lower altitudes of its range in comparison with trees located at high altitudes because this species' survival is severely limited by drought. (Ref. 13)
4. A rapid decline in the growth of the European beech was observed in 1975. In 2003, as a result of the increase in temperatures and the decrease in precipitation, a 49% lower growth rate was observed compared with the pre-decline levels; on the other hand, this growth rate was not related to the age of the tree. (Ref. 13)
5. The growth of European beech decreases with altitude. (Ref. 17)
6. The Leaf Area Index (LAI) may increase, favoured by the rise in atmospheric CO_2, especially in places where the precipitation is high and the climatic conditions are not too hot, according to the Gotilwa+ growth simulation model. (Ref. 25)
7. According to the Gotilwa+ growth simulation model, the average life of beech leaves would increase under climate change conditions due to the longer growth period, which would promote higher production as long as water were not a limiting factor. (Ref. 25)
8. There is an inverse relationship between the tree-ring width and the availability of water in the soil at the start of the growth period. (Ref. 22)
9. Precipitation in December and July is positively correlated with the growth of the European beech while temperature in April is negatively correlated. (Ref. 1)
10. The growth of mature beech trees is limited by summer drought ,and basically depends on the accumulation of snow thaw to satisfy its water requirements in summer. (Ref. 1)
11. Stress caused by long-term drought reduces the productivity of beech trees in the central regions of the Apennines, in accordance with similar trends identified in Mediterranean mountains. (Ref. 21)
12. A decline in growth has been observed in the southern part of its geographic distribution. This decline is expected to worsen if a rise in temperatures is not accompanied by an increase in precipitation. (Ref. 13)

MORTALITY

13. It appears that the European beech has efficient physiological regulation mechanisms, which allow it to maintain itself under the relatively dry Mediterranean climatic conditions. (Ref. 18)
14. In the Tuscany region, a deterioration in the crowns of the European beech and the stone pine was observed due to a decrease in the average annual precipitation, especially in areas with shallow soil and steep slopes. (Ref. 3)
15. There appears to be an interaction between the degree of damage inflicted on trees and various different stress factors, some of which appear to be linked to local conditions (exposure, forestry practices, soil fertility, etc.), while others are connected to environmental parameters such as precipitation. (Ref. 3)
16. In 1991, a fire in Hayedo de Tejera Negra Natural Park in Guadalajara burned European beech and Scots pine trees. Two years after the fire, the percentage of plant cover in the burned and the control plots was similar. However, the European beech had been replaced by Spanish broom. (Ref. 11)
17. Defoliating and sucking insects are the two groups that cause the greatest damage to beech forests. Excessive trunk density is one of the factors that contribute the most to the proliferation of these pest outbreaks once the infestation is established. (Ref. 10)
*18. Cankers and oidium are two of the principal diseases suffered by beech trees since their fine bark and the moist environment in which they live make them vulnerable to attack from various types of fungus. (*Ref. *10)*

REGENERATION

19. In a study carried out on the Montseny massif, the percentage of young beech trees on the lower slopes is only half of that found on the middle and upper slopes (Ref. 20)
20. In the upper limits of its geographic distribution on the Montseny massif, the European beech has increased in density and has expanded at higher altitudes on the mountain with the establishment of new, vigorous trees. (Ref. 20)
21. In a burned European beech forest, its post-fire saplings are rarely mixed with other species. (Ref. 27)
22. The high soil moisture content, precipitation and temperatures during the growing season increases sapling density, while frost in the spring and autumn decreases sapling density. (Ref. 26)
*23. Fruit production increases in trees that show signs of crown degradation. The increase in allocation to reproduction may be the beech tree's strategy for coping with the ecological limitations that tend to limit its establishment. (*Ref. *26)*
24. Saplings in clearings survive better than those located in the undergrowth, regardless of how much water is available. (Ref. 23)
25. The intensification of the summer drought could prevent saplings becoming established in the undergrowth, due to the inability of the saplings to simultaneously endure water stress and tolerate shade at the same time. (Ref. 23)

European beech (*Fagus sylvatica)*

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below.

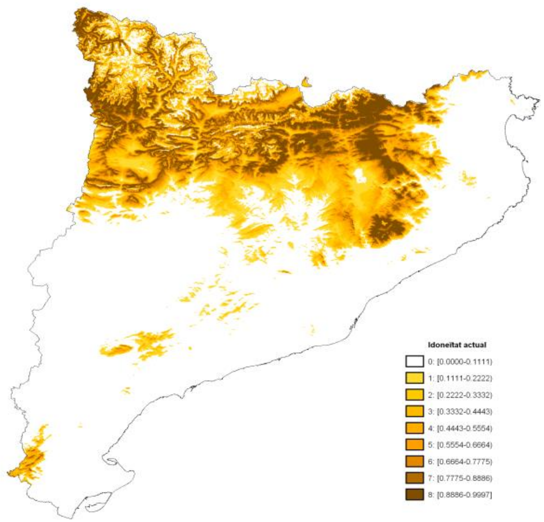
DISTRIBUTION

- Climate change may lead to a **drastic reduction in the numbers of European beech** and sessile oak trees in locations where the macroclimate is unsuitable. (Ref. 6)
- The increase in temperatures may give rise to a rapid decrease in the growth of the populations in lower altitudes and a consequent decline in the distribution of the European beech tree in southern Europe. (Ref. 13)
- The geographical distribution of the European beech depends on its inability to tolerate summer drought in lower-lying areas and winter frost in higher areas. (Ref. 17)
- The beech does not have an effective strategy for conserving water and this is reflected in its distribution. In dry environments there is a considerable survival risk of beech populations subjected to extreme temperatures. (Ref. 28)
- Beech forests are being replaced by Mediterranean holm oak forests, probably as a result of global warming. (Ref. 20)
- Spring temperatures and precipitation are the main variables that determine the distribution of beech trees affected by drought. (Ref. 6)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE EUROPEAN BEECH:

CURRENT SUITABILITY:

The extent to which the European beech was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).



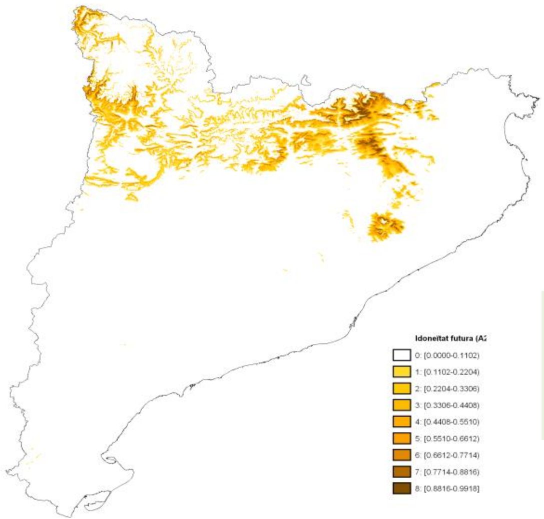
Current suitability map for the European beech. Source: Ninyerola *et al.* 2009

The areas indicated in the table are the hectares in which the European beech exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	633,936	70,568
%	19.6	2.2

At present, the European beech is found across 19.6% of the surface area of Catalonia, in accordance with the topo-climatic variables. With the A2 storyline, this percentage would decrease to 2.2%.

PROJECTED SUITABILITY (A2 STORYLINE):



The extent to which the European beech would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the European beech. Source: Ninyerola *et al.* 2009

PREVENTIVE ACTIONS:

- The European beech responds rapidly to tree thinning by increasing its productivity. (Ref. 5)
- A 15-year interval between moderate and intensive thinnings is considered optimal for a beech forest. (Ref. 5)
- In a field experiment, the percentage of colonisation by arbuscular mycorrhizal fungi (*see Glossary*) was higher in the more recently logged plot. On the other hand, the percentage remained stable in the non-managed plot. (Ref. 4)
- Excessive tree trunk density is one of the factors that promote the proliferation of outbreaks of defoliating and sucking insects, once the central point of the infestation has become established. (Ref. 10)

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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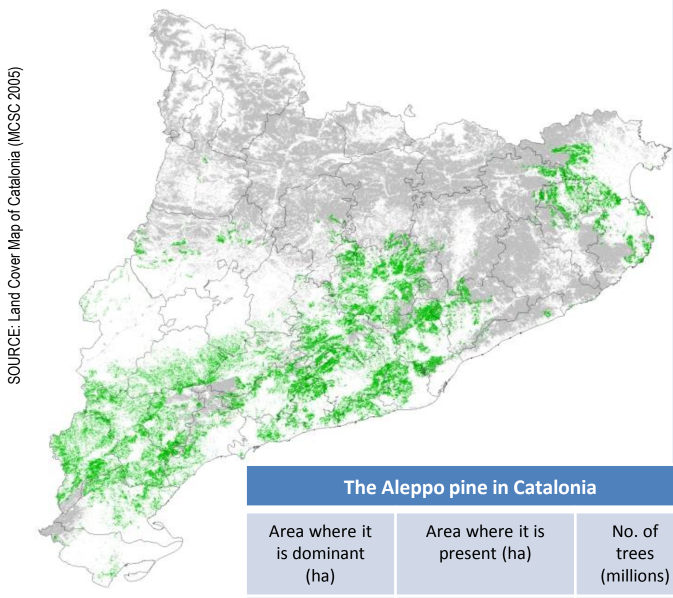
Aleppo pine *(Pinus halepensis)*

Distribution and structure

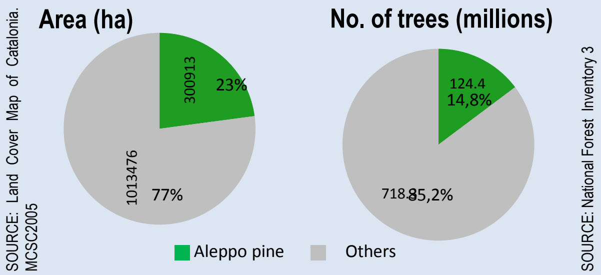
Distribution of the Aleppo pine in Catalonia

The Aleppo pine is found along most of the Mediterranean coast as well as lower and warmer parts of central Catalonia and the Ebro River Valley.



The Aleppo pine in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
300,913	393,184	124.4

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

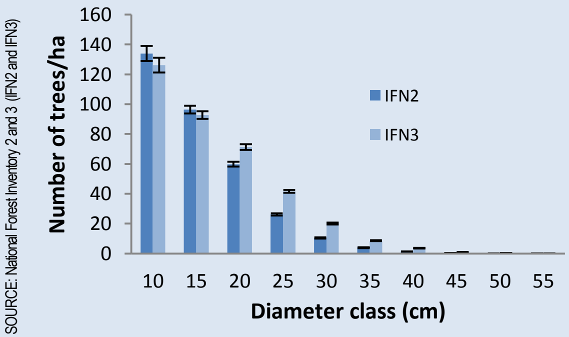


Aleppo pine forests account for 23% of the total forest area in Catalonia, and 14.7% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

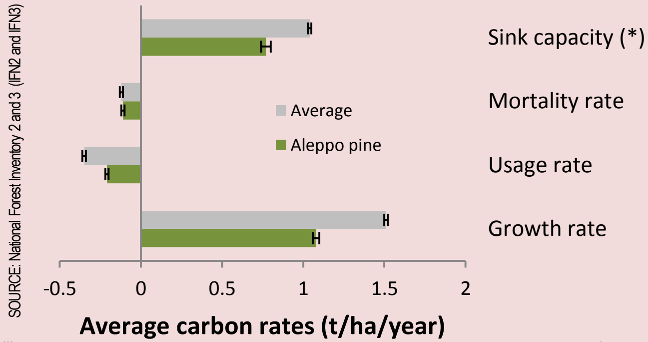
Structure of the Aleppo pine population

The Aleppo pine forests are young and dense, with a large number of trees per hectare and most being below the 20 cm diameter class.



Average carbon (C) rates

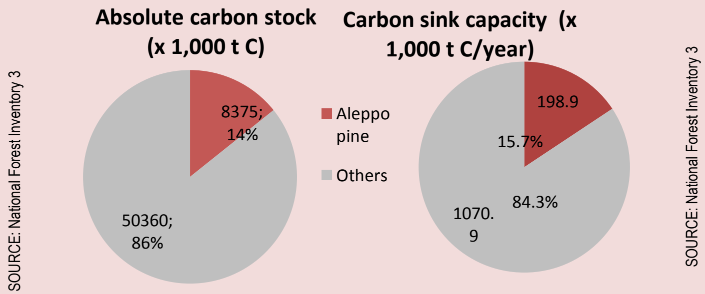
The average carbon sink capacity for the Aleppo pine between the years 1990 and 2000 was **0.77 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

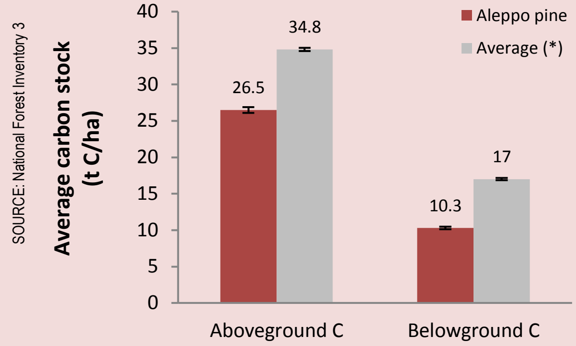
The absolute carbon stock of Aleppo pine forests is **8.3 million t C** (tonnes of carbon). Their carbon sink capacity is **198.9 thousand t C/ha.**



Carbon stock and sink

Average carbon (C) stocks

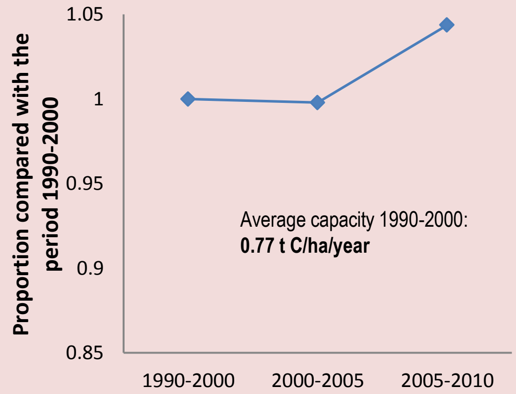
Aleppo pine forests store fewer tonnes of C/ha than the average amount stored by other species, with regard to both aboveground and underground carbon.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the Aleppo pine forests' average carbon sink capacity increased during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors	9, 10		
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation	1, 2, 3, 5, 6		16
Higher temperature			
More competition	2		
Large trees			
Higher carbon reserves in trees	1		
More erosion			
Thinner and more compact soil	5		
Adverse topography (*)	5		

Regen. 16

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors			
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude	11	11	
Less precipitation	11, 12	11, 12	
Higher temperature	11, 12	11,12	
More competition			
Large trees	13	13	
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors	8		23,24 (**)
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			26, 31
Less precipitation			33 30 16, 34
Higher temperature			
More competition			20, 22
Large trees			25, 28, 29
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			26,29,30

(**)15,17,19,21,34,35,37

Legend

Without additional factors	With additional factors
Slight effect	Decreases the effect
Moderate effect	Does not change the efect
Severe effect	Worsens the effect
Very severe effect	Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Aleppo pine *(Pinus halepensis)*

GROWTH

1. A reduction in winter and spring precipitation would lead to a reduction in radial growth, since it depends on this directly, and, indirectly, would also reduce carbon absorption. This reduction would be a plausible cause of the decline of forests. (Ref. 46, 56, 45, 55)
2. The growth of the Aleppo pine, both in open and closed forests, is related to annual precipitation. For this reason, competition for water is greater in very densely reforested areas and thus growth is lower. (Ref. 36)
3. In some of the drier areas, Aleppo pine has shown a large reduction in growth as a result of the droughts of 1994-1995, 1999 and 2005. (Ref. 55)
4. Global warming tends to increase photosynthesis rates in Aleppo pine during the cold seasons when low temperatures are the limiting factor. (Ref. 50)
5. Soil moisture content is positively correlated with photosynthesis rates. (Ref. 50)
6. In Mediterranean forests, the NDVI (see *Glossary)* of the Aleppo pine decreased during the drought of the summer of 2003. (Ref. 29)
7. *Ozone and water stress reduce gas exchange rates. (Ref. 27)*
8. In areas that burned twice (fire return intervals of under 16 years), lower growth was observed in the height and diameter of pines that regenerated post-fire, resulting in: a 3-year delay in the start of reproduction, a 52% reduction in the number or reproductive pines and 36% smaller than average pine cones. All together, this resulted in a structural simplification of the forest. (Ref. 15, 18, 17)

