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Country report

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Asunción CÁMARA OBREGÓN

Summary

Introduction

The concept of sustainable forestry production appeared and started to be applied in Spain, as in others European countries in the first half of the XIX century, with Forest Planning and the first basic forestry techniques. At present, the maintenance, care and improvement of forests is not governed by simple production criteria, but rather by the concept of the multifunctional forest, of which there are some key examples in the Iberian Peninsula, as the sylvo-pastoral systems of the Mediterranean environment.

Forestry in Spain had to deal very often, from the beginning of its application with harsh site conditions, particularly a climate characterised by irregular precipitations, a drought period that can elapse for several months, and difficult conditions for reforestation or natural regeneration. This explains a long tradition of fitoclimatic studies and the development of practical guidelines and rules for silvicultural treatments or matching species to site for reforestation programs, this applied to an important range of tree species.

The concern about the likely impacts of climate change on forests and forestry started several decades ago, but the first set of publications arose promoted by the Spanish Society of Forest Sciences, in the form of two special issues of the journal Cuadernos de la Sociedad Española de Ciencias Forestales (http://www.secforestales.org/).

The current situation is an increasing awareness of the impacts and opportunities for the forest sector in relation to the mitigation, as well as a demand for the managers of practical rules of adaptation derived from the research and development projects.

Preamble: short description of Spanish forests

The peninsular part of Spain belongs to three biogeographical regions (Atlantic, 5.5 Mha, alpine, 0.9 Mha and Mediterranean, 43Mha), with possible further consideration of a continental Mediterranean area. The Canary Islands belong to the Macaronesic region, and account for 0.7 Mha. This diversity has to be taken into account when studying climate change impacts as well as when implementing adaptation and mitigation strategies.

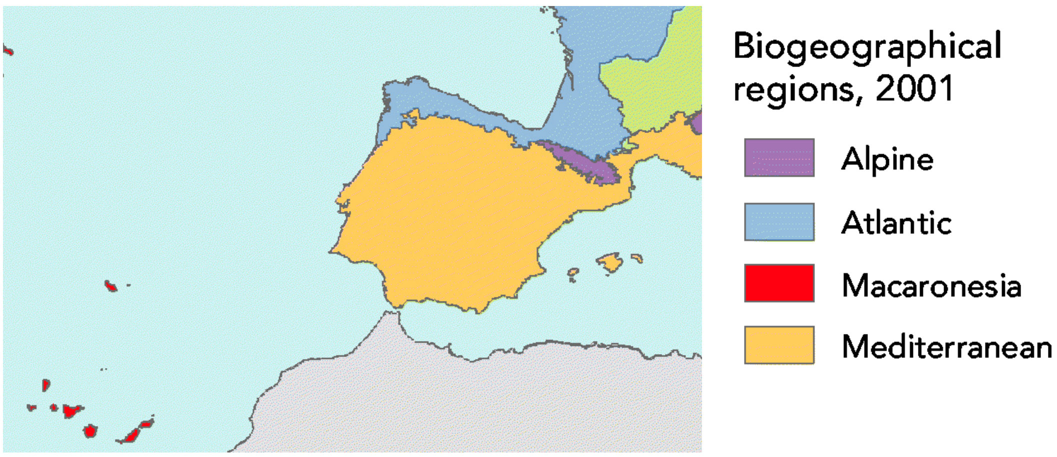


Figure 1 : Biogeographical regions of Spain (from European Environment Agency, 2001).

The area of Forest and other wooded lands in Spain is 26.273.235 ha, of which 56% is considered as forests (tree cover of more than 5%), 35% shrubs and open forest (tree cover less than 5%) and 9% as herbaceous natural vegetation (Plan Forestal Español, 2004). Thus 52% of the Spanish territory is covered by natural or semi-natural vegetation.

Spanish forests and forestry have the following main indicators of growing stock and productivity:

- the area of forests is 18.26 million hectares (ha), with 39.6% of conifers, 29.1% broadleaves and the remainder as mixed stands;
- the growing stock is 915 million cubic meters (m^3), i.e. approximately 50 m^3/ha, much higher than the NSI2;
- the current annual volume increment approximates 35,5 million m^3 of solid;
- roundwood removals are estimated to be 18 million cubic meters (m^3), so only a half of the annual net increment; the remaining half being a rapidly increasing growing. The annual fellings takes into consideration the burned timber derived from forest fires.
- The total carbon sink has been estimated as 7395GgC in the form of permanent forest land and 1735 GgC in the form of afforested agricultural land or degraded lands in 2006 (MMA, 2008).

Spanish forests are very diverse in terms of species composition, productivity, ownership and management. Public Institutions (the State and municipalities) own about one third of the forests, and the other two thirds are privately owned, mainly by non-industrial owners in individual or collective ownership regimes. The forest administration manages public forestry and a portion of private forest, in which a contract has been established between the owners and the administration. Each regional government has its own forest policy, with emphasis on management for different goals, depending on biogeographic and socioeconomic constraints and influences.

The ownership of this forest land corresponds to the State and regions (6%), municipalities (26%) or private owners (68%). In the case of public forests (belonging to the State, regions or municipalities) it is the regional forest service the institution in charge of the management. The private owners are very diverse (industrial groups, individual owners, collective owners) in terms of management objectives and form of management (no active management, direct active management, indirect management by the regional forest services trough a contract).

Although timber production has been at the root of sustainable forest management in Spain, the increasing importance of indirect goods and services provided by forestry are taken into consideration in forest management. The Spanish Forest Plan has estimated annual incomes of 1.22 million € and 0.64 million € from services related to protection and biodiversity conservation and those related torecreation, respectively.

1. Impacts

As a result of its geographical situation and socio-economic characteristics, Spain is very vulnerable to climate change, as it has become increasingly manifest in the most recent assessments and research. The most serious environmental problems aggravated by climate change are: decreases in hydric resources, natural regression of coasts, loss of biodiversity and natural ecosystems, and increased soil erosion. Other effects of climate change will have serious additional impacts on the economic sectors (OECC, 2008).

1.1. Observed impacts

Some of the facts described in this section are probably linked to climate change and also to several other processes of global change currently affecting Spain, particularly the abandonment of rural areas and lack of active forest management in many areas, amongst many others processes.

1.1.1. Observed climatic evolution

Europe has been warming by on average 1ºC during the last century, which is more than the average global trend, and Spain is warming at a faster rate than the European average (between 1.2 and 1.5 ºC in the last century). During the 20th century, and particularly in the last third of the century, the temperatures generally rose, with the effect being clearer in spring and summer. Between 1850 and 2003, the annual average of maximum and minimum daily temperatures increased at a rate of 0.12ºC/decade and 0.10ºC/decade, respectively.

The oldest reliable temperature data available for Spain date back to the second half of the XIXth Century. The data show a generalized trend of increasing temperatures, with values between 1 and 2ºC in the period 1850 and 2005, although the trend is not spatially or temporarily homogeneous. In fact, for the 20th century, three periods of increasing (1901-1949), decreasing (1950-1972) and rapidly increasing temperatures (1973-present) can be considered. The regions most affected by the warming are those located on the east of the Iberian Peninsula, in a strip along the Mediterranean coast between Girona and Málaga. A clear increase in the number of hot days, similar in magnitude in the last 30 years to the pattern of the last 150 years, indicates an increased likelihood of heatwaves (as in 2003) (Abadanes et al, 2007).

As regards precipitation, the trends are not as easy to interpret because of the complexity of their spatial and temporal distributions. Nevertheless, analysis of data corresponding to the second half of the 20th century (1949-2005) reveals a negative trend in most of Spain, but most clearly in the Cantabrian region (-4.8 mm/year in Santander and -3.3 mm/year in Bilbao) and the southeast. It is clear that the hydric availability is decreasing because of increased evapotranspiration.

Spanish scientists are nevertheless far from reaching a clear agreement even as regards the observed changes in the climate. Sanz Donaire (2008) analyzed series of temperatures from the second half of the 19th century and precipitations from the beginning of the 20th century, and highlighted the randomness of the data, and stated that they do not enable conclusion that a real climate change is occurring. Quereda et al (2000) analyzed the changes in temperatures recorded at weather stations in the Mediterranean area, and concluded that the thermal stability hypothesis could not be rejected and that the slight trend towards increases during the second half of the 20th century may be caused by an urban effect.

1.1.2. Impacts on ecosystem dynamics and functioning

1.1.2.1. Phytoclimatic regions of Spain

Spain has a long tradition of phytoclimatic studies, aimed at relating the climate subtypes, usually defined at a local Spanish scale, to the forest types thriving in these areas (Allué, 1990). In a detailed analysis of the observed patterns of change, in which 1970 is considered as the threshold for comparison, Allué (1995) concluded that there is a clear trend of worsening climatic conditions (i.e. greater water deficit) in most of Spain, which affects areas with already a dry Mediterranean climate, and also mountainous Mediterranean areas. The intensity of the change is also different, but in many cases is strong enough to alter the optimum forest type in the area, always with changes in the direction: marcescent broadleaved- sclerophyll forests- steppes –semi-desert.

The map shown below provides the information in a graphical format, enabling identification of several nuclei of changes: Castille, Navarra, La Mancha and Andalucía; the red arrows on the map show trends more evident of changing phytoclimatic conditions. On the other hand, some areas of improved climatic conditions - always in the sense of improved water availability for vegetation - appear at the northern face of the Cantabrian range and parts of the central and Iberian mountain range facing the humid northwestern winds.

Allué considers that these studies indicate that the damage to Mediterranean broadleaved species, which are ubiquitous, synchronic and unspecific, is mainly driven by climate, rather than by particular pathologies. Furthermore, the author considers that the most challenged species are those with a narrow range of optimum ecological conditions, and thus less able to shift towards other areas. The changes would lead to a breakdown of plant associations and to a simplification of their composition.

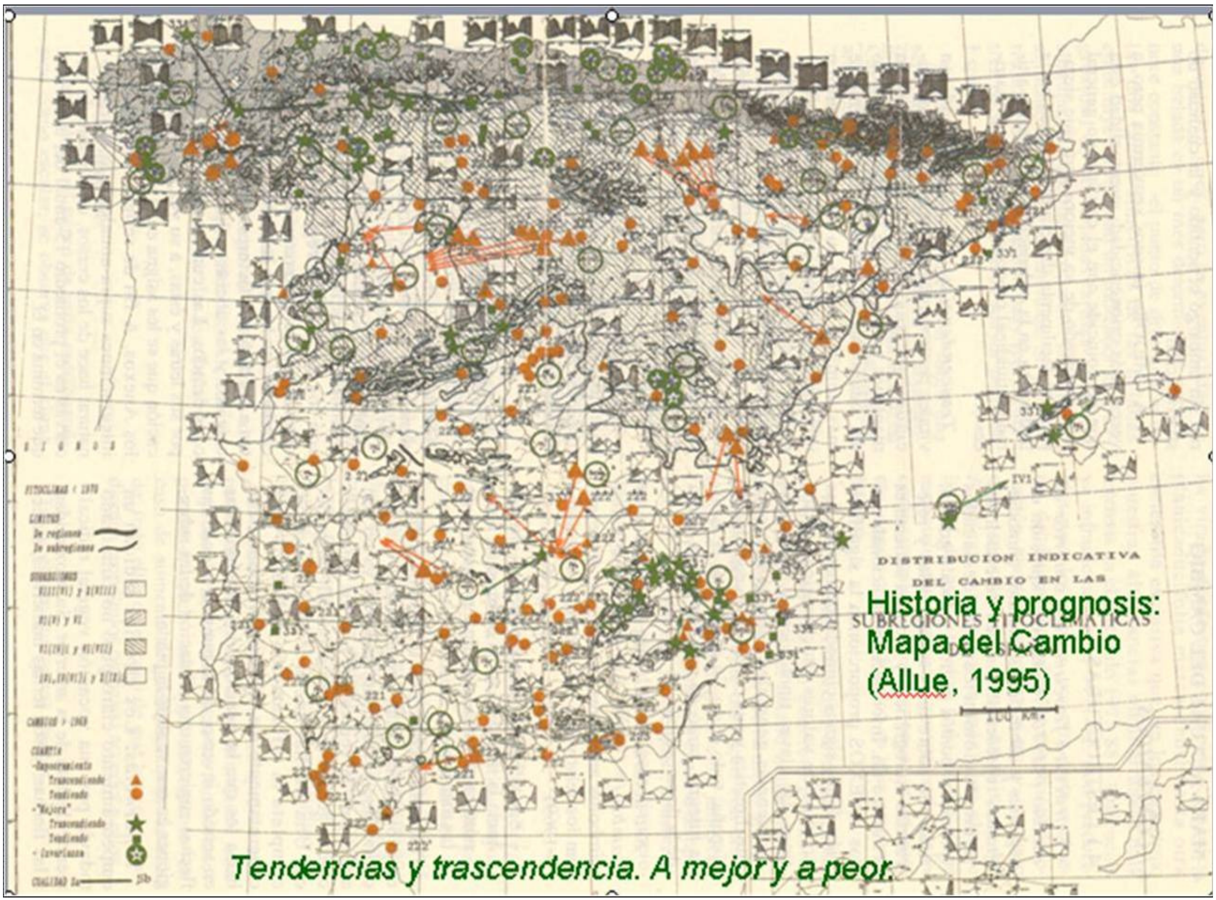


Figure 2 : The map of the change. Red points show trend to worsen climatic subtypes (mainly in terms of water deficit). Red triangles are current processes to worsen climatic conditions. Red arrows show changes to a different climatic subtype spatially (ALLUÉ, 1995).

