9. IMPACTS ON THE FORESTRY SECTOR

Carlos Gracia, Luis Gil and Gregorio Montero

Contributing authors

J. Ezquerra, E. Pla, S. Sabaté, A. Sánchez, G. Sánchez-Peña, J. Vayreda

Reviewers

J. Martínez Chamorro, S. Mutke Regneri, M. J. Sanz

ABSTRACT

In Spain, forests take up around 15 million hectares, to which must be added 11.5 million hectares of different types of shrublands and pastures on forest land. This forest area as a whole produces 1,200 million Euros per year (without considering livestock farming production) of which timber represents around 800 million. Society receives other goods and services from the forest, which, at present, are difficult to quantify economically, but are, however, very important. Among these we can highlight protection against erosion, control and regulation of the hydrological cycle, the contribution to conserving biodiversity and the recreational use.

Some species of pines or oaks originated millions of years ago and have survived several climatic fluctuations. Adult trees are capable of resisting a certain degree of environmental stress, but the forest is more sensitive during the regeneration phase. Together with climate change, environment retreat increases the sensitivity of the species, as many forests cannot now reoccupy previous territories, due, for example, to problems of erosion resulting from a lack of plant cover.

Forest pests and diseases can play a fundamental role in the fragmentation of forest areas. Some perforating or defoliating species can complete up to two biological cycles per year or increase their colonisation area as a consequence of more benign winters.

The physiology of most forest species could be profoundly affected. The vegetative period of deciduous trees is lengthened. The renovation of leaves and thin roots in evergreens is accelerated, altering the plant's internal carbon balance. The greater carbon consumption the tree needs to invest in order to renew these structures increases the consumption of reserve carbohydrates, thus making forest ecosystems more vulnerable. There is a high risk that many of our forest ecosystems will become net carbon emitters during the second half of this century. Culminal mountain areas, the more xeric environments and riparian forests could become more vulnerable to climate change.

In view of the foreseeable changes, an adaptational strategy is recommendable. Resalveo of the underbrush to reduce pies density has proved to be an efficient treatment that improves the response of these forests to climate change. Control and adjustment of exploitation turns and intensities should be considered as an option for optimising the response of the forest. Equally important is the careful selection of the origins of the seeds in reforestation, for appropriate management of genetic diversity.

Among the most pressing needs for the future, we can highlight the need for more accurate knowledge of the subterranean biomass of our forest species, given the primordial role played by the underground fraction in the response by the forests to disturbances, necessary for establishing the values of the carbon accumulated in our forests, and also to establish or consolidate networks for the observation and analysis of the ecophysiological factors determining regeneration and, as a whole, the response of the forest to environmental changes; another aim involves promoting the development and application of forest growth models, especially those based on physiological processes, aimed at predicting the response by the forest to environmental changes or management patterns.

9.1. INTRODUCTION

Forests constitute one of the most complex natural landscape units with regard to function, structure and dynamics. Since time immemorial, man has made use of the different products and services that forests have provided him with: timber, firewood, fruits, resins, fungi, shelter and protection, recreation, etc. This diversity of products constitutes the best indicator of the complexity involved therein.

In past times, forests were used according to the needs of the neighbouring populations and communities, regardless of the production capacity. There was no concept of sustainable forestry production, which appeared in the first half of the XIX century, with the generalised application of Forest Planning and the first basic forestry techniques.

At present, the maintenance, care and improvement of forests is not governed by simple production criteria, however important these may be, it being fundamental to consider the need of different countries to avail of abundant and well-distributed forest areas as a basis for biological and social balance. In industrialised societies, such as ours, there is a deep-rooted concept of the multifunctional forest, a generated structure of biological diversity and a source of multiple products, services and uses – a multiple-use function of our forests. In this sense, the forest and sylvo-pastoral systems of the Mediterranean environment constitute a clear example of sustainable management of multifunctional forests.

The scope and importance of the Forestry Sector in Spain is reflected in the area occupied by forests in our country, in the characterisation and quantification of the products and services provided to society by these lands; and, for those products for which sufficient information is available, in the description of the industrial sectors associated with this sector.