MORTALITY

9. Aleppo pine has water-saving mechanisms to cope with drought. In response to water stress, it shows a rapid increase in water use efficiency and water availability, thanks to its root penetration into deep soil layers. (Ref. 9, 20, 51)
10. In response to midday water stress, the Aleppo pine shows substantial stomatal closure, which allows it to maintain its water potential stable. (Ref. 32)
11. The pine processionary moth (*Thaumetopoea pityocampa*) is a pest in pine forests related to the NAO indices *(see Glossary)* that most severely affects pine species that grow at middle-high altitudes. A negative NAO episode brings mild temperatures and moist conditions, which favour the processionary moth. (Ref. 25)
12. Up to 3 years after a negative NAO episode *(see Glossary*) defoliation episodes caused by the pine processionary moth can be observed. (Ref. 25)
13. Damage caused by several defoliating species (*Pachyrhinus*) has been found in young pines. (Ref. 22)
14. *Defoliating beetles (Coleoptera, Curculionidae) prefer to eat pine needles from the previous season. (Ref. 22)*
15. The Aleppo pine is a species adapted to fire-prone habitats and is frequently used for reforestation and restoration, since it exhibits a certain degree of adaptation to fire, with strategies such as natural post-fire regeneration. (Ref. 42, 41, 40, 39, 4, 53, 52)

REGENERATION

16. A prolonged drought hinders the recolonisation of burnt areas by species that normally germinate by seed after fires, such as the Aleppo pine. (Ref. 33)
17. The Aleppo pine has serotinous pinecones, which protect the seeds from fire damage, insulating them and favouring their opening post-fire in order to release the seeds. (Ref. 42, 58)
18. *Both the NDVI values (see Glossary) and the spatial structure of Aleppo pine forests have tended to recover during the period 1997 -2007 after the extensive fires of 1995. (Ref. 60)*
19. High regeneration of Aleppo pine was the dominant pattern in the study area (an Aleppo pine forest in Montes de Castejón in the Ebro valley), where over 70% of the burned area tended to recover to pre-fire conditions. (Ref. 60)
20. The high density of seedlings in the regenerated areas produces high intraspecific competition, which would decrease the production of pinecones per tree and, in the event of any new fires, result in an insufficient quantity of seeds stored for a new recolonisation. (Ref. 40)
21. The Aleppo pine is a species that reproduces very early (5-7 years) and allocates a large amount of resources to seed production, which accumulate in the crown. This ensures natural regeneration in the case of new perturbations (such as a new fire) in the future and reduces the risk of not reaching maturity. (Ref. 40, 44)
22. The number of reproductive trees in young pine forests (regenerated forests) is higher in less dense areas, where thinning was carried out, and, moreover, the production of pinecones per tree was higher in these areas because of lower competition for water, light and nutrients. (Ref. 37)
23. Rodents are the main predators of Aleppo pine seeds in burnt areas. (Ref. 6)
24. A third fire in areas that have already been burnt could seriously limit the natural regeneration of Aleppo pine. (Ref. 15)
25. The high recurrence of fire promotes a large increase in young and immature pine stands, with little capacity for regeneration and a high risk of not reaching maturity. (Ref. 13)
26. Elevation is the only significant topographic variable that determines changes in the composition of forests after fire. Twenty years after the fire, limited regeneration of Aleppo pine was found, especially above 1,000 m (Ref. 4)
27. *The recruitment of saplings occurs immediately after a fire, both in areas burnt once and twice; however the density is lower in the latter. (Ref. 18)*
28. After 5 years Aleppo pines start to make pinecones, however, 15-year fire return intervals are considered the minimum time required by the Aleppo pine to recover after a fire, since this is the time needed to create a seed bank capable of reducing the risk of not reaching maturity. (Ref. 18, 58)
29. Ten years after the fire, regeneration varied between 0.006 pines/m2 and 20.4 pines/m2. The highest regeneration was observed in forests with large amounts of branches on the ground, which create suitable microclimatic conditions, on north-facing slopes, where the prior basal area was large, and in terraced locations. (Ref. 48)

30. Some studies indicate that the variables annual precipitation and slope were of little importance with regard to regeneration. (62) On the other hand, others suggest that steep slopes and greater exposure to sunlight result in very low or no regeneration. (Ref. 11)

31. Both the density of Aleppo pine regeneration seedlings and their average height decreased with altitude. Fire severity also affected the average seedling height. (Ref. 5)

32. The regeneration of Aleppo pine after fire depends totally on the seed bank it has stored in the crown. (Ref. 44)

33. Seed release is induced, either by fire or by conditions of low atmospheric humidity. In the first case, they travel short distances: < 30m; while in the latter, wind can disperse them up to 1km. (Ref. 43)

34. After fire, one can observe the natural regeneration due to the “rain” of seeds, which mature during the first days post-fire. Seedling emergence is concentrated in the autumn-winter of the first year and depends on precipitation after the fire. (Ref. 11, 19, 33)

35. Species (such as the Aleppo pine) that keep their seeds inside pinecones have higher germination percentages compared to those with free seeds, since the pinecones protect the seeds from high temperatures. (Ref. 23)

36. Germination rates decrease when the fire exposure time and temperature increase. (Ref. 23)

37. Pinus halepensis has higher germination rates than *Pinus sylvestris* and *Pinus nigra*. Its post-fire germination comes from the seed bank in the soil or the crown, but never from seeds on the surface of the soil. (Ref. 23)

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below.

DISTRIBUTION

-Twenty years after successive Aleppo pine and maritime pine fires, the Aleppo pine population is decreasing and the scrub brush is increasing. Therefore, the resilience of the forest ecosystem appears to be very low. (Ref. 3, 16, 17)

-The most severely burned plots of Aleppo pine and holm oak (dead trees with only the occasional live branch at the top of the crown) have turned into mixed forests or scrubland. (Ref. 4)

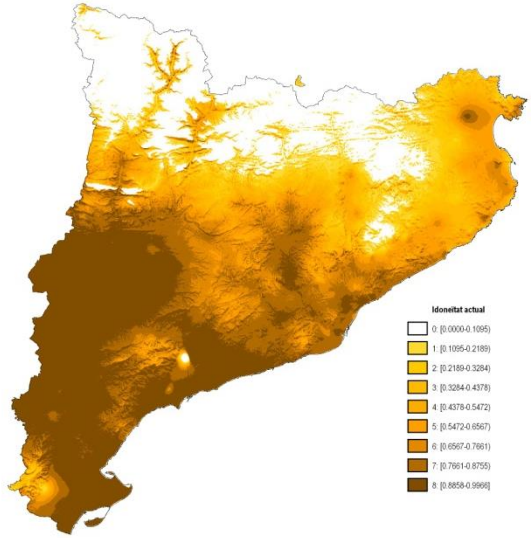
- It is expected that fire regimes in the Mediterranean Basin are increasing in recurrence, something that may lead to drastic changes in the distribution of Aleppo pine forests. (Ref. 18)

OTHERS

- Pioneer species such as the Aleppo pine can accumulate large quantities of standing dead tree biomass and thus promote fire during the first stages of succession. (Ref. 2)
- The highest levels of serotiny (*see Glossary)* were recorded on south-facing slopes. (Ref. 37)
- The erosion rates observed after a fire are relatively high, especially under severe fire conditions. (Ref. 47)
- Many forest pest species are highly dependent on temperature in their dynamics. (Ref. 25)
- During the summer of 1994 in eastern Spain, over 100,000 hectares of Aleppo pine forest was burnt. (Ref. 39)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE ALEPPO PINE:

CURRENT SUITABILITY:



Current suitability map for the Aleppo pine. Source: Ninyerola *et al.* 2009

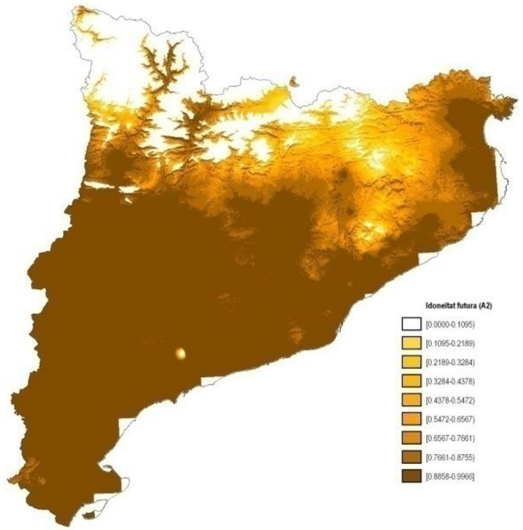
The extent to which the Aleppo pine was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the Aleppo pine exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,958,140	2,544,832
%	60.7	79

Aleppo pine forests currently cover 60.7% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would rise to 79%.

PROJECTED SUITABILITY (A2 STORYLINE):



The extent to which the Aleppo pine would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the Aleppo pine. Source: Ninyerola *et al.* 2009

PREVENTIVE ACTIONS:

- Differences in the defoliation percentage have been found depending on the silvicultural practices adopted: the more intense the practice, the higher the percentage of defoliation recorded. (Ref. 22)
- Good forest management policies improve growth, reproductive processes, advance the age of maturity and increase the size of the seed bank and the number of serotinous pinecones. Therefore, they reduce the risk of not reaching before new disturbances. Thinning as a silvicultural tool can mitigate the negative impacts of global warming. (Ref. 55, 39, 13)
- Thinning 5 and 10 years after a fire improved growth and increased the number of seeds stored in the crown, leading to a more successful regeneration and resulting in biodiversity levels similar to those found in mature forests. (Ref. 41)
- Thinned tree plots show an increase in the percentage of pines that produce pinecones for the first time (50.4% compared with 13.3% in the control plots); it shortens the non-productive period and increases the number of pinecones per pine tree. (Ref. 61)
- Traditional timber extraction practices do not threaten the regeneration of the Aleppo pine, as long as the initial seedling density is high enough. (Ref. 33)
- Silvicultural practices did not have a significant impact on fauna. (Ref. 41)
- Despite the negative effect of timber extraction of the survival of young trees, the density of seedlings 4 years post-fire in the thinned areas was high: 3.3 plants/m2. (Ref. 33)
- Timber removal reduced sapling growth - the height was significantly higher in the control plots. (Ref. 33)
- The density of saplings decreased from 0.66 seedlings/m2 9 months after the fire to 0.24 seedlings/m2 39 months after the fire. (Ref. 24)

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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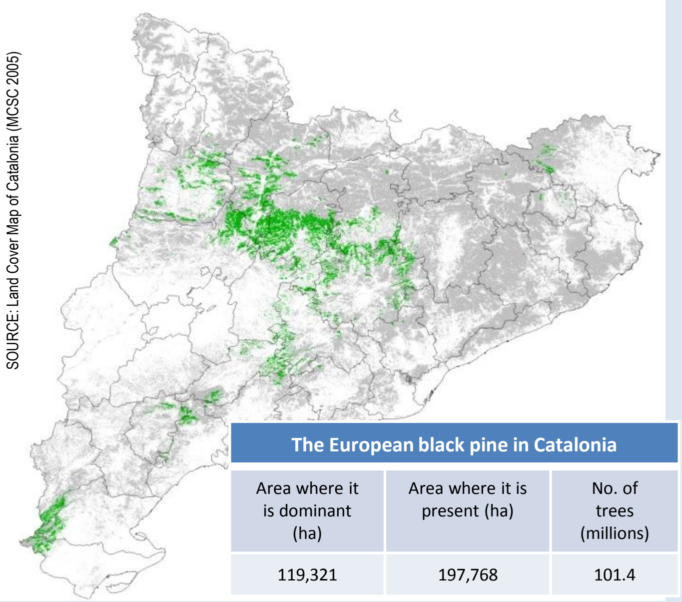
European black pine (*Pinus nigra*)

Distribution and structure

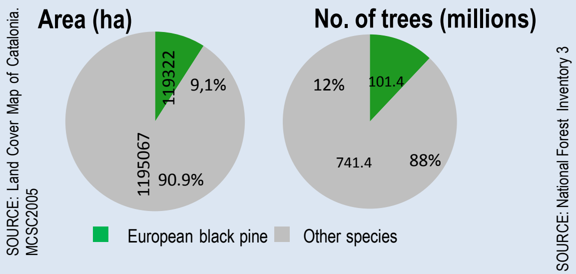
Distribution of the European black pine in Catalonia

In Catalonia, the European black pine is found in parts of the central pre-Pyrenees, at altitudes of between 500 and 1,200 metres; as well as in the Els Ports de Tortosa-Beseit Mountain Range.



The European black pine in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
119,321	197,768	101.4

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

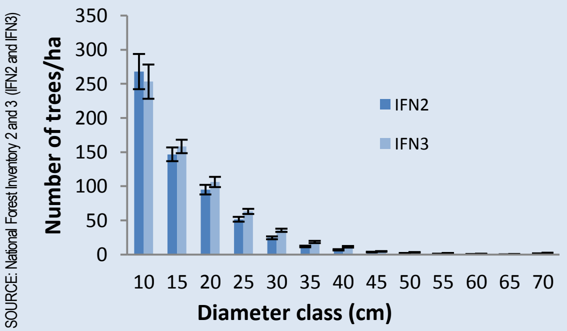


European black pine forests account for 9.1% of the total forest area in Catalonia, and 12% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

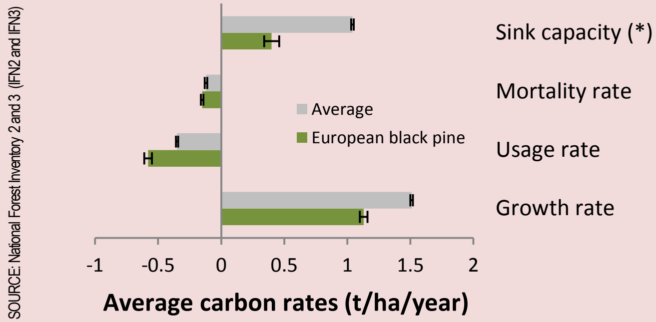
Structure of the European black pine population

The European black pine forests are very young, with most trees being below the 20 cm diameter class.