Among the terrestrial ecosystems, the forest and shrub lands have increased their area as a result of increasing temperatures, CO2 and difuse eutrophization, but mainly because of anthropic processes: the secondary succession from pastures and abandoned agricultural lands, with the adding of intense and successive perturbations (Mesa-Jimenez 2002, Costa et al. 1998). The land use has produced a mosaic of ecosystems with different degrees of maturity, forming heterogeneous landscapes which favours the maintenance of biodiversity.

1.1.2.2. Vegetation phenology

Spain is one of the countries where phenologic changes are expected to be strongest (Valladares et al, 2005). Leaf unfolding now occurs 20 days earlier than 50 years ago in Catalonia, with a range from 30 days for apple trees, elms and fig trees, 15 days for poplar or almond trees, to none for trees more dependent on photoperiod or soil water availability (Peñuelas et al. 2002).

On the other hand, there is also a shift in flowering and fruiting, with an average advance of 10 days in relation to 1970. The life cycles of animals are also affected, for example in NE Spain butterflies appear 11 days earlier than in 1970. This may be significant considering the risk of late frost, although frost is also less severe due to the warming effect. The changes in plant phenology and bird migration suggest that climate warming may lead to decoupling of species interactions, for example, between plants and their pollinators, and between birds and their plant and insect food supplies (Peñuelas and Fillella, 2001). The average advance in phenophases in spring is about 3-4 days per decade.

Thus climate change has advanced the biological spring and delayed the arrival of biological winter. The presence of green cover over a longer period generates a cooling effect that mitigates warming by sequestering more CO2 and increasing evapotranspiration. However, these effects would decline if droughts become more frequent or if less water was available later in the summer. In fact, an early onset of vegetation green-up and a prolonged period of increased evapotranspiration appear to have lowered soil moisture and enhanced recent summer heatwaves in Europe (Peñuelas et al, 2009).

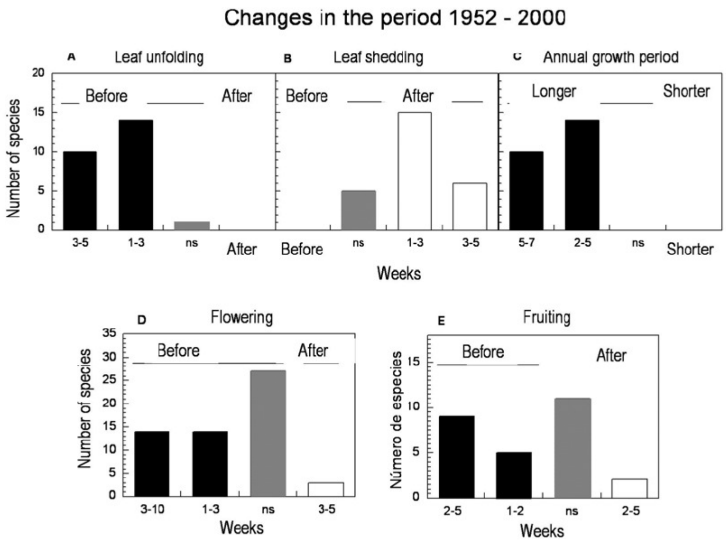


Figure 2 : Frequency of plant species with life cycles that have been altered in the last five decades (from 1952 to 2000) in Cardedeu (Vallès Oriental, Barcelona). (Peñuelas et al, 2002).

1.1.2.3. Vegetation distribution area

In Spain palaeoecological studies have revealed numerous displacements from the distribution zones of certain species and plant formations in response to past climate changes. However, there still is not much evidence of responses to the present warming. Recently, the distribution of vegetation in Montseny was compared with the distribution in 1945, and a progressive substitution of temperate ecosystems (e.g. beech forests) by Mediterranean ecosystems (e.g. Holm oak forests) was observed (Peñuelas and Boada 2003). Furthermore, beech forests have increased at maximum altitudes (1600-1700 m). Heathlands of Calluna vulgaris are also being replaced by Holm oak forests at intermediate altitudes, so that the Holm oak is now found at the unexpected height of 1400 m (Peñuelas and Boada 2003). Something similar has been observed in the Pañalara Massif, in the Guadarrama mountains, where two shrubs (Juniperus and Cytisus) are becoming increasingly abundant at altitudes at which pastures previously dominated (Sanz-Elorza et al. 2003). It must be considered that in relation to mountainous areas, migration towards higher altitudes is accompanied by a reduction in the total area of each habitat, and species that have particular requirements as regards area may become extinct. However, observations of altitudinal migrations of key plant species in terrestrial ecosystems must be considered with care, as the effects are not only attributable to climate change. Smaller numbers of cattle, with the consequent decrease in pressure by herbivores, and other changes in land uses, are to a certain extent involved in these migrations (Valladares et al, 2005).

If the altitudinal and latitudinal movement of vegetation is unlikely, then drought and climatic extremes will cause change in communities and may lead to local extinction of the most poorly adapted species. Changes in the dominant species would produce a change in productivity, and thus significantly affect carbon storage by plants. The progressively worsening water situation can already be seen in some Holm oak forests, and in pine forests and other Mediterranean forests at their hydric limit, with evapotranspiration rates equal to those of water availability (Peñuelas 2001). In these forests, the worsening conditions of aridity during the summer may be the main reason for the mass decay of trees, or at least a contributing factor. There are now clear indications that the increase in aridity and in temperature will not only negatively affect the net primary production of existing plant species, but will also lead to their substitution by other species, more resistant to the new climatic conditions (Peñuelas et al. 2001, Martinez-Vilalta et al. 2002a). For instance, the increase in climatic aridity may compromise the survival of several populations of P. sylvestris in the Mediterranean basin (Martínez-Vilalta and Piñol 2002) and species like Quercus coccifera and Q. ilex may be gradually replaced by more drought resistant species, such as Pistacia lentiscus and Phyllirea latifolia (Filella et al. 1998, Ogaya and Peñuelas 2003, Vilagrosa et al. 2003). On the basis of the hydric strategies of the main functional groups of Mediterranean woody plants, it has been suggested that the first local extinctions would threaten the relictic lauroid sclerophylls of the Tertiary (e.g. Myrtus, Arbutus, Viburnum), followed by arboreal sclerophyll plants (e.g. species of Quercus), whereas chamaephytes (e.g. species of thyme Thymus spp.), the xerophytic malacophyllous plants (e.g. rock rose Cistus spp.) and in general the summertime deciduous shrubs would be less affected or even favoured (Fig. 2.5). In the zones of the Peninsula that are now at their climatic limit for plant formations like thyme and sage fields, climate change could involve the permanent disappearance of plant cover and subsequent desertification, as can now be seen in semi-arid rosemary fields in Murcia, where no re-colonisation was registered ten years after cutting down the vegetation (Castillo et al. 1997). In the short term, changes in the relative dominance of the woody forest species are already being registered, which confirm the predictions (Valladares et al, 2005).

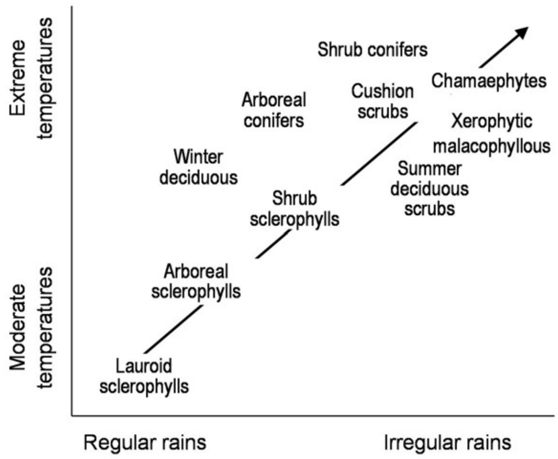


Figure 4 : Distribution of the main functional groups of Mediterranean woody plants according to climatic conditions and impact related to climate change on their populations (arrow). (Valladares et al, 2005).

The experimental manipulation of rain and temperature at stand level by Lloret et al (2009) led to the conclusion that directional climate change towards drier conditions would result in a change in the recruitment of the plant community, which tends to differ from the dynamics of adults, suggesting that potential adult mortality would not be compensated by seedling recruitment, thus enhancing shifts in community composition.

Although it has been established on numerous occasions that when vegetation cover is high (when the leaf area index – LAI – increases), there is less water available in the ecosystem due to an increase in transpiration (Rambal and Debussche 1995), the forest can serve to capture water in certain Mediterranean conditions. Experimental data and numerical simulations indicate that the presence of tree masses on coastal mountain slopes significantly favours the formation of summer storms and the collection of water which, in the form of more or less dense fog, rises from the sea (Millán 2002). Although these local effects of the forest on microclimate and rainfall are evident and have been proven, their influence on regional climate (macroclimate) is less clear. In simulations of the effects of extensive deforestation in Spain and France, it has been found that the forest only favours rains when these occur in summer by means of vertically developed clouds, in whose formation forest transpiration can actively intervene (Gaertner et al. 2001).

1.1.2.4. Insect phenology and distribution area

Climate change is favouring the rupture of some interactions and the establishment of new ones. An example of new interactions is being observed in the Mediterranean mountains in the behaviour of the pine caterpillar, whose altitudinal range is increasing because of the mild winter temperatures; as a consequence the caterpillar is now infesting the native populations of Scots pine situated further up the mountain (Hódar et al. 2003).
Increased temperatures and the consequent lengthening of the optimum periods for the development of pests and diseases may have a greater and more long lasting impact on the vegetation upon which they feed. The conifer perforators Ips acuminatus and Ips sexdentatus can complete up to more than two generations in one year, if the flight of adults is advanced by one month as a result of the temperature increase, and prolonged throughout the autumn. Defoliators such as Diprion pini may habitually develop two cycles. However, the greatest threat is undoubtedly that posed by the pests and diseases exogenous to the environment, the so-called alien species or quarantine organisms (Gracia et al, 2005).

1.1.2.5. Global productivity

The increase in productivity of the Spanish forest that the comparison between IFN1, IFN2 and IFN3 clearly shows is mainly due to the increase in the average timber stocking and the colonization of agricultural and shrub lands by trees, although there is no clear trend of increasing productivity derived from nitrogen deposition or increased CO2 concentrations. Some studies on tree rings and relations to climate are referred to below.