Average carbon (C) rates

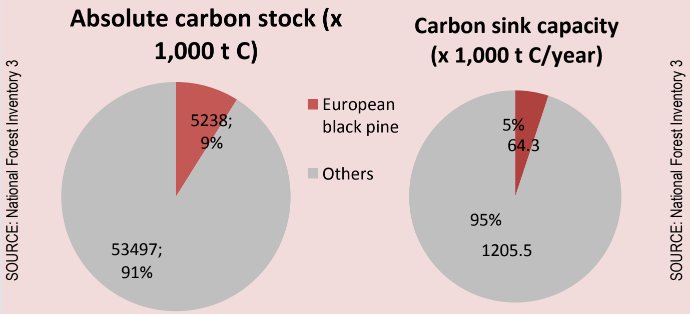
The average carbon sink capacity for the European black pine between the years 1990 and 2000 was **0.4 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

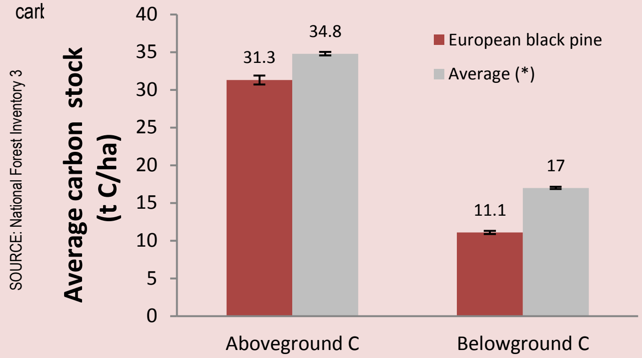
The absolute carbon stock of European black pine forests is **5.2 million t C** (tonnes of carbon). Their carbon sink capacity is **64.3 thousand t C/ha.**



Carbon stock and sink

Average carbon (C) stocks

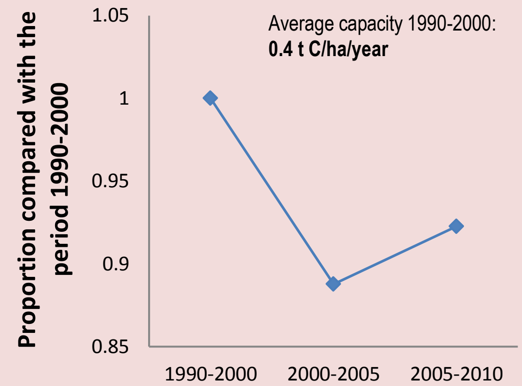
European black pine forests store fewer tonnes of C/ha than the average amount stored by other species, with regard to both aboveground and underground cart



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the European black pine forests' average carbon sink capacity increased during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors	17	17	
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude	1, 14 / 15	14	
Less precipitation	4,6,7,8,10,11,13,15	10, 11	21
Higher temperature	1,4,7,11	11	
More competition	10	10	
Large trees	5 / 2,10,15	10	
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil	2,16		
Adverse topography (*)			

Legend

Without additional factors		With additional factors
Slight effect		Decreases the effect
Moderate effect		Does not change the efect
Severe effect		Worsens the effect
Very severe effect		Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors		23	22,27,29,30,36,37
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			24,31,32,33
Higher temperature			
More competition			24
Large trees		19,20	20,35
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors		26	
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude	25	25	
Less precipitation	25	25	
Higher temperature	25	25	
More competition			
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

European black pine (*Pinus nigra)*

GROWTH

1. European black pine populations situated at low altitudes show a negative correlation between the average temperature and growth. (Ref. 3)

2. The oldest European black pine trees show lower than average growth, which also depends on the soil conditions. (Ref. 3)

3. When precipitation is not a limiting factor, temperature correlates positively with growth. (Ref. 5)

4. If periods of global warming continue and certain drought thresholds are exceeded, growth could be affected. (Ref. 25)

5. Dominant trees show a more plastic response because they recover back to their normal growth more quickly after a drought. (Ref. 24)

6. Plant development during a drought depends on the balance between light and moisture limitations. (Ref. 24)

7. With regard to temperature, hot, dry summers reduce the growth of *Pinus nigra*; while warmer springs and winters and cold autumns increase growth. (Ref. 24, 21)

8. With regard to precipitation, drought in the months of May and June was the main factor that limited growth. A warm winter, on the other hand, favoured growth. (Ref. 20, 21, 18)

9. In drier areas, the growth response to drought depends on precipitation; while in more temperate locations it depends on the annual water balance. (Ref. 34)

10. The probability of damage to the tree crown, considered as a deterioration, increased with the size of the tree, competition and drought in spring and summer. (Ref. 43)

11. The reduction in growth and generalised defoliation in pine tree plantations leads us to think that in dry places subject to periods of severe drought, tree persistence may be compromised given that warmer and drier conditions are expected in the future. (Ref. 43)

12. Pinus nigra responded positively to higher temperatures at the start of the growth period. (Ref. 18)

13. Precipitation in summer months and winter temperatures have a positive effect on growth; while summer temperatures have a negative effect. (Ref. 26)

14. Trees that grow in locations at lower elevations and in drier climates are more vulnerable to temperature-induced drought. (Ref. 6)

15. At locations at higher elevations and in drier climates, trees with a greater than average age (which correlates with elevation over 1,500 m) suffer more effects on growth in the long-term (warming) and in the short-term (drought). (Ref. 6)

16. *Pinus nigra* accesses sources of water deep underground during dry summers. (Ref. 36)

17. The European black pine exhibits efficient stomatal control, which reduces water loss due to transpiration. (Ref. 19)

18. Soil surface desiccation causes rapid stomatal closure. (Ref. 19)

MORTALITY

19. Survival increases with the size of the tree and decreases with the damage suffered to the crown during fires. (Ref. 33)

20. The survival of large trees and their seed production rate indicate that they are the main post-fire seed sources. (Ref. 33)

21. Seedling survival depends mainly on abiotic factors such as summer drought. (Ref. 29)

22. The seeds of *Pinus nigra* cannot withstand 5 minutes of exposure to temperatures over 110ºC. (Ref. 1)

23. Seedling mortality is high and the proximity of the trees that produce seeds is decisive for their establishment. (Ref. 46)

24. Saplings do not withstand summer drought or competition with other species that appear after a fire (grasses and shrubs). (Ref. 46)

25. The pine processionary moth (Thaumetopoea pityocampa) is a pest in pine forests related to the NAO indices (see Glossary) that most severely affects pine species that grow at middle-high altitudes. A negative NAO episode brings mild temperatures and moist conditions, which favour the processionary moth. Defoliation episodes caused by the pine processionary moth can be observed up to 3 years after a negative NAO episode. (Ref. 16)

26. *Matsococcus feytaudi* is an insect that causes the generalised mortality of *Pinus nigra* forests on the island of Corsica. (Ref. 18)

REGENERATION

27. The establishment of European black pine seedlings improves in conditions of high vegetation cover, which are not the conditions that occur in burnt areas. Therefore, the regeneration of this species is highly limited after a fire. (Ref. 31)

*28. The germination rate decreases as the quantity of ash increases, since the latter has an inhibiting effect and seedlings exhibit a higher mortality rate. (*Ref. *38)*

29. The late flowering and lack of serotinous pinecones (*see Glossary*) indicate that the European black pine did not develop historically under frequent fire conditions. (Ref. 45)

30. Under normal conditions, the natural regeneration of *Pinus nigra* is not limited by its seeds, despite the fact that their production differs greatly from one year to the next. However, if a European black pine suffers from a fire, the density of its seeds is not high enough to allow for natural reforestation in that area. In these cases, regeneration is slow and risky. (Ref. 29, 46)

31. CO_2 enrichment treatments on saplings increased total biomass, leaf biomass and leaf area of the seedlings; while water restriction treatments decreased leaf area and leaf biomass. (Ref. 2)

32. If spring precipitation is high, the number of surviving saplings increases even if the summer is dry. (Ref. 39)

33. The decrease in European black pine recruitment density under conditions of drought highlights the threats to the maintenance of its population, even in the absence of fire. (Ref. 4)

*34. The predation of post-fire seeds by various groups of animals and the low emergence of seedlings, along with the low availability of seeds in burnt areas, do not bode well for the European black pine's post-fire recolonisation. Its distribution range may even be affected. (*Ref. *32)*

35. Plots with medium and large trees have a higher establishment of seedlings than plots dominated by small trees, which have very low regeneration values, since large trees produce more pinecones and with greater frequency. (Ref. 31, 33)

36. The European black pine regeneration in the absence of fire is quite good. On the other hand, after fires the regeneration of seedlings almost disappears. (Ref. 37)

37. Populations of *Pinus nigra* and *Pinus pinea* do not exhibit any adaptation to fire: their flowering was insignificant even 15 years after the fire and none of the pinecones produced were serotinous (*see Glossary*), this suggests that the European black pine can only withstand fire if it is of low intensity. (Ref. 44)

*38. The seed cover only protects the seeds up to 70ºC (germination rate of over 90%), which is a very low temperature for a forest fire. Higher temperatures and longer exposure times decrease the germination rate. (*Ref. *15, 8)*

*39. The success of regeneration depends on the seed banks or the phenology of the seeds (they take 2 years to mature and are dispersed during the spring of the third year) and the fire severity, which affects the opening of the pinecones. (*Ref. *15)*

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below.

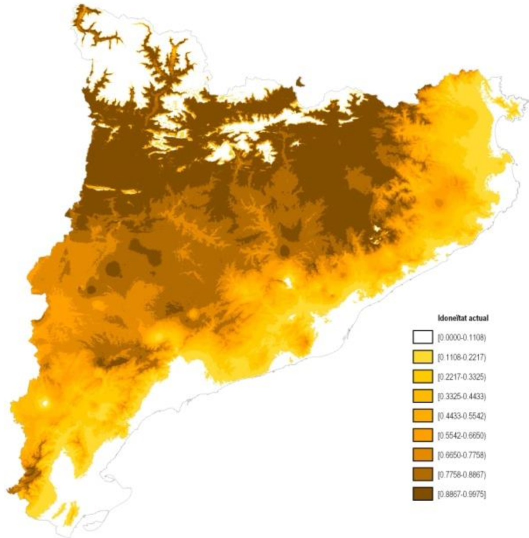
DISTRIBUTION AND VULNERABILITY

- The severe reduction in growth and generalised defoliation in pine plantations lead us to think that, in dry places subject to periods of severe drought, their persistence may be compromised given the warmer and drier conditions expected in the future. (Ref. 43)
- It is predicted that growth under future climatic conditions will decrease, despite the fact that there may be an increase in growth in areas further north due to a moderate increase in individual growth. (Ref. 26)
- Some species of *Quercus* and *Pinus* have shown regeneration, while the European black pine forests did not recover. (Ref. 40).
- Large plantations of European black pine have disappeared recently due to their sensitivity to fire. (Ref. 35)
- The different post-fire recovery patterns have led to the dominance of pines in more temperate locations and the co-dominance of pines and oaks in drier locations. (Ref. 14)
- Models show that 30 years after a fire, 77-93% of the plots dominated by *Pinus nigra* are later dominated by other communities (*Quercus ilex, Quercus cerrioides*, etc.). (Ref. 37)
- Fires may decrease the general distribution of some pine species, especially *Pinus nigra* and *Pinus sylvestris,* resulting in a change in soil cover due to their low regeneration capacity. (Ref. 37, 10)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE EUROPEAN BLACK PINE:

CURRENT SUITABILITY:

The extent to which the European black pine was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).



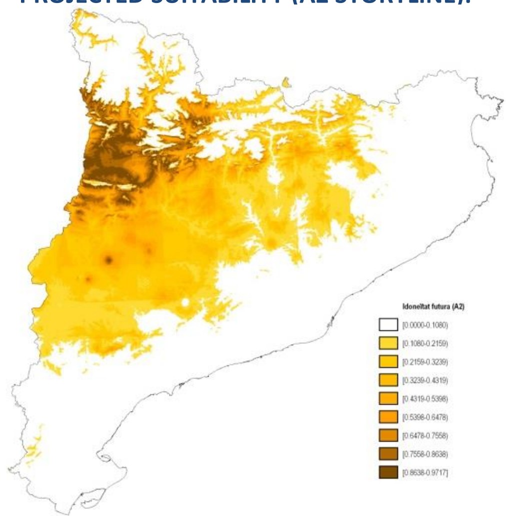
Current suitability map for the European black pine. SOURCE: Ninyerola *et al.* 2009

The areas indicated in the table are the hectares in which the European black pine exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,871,004	301,516
%	58	9.3

European black pine forests currently cover 58% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage could decrease to 9.3%.

PROJECTED SUITABILITY (A2 STORYLINE):



The extent to which the European black pine would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the European black pine. Source: Ninyerola *et al.* 2009

PREVENTIVE ACTIONS:

- In *Pinus nigra* plantations, thinning may be a useful adaptation measure against climate change, since it reduces the species' vulnerability to drought. The thinning of plantations does not affect water use efficiency, though if periods of global warming continue and if certain drought thresholds are exceeded, trees growth could be affected. (Ref. 4)
- Bearing in mind the prediction of hotter, drier conditions, the management of Mediterranean forests should focus on local factors that modulate the negative effects of drought on the growth of trees in both dry and wet sites. (Ref. 10)
- The use of shrubs as protector plants is a technique that offers financial and ecological advantages, which improves the state of the seedling (*see Glossary*) water relations and thus reduces summer mortality caused by drought. (Ref. 22)
- A combination of plantations of pines and oaks is proposed for the restoration of degraded land, due to the complementary characteristics of these trees. (Ref. 33)
- Forest managers are advised to carry out controlled burns in the autumn instead of the spring, to reduce the fuel load and have a lower impact on the trees. (Ref. 46)

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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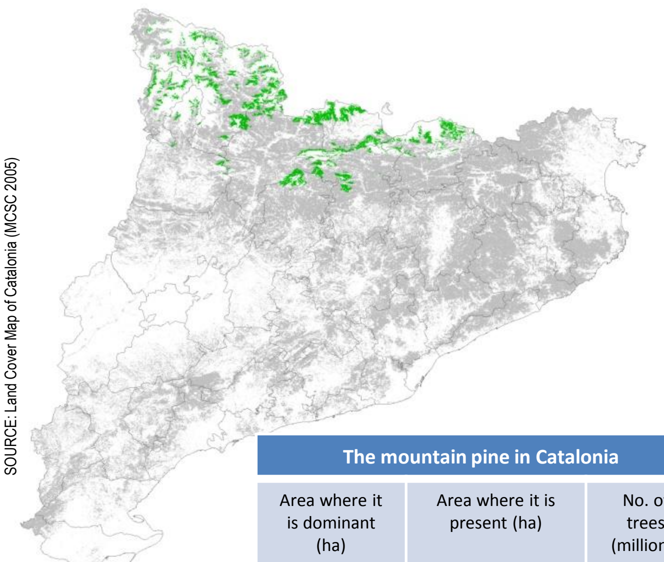
Mountain pine (*Pinus uncinata*)

Distribution of the mountain pine in Catalonia

In Catalonia, the mountain pine is found in all parts of the Pyrenees, from the Aran Valley to the Camprodon Valley, at altitudes of between 1,600 and 2,400 m.

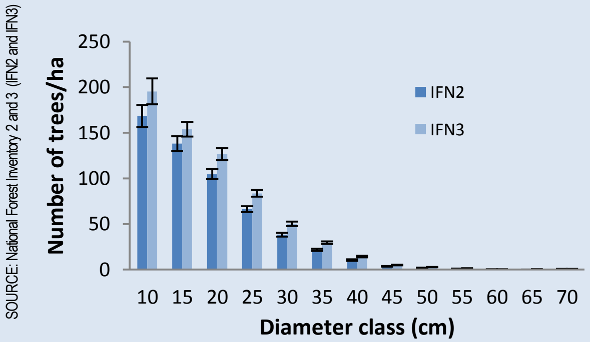


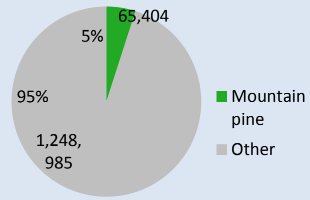
The mountain pine in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
65,404	105,024	48

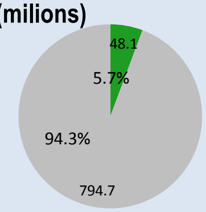
The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

Structure of the mountain pine population

The mountain pine forests in Catalonia are very mature since quite a lot of the trees belong to large diameter classes.





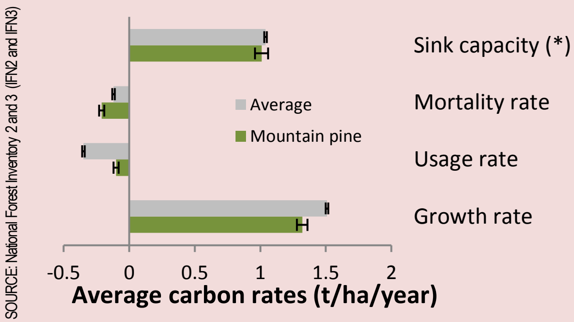


Mountain pine forests account for 5% of the total forest area in Catalonia, and 5.7% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

Average carbon (C) rates

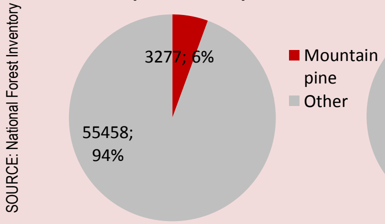
The average carbon sink capacity for the mountain pine between the years 1990 and 2000 was **1.01 t C/ha/year.**

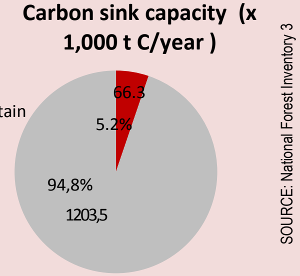


(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

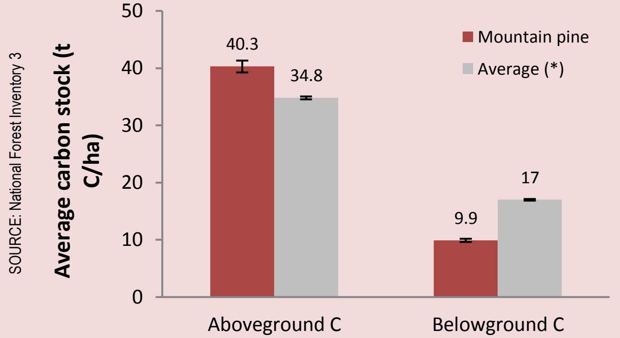
The absolute carbon stock of mountain pine forests is **3.2 million t C** (tonnes of carbon). Their carbon sink capacity is **66.3 thousand t C/ha.**





Average carbon (C) stocks

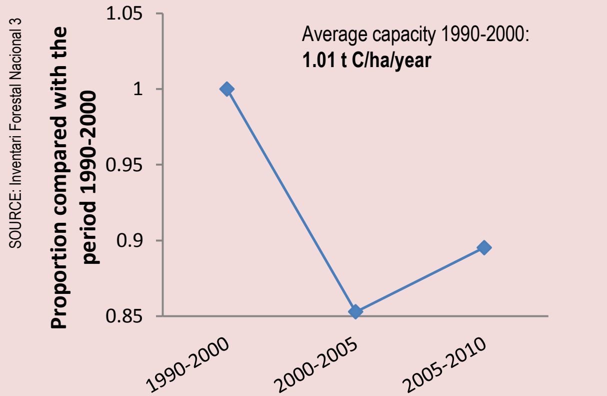
Aleppo pine forests store slightly more tonnes of aboveground C/ha than the average amount stored by other species, and slightly less underground carbon.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

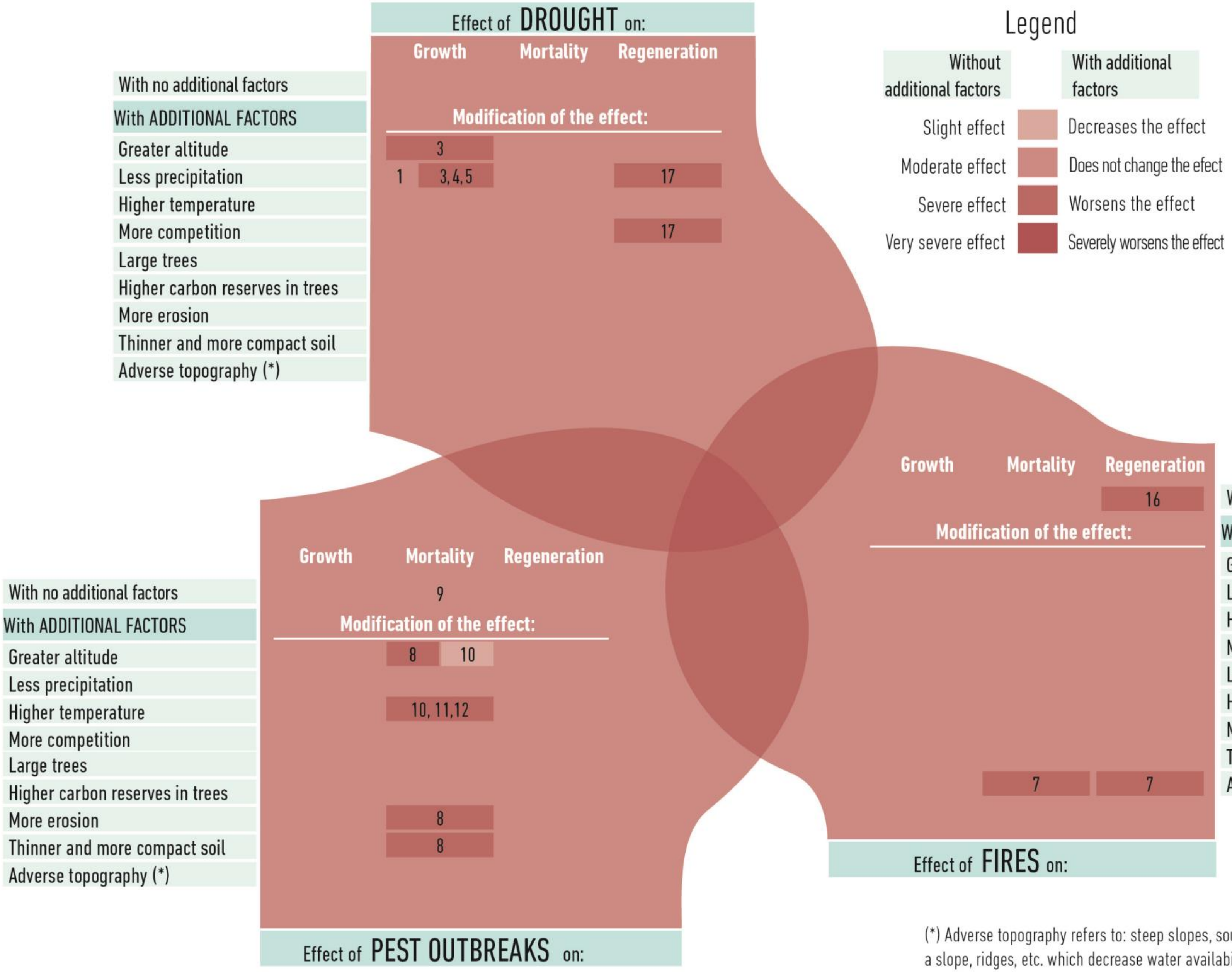
With regard to the reference interval (1990-2000), the mountain pine forests' average carbon sink capacity decreased markedly during the period from 1990-2000 to 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Mountain pine (*Pinus uncinata*)



Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Mountain pine (*Pinus uncinata*)

GROWTH

1. According to the NDVI (*see Glossary*), no effects of the 2003 drought were observed in the high mountain forests of mountain pine (Ref. 14)

2. Autumns and winters with mild temperatures favour the growth of some species, including the mountain pine. (Ref. 12, 13)

3. The increase in ozone exposure causes chlorosis in mountain pine forests in some parts of Catalonia (this has been observed in La Cerdanya) and leads to an increase in the occurrence and intensity of visible damage and a reduction of between 24% and 29% in root biomass, which makes the trees more vulnerable to other factors such as drought. (Ref. 10, 4, 17)

4. The increase in the CO_2 concentration under warmer conditions does not appear to compensate for the negative effects of the lack of water on growth. (Ref. 2)

5. The high mountain populations show an increase in growth induced by the warmer climate during the vegetative growth phase. However, reductions in in growth due to water stress in summer have also been recorded. (Ref. 11)

6. A greater growth in the trunk was attributed to a great extent to the increase in temperature and, to a certain degree, to an increase in the atmospheric CO_2 concentration in an experiment in the Swiss Alps. However, another experiment in a greenhouse indicates that the CO_2 concentration did not have a significant effect on the average growth rate of the mountain pine (Ref. 7, 1)

MORTALITY

7. In Alpine ecosystems, the impact of fire is generally eclipsed by other disturbance factors such as the effects of wind, landslides, decomposition due to fungi and to climate change or soil use. (Ref. 26)

8. It appears that colonisation by fungi was higher in trees situated on ridges. (Ref. 24)

9. The growth rate of the larvae of the pine processionary moth and the relative mortality of trees infested by the moth in a field experiment were not different when using host trees grown under conditions of high atmospheric CO_2 or control trees. (Ref. 20)

10. Snow cover increases the mortality of pine processionary moth larvae in the mountain pine, although the initial larval stage is not affected by low temperatures nor the increase in CO_2. (Ref. 20)

11. The host species does not have a significant effect on the final survival of the pine processionary moth. On the other hand, the number of feeding hours during the cold period does affect the moth. (Ref. 3)

12. An increase in temperature makes the pine processionary moth emerge prematurely. (Ref. 8)

13. *Heterobasidion annosum is a fungus that is considered to be one of the most important pathogens of conifers, although no serious infestations have been observed in Spain.* (Ref. 18)

*14. Heterobasidion annosum persists in mountain pine plantations for a long time. The disease expands slowly outwards from the point of origin, and the regressive death of pines affected by the fungus lasts for decades. (*Ref. *28)*

15. El mycelia of Heterobasidion annosum remain active in the stumps and roots of dead pines and are capable of spreading from the latter and infesting live trees. (Ref. *28)*

REGENERATION

16. The late flowering and absence of serotinous pinecones (*see Glossary*) in the mountain pine suggest that it is a species that is not adapted to fire. (Ref. 27)

17. Mountain pine seeds exhibit very low germination rates and this species prefers north-facing slopes with a low density of trees and good availability of water. (Ref. 6)

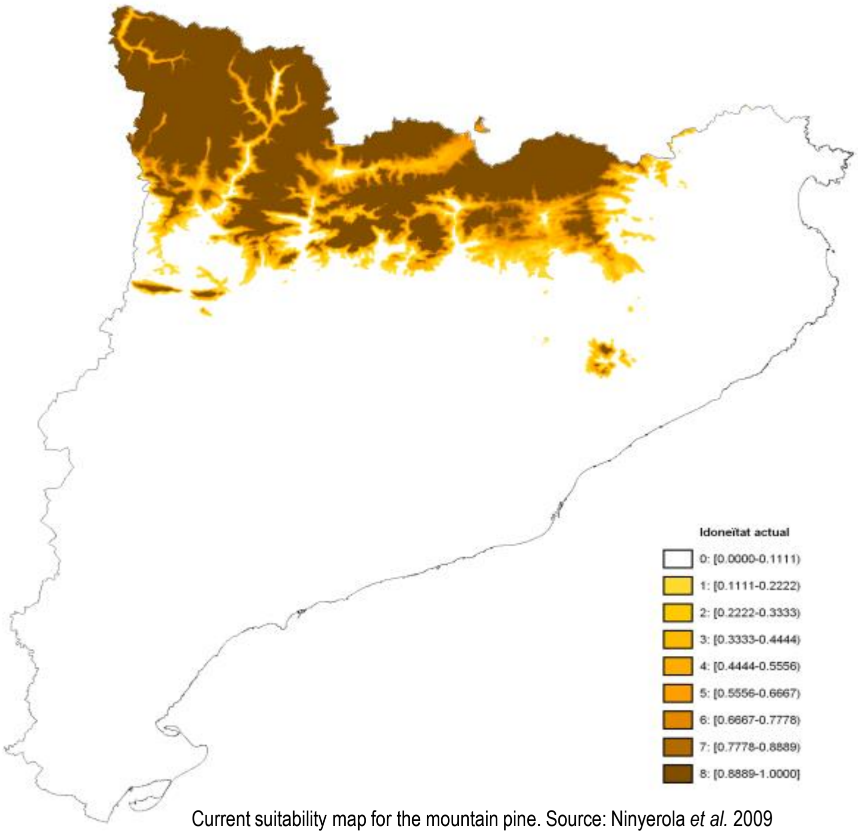
The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below**.**

DISTRIBUTION

- By the end of the century the mountain pine is expected to migrate northwards and upwards, into habitats currently occupied by alpine plant species. (Ref. 16)
- The pine processionary moth is expanding its geographic distribution in Europe as a result of higher survival rates during winter in a warmer climate. (Ref. 3)
- During the period 1956-2006 the area of mountain pine increased by almost 9,000 hectares in the Catalan Pyrenees (an increase of over 16%) and the average canopy cover also rose from 31% to 55.6%. This expansion occurred basically on the northern slopes and at low altitudes and was principally a result of socio-economic factors. (Ref. 1)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE MOUNTAIN PINE:

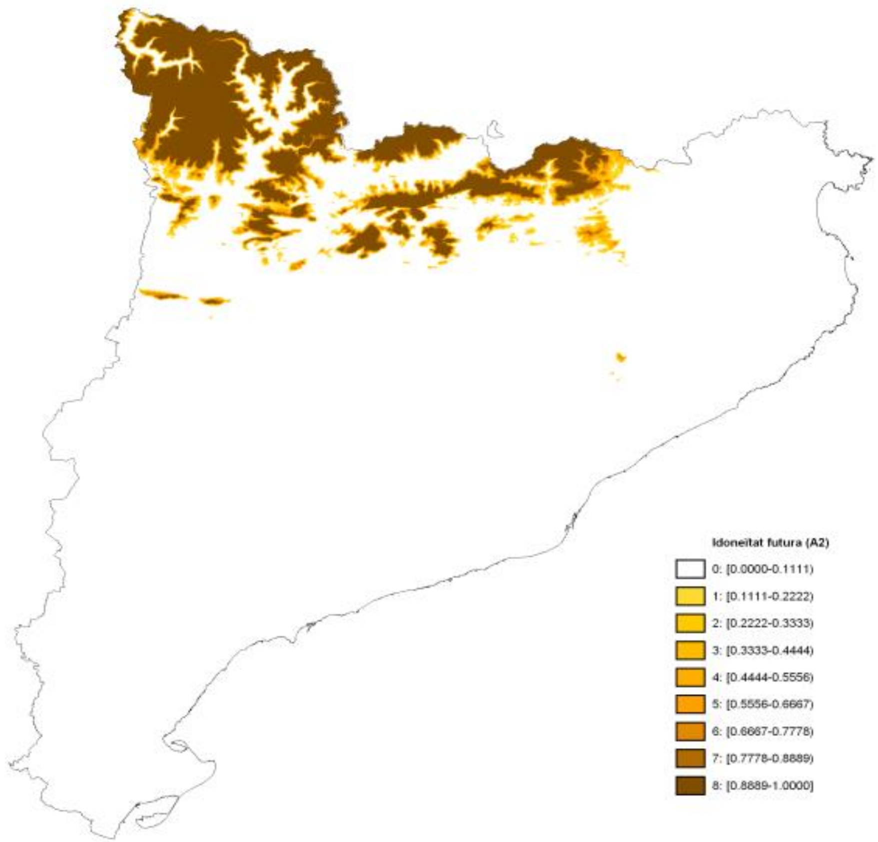
CURRENT SUITABILITY:



Current suitability map for the mountain pine. Source: Ninyerola *et al.* 2009

The extent to which the mountain pine was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

PROJECTED SUITABILITY (A2 STORYLINE):



Projected suitability map (A2 storyline) for the mountain pine. Source: Ninyerola *et al.* 2009

The extent to which the mountain pine would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

The areas indicated in the table are the hectares in which the mountain pine exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	579,968	324,140
%	18.0	10.0

At present, the mountain pine is found across 18% of the surface area of Catalonia, in accordance with the topo-climatic variables. With the A2 storyline, this percentage would decrease to 10%.

PREVENTIVE ACTIONS:

NO INFORMATION WAS FOUND

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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(2) Andreu-Hayles, Laia; Planells, Octavi; Gutierrez, Emilia; et al. Long tree-ring chronologies reveal 20th century increases in water-use efficiency but no enhancement of tree growth at five Iberian pine forests. GLOBAL CHANGE BIOLOGY Volume: 17 Issue: 6 Pages: 2095-2112 DOI: 10.1111/j.1365-2486.2010.02373.x Published: JUN 2011

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(10) Kefauver, Shawn C.; Penuelas, Josep; Ustin, Susan L. Improving assessments of tropospheric ozone injury to Mediterranean montane conifer forests in California (USA) and Catalonia (Spain) with GIS models related to plant water relations. ATMOSPHERIC ENVIRONMENT Volume: 62 Pages: 41-49 DOI: 10.1016/j.atmosenv.2012.08.013 Published: DEC 2012

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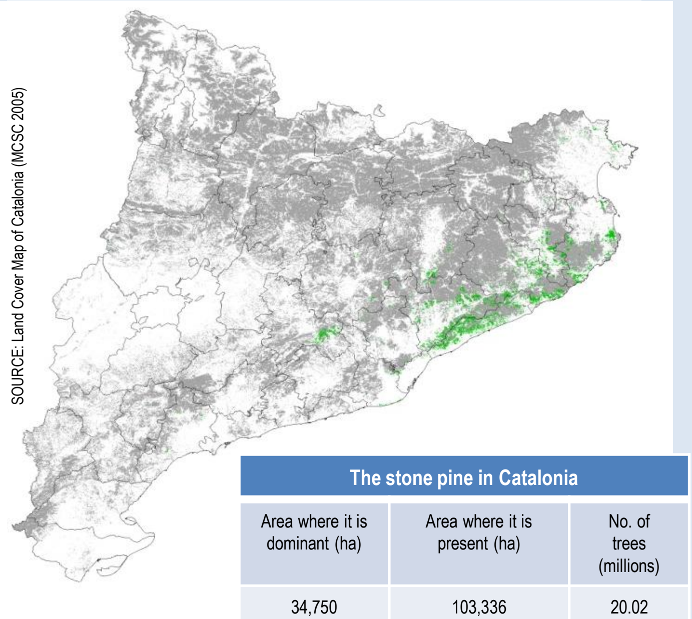
Stone pine (*Pinus pinea*)

Distribution of the stone pine in Catalonia

The stone pine grows close to the coast, at altitudes of up to 1,000 metres.