Tree rings vary greatly between years in response to climate changes in recent centuries, although the variations depend on the species. Holm oak is considered a drought resistant species, but is also able to exploit the water table, thus showing less oscillation than species that are more dependent on rainfall, such as Aleppo pine (Ferrio et al. 2003).

Most dendrochronological variables (tree ring width, isotopic composition, anatomical traits and density) have shown increasing variability during the second half of the 20th Century, in relation to an increase in climatic variability and frequency of extreme events (Tardif et al. 2003). The trees display clear synchronization with climate and the effect of site variables on diameter growth becomes less in relation to the direct effect of climate. Increased within-year variation in growth indicates an overall lengthening of the vegetation growth period. An increase in the between-year variability has also been observed in subalpine stands (Camarero and Gutiérrez 2004).

In the Central Pyrenees, an increase in the climatic variability from 1950 onwards led to an increase in between-tree variance and hampered rise of the timberline in relation to the first half of the 20th Century (Camarero and Gutiérrez 2004).

1.1.3. Disturbances and extreme events

There are many extreme events related directly or indirectly to forestry in Spain, of which forest fires are the most important. We can mention the forest fire waves of 2006 in northwestern Spain, the drought of 2004, windstorms in 2009.
Mediterranean ecosystems have been and are currently exposed to disturbances that may be episodic, such as intense drought and fires, or chronic, such as overexploitation and herbivory. Fire, and subsequently, grazing, had a very significant influence on the evolution of vegetation during the second half of the Holocene. The increased aridity was, in many cases, little more than a background influence. Given the frequency and intensity of the disturbances, the differential sensitivity of the species is a very important mechanism in terms of the composition and spatial and temporal dynamics of plant and animal communities. However, climate can cause significant variations in the effect of the disturbances on the ecosystems; damage by herbivory of woody plants depends on the amount of annual rainfall, and the impact is greater in dry years (Zamora et al. 2004).

1.1.3.1. Drought

Drought is one of the major factors that produces damage in trees, according to the results of the level 1 European network in Spain (DGB, 2007). According to the results for 2007, 21.6% of the total number of trees in the plots were damaged by drought and the most severely affected species were Quercus ilex, Pinus halepensis, Pinus sylvestris, Pinus nigra, Quercus suber and Quercus faginea, in that order. The only factor more important than drought was the presence of insects.

Drought limits plant growth and survival, by acting as a selective stress filter for plants, according to their tolerance to hydric stress (Valladares et al, 2005). In a comparative study of the hydraulic architecture of nine woody species, it was shown that although Ilex aquifolium, Phillyrea latifolia and Juniperus oxycedrus were resistant to cavitation of the xylem caused by drought, Quercus ilex, Arbutus unedo and Acer monspessulanum were much more vulnerable (Martinez-Vilalta et al. 2002b). It was also observed that the different vulnerability to cavitation was related to the hydric potentials that each species showed in the field, confirming the existence of different hydric strategies so that the species that grow together have different levels of stress during summer drought, and with different safety margins with regard to embolisms.
The summer of 1994 severely damaged many forests and shrublands on the Iberian Peninsula (80% of the 190 peninsular sites studied presented damaged species, Peñuelas et al. 2001). Holm oaks, for example, dried up in many sites (Lloret and Siscart 1995). In parts of the Iberian System mountain range in Aragón, intense defoliation was observed, along with drastic changes in anatomy and growth, although the trees recovered after the drought (Corcuera et al. 2004). Isotopic studies showed that in the following years these Holm oak forests continued to be affected, so that they used less water than was available to them, and loss of soil nutrients was favoured (Peñuelas et al. 2000). The different severity of the effects on the different forests in the country was determined, among other factors, by 1) the orientation of the slopes (greater damage on the sun-facing slopes) (Peñuelas et al. 2000), 2) soil depth (less damage in the deeper soils that were more penetrable by the roots, for example, soils on schists) (Lloret and Siscart 1995), 3) the dominant species (Peñuelas et al. 1998), and 4) forest management (thinned forests less affected than the dense ones) (Gracia et al. 1999). The degree of damage varied depending on the functional type and on the evolutionary history of the different species (Peñuelas et al. 2001). The genera Lavandula, Erica, Genista, Cistus and Rosmarinus, which have diversified under Mediterranean climatic conditions (i.e. after the 3.2 million years of the Pliocene) were initially more affected by drought than genera that had evolved previously (e.g. Pistacia, Olea, Juniperus, Pinus and Quercus), but recovered much better after several years of higher water availability. The post-Pliocene Mediterranean species therefore appear to be more resistant to an unpredictable environment, with great seasonal and inter-annual variability and which is subject to frequent droughts. An understanding of these responses is important in order to predict the future composition of the communities in a scenario of climate change (Valladares et al, 2005).

1.1.3.2. Forest fires

There is no clear evidence of an increase in the number or intensity of forest fires in direct relation to climate warming. It is clear that the information on the annual number of fires and burned areas depends on many factors, such as the climatic conditions in a particular year, and also the rapidity and efficiency of the fire fighting response.
The area burned in Spain between 1970 and the present increased clearly during the 1990s and early 1990s, with a subsequent decrease and stabilization up to 1996, probably because of improved forest fire fighting systems. An increase in the frequency of large fires (area burned greater than 500 ha) has been suggested, although the statistics do not show any clear trend.

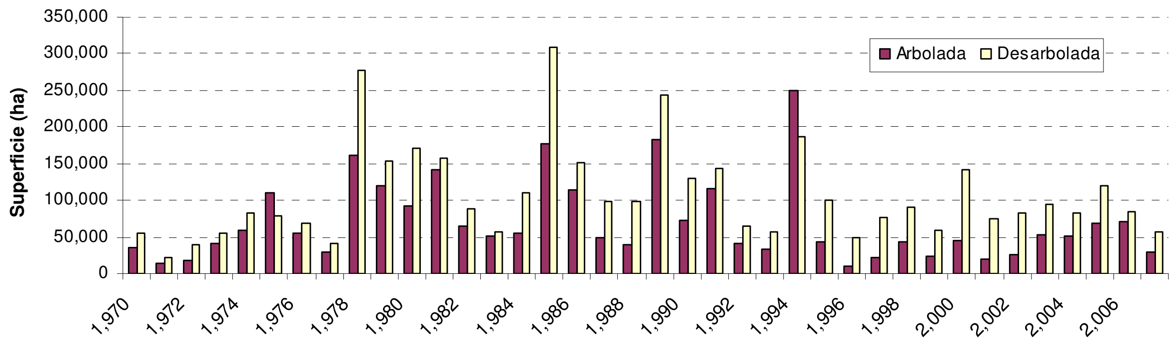


Figure 5 : Forest and other wooded land affected by forest fires in Spain since 1970. Source: Forest Fires National Statistics, Ministry of Environment.

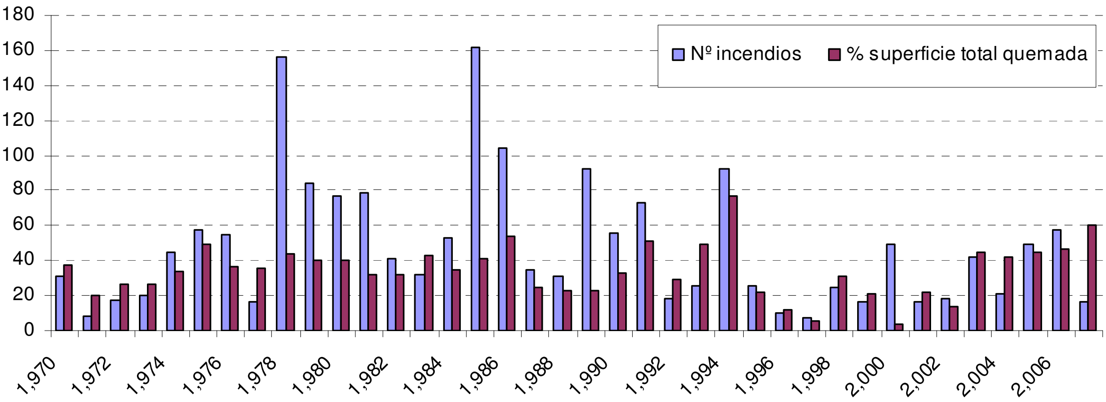


Figure 6 : Evolution of the number and percent of area burned in big fires (area burned more than 500 ha). Source: Forest Fires National Statistics, Ministry of Environment.

Pausas (2004) observed a slight trend towards decreasing summer precipitations and increasing temperatures, suggesting a decrease in fuel humidity, and an increase in number of fires and burned area in the last century was revealed by analysis of 350 weather stations and forest fires in eastern Iberia. Piñol et al (1998) also observed an increase in the fire risk indices for Aleppo pine, in relation to an increase in maximum temperatures.

It is well known that drought increases the fire risk period and provides conditions that favour ignition because of the decreased humidity of fine fuels. Furthermore, drought has a negative effect on preventative and fire-fighting measures (Vélez, 1995).

1.2. Expected impacts

Past and recent impacts are mainly based on observations. On the contrary expected impacts are mainly based on several kinds of models: Global Circulation (climatic) Models (GCM) at the planet level; Regional climatic models that downscale previous models in order to take into account local factors that influence the local climate; vegetation models that represent vegetation behaviour, including forest impacts for given changes in climate; other models are developed in accordance with objectives and needs, concerning for example fauna. Moreover, all these models depend on the expected atmospheric characteristics (Greenhouse gas concentration) and on climate parameters (temperature, precipitations…) that come from a given socioeconomic scenario for the future (special report on emissions scenarios proposed by the international panel on climate change: SRES-IPCC).

1.2.1. Expected climatic evolution

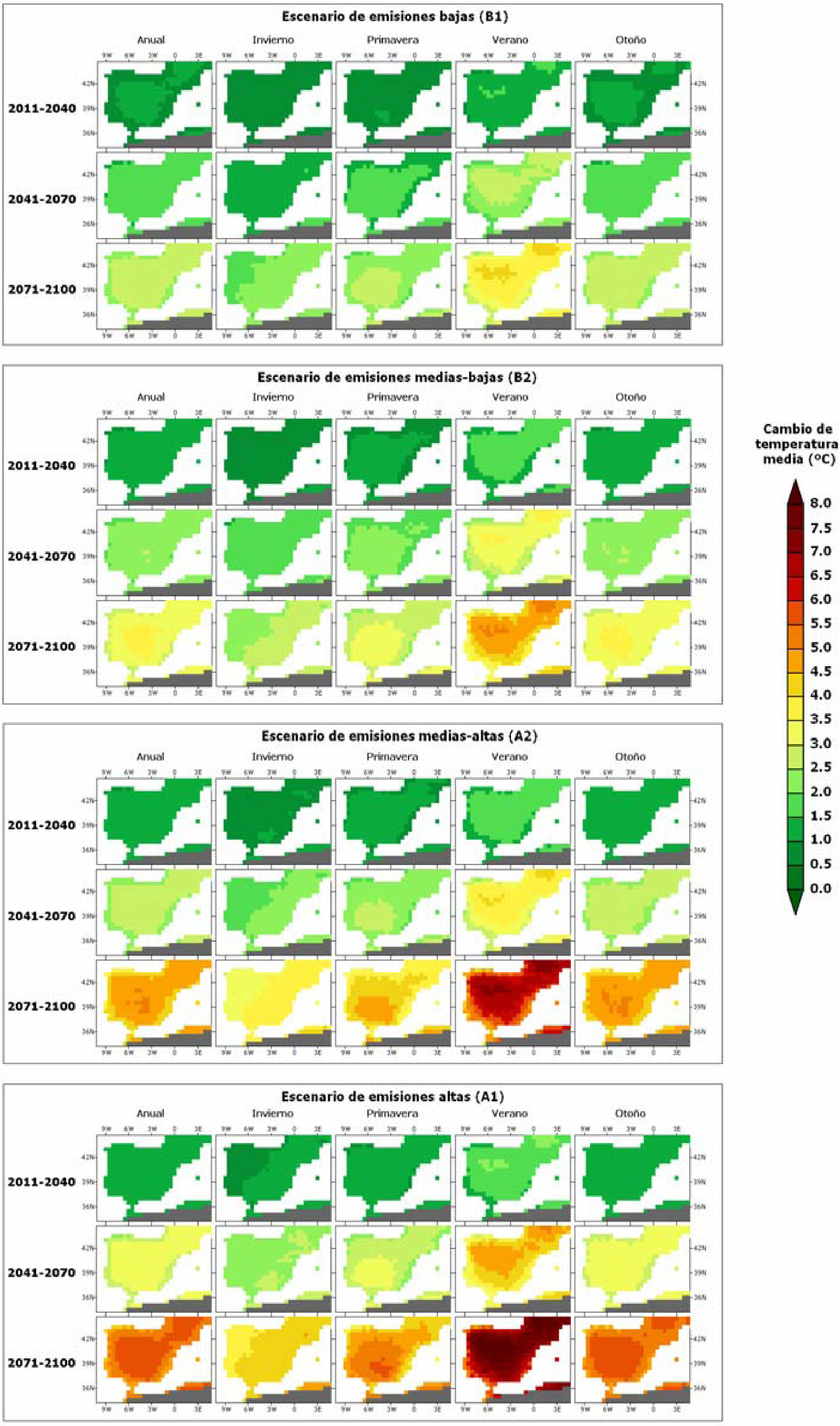
The production of regionalized climate scenarios has recently undergone important advances in Spain. The National Agency of Meteorology (AEMet) is in charge of producing quantitative scenarios that are fundamental for assessing future impacts, vulnerability and hazards in relation to hydric resources, coastal areas or biodiversity, according to the three main topics covered by the Spanish Adaptation Plan to climate change (PNACC) (OECC, 2008).