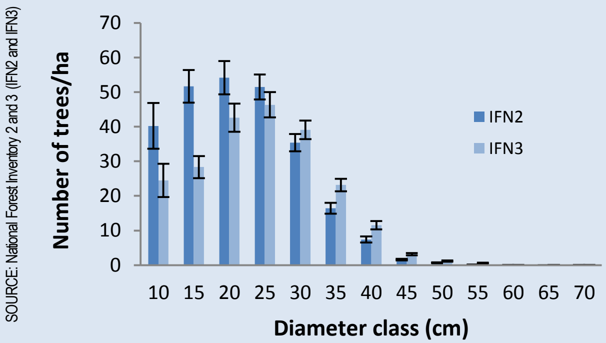


The stone pine in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
34,750	103,336	20.02

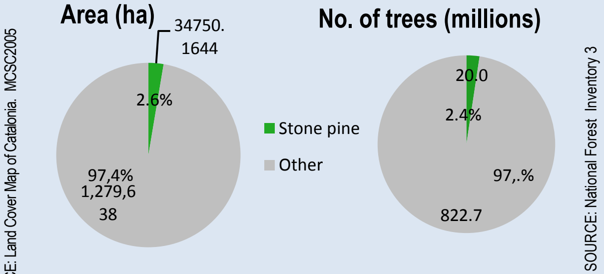
The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

Structure of the stone pine population

The stone pine forms dense forests with considerably large trees. The data from IFN3 reveal a more mature structure than those from IFN2.



Distribution and structure

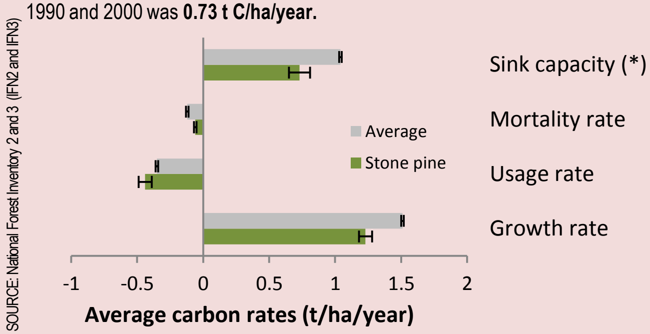


Stone pine forests only account for 2.6% of the total forest area in Catalonia, and 2.4% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

Average carbon (C) rates

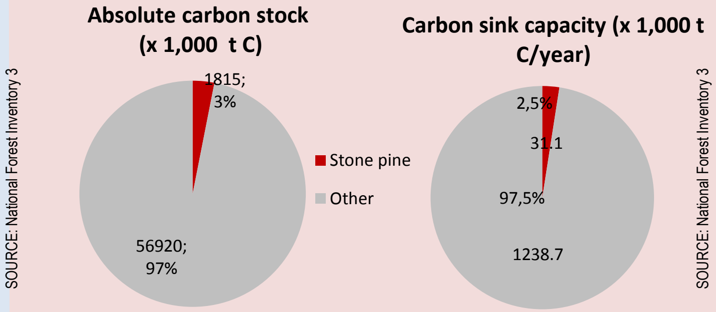
The average carbon sink capacity for the stone pine between the years 1990 and 2000 was **0.73 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

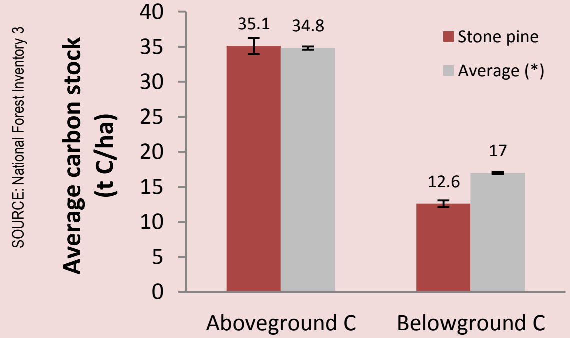
The absolute carbon stock of stone pine forests is **1.8 million t C** (tonnes of carbon). Their carbon sink capacity is **33.1 thousand t C/ha.**



Carbon stock and sink

Average carbon (C) stocks

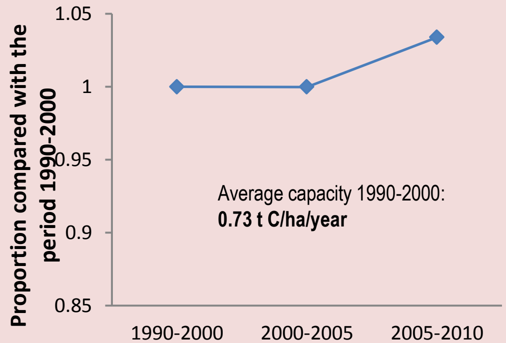
Stone pine forests store 35.1 tonnes of C/ha in the aboveground fraction, almost the same amount as the average, and 12.6 tonnes of C/ha in the underground part.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the stone pine forests' average carbon sink capacity increased during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors		8	18, 21
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation	1, 3, 4, 6	7, 12	
Higher temperature	1, 2; 4		
More competition			20
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil	4	12	
Adverse topography (*)		12	

Legend

Sense factors addicionals		Amb factors addicionals
Slight effect		Decreases the effect
Moderate effect		Does not change the efect
Severe effect		Worsens the effect
Very severe effect		Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors		10, 11	9, 21, 22
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature			
More competition			15
Large trees		9	16
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			15
Adverse topography (*)		9	15

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors		14	15, 17, 23
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature			
More competition			
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Stone pine (*Pinus pinea)*

GROWTH

1. The stone pine has a high gas exchange sensitivity and a high water potential due to the combined effects of drought and high temperatures at the end of the drier and warmer summers. (Ref. 23)
2. Net photosynthesis rates decreased with an increase in the temperatures. (Ref. 23)
3. In southern Portugal, the radial growth of the stone pine is positively related to precipitation. (Ref. 3)
4. The decrease in root growth is greatest in stone pines in the areas where the summer drought is most severe, where the winter temperatures are lowest and where soils have low water retention. (Ref. 3)
*5. An increase in UV radiation may be beneficial for Mediterranean pines, partially decreasing the adverse effects of the summer drought. However, the positive effect of radiation will depend on higher precipitation levels in summer. (*Ref. 12, *17)*
6. The length of the leaves is influenced by climatic conditions and by the water availability in the location where the pines grow. The tree's longevity depends on the position of its leaves and the effect of drought. (Ref. 18)

MORTALITY

7. The stone pine is vulnerable to high levels of embolism in the roots, which limits water absorption when the water is scarce and during summer periods can even lead to the death of the roots. (Ref. 15)
8. Stone pines in a Mediterranean dune system are less seriously affected by summer drought since they can have very deep root systems, which allow them to access water from far beneath the surface. (Ref. 4)
9. In general, the larger pines survive fires, since the flames do not burn the entire crown. However, smaller trees and those growing on steep slopes generally die since they suffer greater damage. Moreover, the regeneration of the stone pine is not so good. (Ref. 10)
10. If the stone pine can survive a fire, this is generally because some of the somewhat isolated or very isolated trees withstand the flames thanks to their thick bark and the umbrella shape of their crown. (Ref. 10)
11. The stone pine has an exceptional capacity for post-fire survival. (Ref. 19)
12. In Tuscany, the stone pine crown condition and the European beech deteriorated due to the decrease in average annual precipitation, especially in locations where the stand conditions are poor: thin soils, steep slopes, etc. (Ref. 1)
*13. The probability of mortality for the stone pine increases with the percentage of scorched crowns and the depth of charring of the bark. (*Ref. *20)*
14. *Tomicus destruens* excavates galleries in the bark. Its attacks can kill the tree. (Ref. 14)

REGENERATION

15. The production of pinecones and seeds is closely related to the space between trees and soil water retention capacity. (Ref. 9)
16. The quantity of seeds depends on the number and size of the pinecones, and the number of viable seeds in each pinecone. The production of pinecones depends on the vigour and health of the tree and on its size. (Ref. 2)
17. Pest outbreaks and predators reduce the number of available seeds. (Ref. 2)
18. Seed germination decreases when the drought increases. (Ref. 26)
*19. Planted forests have lower regeneration and lower diversity levels compared to natural forests. (*Ref. *24)*
20. Low stand densities do not assure the survival of one-year-old saplings, but they are sufficient for older saplings. (Ref. 16)
21. The stone pine is a species that has great difficulty in regenerating naturally, both under the canopy cover of its own species and under the cover of other species, and above all due to the short seed dispersal distance, the seedling incapacity to establish in burnt environment s and the low survival rates of those that do manage to germinate. (Ref. 10, 22)
22. Stone pine populations do not exhibit any adaptation to fire: flowering is insignificant, even 15 years after the fire, and none of the pinecones are serotinous (*see Glossary).* (Ref. 27)
23. In pinecones infected by *Dioryctria mendacella,* the germination of seeds, their weight and the number of seeds are significantly lower than in healthy pinecones. (Ref. 11)

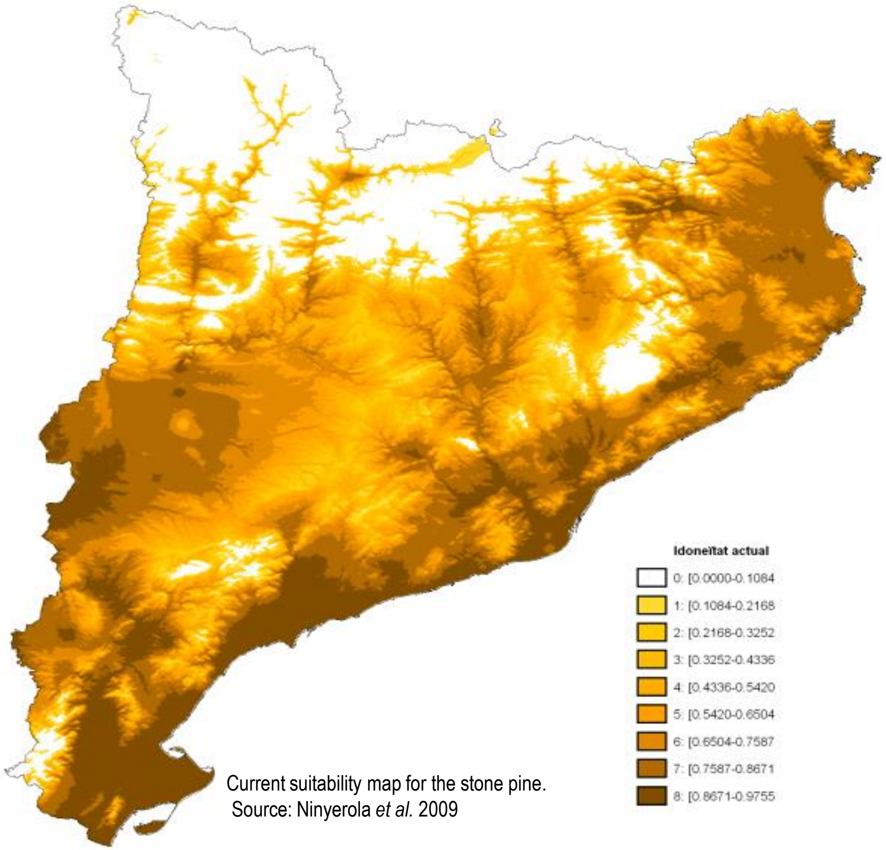
The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below.

DISTRIBUTION

The pattern of variation observed in the morphological and physiological characteristics of the stone pine may allow it to adapt to short-term water deficit. (Ref. 25)
- Fire substantially modifies the distribution of the stone pine in Catalonia and presents a large number of difficulties that hinder its natural regeneration. (Ref. 10)
- The pine shoot beetle *Tomicus destruens* colonises all pine species, and global warming may cause it to move to higher altitudes and latitudes. (Ref. 8)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE STONE PINE:

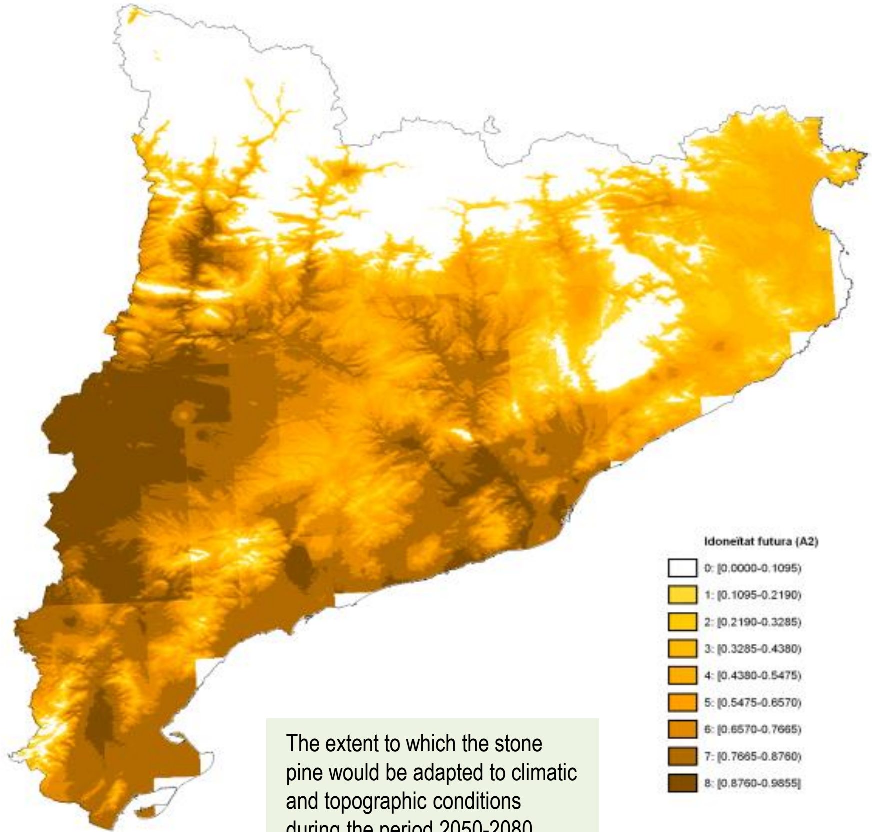
CURRENT SUITABILITY:



Current suitability map for the stone pine.
Source: Ninyerola *et al.* 2009

The extent to which the stone pine was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

PROJECTED SUITABILITY (A2 STORYLINE):



The extent to which the stone pine would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the stone pine. Source: Ninyerola *et al.* 2009

The areas indicated in the table are the hectares in which the stone pine exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,892,818	1.661.772
%	58,7	51,6

Stone pine forests currently cover 58.7% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would decrease to 51.6%.