The regionalized scenarios for Spain have been obtained from the set of European models used in the PRUDENCE research Project of the EU, taking into account the emission scenarios proposed by the IPCC. The spatial resolution of this database is 50×50 km^2. The projections for the 21st Century indicate the following (AEMet, 2009):

1. A trend of increasing temperatures is forecast for all regions, with a marked acceleration after 2050 in the case of high emission scenarios. For the period 2011-2040 there are no clear differences among the emissions scenarios, but for the last third of the Century there are important differences among scenarios.
2. Not all regions will undergo warming to the same degree, which will be in any case stronger in summer than in winter. On the other hand, as the increasing trend in winter is similar among regions, in the other stations the regional differences are important: Spring warming will tend to be greater in the southern half of the Peninsula, whereas autumn and summer warming will be greater in the inner regions than in coastal regions.
3. For all the regions, maximum daily temperatures will increase faster than the average temperatures and, as minimum daily temperatures will also increase but at a lower rate than average temperatures, the daily oscillations in temperature will increase, particularly for the worst emission scenarios.

The scenarios for rainfall and other climatic variables show a less homogeneous pattern, although a general reduction is forecast, particularly for the second half of the century and under the high emission scenarios:

1. For the period 2011-2040 a general reduction in annual rainfall is forecast, with average values of -5% in the north and east, and close to -10% in the southeast. There are no evident differences among emission scenarios.
2. In the last third of the 2lst century the differences among emissions scenarios are clear: -25% in the north under A1 but only -15% under B1, -30% in the south under A1, but only -20% under B1. This is considered as a demonstration of the interest of mitigation measures on a global scale.
3. A general trend toward reduced average air humidity, higher insolation due to the reduced cloud cover and no changes in wind speed.


Escenario de emisiones bajas (B1)
Escenario de emisiones medias-bajas (B2)
Escenario de emisiones medias-altas (A2)
Escenario de emisiones altas (A1)
Anual
Invierno
Primavera
Verano
Otoño
2011-2040
2041-2070
2071-2100
Cambio de temperatura media (ºC)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
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2.0
1.5
1.0
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1.

Figure 7 : Annual and seasonal predicted changes in temperature for different climatic scenarios of IPCC. Source: AEMet, 2009

1.2.2. Impacts on ecosystem dynamics and functioning

Some 31.5% of the Spanish territory is considered to be seriously affected by desertification, a combined process of erosion and salinization promoted by anthropogenic activities under arid conditions. The projected climate changes will generally worsen these problems, in combination with the expected increase in forest fires. It is clear that soil use, and especially soil use changes cause the soil to be a net sink or carbon emitter. As a consequence of the increase in temperature and drought, the models forecast a reduction in organic soil carbon, particularly in northern Spain and in areas already rich in soil carbon, such as meadows and forests.

1.2.2.1. Vegetation phenology

The observed phenological changes listed above have occurred, with warming only 50% or less than that expected for the 21st century. As many ecological, agricultural and socioeconomic and sanitary factors are highly dependent on plant and animal phenology, phenological recording by international monitoring networks become increasingly relevant (Peñuelas and Filella, 2001).

1.2.2.2. Vegetation distribution area

The upper limit of the forest, limited by temperature, advanced in the most favourable periods of the Holocene by between one and three centimetres a year and in the Central Pyrenees, advances of between 20 and 80 centimetres a year were recorded during the last century (Camarero 1999). The predicted climate change would allow for the spread of thermophilic species, but the decrease in rainfall would halt this advance, harm those species that were not tolerant to drought and negatively affect the lower limit of the forest (limited by hydric availability). Woody vegetation might spread towards higher mountain areas and the communities already existing in these areas would become rarer or extinct. In many cases, the only possible migration is towards northern latitudes. However, migration rates would not be efficient in the current scenario of global climate change because, on one hand, the changes are occurring rapdily, and on the other, the territory is very fragmented, which significantly restricts the possibility of latitudinal or altitudinal migrations of vegetation. It should also be pointed out that the Iberian Peninsula is the southern limit for the distribution of many species (e.g. Pinus sylvestris, P. uncinata), relict populations of which are often isolated in mountain massifs (Valladares et al, 2005).
The negative relationship between the rate of advance of the tree limit and the variability in temperatures in some months (e.g. March) derived from changing climate suggests that the displacement of the trees to higher elevations due to increased temperature in the Central Pyrenees will be limited.
From an evolutionary point of view, species tend to be quite conservative and to respond to disturbances by migrating rather than through adaptation. However, migration in the currently fragmented landscape is quite unlikely. The slowness of certain ecological processes, like the natural regeneration of Quercus species, compromises the long-term viability of the ecosystem, as one of the characteristics of climate change is the acceleration of rates of change. Rapid microevolutionary processes are not operative for long-lived, slow-growing species such as oaks, essential in many terrestrial ecosystems. Ecophysical adaptation to local environmental conditions is difficult for woody species because of the rapid rate of environmental change. If the plants cannot follow climate change by evolving, they can

attenuate its adverse effects by means of short term responses (acclimatisation, phenotypical plasticity). However, plasticity has not generally been maximised during evolution in adverse systems, such as arid or areas of low fertility, but rather the species in these areas tend to make conservative use of the resources involved in moderate plasticity (Valladares et al. 2002). The capacity for physiological and morphological adjustment to new climatic conditions is therefore initially considered as limited for certain species or populations in Mediterranean areas and perhaps also for high-mountain species on oligotrophic soils.

1.2.2.3. Insects, parasites, pathogens

Several semi aggressive bark beetles species such as Ips or Tomicus spp. are normally confined to colonizing weakened, dying or recently dead trees, but aggressive attacks on healthy living trees will arise if certain (eruptive) thresholds are surpassed. A higher density of beetles is required for a mass attack if tree vigour is high, thus an increase in xeric conditions would surely lead to sustained conditions of stress for many pine stands, and to a lowering of the eruptive thresholds, probably promoting a higher frequency of destructive outbreaks by bark beetles (Pérez et al, 2008).
The pine wood nematode (PWN), Bursaphelenchus xylophilus, which is transferred to new host trees by cerambycid beetle vectors (in the genus Monochamus), is the causal agent of pine wilt disease, which has been detected in Portugal. The risk of the spread of such disease has been shown to be directly related to increased temperatures and to hydric stress (Pérez et al, 2008). As some pine species are particularly susceptible, the occurrence of this disease could promote changes in the composition of species in mixed pine stands.

1.2.2.4. Global productivity

The future effects of climatic change on productivity appear to be an increase in net primary production in Atlantic ecosystems, limited by temperature, and a reduction in the Mediterranean region, largely predominant in Spain and where the main factor limiting productivity is water availability (Valladares et al, 2005).
Both the lengthening of the life of deciduous trees and the accelerated renovation of the leaves of evergreen trees, phenomena associated with increased temperature (Gracia et al. 2001, Sabaté et al. 2002), will lead to an increase in the water transpired, which is added to the greater potential evaporation resulting from the temperature rise. In locations with sufficient water to compensate for this greater hydric demand, forest production is expected to increase. However, in locations subjected to hydric deficit, i.e. most terrestrial ecosystems in Spain, changes are expected to range from a reduction in the density of the trees to alterations in the distribution of species (Sabaté et al, 2002).

1.2.3. Disturbances and extreme events

It is clear that the impacts associated to extreme climatic events are more important than those derived from changes in the average climate change. All forecast show an increase in the frequency of extreme events associated with temperature in all the regions of Spain. Summer heatwaves will probably be more frequent and in the last third of the century and for the A2 scenarios, maximum temperatures higher than those considered nowadays as exceptionally high will be reached on more than half of the summer days in the inner Iberian Peninsula (Abadanes et al, 2007). No significant changes were predicted for the extreme events of high rainfall.

The increase in temperatures and change in the rainfall regime, with increase of drought intensity, will most likely change the pattern of frequency and intensity of fires in Spain, particularly in the Mediterranean area. The driving causes of these changes will not be exclusively the climate change, but also the increasing loads of forest fuels and causes of ignition (Vélez, 2000). The fires will produce more carbon emissions.

During the XX century, the fire danger rating index has constantly risen, and will continue to do so in the XXI century. There will be greater incidence in time of high danger zones, the duration of this during the year, and of extreme danger situations. There will probably be a greater frequency of fires with these increases. There will be an increase in ignitions caused by lightning. The abandonment of marginal lands will continue. The more mesophytic vegetation will be replaced by a more xerophytic one. More burnt surface area will lead to more shrubland vegetation. In short, there will be an increase in flamability potential of the territory. The most vulnerable areas will be in the North of Spain, in high mountain or plateau areas, as these will be exposed to a more adverse fire regime than the present one (Moreno, 2005).

Predictions based on GCMs indicate that the convective rain fraction will tend to increase, along with the number of lightening discharges and, consequently, the number of fires caused by lightening (Moreno, 2005).

Three lines of research are relevant to forest fires in relation to climate change: 1. Simulated forest fire systems related to climatic variables. 2. Analysis of the temporal evolution of fires and their relation to climatic conditions. 3 The C content of burned ecosystems and C emissions as a result of fire.

Simulation of fire risk in relation to climatic conditions must also take into account several factors linked to the site, such as the topographic conditions, fuel loads and their spatial distribution. In the corresponding models it is difficult to predict fire behaviour under changing climatic conditions. The SOCFUS model (self-organized critical fuel succession model), based on a concept from statistical physics has recently been proposed as a way of overcoming these difficulties and has been applied to boreal forests, obviously outside Spain (Pueyo, 2007).

Simulations of increased frequency of fires as a result of climate change indicate a gradual dominance by shrublands, which are more susceptible to exposure to ignition sources (Rodrigo et al, 2004).

A preliminary assessment of the impacts of the climate change also forecast an increase of slope instability or floods. Increased torrentiality will cause a greater number of shallow landslides and debris flows, the effects of which have been considered to be exacerbated by changes in land use and reduced plant cover (Corominas, 2005).