PREVENTIVE ACTIONS:

NO INFORMATION WAS FOUND

CORRECTIVE ACTIONS:

NO INFORMATION WAS FOUND

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(3) Campelo, Filipe; Nabais, Cristina; Freitas, Helena; et al. Climatic significance of tree-ring width and intra-annual density fluctuations in *Pinus pinea* from a dry Mediterranean area in Portugal. ANNALS OF FOREST SCIENCE Volume: 64 Issue: 2 Pages: 229-238 DOI: 10.1051/forest:2006107 Published: MAR 2007

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(5) Chambel, Maria Regina; Climent, Jose; Alia, Ricardo. Divergence among species and populations of Mediterranean pines in biomass allocation of seedlings grown under two watering regimes. ANNALS OF FOREST SCIENCE Volume: 64 Issue: 1 Pages: 87-97 DOI: 10.1051/forest.2006092 Published: JAN-FEB 2007

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(7) Escudero, A; Sanz, MV; Pita, JM; et al. Probability of germination after heat treatment of native Spanish pines. ANNALS OF FOREST SCIENCE Volume: 56 Issue: 6 Pages: 511-520 DOI: 10.1051/forest:19990608 Published: AUG-SEP 1999

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(9) Goncalves, Ana Cristina; Pommerening, Arne. Spatial dynamics of cone production in Mediterranean climates: A case study of *Pinus pinea L.* in Portugal. FOREST ECOLOGY AND MANAGEMENT Volume: 266 Pages: 83-93 DOI: 10.1016/j.foreco.2011.11.007 Published: FEB 15 2012

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(11) Innocenti, Margherita; Tiberi, Riziero. Cone and seed pests of *Pinus pinea L.* in Central Italy. Redia Volume: 85 Pages: 21-28 Published: 2002(2003)

(12) Manetas, Y; Petropoulou, Y; Stamatakis, K; et al. Beneficial effects of enhanced UV-B radiation under field conditions: Improvement of needle water relations and survival capacity of *Pinus pinea L* seedlings during the dry Mediterranean summer. PLANT ECOLOGY Volume: 128 Issue: 1-2 Pages: 100-108 Published: JAN-FEB 1997

(13) Molina, J. R.; Rodriguez y Silva, F.; Herrera, M. A. Potential crown fire behaviour in *Pinus pinea* stands following different fuel treatments. FOREST SYSTEMS Volume: 20 Issue: 2 Pages: 266-277 Published: 2011

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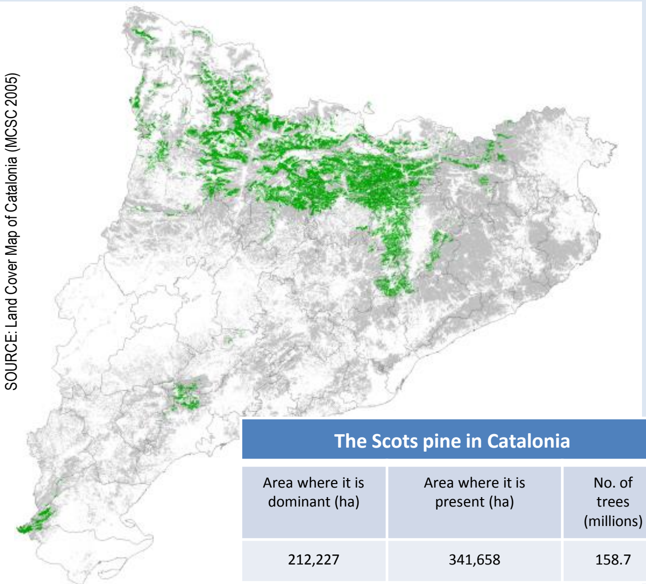
Scots pine (*Pinus sylvestris*)

Distribution and structure

Carbon stock and sink

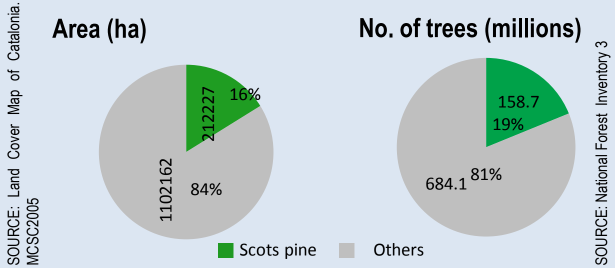
Distribution of the Scots pine in Catalonia

In Catalonia, the Scots pine is close to the southern limit of its global disribution range.



The Scots pine in Catalonia		
Area where it is dominant (ha)	Area where it is present (ha)	No. of trees (millions)
212,227	341,658	158.7

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005

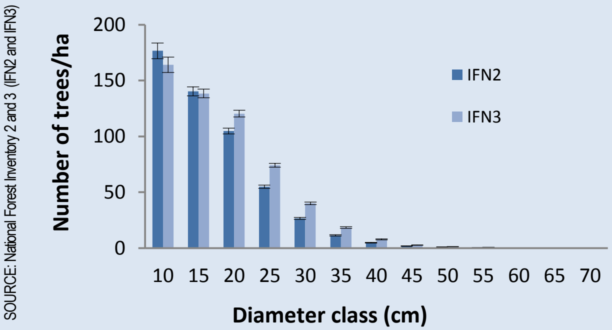


Scots pine forests account for 16% of the total forest area in Catalonia, and 19% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are shown.

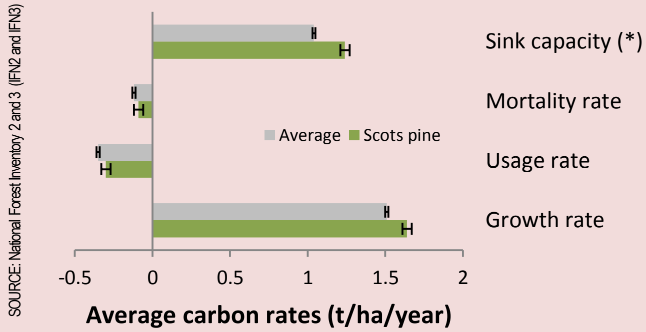
Structure of the Scots pine population

The diameter classes (size structure) of Scots pine forests indicate that they have aged but are still essentially young.



Average carbon (C) rates

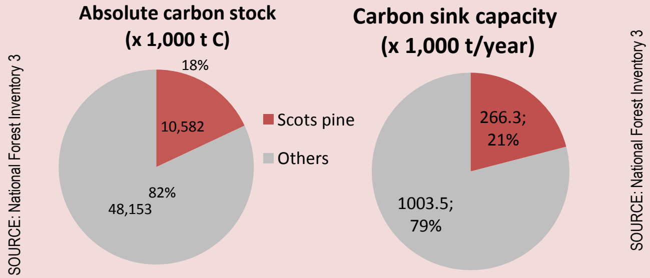
The average carbon sink capacity for the Scots pine between the years 1990 and 2000 was **1.24 t C/ha/year.**



(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

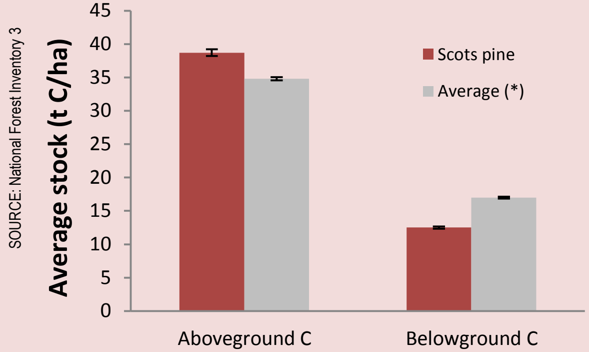
Absolute carbon (C) stocks and sinks

The absolute carbon stock of Scots pine forests is **10.5 million t C** (tonnes of carbon). Their carbon sink capacity is **266.3 thousand t C/ha.**



Average carbon (C) stocks

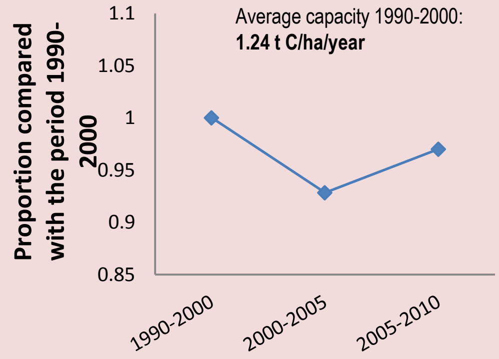
The Scots pine stores **3 times more** carbon in the aboveground part than in the underground part.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

With regard to the reference interval (1990-2000), the Scots pine forests' average carbon sink capacity decreased very slightly during the period 2005-2010 and now seems to be recovering again.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Effect of DROUGHT on:

	Growth	Mortality	Regeneration
With no additional factors	11	14,18	
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude		16	
Less precipitation	1, 2, 3, 4, 12	15, 17, 22, 23	23
Higher temperature	1, 3, 10, 12		
More competition	3, 6, 12	6, 15, 17, 20	
Large trees	3, 5, 12	15	
Higher carbon reserves in trees	5		
More erosion			
Thinner and more compact soil	19	19, 20	
Adverse topography (*)		22	

Drought and pest outbreaks: Grow. 7, 8, 9, 21; Mort. 20, 21; Regen. 8

Drought and fires: Regen. 25, 30

Effect of FIRES on:

	Growth	Mortality	Regeneration
With no additional factors			24, 25, 29, 30, 33, 34
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			28
Less precipitation			25, 33, 34
Higher temperature			28, 31
More competition			
Large trees			
Higher carbon reserves in trees			
More erosion			32
Thinner and more compact soil			
Adverse topography (*)			32

Effect of PEST OUTBREAKS on:

	Growth	Mortality	Regeneration
With no additional factors			
With ADDITIONAL FACTORS	**Modification of the effect:**		
Greater altitude			
Less precipitation			
Higher temperature	13		
More competition	9		
Large trees			
Higher carbon reserves in trees			
More erosion			
Thinner and more compact soil			
Adverse topography (*)			

Legend

Without additional factors	With additional factors
Slight effect	Decreases the effect
Moderate effect	Does not change the efect
Severe effect	Worsens the effect
Very severe effect	Severely worsens the effect

Effect of each disturbance (drought, fires, pest outbreaks) on each variable (growth, mortality, regeneration), as a direct result or the interaction of two disturbances or the addition of other factors (greater altitude, more precipitation, ...).

The numbers refer to the citations from the scientific bibliography. No number means that no information is available.

(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Scots pine (*Pinus sylvestris*)

GROWTH

1. The aridity of the driest sites and the rise in temperatures cause a decrease in growth. (Ref. 28)
2. Carbon and water fluxes are very sensitive to summer precipitation. Transpiration during a dry summer is 40% of an average summer and does not recover after rain. (Ref. 10)
3. The growth of the trunk diameter can be reduced by drought or also by tree characteristics, by competition or by the species richness in the location where it lives. (Ref. 2, 11)
4. Growth is favoured by precipitation, while temperature can have a positive or a negative effect depending on the location. (Ref. 2)
5. The quantity of green leaves and amount of carbon reserves reduce the impact of drought on tree growth. (Ref. 3)
6. The densest plots have higher mortality rates and lower growth rates. However, the growth of the survivors increases since the competition for resources is reduced. (Ref. 12, 28)
7. Mistletoe infection reduces the nitrogen content of the leaves, which has a negative impact on the growth of the Scots pine. (Ref. 3)
8. Defoliation caused by the pine processionary moth reduces both Scots pine growth and its reproductive capacity, causing a decrease in the production of male and female pinecones, the size of the pinecones, seed production (50% less) and their weight (40% less). (Ref. 27)
9. Defoliating and sucking insects are the two groups that cause the greatest damage to Scots pine forests. A high stand density is one of the factors that aid proliferation once the central point of infestation has been established. (Ref. 6)
10. Pines, among other trees species, will invest more carbon in maintaining and producing leaves than they might have lost due to an increase in temperature. (Ref. 25)
11. There is a reduction in leaf area and crown density after episodes of drought. (Ref. 27)
12. The probability of suffering damage to the crown is conditioned by the size of the tree, competition and climatic conditions. (Ref. 26)
13. Frosty days, which are increasingly fewer due to the increase in winter temperatures, are a key factor in determining the capacity of pine processionary moth outbreaks. (Ref. 6)

MORTALITY

14. Between 1990 and 2000, the number of standing dead trees multiplied by 11. (Ref. 28)
15. Mortality rates are higher in small trees, in drier sites and with more competition. (Ref. 28)
16. In the Alps, the mortality of the Scots pine is higher below 1,000 m (Ref. 21)
17. Drought, together with forest structure, can trigger forest decline, which can lead to mortality. (Ref. 26, 4, 28)
18. Populations in humid areas are also vulnerable to drought. (Ref. 11, 28)
19. The depth of the soil reduces the effects of the drought. High mortality is concentrated in areas with shallow soil. (Ref. 25)
20. The structure of the forest, the properties of the soil and mistletoe infection are also associated with defoliation patterns. (Ref. 4)
21. The pine processionary moth (*Thaumatopoea pityocampa*) causes leaf loss that can reduce tree growth and even cause its death. Despite that, it plays an important role in the trophic network of pine forests. (Ref. 30)
22. Drought can lead to a reduction in groundwater recharge, on which the Scots pine depends greatly for the fulfilment of summer evaporation demands. (Ref. 10)
23. In dry locations, competition for water causes mortality, which is negatively correlated with regeneration. (Ref. 28)

REGENERATION

24. After a crown fire, there is no regeneration in the Scots pine, or it is very low and inefficient, and the capacity to recolonise forest edges is restricted to the first 25 m, where 90% of the recruitment takes place. (Ref. 15, 22, 29)
25. Summer drought inhibits Scots pine regeneration and, in zones where there is mortality and defoliation, regeneration is lower and the new saplings tend to be *Q. ilex* and *Q. humilis.* (Ref. 20, 4)
26. *Regeneration does not vary as a function of forest management and is lower in locations where mortality is high. (Ref. 28)*
27. *The effects of drought can be seen years after (2008) the causal episode (2004-2005) . (Ref. 4)*
28. Both the Scots pine and holm oak regenerate well in dry locations. However, the Scots pine is favoured by cooler, higher zones while the regeneration of holm oaks is greater in warmer places. (Ref. 22)
29. In the medium term, the effect of fire leads to a severe degradation of Scots pine forests. The main effects include the conversion of Scots pine forests into shrub land, a decrease in the thickness of the 0 horizon and its degradation and an increase in soil erosion. (Ref. 15)
30. The phenology of the Scots pine is out of phase with crown fires. Seed dispersal takes place from the end of winter to spring, just before the fire season, so that the seed bank that remains in the soil after the fire dies and cannot contribute to the regeneration of the Scots pine. (Ref. 22, 29)
31. High temperatures and exposure time to heat inhibit the germination of the Scots pine seeds. (Ref. 13)
32. Fires cause a clear degradation in the soil and lead to a decrease in the infiltration rate and an increase in soil erosion by water. (Ref. 15)
33. The seed bank that remains in the soil generally dies after a fire and cannot contribute to the regeneration of the Scots pine, which can be replaced by other species in places where it was once dominant. (Ref. 22, 29)

34. The post-fire re-establishment of the Scots pine is only 0.1%, since it does not have regeneration mechanisms. In all other cases, it is expected that forests of holm oaks and other oak species, scrubland and mixed forests of resprouting trees will be the dominant vegetation for 30 years after the fire. (Ref. 29)

The **DISTRIBUTION** and **VULNERABILITY** sections are not represented in the Observed Impacts summary box. The bibliographic citations referring to these factors are presented below. .

DISTRIBUTION

In the last 31 years, 3.6 % of the Scots pine forests in Catalonia have been affected by 32 fires, which burned a total of 67,000 ha, mainly situated in the areas classified as being the driest. (Ref. 29)

- The fact that the Scots pine produces few pinecones makes a change in community more likely after a fire, converting to forests dominated by *Quercus* species or meadows. (Ref. 22)

- *Pinus sylvestris* populations in the Mediterranean Basin are sensitive to increases in summer PET (potential evapotranspiration, see Glossary) and drought and are even be in danger of being replaced by other species. Even the ones that are located in wet and mountainous zones may be vulnerable to drought and other scenarios forecasted by climate change. (Ref. 4, 13, 25)

- 32% of the Scots pine forests in the Iberian Peninsula are vulnerable to fire. This figure could reach 66% in a conservative climate change scenario. The frequency of crown fires may increase and endanger the forests. (Ref. 29)

- Climate changes will modify the fire regimen and thus Scots pine vulnerability in the zones on the edges of its distribution. (Ref. 29)

- A fire in an area that has already been burnt has far more serious consequences on these ecosystems, which could reduce its cover even further. (Ref. 15)

- Mediterranean mountains could lose their role as a refuge for species adapted to the cold, which live in the lower limits of their distribution, leading to a loss of diversity and evolutionary potential. (Ref. 13)

- Pine forests are converting into holm oak forests. This has unknown consequences on the goods and services in these ecosystems. (Ref. 21, 29)

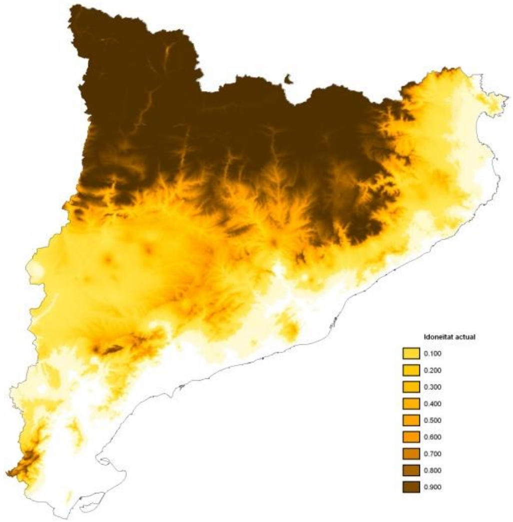
- The best protection for the Scots pine from the pine processionary moth is altitude and low winter temperatures. However, the forecast of global warming will constitute a serious threat for isolated populations in southern Europe. (Ref. 7)

VULNERABILITY

- Analysis of indicators (such as vegetation, geomorphological characteristics, etc.) 14 years after a fire, shows that the Scots pine is not very resilient. (Ref. 15)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE SCOTS PINE:

CURRENT SUITABILITY: 1950-1998



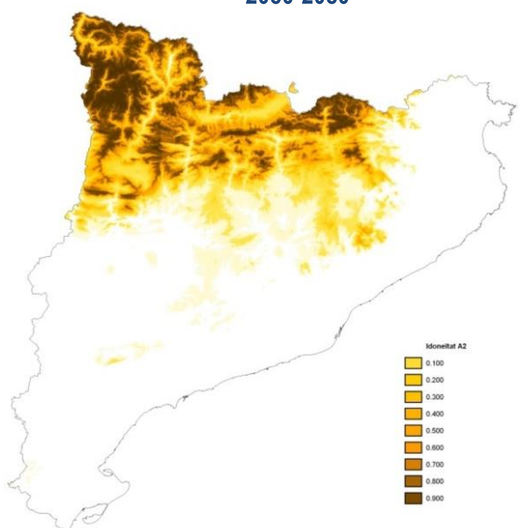
Current suitability map for the Scots pine.
Source: Ninyerola *et al.* 2009

The extent to which the Scots pine was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the Scots pine exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,345,220	459,824
%	41.7	14.2

PROJECTED SUITABILITY (A2 STORYLINE): 2050-2080



Scots pine forests currently cover 41.7% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would decrease to 14.2%.