1.3. Impact monitoring

1.3.1. Usual monitoring system/network

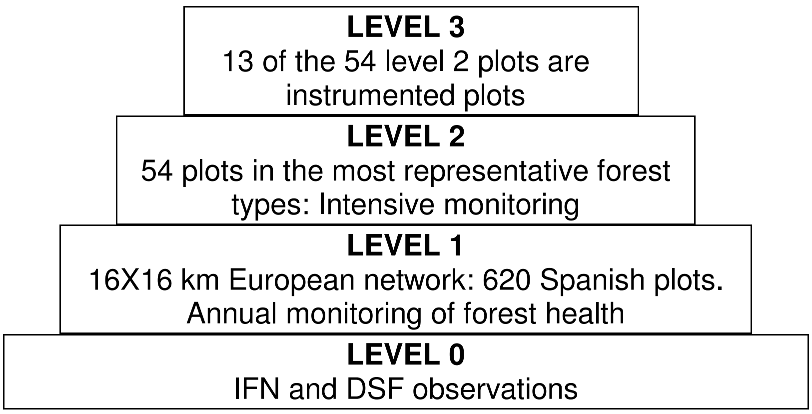
The main forest monitoring network in Spain is the National Forest Inventory (IFN as the acronym in Spanish). The IFN3 has recently been completed in Spain and the field works has already commenced for the IFN4 in a nex cycle of 10 years. There is a permanent set of variable-radii plots in a net of 1x1 km using the UTM coordinates with a periodicity of measurements of about 10 years (http://www.mma.es/portal/secciones/biodiversidad/inventarios/).

This inventory can be considered as level 0, in which the number of plots measured is greater than 90000. Every tree in the inner plot of radius 5 m is measured, and the number of trees of diameter between 2.5 and 7.5 cm are counted. Natural regeneration is also assessed considering the following plant types: less than 30 cm high, between 30 and 130 cm and higher than 130 but of diameter less than 2.5 cm.

One of the main objectives of the fourth cycle of the IFN is to provide enough information to enable calculation of the importance of forest areas as carbon sinks. This would mean installing plots in forest land covered by shrubs, thus increasing the total number of plots. Furthermore, a measurement of a new set of variables related to biodiversity (microstructure, deadwood, age) is being applied in a subsample of plots, and will allow the evaluation of biodiversity and its evolution in time in relation to global change.

The Basque Country has a further inventory developed between the IFN1 and IFN2, with a similar sampling intensity and methodology as the inventories covered by the IFN system. In the case of Catalonia, the IFN is performed in a similar way, but with ecological information on the forest functioning also obtained by measurement of several ecological parameters, as described in the following web page, http://www.creaf.uab.es/iefc/.

The forest damage derived from contamination led to the implementation of a monitoring system of forest health at European level (1986 regulation) (http://europa.eu.int/comm/agriculture/index es.htm). There are three levels of monitoring in the European framework, outlined in the following diagram:



Although level 1 is designed mainly to recover information on forest health, under the European Forest Focus regulation, assessment of the state of forest in relation to climate change is devised. In Spain, the Service of Protection against harmful agents (SPCAN) is in charge of the monitoring, and the results can be viewed at, http://www.mma.es/portal/secciones/biodiversidad/montes_politica_forestal/sanidad_forestal/index.htm. Twenty trees per plot are assessed. The level 1 network was reinforced in some regions of Spain to obtain a 8 x 8 km sampling intensity, as for example in Galicia.

For level 2 forest plots, the on-going monitoring covers soil and nutrient analysis, atmospheric deposition, stand growth, in-situ climatic data, phenology, botanic data, soil solution, vegetation structure, lichen diversity, etc. In this case, the Ministry has permanent collaborations with research centers, such as the Department of Sustainable Use of the Environment (INIA) (http://www.inia.es/), the CEAM Foundation (http://www.gva.es/ceam/) the Technoc School of Forestry in Madrid (http://www.upm.es/centros/euitf.html). Detailed information on the surveys of these plots is available at http://www.mma.es/portal/secciones/biodiversidad/montes_politica_forestal/sanidad_forestal/actividades_y_tareas/red_ce_nivel2/parcelas_red_ce_II.htm.

A subset of instrumented plots are visited fortnightly and detailed information about soil parameters, climate, vegetation structure, production, phenology and health status are measured. The following types of forest are represented: northern maritime pine forest, mountain Scots pine forest, Evergreen oak forest, stone pine forest over dunes, open forest of cork oak, beech forest, black pine mountain forest, Aleppo pine mountain forest, Aleppo pine coastal forest, Scots pine forest of the Castillian Plateau, open evergreen oak forest, oak forest and maritime pine forest of the Castillian Plateau.

No detailed information about the quantification of carbon fluxes is available for the plots, although some new objectives have been established for this network in particular to study the evolution of forest ecosystems in relation to climate change.

A national biodiversity inventory is also carried out by the Spanish DGB with the form of a series of atlas structured in taxonomic groups (see http://www.mma.es/portal/secciones/biodiversidad/inventarios/inb/).

1.3.2. Specific monitoring system/network

Some plots or small networks of plots have been established in the framework of European projects at a regional scale. Carbon fluxes have been measured in an Aleppo pine forest and a nearby shrub plot with the eddy-covariance technique in the framework of the MEDEFLU EU project, showing a fixing rate of 89 g C m-2 year-1 in the forest ecosystem (Sanz et al, 2001).

The possibility of using remote sensing to recover information on carbon emissions and sinks has not been fully developed. González Alonso et al (2005) presented several possible ways of relating the normalized difference vegetation index (NDVI) and data of the NFI and biomass. Navarro et al (1998) studied the effects of drought in open evergreen oak forest, using LANDSAT-TM images.

The detection of change in fire occurrence requires the maintenance of the General Statistics of Forest Fires (EGIF) database on forest fires in Spain, which is managed by the General Direction for Biodiversity (MIMAM). See: http://www.mma.es/secciones/biodiversidad/defensa_incendios/estadisticas_incendios/

1.4. Impact management

In the case of extreme events as forest fires, die-backs derived from droughts or windstorms, the impacts are both managed by the Spanish State (through the Directorate General for Biodiversity) and, mainly, by the Regional Ministry in charge of forest affairs in each regional government. Even if it is the regions who can establish particular regulations, the state is in charge of the basic coordination of fighting activities and the support with fighting equipment the regional governments, in application of the Spanish Forest Plan and several other regulations, as the RDL 11/2005 "Urgent measures about forest fire fighting". In the case of restoration activities, each regional government can promote special lines of grants for felling damaged or burned tree or reforest affected areas.

In relation to forest fires, there is an important program of international cooperation, mainly at the European level, from which Spain usually benefits from equipment and human resources, and also support other countries (see http://www.mma.es/portal/secciones/biodiversidad/defensa_incendios/pdcif/cooperacion.htm).

2. Adaptation

2.1. General adaptation strategy and policy

Spanish national strategy and policy for adaptation is ruled by the Plan Nacional de Adaptación al Cambio Climático – PNACC (OECC, 2006. http://www.mma.es/secciones/cambio_climatico/areas_tematicas/impactos_cc/pdf/pna_v3.pdf). Main objective of the National Plan is to integrate the adaptation to climate change within the strategic planning of management in different sectors of the country. To do this, the Plan defines the main guidelines to help the different public administrations and private organizations to identify the best options for adaptation, facilitating them the better available knowledge, tools and methods. The plan integrates the different project and initiatives related with adaptation proposals, favouring the iterative work and the interchange of experiences.

Specific objectives of the Plan are:

- To develop the regional climate scenarios for the Spanish territory
- To develop and apply suitable methods and tools foe evaluating the impact, the vulnerability and the possibility for adaptation to climate change on different economical and social sectors and ecological environments in Spain
- To identify the most accurate requirements concerning Research + Development + Innovation in relation with climate change
- To generate a permanent flow of knowledge and information about the current projects
- To promote the participation of the different stakeholders in the different areas, sectors and systems affected by the need of adaptation to climate change
- To elaborate specific reports including the results derived from evaluations and project activities, and in general, from the whole Plan.

The Plan recognizes sixteen economical, social or ecological areas largely vulnerable to climate change, where adaptation measures are highly requires. These areas are

Biodiversity	Mountain areas	Tourism
Water resources	Soil protection	Insurance – Finances
Forests	Sea fish and ecosystems	Urban development
Agriculture	Transport	Building
Coast lands	Human Health	
Continental fish and hunting	Industry and Energy	

For every of the abovementioned sectors, the Plan identifies the effect of those most severe impacts, and defines the main important lines of work in adaptation.

2.2. Forest adaptation measures

2.2.1. Political level

The PNACC (OECC, 2008) considers very general lines of adaptation for the forest sectors, as listed below:
- Drafting of guidelines and evaluation of the techniques and models required to implement an adaptive forest management for climate change.
- Development and application of forest growth models under different climate change scenarios.
- Assessment of the response of vegetation to a variety of adverse situations (droughts, fires, etc.).
- Evaluation of a system of climate change indicators for forests and implementation of an early warning system.
- Evaluation of the carbon balances for different types of forest ecosystems.
- Evaluation of above and below-ground biomass of Spanish species and forest systems.

Silvicultural treatments would imitate, assist or promote the natural adaptation processes, as species dispersión and migration, mortality or colonization, changes in th especies dominance and composition and changes in the disturbance regime. The goal would be to avoid catastrophic changes, pointing the Management to a possible future state (Allué 1995).

One of the more important issues at a general level is to promote the availability of genetic material and tree breeding programs taking into consideration the traits related to plasticity, and specially drought resistance. The maintenance of an adequate level of interspecific genetic variability and the application of this consideration even at the stand level in reforestation programs are further necessary. The Spanish strategy for the conservation of genetic forest resources takes into consideration the climatic change as a threat for this conservation (MMA, 2006). In the last decades, Spain has undertaken an important activity to catalogue and crop plant reproductive material from different provenances, including many restricted seed areas, being most of the information available at http://www.mma.es/portal/secciones/biodiversidad/montes_politica_forestal/recursos_geneticos_forestal/.

The reforestation of slopes and the choice of species well adapted to site are commonly considered as good adaptation measures for many purposes. As an example to increase risk of slope instability, Corominas (2005) considers that the impact of increased surface slides and debris flow can be mitigated in this way. The growth of forests also constitutes a clearly sustainable element for protection against erosion or rockfalls (protection forest). Priority should therefore be given to reforestation and fire-fighting policies in the future.

The change in the fire regime will affect fire-fighting and prevention policies, and policies dealing with soil conservation and desertification, biodiversity conservation and land use (Moreno, 2005). Specifically for the forest sector, management schemes based on the total exclusion of fire must be modified. Fire could be incorporated as a management tool in order to reduce fire hazard in a given area, but the extent of such use is still under debate. The option of fighting all fires in an environment of danger and increasing risk might simply be technically impossible and economically unfeasible. Furthermore, from the ecosystem management point of view, some of these could be managed taking fire into consideration, that is to say, by periodically incorporating fire into management schemes. There appears to be a need to revise fire fighting policies, fundamentally through changes in prevention strategies and, specifically, fuel management techniques.

Some authors have consider that certain conservation and land use policies have promoted the development of dense and continuous stands with high forest fuel loads, even creating new stands on agricultural lands which had not received the necessary tending operations, exacerbating the fire risk. Basic studies on the management objectives of these stands in relation to present and past socioeconomic and climate conditions as well as their vulnerability to global change should be promoted, in a context of an increasing importance of vegetal cover as regulators of water and carbon cycles. Agroecology studies should be encouraged as a way to obtain basic future information.

2.2.2. Management level

Despite the evident interest on application of adaptation measures to climate change at the forest management level, only in the recent years it has started a common effort to apply some of these measures. Considering the main particularities of Spanish forests, ecosystems and species, and analysing the main impact related with and increasing trend of temperatures and a reduction in the availability of water resources, the first adaptive measures that have been applied are related to improve the water status of the plants. Among these measures we can mention:

1. Management of stand density to improve water availability.

Thinning has been proposed as a useful tool to reduce losses of water by transpiration and especially to improve water status of the plants. There are many proposals for intensive application of thinning on coppice stands of evergreen oaks, as Quercus ilex forests in Catalonia (Gracia et al. 2001) or Quercus pyrenaica in Central Range and Northern Plateau (Bravo et al. 2008). Applied thinnings are in some cases severe, with felling intensity of more than 50% of the standing trees in the heaviest treatments, particularly in the case of high densities of wild ungulates or domestic cattle able to control the resprouting. Despite this severity, application of this thinning system allowed the survival of a large amount of trees after the severe summer drought episodes on 1994 and 2003. Lighter thinning are more appropriate where the resprout should be controlled by the stocking itself.

The forest services in Valladolid province (Castilla y León) has proposed to apply intense early thinning of stone pine (Pinus pinea L.) stands. After episodes of mortality, decay and delay in the beginning of fruit (pine nuts) production, thinnings are nowadays applied in advance (at the age of ten, instead of twenty), with a more severe intensity (stand density is reduced to 300 – 400 stems/ha at 10 years old) and delaying pruning application up to 25 years. A large increment in growth and a reduction in summer decay episodes is nowadays detected (Calama et al. 2008; Gordo et al. 2009). In general terms, early thinning of slow-growth conifers is a good tool for the manager.

2. Improving techniques in reforestations

Traditional afforestation techniques have focused on the elimination of the surrounding vegetation, in order to reduce the negative effect of competition on the installed seedling. Nevertheless, in semi-arid environments, as can be considered the main part of the Spanish Mediterranean coast, processes of facilitation among plants are commonly detected (Gomez-Aparicio et al. 2004). Nowadays, information from these theoretical processes is taken into account in the afforestation planning, maintaining shrubs as nurse plants for reforestations (Castro et al. 2004) in coniferous and evergreen forests in Sierra Nevada.

General trends of adaptation in relation to reforestation are the use of special machinery for spot site preparation, improvement of plant quality and its ability to survive in adverse conditions, use of tree shelters, particularly for broadleaves or species mixtures.

In the autonomous region of Valencia there has been a great investment in improving and applying innovative reforestation techniques for arid environments in order to increase the rates of survival and development and increase the resilience of these new stand against climate change impacts. A main example is the reforestation practices over more than 5000 ha in Alicante province (Vilagrosa et al. 2008), in a mainly degraded natural shrublands. In this area, with annual amount of rainfall under 300 mm, reforestation with shrubs species as Pistacia lentiscus, Rhamnus lycioides or Olea europaea has been carried. Among the applied techniques there are the application of organic mulch, specific tree-shelter or plantation on micro-catchements, which improve the ability for water capture. In the same region there is actually a great plan to increase the resilience of Pinus halepensis stands against increasing trend in drought and fire by promoting the plantation of broadleaves species as evergreen oaks (Quercus ilex, Quercus coccifera) or other deciduous species, as Acer opalus or Fraxinus ornus.

3. Development of growth models including climate scenarios

Finally, a third main line in ongoing adaptation measures comes from the recent development and application of forest growth models in the practical management of the forests. In this sense, nowadays there have been constructed empirical growth models for the mains species in Spain, which are nowadays including climate variables, to facilitate its application under changing environments. Together with this, there are in development two main platforms - SIMANFOR (www.simanfor.es) and GESMO for helping the simulation of stands development under different environmental and economical scenarios.

4. Selection of thinning intensity and thinning interval in Mediterranean forests.

The effect of thinnings on soil and tree carbon balance has been only partially studied in Spain. In the case of Mediterranean ecosystems, as the mobilization of reserve carbohydrates is the main process making evergreen oaks able to produce new shoots after thinning, it has been considered pertinent to establish the time needed by the plant to bring reserves back to the levels existing previous to thinning (at least 20 years, Gracia et al, 2005). As a result of the application of the GOTILWA+ model to Scots pine and Holm oak, Gracia et al (2005b) concluded that the intensification of thinning intensity or the increase of its frequency (from a baseline of 15 to 20 years for thinning rotation, and a set species-specific residual basal area) will have a negative effect on soil carbon amounts and tree growth. The results of these simulations seem to be highly dependent on the current management practices which have been set as the baseline. In the adaptation of Mediterranean forest management to climate change, the reduction of hydric availability seems to be a key factor.

5. Silvicultural actions to enhance regeneration

Several activities have been proposed or are in fact being used to enhance regeneration in an scenario of climate change. These include the use of advance regeneration in pinewoods (Bravo et al, 2008), the lenghtening of regeneration periods, particularly in black pine (Alejano et al, 2008), the application of reduced gaps for regeneration in Scots pine forests (Pardos et al. 2007), or even planting areas where natural regeneration has not been obtained. The practical application of such proposals is in fact not easy: advance regeneration produces a real recruitment of trees only for species with a certain degree of tolerance, or in the case of open stands. On the other hand, a change in the species to be promoted in the regeneration could be an alternative to an excessive increase of regeneration periods.

The increased risk of fire predicted is a factor that must be included in any forest management plan. Furthermore, the scenarios upon which some of the present plans have been based, in relation to situations of risk, may become worse. This means that the barriers designed to stop fires, along with the associated fire fighting techniques, may not be as effective as was originally thought. This planning ought to take into account the vegetation dynamics resulting from fire, along with the associated risks, under scenarios of increasing danger. In prevention actions, the dimension of the defence elements should be considered in view of the increasing linear intensities of the fire fronts (Moreno, 2005). These considerations are in fact too general and should be further analyzed to give clear guidelines.

6. Silvicultural actions aiming to follow the natural trends of species change. This is a proposal coming mainly from forest managers, who, as a matter of fact, notice the regeneration of beech under Scots pine forests, maritime pine does in low elevation areas of Scots pine or holm oak under the cover of stone pine. These soft silvicultural actions are in fact cheap and give rise to better adapted stands.

2.3. Research studies as regards forest adaptation

Ongoing since 2006, there exist and specific Action within the Spanish National Program for Applied Research on Agriculture and Forest Resources and Technologies devoted to the role of the agricultural and forest lands as carbon sinks. The main objective of the Action is to promote and finance the execution of Research and Technological Projects carried by public and private research centres, focusing on the different potentialities of forests and agriculture lands to contribute to attain the compromises acquired by Spain in the Kyoto's protocol. During 2007, a total of 32 research projects were funded with more than 2 million euros. Within the Action, there is a specific line of research related with adaptation, whose main objective is the Management of forest and agriculture systems to attain its adaptation to climate change, covering:

- Analysis of the effect of climate change over forest and agriculture ecosystems and species
- Definition of good practices and measures of management for adaptation taking into account topics as pests resistance, drought resistance, fire…
- Development of guidelines and tools for decission support systems, including cost and benefits analysis of the proposed adaptation measures

A more general line promoting research on forest adaptation techniques is derived in 2008 from the National Strategy on Energy and Climate change, of the Science and Innovation Ministery (http://web.micinn.es/), with a basic subprogram focusing on non-energetic mitigation, climate survey and adaptation. Main aim of the program is to fund the research required to attain the adaptation lines identified and proposed in the PNACC (see paragraph 2.1), paying special attention to the sectors of health, tourism, agriculture and forests.

A third line of promotion of research on forest adaptation is carried by the so called Singular Strategy Projects (PSE), which are large multidisciplinary projects, whose main objective is to integrate and transfer knowledge among research centres and industrial and technological sectors, covering Strategy requirements for the country. Actually, two ongoing PSE are related with forest mitigation and adaptation:

- PSE on Energetic Cultivars, where special attention is paid to short rotation forest systems
- PSE on Sustainable Forest Management, with four main lines focusing on forest adaptation, genetic improvement, forest management practices and modelling and decision support systems under changing climate scenarios

The purpose of the Interreg IIB Atlantic space REINFORCED, lead by the European Institute of Cultivated Forests, is to pool the capacity of 12 institutions to face the transnational issue of adapting Atlantic forests to climate change, considering the establishment of a network of arboretums with the aim of moving species to a different climate condition, and a network of demonstration stands to compare silviculture as is usual with other adaptive measures (http://www.iefc.net/).

3. Mitigation

The role of Spanish forest for climate change mitigation has been studied in specific monographies (Bravo et al, 2007), which shows a value of carbon stored in the aboveground biomass of trees of 670 M t CO_2, whereas for a total value of carbon in forests, Gracia et al (2004) increase this figure to 2050 M t CO_2, with an annual net increase in sequestration equivalent to 40 million tons. The balance between inventories, IFN2 (1986-1996) and IFN3 (1997-2006) has been studied in detail for some mountain ranges (Bravo et al, 2007) providing the values of increasing C (new forests, growth of existing trees, ingrowth) and negative ones (fellings, natural mortality) leading to a net increment of 54.6%.

Forest mitigation is highly dependent on the climate-energy policy at the international level, and on the energy markets. It is also dependent on forest adaptation and impacts, particularly forest fires. Timber and fibre production may be altered by climate change and by increased fire danger. Variations in climate will mean that currently productive areas will cease to be so, and vice versa. The possibility of forest fires will have to be included as a negative element when planning forest plantations (Moreno, 2005).

3.1. Carbon accounts

3.1.1. Spanish carbon account

Spain has the typical profile of an emitter country, with the energy sector responsible for 78.5% of the total emissions and CO2 the most highly emitted gas. Total emissions increased between 1990 and 2006, by on average 50.6%. (see http://unfccc.int/ghg_data/ghg_data_unfccc/ghg_profiles/items/4625.php). For the period 2008-12, Spain is committed to increasing emissions by 15% with respect to the base year (1990), which is within the scheme of an emission allowance trading within the EU, i.e global reductions in emissions of 8%. Even so, the previsions of the government (II Plan de asignación) consider an increase of 37% the most likely estimation.
We understand that the role of forestry in sequestering carbon is very important in this scenario. The Kyoto Protocol makes provisions for the inclusion of land use, land-use change and forestry activities (LULUCF) by parties as part of their efforts to implement the Protocol and contribute to mitigating climate change. Spain elected forest management and cropland management under Article 3.4, of the Kyoto Protocol and to account for each activity under Article 3.3 and elected activities under Article 3.4, at the end of the commitment period. In the case of Spain, C sequestration counterbalances roughly 8% of the emissions.

Table 1 : GHG emissions results for Spanish forest sector in Gg CO_2 (http://unfccc.int). Negative emissions correspond to sequestration.

Year	Year	1990	1995	2000	2005	2006
Emissions	Gg CO_2-eq	287687	318778	385117	440887	433339
LULUCF	Gg CO_2	-26931	-28097	-31900	-33072	-33002

The reporting of emissions is conducted in Spain by the Directorate-General for Quality and Environmental Evaluation (DGCEA) of the Ministry of Environment, which is generally responsible for inventory planning, preparation and management. The consultancy company SA AED plays a key role in supporting the DGCEA in the implementation of the functions of inventory preparation and management. The main responsibilities for LULUCF correspond to the Directorate-General for Biodiversity.

Many problems remain to be solved in relation to LULUF. Spain has considered the following parameters for reporting: minimum tree cover of 20%, minimum land area of 1ha, minimum tree height, 3 m. The tree cover differs from that which Spain uses for reporting under the Convention and to the FAO (10%), thus separate calculations will be made in the next national reports. Research on soil organic carbon is being undertaken and the results will be reported in future submissions, while dead organic matter is considered constant under the tier 1 method. In the 2006 NIR, Spain stated that emissions from forest fires were not reported because no land-use change occurred as a result, but noted that it is evaluating the possibility of including emissions from forest fires, as recommended by the IPCC good practice guidance for LULUCF. No information is yet available for categories other than forest land (cropland, grassland, wetland) or gases other than CO2 (UNFCCC, 2007).