The extent to which the Scots pine would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the Scots pine. Source: Ninyerola *et al.* 2009

PREVENTIVE ACTIONS:

- Silviculture and adaptive forest management can be essential tools for the adaptation of dense Mediterranean forests under the drought conditions predicted by most climate models. (Ref. 28)
- The varied responses of different species suggest a greater natural resistance to fire by deciduous trees compared to that of conifers, including the Scots pine. (Ref. 17)
- The structure of the forest has important implications for forest management practices such as thinning and sustainable felling. These techniques can be used as tools to mitigate the effects of climate change in high-density areas. (Ref. 4)

CORRECTIVE ACTIONS:

- Given the poor post-fire regeneration of the Scots pine, conservation and restoration plans for the Mediterranean Basin should be reconsidered. (Ref. 22)
- Assisted migration may be of limited value as a management tool for accelerating the migration of species and facilitating the persistence of forests in temperate zones. (Ref. 20)
- From the point of view of restoration, it is important to define strategies that decrease the combustibility of shrubs that succeed pines after a fire. (Ref. 15)

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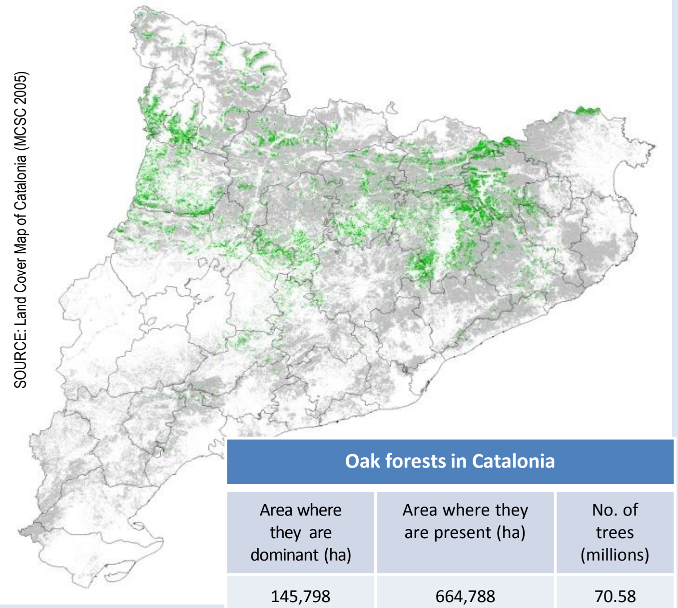
Oaks (*Q. humilis, Q. faginea, Q. petraea, Q. robur*)

Distribution and structure

Carbon stock and sink

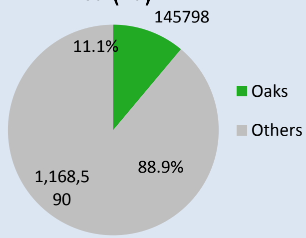
Distribution of oak forests in Catalonia

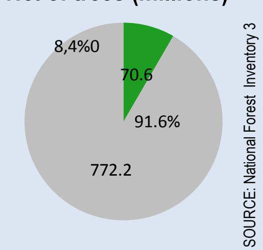
In Catalonia, oak forests are mainly found in the lower parts of the mountains in the pre-Pyrenees.



Oak forests in Catalonia		
Area where they are dominant (ha)	Area where they are present (ha)	No. of trees (millions)
145,798	664,788	70.58

The area where the species is present was corrected by the factor resulting from dividing the dominant MCSC/dominant IFN3 in order to make the two sources uniform. SOURCES: IFN3 and MCSC2005



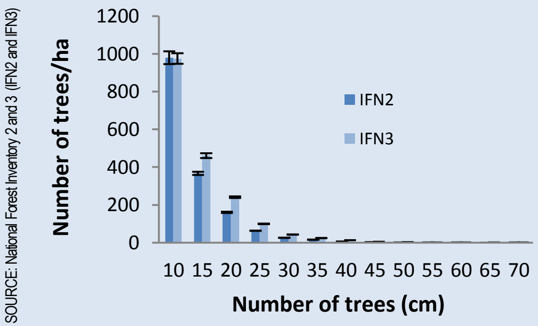


Oak forests account for 11.1% of the total forest area in Catalonia, and 8.4% of the total number of trees.

Trees with a normal diameter of over 7.5 cm are counted

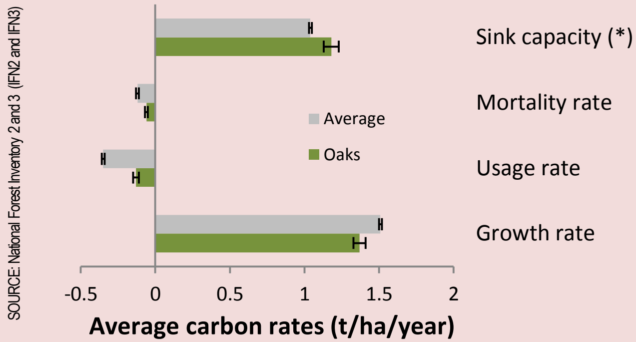
Structure of the population of oak species

Oak forests are very young, with high a high density of trees in the 10-cm diameter class. However, one third of the oak forests are in the 15-cm diameter class and there are virtually no trees with diameters of over 30 cm.



Average carbon (C) rates

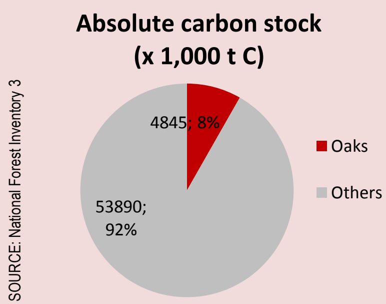
The average carbon sink capacity for oak forests between the years 1990 and 2000 was **1.18 t C/ha/year.**

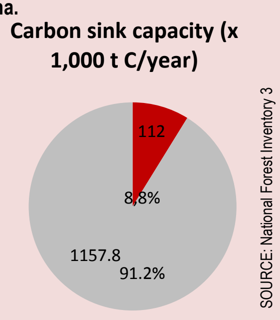


(*) The annual carbon sink capacity is calculated by subtracting the mortality rate and the usage rate (in tonnes of carbon/ha/year) from the growth rate

Absolute carbon (C) stocks and sinks

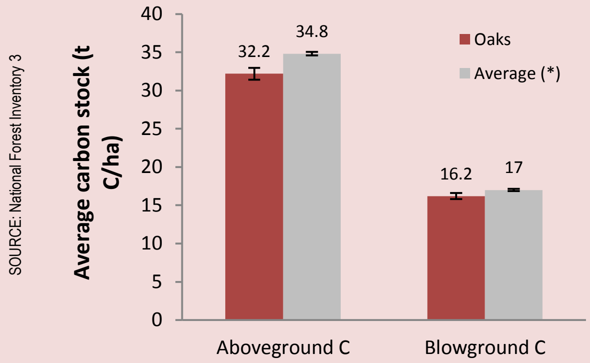
The absolute carbon stock of oak forests is **4.8 million t C** (tonnes of carbon). Their carbon sink capacity is **112 thousand t C/ha.**





Average carbon (C) stocks

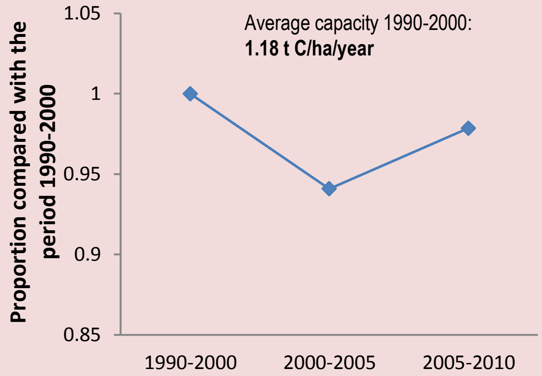
Oak forests store a little less carbon per hectare than average, both with regard to the aboveground and the underground parts.



(*) The average is calculated using data from all the species in Catalonia.

Change in the carbon sink capacity

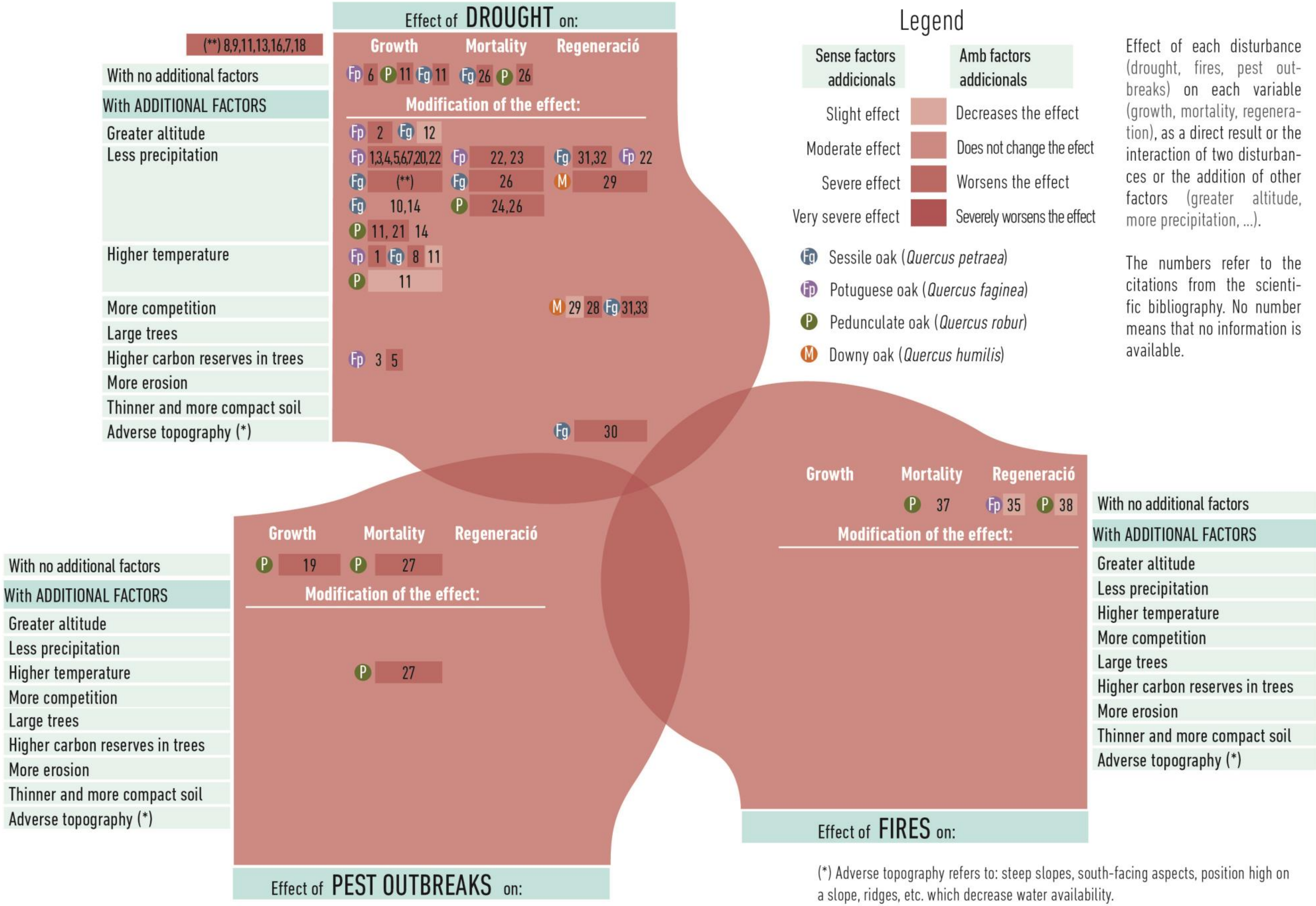
With regard to the reference interval (1990-2000), the oak forests' average carbon sink capacity decreased during the period 2000-2005 and then recovered during the period 2005-2010.



Proportion of the carbon sink capacity compared with the reference period (1990-2000)

The values were obtained by adjusting a statistical model with the information of the sample plots from the two IFN for all the conifers and broad-leaved trees, bearing in mind the effect of the structure of the forest, climate data and the temperature trends between IFNs.

Oaks (*Q. humilis, Q. faginea, Q. petraea, Q. robur*)



(*) Adverse topography refers to: steep slopes, south-facing aspects, position high on a slope, ridges, etc. which decrease water availability.

Oaks (*Q. humilis, Q. faginea, Q. petraea, Q. robur*)

GROWTH

1. The width of the growth rings in oaks correlate positively with spring precipitation and negatively with winter temperatures. (Ref. 1)
2. Oaks growing at medium elevations produce larger shoots than in other locations and exhibit greater apical bud growth *(see Glossary)*. (Ref. 2)
3. Drought reduces the growth of oak trees, but not their carbon reserves. This suggests that under conditions of water stress, growth is not limited by the lack of reserves. (Ref. 45)
4. The vegetative and reproductive growth of oaks is more affected by summer drought than the holm oak. (Ref. 27)
5. Oaks require greater water availability in order to increase growth and simultaneously store starch and nitrogen. (Ref. 47)
6. During the droughts of 1993 and 1994, severe defoliation occurred in oak populations, which in these years showed lower root and longitudinal growth. (Ref. 10)
7. The decrease in the growth of oaks that occurs in dry years contrasts with the increase that occurs in years with high precipitation levels. (Ref. 10)
8. The growth of the sessile oak is higher if precipitation between May and July is high. On the other hand, warm and dry autumns lead to a decrease in growth. (Ref. 26)
9. An increase in the frequency and intensity of drought could affect the growth of the European beech, the Scots pine and the sessile oak. (Ref. 26)
10. The sessile oak does not suffer a very large decrease in sap flow under experimental conditions in which rain is excluded, probably because it has deeper roots than the European beech. (Ref. 50)
11. With drought conditions, seedling vertical growth and stem diameter growth are reduced in the pedunculate oak and the sessile oak; while an increase in temperature only stimulates stem diameter growth and root longitudinal growth. (Ref. 3)
12. At medium and high altitudes, the European beech and the sessile oak have longer growing seasons, so that global change may lengthen the growing period of these populations across an altitudinal gradient. On the other hand, populations growing at lower altitudes may lose their leaves more quickly and have a shorter growing period. (Ref. 49)
13. During the 2003 drought, the sessile oak exhibited a significant reduction in leaf biomass compared with that of 2004. (Ref. 25)
14. In one experiment, sessile and pedunculate oaks subjected to water stress were manually defoliated for two years. This defoliation did not decrease the width of the branch growth rings; however, stomatal conductance was reduced by drought. (Ref. 48)
15. *In full sunlight, the water use efficiency of sessile oak saplings was 10-15% higher than in the pedunculate oak. The difference between the two species remained during the drought, despite the fact that growth decreased. (Ref. 38)*
16. The sessile oak was less sensitive to drought than the European beech. (Ref. 20)
17. In one experiment with the sessile oak and the Scots pine, the oak was more sensitive to treatments (increase in CO_2, increase in different concentrations of O_3 and different irrigation schemes) of high levels of CO_2 and irrigation, which made them increase in biomass. (Ref. 5)
18. An increase in CO_2 concentration and greater water availability increase the growth of the sessile oak, while if only CO_2 is increased and there is no water made available, growth is lower. (Ref. 5)
19. Pedunculate oak trees infected by the fungus *Fusarium eumartii* exhibited a root growth of 2.24 mm between 1961-1994, while in non-infested trees it was 3.57 mm. (Ref. 39)
20. Bud size is severely reduced both in the Portuguese oak and in holm oaks during extremely dry years. (Ref. 27)
21. Periods of drought can produce a decline in the pedunculate oak population, since they act as a growth reduction factor. (Ref. 39)