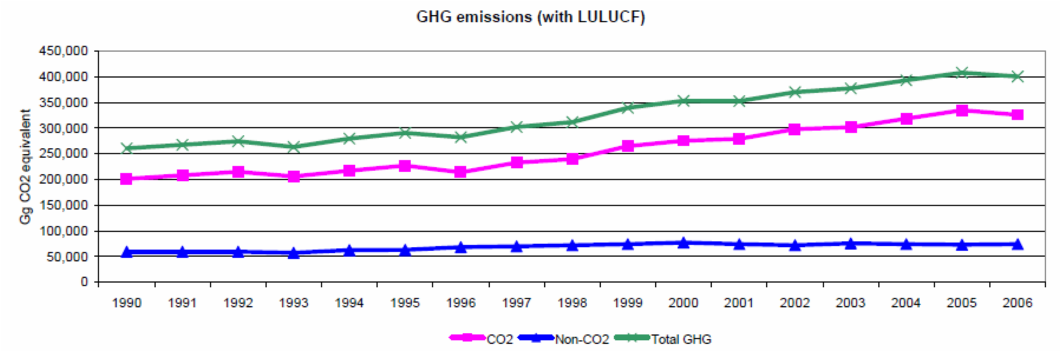


Figure 8 : Evolution of GHG emissions with LULUCF for Spain.

3.2. *Political processes, instruments and strategies for mitigation*

The Secretary of State for Climate Change is the main person in the Spanish Ministry of Environment in charge of the policies aimed at preventing climate change. The Spanish Meteorology Agency is included in the Secretary (http://www.mapa.es/es/ministerio/pags/organigrama/funciones/SECambioClimatico.htm).
The Spanish Office of Climate Change depends on the Secretary and is in charge of the coordination of the Spanish Policy in relation to the regional governments, the EU and other international institutions.

The Spanish Climate Change and Clean Energy Strategy (EECCEL) includes a series of policies and measures to mitigate climate change, to palliate its adverse effects, and to enable fulfilment of the commitments assumed by Spain, facilitating public and private initiatives aimed at increasing efforts of all kinds and from all sectors to fight against climate change, focusing on reaching the objectives under the Kyoto Protocol.
The EECCEL considers that the increasing trend of GHG emissions in the 1990-2005 period responded to rapid, sustained economic growth, and to an increase in population in recent years. The effort made by Spain in matters of Energy Saving and Efficiency was insufficient, but the report also shows that the per capita emissions reach about the average of EU-15.

The EECCEL states that the target established by the Government for the five-year period 2008-2012 is that Spain's totals do not surpass a 37% increase with respect to the emissions in the base year. This represents a difference of 22 percentage points with respect to +15%, 2% of which must be obtained by means of sinks and the rest (20%) by means of flexible mechanisms (acquisition of carbon credits). In order to reach the said objective of +37%, the National Allocation Plan (NAP) 2008-2012 requires additional measures to obtain reductions of 27.1 Mt of CO_2 eq. A Plan of Urgent Measures considers reductions of 12.091 Mt CO_2 eq/ year and so other additional measures are still necessary to provide reductions of 15.033 Mt CO_2 eq/ year.

The most recent rulings for residential building is the Technical Building Code (CTE, Royal Decree 314/2006, 17 March 2006), a legal framework establishing the requirements to be fulfilled in terms of basic security and habitability established by the Spanish Building Law as a means of harmonizing the existing national regulation with the EU rulings in this matter. It includes measures aimed at ordering and turning end-use energy consumption into a sustainable consumption in the construction sector, so as make rational use of the necessary energy to be used by buildings, to reduce energy consumption and establish the obligation to incorporate energy efficiency criteria and the use of solar, thermal and photovoltaic energy in certain buildings (new or to be restored, with special characteristics). The measures will affect more than half a million houses every year, with the objective of multiplying by ten the surface of solar panels and reach 4.5 Ms m2 by 2010, as opposed to 581.000 in 2005. CTE requirements are expected to reduce energy consumption of buildings by 40% as compared with the consumption resulting from the construction criteria used at present.

Another important planning instrument is the new Renewable Energy Plan 2005-2010 approved by the Government in August 2005, which will avoid emission of 76.9 Mt CO_2 to the atmosphere, with a total financial support of 8,492 M€ with public money.The Plan aims towards a 12.10% contribution of renewable sources of the total Primary energy consumption by 2010, an electricity production with these sources of 30.3% of the gross electricity consumption, and 5.83% biofuel consumption over the gasoline and gasoil estimate for transport.

As regards the forest-based sector, the main objective is to increase the capacity of CO_2 sequestration from the atmosphere by wood stocks and to comply with the objective of compensating 2% of the base year emissions by LULUCF. The measures considered for accomplishment of these objectives are very general:

• To increase forest surface, by means of forestation and reforestation of abandoned or degraded farming land, taking into account the objective of adapting woods to the expected climate change.

• To restore the soil cover by means of suitable forestry actions and native tree species.

• To improve research and development activities regarding the role of the forest sector in the capture of GHG emissions, including carbon sequestration, forestry and remote sensing techniques.

• To establish preventive actions to avoid forest fires. These plans shall focus on forestry and maintenance and improvement of the present efficiency level in forest fire extinction and on the follow up and control of the action and effects of the different harmful agents acting on Spanish forests.

• To increase carbon absorbed in agricultural systems by means of reduction in tillage, ecological production, integrated production, withdrawal of land from cultivation, implementation of ligneous cultures replacing herbaceous or other of lower storage, the forestation of farm land, etc.

• To improve the sustainable management of forest ecosystems through increased forest surface, the exploitation of forest mass and the maintenance and improvement of forest resources.

• To establish an institutional and legislative framework to encourage participation of the private sector in increasing the carbon capture capacity of Spanish sinks.

• To promote the Natural patrimony Fund created by the Forest Law of 10/2006, for investment in preventive works, sustainable forest management of woodlands, etc.

• To develop and design an agile, exhaustive, precise and effective information system for obtaining knowledge and determining the amount of carbon absorbed by the land use, land-use change and forestry in Spain.

A delegated governmental committee considering climate change identified six strategic lines to face climate change, including forest policy and sinks. Within this line there is a specific plan to reforest 60000 ha by 2012, mainly public land.

The fight against climate change may produce restrictions, but also opportunities in Spain: mitigation can reduce the external dependence on fossil fuels and alleviate environmental problems, such as urban contamination. Land use planning could also be improved and clean transport systems promoted. Some companies should invest in the adaptation process, with positive results on the development of new technologies and improved or produced with less carbon inputs (Abadanes et al, 2007).

3.3. Forestry as a source of bio-energy

In Spain, 80% of the GHG emissions are derived from the energy sector, and the renewable energies have been considered as an important alternative to reduce emissions and biomass among them as producing a neutral emission effect. The new Renewable Energy Plan (PER) 2005-2010 proposes the objective of a 12.10% contribution of renewable resources of primary energy consumption by 2010. The current situation clearly shows that the biomass are the less developed among the renewable energies in Spain.
The target of the PER for 2010 and the production in 2004 and the general evolution are shown in table 2 and figure 8. Installed electric power will have to rise till 1695MW, from which 722 are allotted to co-combustion in thermal plants.

Table 2 : Energy production from biomass in Spain (thousand tons of oil equivalent, ktoe).

Year	Thermal	Electrical	Total
2004	3487	680	4167
Target for 2010 (PER)	4070	5138	9208

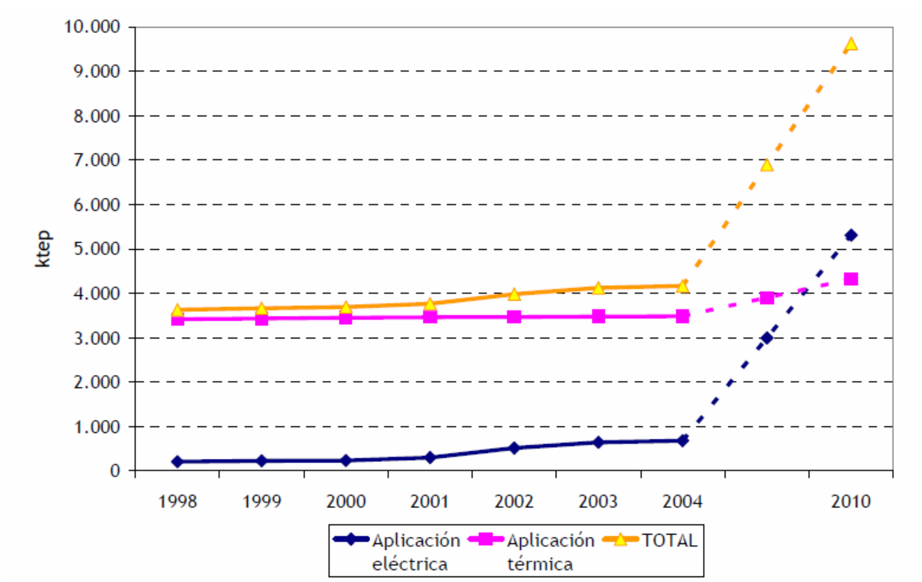


Figure 8 : Evolution of biomass use for energy production in Spain. Source: Spanish PER

The share of forest biomass is difficult to calculate, although it is clear that recent initiatives for new power plants are mainly linked to the use of forest and agricultural industry residues, and that forest energy crops (short rotation coppice) would be important within the group of energy crops. One of the key elements for the previous points is the Royal Decree RD 661/2007, which establishes the grant system for alternative energy production. The Decree allocates a large portion of the incentives to power plants that utilise biomass from energy crops.

The PER considers that the reductions in emissions in 2010 derived from the plan (using as comparison of electrical production, a natural gas combined cycle power plant and a thermal power plant -in the case of co-combustion- and a communal gas oil heat boiler for thermal plants) correspond to 7.364 kt CO2 saved with electrical uses and 1.788 kt CO2 for thermal uses.

From a forestry point of view, three sources of biomass may be useful for energy production in Spain: logging residues (the only directly available resource, estimated by the PER as 1373 ktoe per year), timber industry residues (already used for energy or recycled for reuse in the wood chain, and energy crops, which are not yet an economic reality). The impact of the promotion of the wood use for biomass on the timber industry, which has not yet been fully addressed, and the economic sustainability of such exploitation are two major considerations. The logistics of primary forest biomass crop, storage, management and transport, and the new development or adaptations of machinery for biomass cropping are key issues as regards posing this question in terms of the cost of biomass in relation to the economic value of the energy produced.

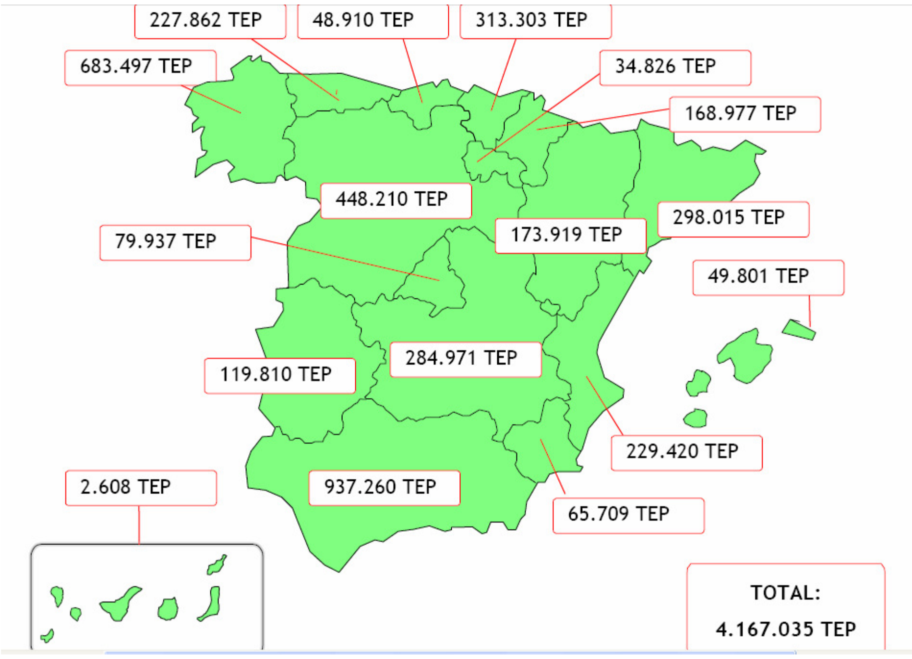


Figure 9 : Regional distribution in the biomass use for energy in Spain in 2007. Source: Spanish PER

Several research projects are currently being undertaken to determine the costs, availability of resources and productivity of short rotation coppice of eucalypts, willow and poplar (see Sixto et al, 2007, for a review on poplar).Several subprojects within the ECOCOMBOS project consider the logistics, plantation management, breeding and time studies (see http://www.serida.org/proyectodetalle.php?id=341). The interest expressed by energy companies in forest biomass is evident and many experimental plantations have been established in the last 3-5 years. The overall objective of the ENCROP project is to promote the cultivation, production and use of lignocellulosic energy crops at the European level.

Seven countries are participating in the European Biomass Association (AEBIOM). The Spanish partner is the engineering consulting ESCAN (see http://www.encrop.net/ for more details on the project)
Many initiatives to promote the establishment of energy plants come directly from the regional governments in the framework of the Spanish PER: The levels of power considered in the main regions are: Galicia, 80 MW; Castilla-León, 57MW; Castilla-La Mancha, 32 MW, and the Basque Country, 100 MW. It is difficult to differentiate between plants that use predominantly agricultural residues and those that use chips or pellets.

3.4. Research studies on mitigation

Análisis a partir de los inventarios forestales nacionales revelan que los bosques españoles han actuado durante buena parte del siglo XX como sumideros de carbono y que todas las comunidades autónomas españolas acumularon carbono en sus bosques durante el periodo 1990-1998, aumentando la cantidad de carbono acumulado en relación al periodo 1974-1987 (Rodríguez-Murillo 1997, 1999). La acumulación osciló entre 4,5 ton de carbono por hectárea y año en Galicia (2,0 en el periodo anterior) a 1,1 en Murcia (0,27 en el periodo anterior). Este efecto se atribuye a las repoblaciones realizadas desde los años 40 del siglo XX y a los cambio más recientes en usos agrícolas y ganaderos, que han contribuido al aumento de las superficies arboladas y de la densidad de masa de los bosques (Rodríguez-Murillo 1999). Respecto a las emisiones de gases de efecto invernadero (CO_2, CH_4, CO, N_2O y CFC NO_x) – JP- procedentes de incendios forestales en el periodo 1970-2001 el valor promedio es de $21,5*10_6$ toneladas en el conjunto del Estado español para las emisiones directas; las emisiones diferidas son, en promedio, 3,8 veces superiores a éstas (Prieto y Rodríguez-Murillo 2003). Galicia fue la comunidad autónoma que más contribuyó a las emisiones totales de gases con efecto invernadero como consecuencia de los incendios forestales. De todas formas es preciso hacer constar que los datos de las emisiones totales estimadas de CO_2 procedentes de incendios forestales suponen sólo un 1% del total de las emisiones estimadas en el Estado español de dicho gas. El balance de carbono de los ecosistemas forestales no es comparable al de los demás ecosistemas terrestres, pero es de estos ecosistemas de los que se dispone información más precisa.

One of the most important challenges for the mitigation role of Spanish forests is the possibility that, under a scenario of climate change, the forests start being net emitters of carbon, rather than sinks, thereby worsening the process. This possibility has been indicated from the results of application of the GOTILWA+ model (Gracia et al, 2005) in the form of maps of net primary production from 1990 to 2080. After a period of roughly 50 years of increasing NPP, the effect of drought would led to a net emission process (Gracia et al, 2005).

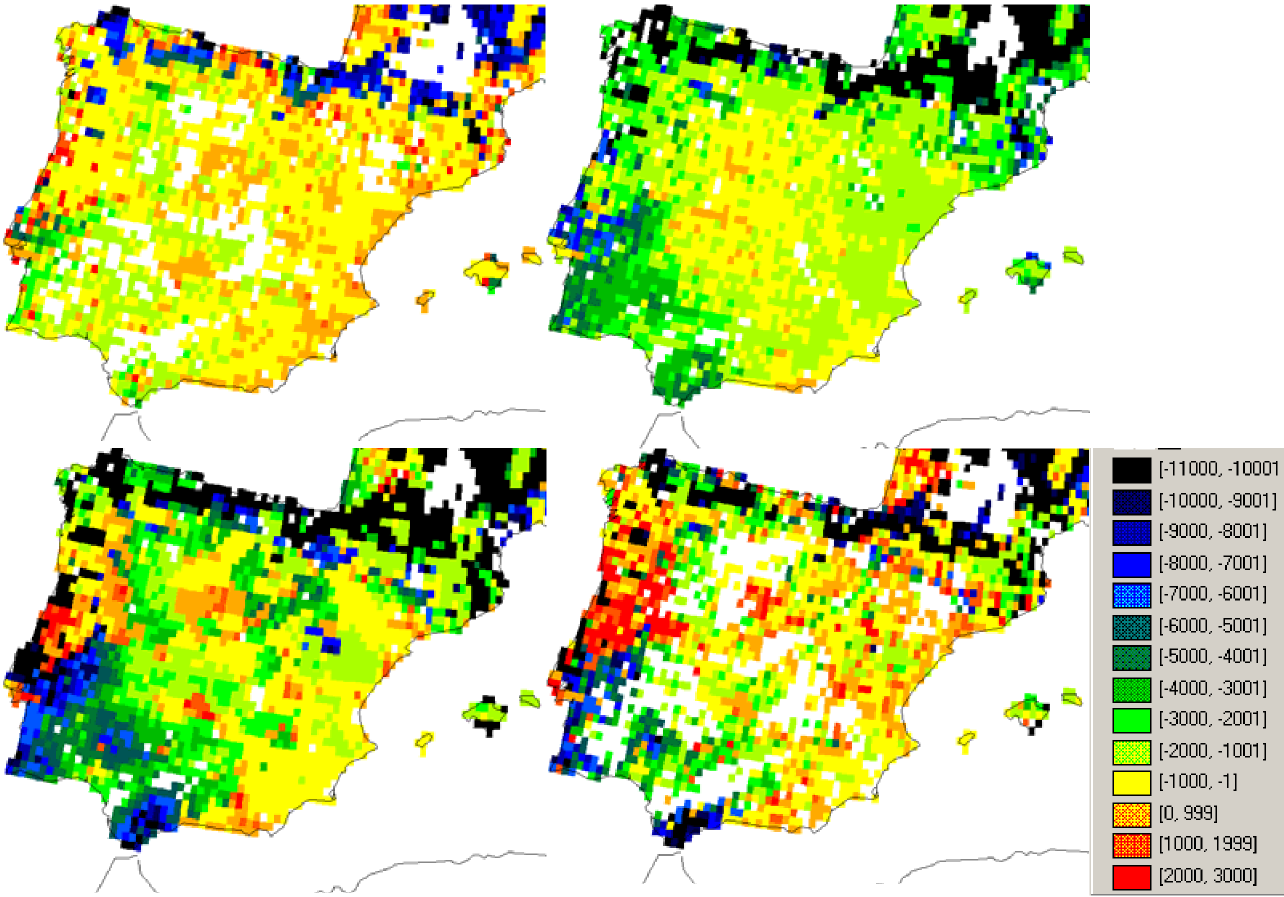


Figure 10 : Forecast maps of net primary production from 1990 to 2080. Source: Gracia et al, 2005

Many research activities are directly concerned with determining carbon storage in biomass and soils, the effects of silviculture on such carbon pools and, in a few projects, the carbon storage in the wood-based sector in Spain. There are some broad scope studies that include methodological information (Bravo et al, 2007; Montero et al, 2005) and many others that are limited to the study of regional cases or some particular species.
In the framework of the Spanish National Research, Development and Innovation Plan, a specific Mobilization Action call for forest carbon sinks was open for 2004-2007, leading to 32 funded projects and a set of research results that may help in the optimization of forest practices for mitigation and for improving the LULUCF methodological approach in the Spanish inventory of GHG emissions.

Some of the results are grouped below considering thematic areas:
Land use changes. The RothC model was applied by Charro et al (2007) to Aleppo pine plantations to simulate carbon sequestration throughout a century, with the result of a progressive increment in soil carbon with tree age. The effect of carbon sequestration in agricultural land partially planted with fast growing tree species was studied in a chronosequence, by Pérez Cruzado et al (2007), and the aboveground biomass and the litter layer were found to have a large capacity for fixing carbon and probable depletion of soil carbon in a period of 10-15 years.
Estimation of carbon in soils. The CO2 FIX model is the most widely used in Spain to estimate C in the forest stand, the soil and the chain of wood products. Determination of C pools in soil for the whole of Peninsular Spain is difficult because of the wide range observed (4 kg C m-2- 30 kg C m-2). Rodríguez Murillo (2001) estimated the total content of carbon in soils of Peninsular Spain to be 3.7 Pg, a value since considered to be quite accurate.

Silviculture and carbon sequestration. Several studies have tried to compare the carbon sequestration effects derived from changing the stand structure, thinning regime or management of woody debris, mainly in pine stands (Río et al, 2008; Balboa et al, 2006). In most cases, the models applied were not sensitive to climate change and the duration of carbon storage as wood products was only taken into account indirectly.
Rotation length. Several studies have been conducted as regards lengthening of the rotations, but no definitive results have been obtained. The proportion of carbon stocks in the final harvest, relative to the total fixed carbon in the stand, is always higher for longer rotations. However, a short rotation system produces higher carbon MAI values, regardless of the site index (Bravo et al., 2006). Bravo and Diaz-Balteiro (2004) showed that more extensive management systems, involving lengthening the rotations, results in higher economic returns compared with traditional management with shorter rotations, but only if carbon sequestration income is included in the analysis.

In any case, the forest management practice options available for reducing emissions and/or increasing carbon stocks can be grouped into four general strategies, adapted to the forestry conditions in Spain (Bravo et al, 2005):
1. Maintaining or increasing the forest area by reducing wildfires, deforestation and degradation, and through increased areas of plantations or natural expansions of forest land (e.g., afforestation of abandoned lands).
2. Maintaining or increasing the stand-level carbon density through appropriate silviculture techniques (e.g., thinning, partial harvests, species composition, etc.).
3. Maintaining or increasing the landscape-level carbon density through forest conservation, longer rotations, fire management, and pest and disease control.
4. Increasing off-site carbon stocks in wood products and enhancing fuel and product substitution by forest-based products (e.g., biomass, building materials, etc.).

4. Conclusion

1. There are many ongoing projects and administrative activities related to climate change and its influence on terrestrial ecosystems nowadays in Spain. There is then an important amount of information on the observed and predicted impacts. Even if the main drivers of the impacts are somehow difficult to identify, it becomes clear that Spain is very vulnerable to climate change.
2. The most important challenge of climate change in Spain in relation to the forest sector is the foreseen increment of forest fire regime intensity. This is in clear relation to the biodiversity conservation policy or the water cycle. An active management to prevent forest fires considering a scenario of warming and water deficit, even if already applied in most cases, seems to be strictly necessary. Policies aiming at increasing at any cost the forest cover or to leave unmanaged and forest fuel overloaded stands can not be considered appropriate.
3. There is a general lack of applied guidelines to face climate change. Most of the documents or political initiatives consider very general measures which do not go into deep in the forest sector. There is also a lack of definition of some proposals, particularly in those related to adaptation, and there are even contradictory recommendations depending on the author, probably because some of thestudies have been only limited to ascertain some objectives, showing the need to study the recommendations from a holistic perspective.
4. Even if the research activity in this field increased very fast in the last decade, dry land forests of Mediterranean-type regions have received less attention than temperate forest at the European level. There is then a gap in scientific knowledge and a serious limitation in our capacity to anticipate and mitigate the effects of climate change.
5. The political processes regarding mitigation are numerous, and biomass will be very likely promoted as a source of thermal and electric energy. This policy can be considered in relation to the preventive actions against fire risk. The opportunities for the forest sector with the promotion of solid timber use are also clear. Even so, it is important to be aware that the mitigation by forests could be jeopardized in the future if the climate change impacts are too strong and the extreme events of forest fires and drought too frequent. The importance of forest soils as carbon sinks (or emitters) should be addressed for any mitigation measure proposed.

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