MORTALITY

22. Summer drought affects leaf area, leaf biomass per unit area and leaf senescence, but not acorn production in the Portuguese oak. (Ref. 27)
23. If droughts are more severe and frequent due to greater climatic variability, massive mortality of marginal populations of Portuguese oak is to be expected. (Ref. 10)
24. Some results indicate that the pedunculate oak is less resistant to drought than the sessile oak. (Ref. 38)
25. *Defoliation causes a reduction in the fine root biomass of the pedunculate oak and sessile oak saplings. (Ref. 16)*
26. The natural factors responsible for the most important damage to the pedunculate oak and the sessile oak in central Europe are drought and the resulting defoliation. (Ref. 48)
27. The fungus *Phytophthora cinnamomi* causes the sudden mortality of oak species and can be recognised by the wilting of new shoots. Its reach is probably limited by its vulnerability to frost. (Ref. 22, 30)

REGENERATION

28. After an episode of drought in 2005 in a mixed forest of Scots pine and downy oak, the incorporation of oak saplings was abundant, especially in the plots where the pines had suffered the most defoliation and mortality. (Ref. 15)

29. The germination rate of the downy oak was higher under shrubs such as common boxwood (*Buxus sempervirens*) and common juniper (*Juniperus communis*), which offer the seedlings shade and protection and increase survival rates, since they protect them from grazing and summer drought. (Ref. 43)

30. The establishment of sessile oak seedlings depends on site conditions, the availability of light and water and the origin of the seeds. (Ref. 17, 34)

31. Water deficit may be the main cause of the mortality of sessile oak seedlings in more open micro-habitats, while in more closed forests, light levels were insufficient. (Ref. 34)

32. Seedling capacity to establish is a limiting factor for the Pyrenean oak and the sessile oak - two species especially sensitive to drought. (Ref. 34)

33. Sessile oak and Pyrenean oak seedlings planted under dense pine cover are more vulnerable to summer drought and more likely to exhibit delays in growth than saplings planted under average densities. (Ref. 37)

34. The regeneration of the pendunculate oak is quicker than that in the sessile oak during the first stages of regeneration. (Ref. 38)

35. Portuguese oaks resprout immediately after fires and dominate during the first few years. (Ref. 18)

36. The post-fire recovery patterns of mixed forests of Scots pine and Portuguese oak have led to the dominance of the Scots pine in more temperate locations and to the co-dominance of pines and oaks in the driest places. (Ref. 18)

37. After a fire in Portugal that burnt 6,000 ha of mixed forest, the abundance of maritime pine and pedunculate oak seedlings was similar in the burned plots and the non-burned plots. (Ref. 32)

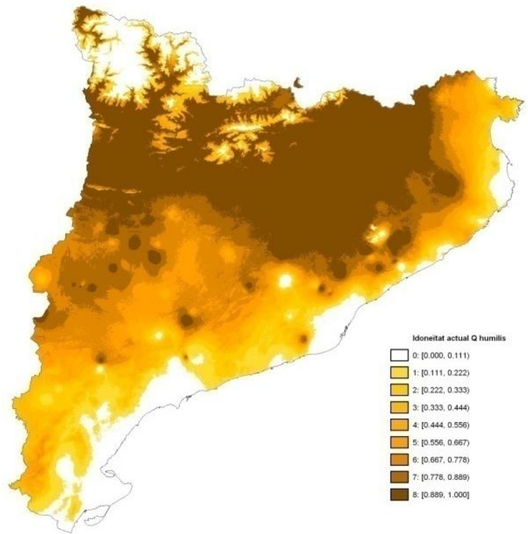
38. Pedunculate oak forests show greater resistance and capacity for recovery after a fire than pines, which implies greater stability in the maintenance of ecosystem goods and services. (Ref. 59)

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE PEDUNCULATE OAK:

No information is available on the topo-climatic suitability atlas for the pedunculate oak. It is an oak species not frequently found in Catalonia.

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE DOWNY OAK:

CURRENT SUITABILITY:



Current suitability map for the downy oak.
Source: Ninyerola *et al.* 2009

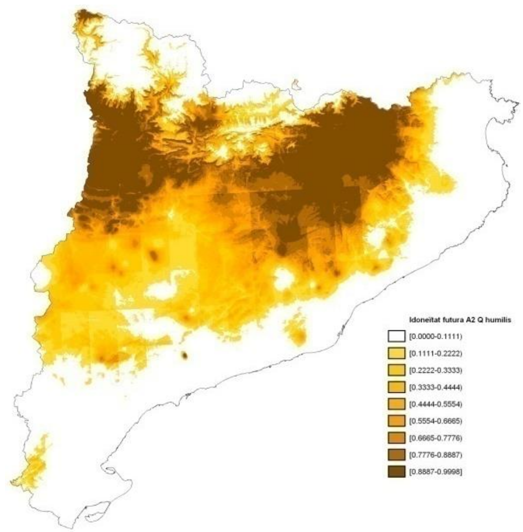
The extent to which the downy oak was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the downy oak exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	2,113,468	1,028,976
%	65.6	32

Downy oak forests currently cover 65.6% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would decrease to 32%.

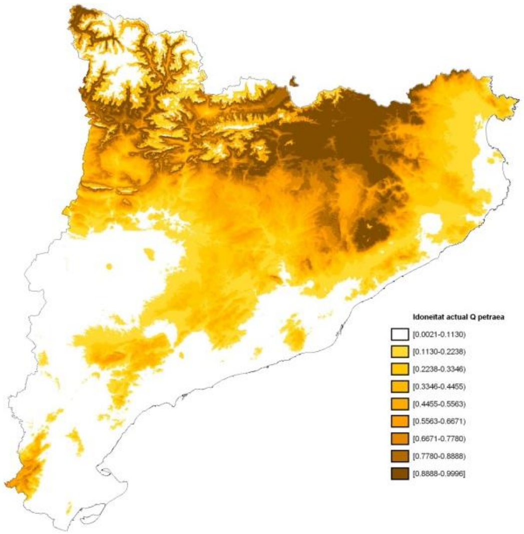
PROJECTED SUITABILITY (A2 STORYLINE):



The extent to which the downy oak would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

Projected suitability map (A2 storyline) for the downy oak. Source: Ninyerola *et al.* 2009

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE SESSILE OAK:



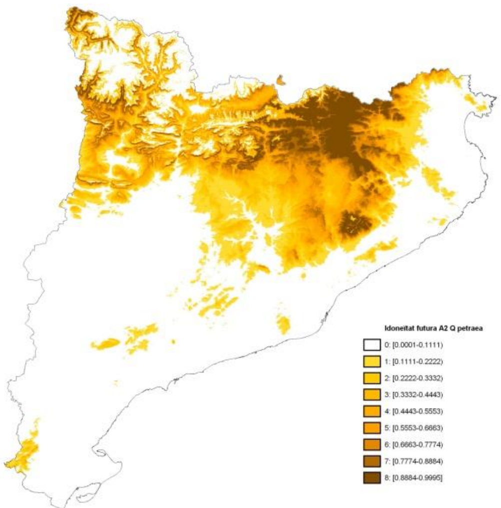
Current suitability map for the sessile oak. SOURCE: Ninyerola *et al.* 2009

The extent to which the sessile oak was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the sessile oak exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	932,008	549,280
%	29	17

PROJECTED SUITABILITY (A2 STORYLINE):

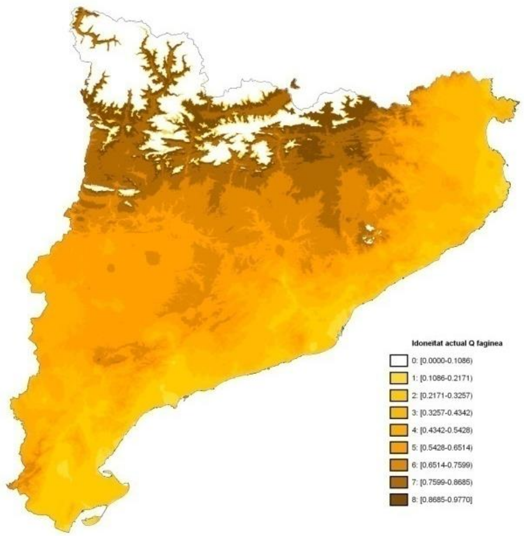


Projected suitability map (A2) for the sessile oak. Source: Ninyerola *et al.* 2009

Sessile oak forests currently cover 29% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would decrease to 17%.

The extent to which the sessile oak would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

TOPO-CLIMATIC SUITABILITY ATLAS FOR THE PORTUGUESE OAK:



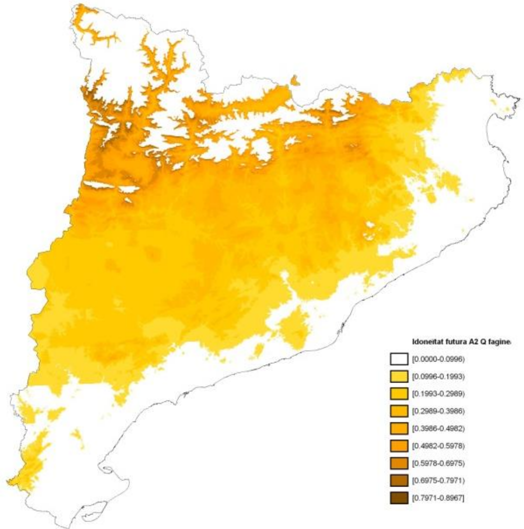
Current suitability map for the Portuguese oak. SOURCE: Ninyerola *et al.* 2009

The extent to which the Portuguese oak was adapted to climatic and topographic conditions during the period 1950-1998 represents its current suitability. The dark colours indicate greater suitability (combination of topographic and climatic conditions under which a species currently lives) and the light colours lower suitability or unsuitability (white).

The areas indicated in the table are the hectares in which the Portuguese oak exhibits a climatic suitability of 50% or more, and the % that this represents compared with the total area of Catalonia, both currently and in the future A2 storyline.

	Current	A2
Area (ha)	1,780,436	285,380
%	55.2	8.8

PROJECTED SUITABILITY (A2 STORYLINE):



Projected suitability map (A2 storyline) for the Portuguese oak. Source: Ninyerola *et al.* 2009

Portuguese oak forests currently cover 55.2% of Catalonia depending on the topo-climatic variables. With the A2 storyline, this percentage would decrease to 8.8%.

The extent to which the Portuguese oak would be adapted to climatic and topographic conditions during the period 2050-2080, representing its projected suitability for the A2 storyline.

PREVENTIVE ACTIONS:

-The sessile oak does not suffer from as marked a decrease in sap flow as the European beech. Thus, it could make a positive contribution to the maintenance of the diversity of species in mixed forest ecosystems subject to severe drought. (Ref. 25)

- The opening up of Scots pine clearings may represent an improvement in the drought tolerance of sessile oak saplings. (Ref. 29)
- Moderate reductions in tree cover can improve the establishment of Pyrenean oak and sessile oak seedlings. However, extreme droughts can prevent the success of any silvicultural actions. (Ref. 31)

CORRECTIVE ACTIONS:

- After a fire in September 2003 in central Portugal, a replanting campaign was carried out. For 21 months, the survival and height of the trees were measured. It was concluded that the use of natural regeneration through resprouting might be a cheaper and more efficient technique than planting to restore burned forests. (Ref. 53)

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- **Arbuscular mycorrhizal fungi:** A mycorrhiza is the symbiotic association between a fungus and the roots of a vascular plant such as a tree. In the case of arbuscular mycorrhizal fungi, the fungus colonies the host plant's roots intracellularly. Mycorrhizae are an important component of soil life and soil chemistry. *(Wikipedia)*
- **Apical bud:** The terminal or topmost bud on a stem. (*Royal Horticultural Society: http://www.rhs.org.uk/Gardening/calendar/March/Glossary/Apical-dominance)*
- **NAO Index** The North Atlantic Oscillation (NAO) index. The NAO index is a climatic phenomenon in the North Atlantic Ocean based on the surface sea-level pressure difference between the Subtropical Azores High and the Subpolar Icelandic Low. The east-west oscillation movements of this Icelandic low and the Azores high control the strength and direction of the winds. A positive index (**NAO+**) gives rise to very little precipitation in Southern Europe and the Mediterranean Basin; whilst a negative index (**NAO-**) leads to cool temperatures and moist conditions in these regions.
- **NDVI:** *Normalized Difference Vegetation Index.* It is an indicator that estimates the quantity, quality and development of vegetation.
- **Seedling:** A young plant, especially one raised from seed and not from a cutting. *(Oxford Dictionary* http://www.oxforddictionaries.com*)*
- **Sapling:** A young tree, especially one with a slender trunk. *(Oxford Dictionary* http://www.oxforddictionaries.com*)*
- **Serotiny / serotinous pinecones:** This is a strategy that increases a tree's resistance to fire by storing the seeds inside the pinecones, protecting them from heat and delaying the seed release. (35)
- **PET, Potential evapotranspiration:** The amount of water that could potentially be evaporated and transpired in a given climate, by uniform vegetation cover, if there were sufficient water available. Therefore, it includes the plant and soil evaporation in a specific region and within a given timeframe. (*Royal Horticultural Society: http://www.rhs.org.uk/Gardening/calendar/March/Glossary/Apical-dominance)*

CONCLUSIONS:

Missing information

In all species dealt with here, some parts of the statements are missing. In many cases, the statement referring to pest outbreaks is the one that contains the least amount of information. The information on pest outbreaks is probably contained in other types of non-scientific bibliography: management guides, forest health guides, etc., which were not consulted for this bibliographic metadata extraction, which focuses solely on scientific articles.

In other cases the boxes left blank indicate real gaps in our knowledge, subjects on which no data is available. A clear example of this is the case of the mountain pine. The infographic on the mountain pine is very empty because there is very little bibliography on this species: only 28 articles were used to complete it, whilst around 70 were consulted for the cork oak or the holm oak. This means that, at a glance, a superficial conclusion on the impacts of drought and fires observed in the mountain pine may appear to be rather ineffective. On the other hand, despite the scant information available on this species, its distribution range and its characteristics suggest that it should be far more vulnerable to drought and fire. Up to now in Catalonia there have hardly been any fires that have affected mountain pine forests, so it is hard to know what would happen to this forests in the short, medium and long term.

These gaps in information may serve to highlight in which areas economic resources and research should be focused in order to fill them in, since this information constitutes a vital tool for decision making.

One important absence from the metadata extraction carried out is connected to the 'Recommendations for adaptive forest management'. In most cases, very little information has been found in the articles and in some cases none at all. This information could be found in forest management guides such as ORGEST (Orientacions de Gestió Forestal Sostenible per a Catalunya [Sustainable Forest Management Guidelines for Catalonia]), but these books do not provide guidelines on adaptive management for climate change. Similarly, it has not always been possible to find bibliography dealing explicitly with the distribution and vulnerability of a given species. Therefore, some of the fact sheets only contain one of these two sections.

Vulnerability

Thanks to all the information compiled in this bibliographic metadata extraction on the impacts observed in the nine tree species covered, in addition to consultations with some experts, it has been possible to draw up a qualitative classification of their vulnerability to drought and fires. Information on pest outbreaks was obtained to allow a ranking to be created for this subject.

The jump from one species to another is not proportional, but rather only constitutes a qualitative order. In some cases it was very hard to order the species, so there main groups were created, within which the order is uncertain. In the case of the mountain pine, there was so little information available on drought and fires that a question mark was added, since it was not at all clear where is should be placed. A question mark was also added in the vulnerability to fire section for the European beech.

Some clarifications on <u>vulnerability to drought</u>:

-In general, pine trees are more resistant to water stress: However, if they are affected, they find it hard to recover. On the other hand, holm oaks and other oak species, and broad-leaved

Observed and forecast impacts on the most common tree species in Catalonia

CONCLUSIONS:

trees in general, are more able to recover (they can resprout) and also to regenerate after episodes of drought.

Some clarifications on vulnerability to fire:

- The vulnerability of the Aleppo pine to fire is relatively low as long as at least 15-20 years elapse between fires. If the fires are more frequent, the pine does not have time to make viable seeds.
- The stone pine is not very well established after a fire and has a low capacity for seed dispersal.