9.1.1. Spain's Forest Area

Forest Law 43/2003, dated November 21st 2003 defines forest area in the first section as "*...all land on which forest species of trees, bushes, shrubs or herbaceous species grow, whether this be spontaneously or through sowing or planting, which fulfil or can fulfil functions related to the environment, protection, production, culture, landscape or recreation...*" . Making use of this definition, Spain's Forestry Plan estimates the national forest area at 26,273,235 ha, which is 51.4% of the country's area. This area can be classified according to the type of plant cover it sustains (table 9.1):

Table 9.1. *Distribution of Spain's forest area according to cover.*

Type of cover	Area (ha)	Type of species	Area (ha)
dense forest (FPC>5%)	14.732.247	Conifers	5.833.970
		Broadleaved	4.287.084
		Mixed	4.581.729
open woodlands (FPC<5%)	9.228.407		
grasslands	2.312.581		

FPC=Foliage Projective Cover

The ownership of this forest land corresponds to the State, the Regional Autonomies, local organisms and private individuals, in the proportion presented in the following pie chart:

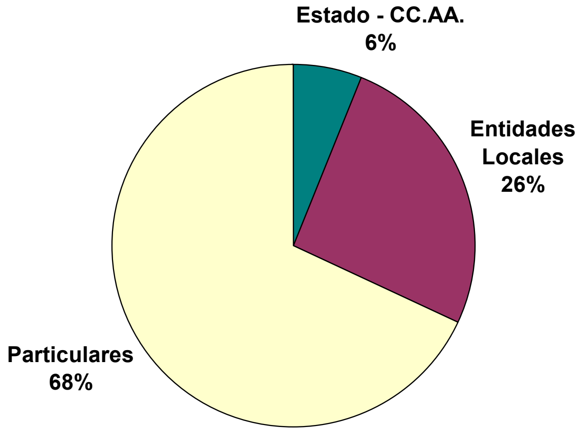

Fig. 9.1. *Ownership of forests in Spain (State-Regional Autonomies; Local institutions; Private owners)*

9.1.2. Forestry production: Quantification and Valuation

The lack of an exclusive source of forest statistics and the non-existence of central markets of forestry products hinder the quantification and valuation of products of commercial interest. It is also necessary to include in forestry production a series of goods and services that forest ecosystems provide to society, the valuation and quantification of which must be developed through indirect methods (surveys, contingency valuation, etc.). These conditions will hinder the valuation and quantification of forestry production in general.

9.1.2.1. Products of commercial interest

The use of forestry products, in accordance with Forest Law, corresponds to the forest owners. The regulation thereof is, however, the responsibility of the pertinent forestry administration, which constitutes a guarantee for the persistence and sustainability of the forests and the associated production. Table 9.2 shows the annual quantification and valuation of the different forestry products, valued once extracted from the forest but not industrially transformed. Total non-transformed forestry production totals 1,200 million Euros annually (without considering livestock farming production). This figure means that annual average revenues from forestry (considering only products of commercial interest) could total 45.67 €/ha.

9.1.2.2. Timber production

The main production of commercial interest obtained from forests is timber, the value of which is estimated at 800 million Euros per year. In Spain, annual extraction of timber totals 18,000,000 m^3. A global indicator of the sustainability of timber production is the comparison between production and the annual growth of the exploitable stocks accumulated in our forests. According to the Spanish Forestry Plan (SFP) spanish forests accumulate 675,000,000 m^3 of timber, with an annual growth rate of around 35,500,000 m^3. This means that only 50% of annual growth is extracted from the forests, which guarantees compatibility between the persistence and spread of forest cover and the timber industry.

Table 9.2. *Valuation and quantification of forestry products of commercial interest*

Product	**Category**	**Production (10^3 tm/year)**	**Valuation (10^6 €/year)**
Timber	Conifers	9082 *	396
	Broadleafs	5696 *	253
	Unclassified	3289 *	143
Firewood	Gross firewood	1250	40
	Fine firewood	2000	
Cork		85	90
Resin		4.2	2.5
Fruits	Acorns	400	19
	Chestnuts	20	13
	Pine kernels wit shell	6	18
Fungi		9	30
Medicinal plants		3	0.03
Game		1326000 +	155
Continental fisheries		834680+	25
Honey		0.02	0.06
Logging	Sand	1500	0.38
	Gravel	1750	3
	Stone	3000	1.6
Livestock		140000**	
Others			9
TOTAL TIMBER			800
TOTAL NON-TIMBER PRODUCTS			400
TOTAL FORESTRY PRODUCTS			1200

* 10^3 m^3 with bark ; + licences issued; ** tons in fresh weigth, not valued economically. *Fuente Anuario de Estadística Agraria* (AEA) (annual agriculture statistics source).

The apparent consumption of timber in Spain (extraction + import – export) is estimated at 32,500,000 de m^3. The deficit between production and consumption is currently covered by imports, both of lumber and of transformed products (pulp, paper, sawn timber, furniture...). Average timber consumption per inhabitant and year in Spain is 0,8 m^3. The fact that this figure is lower than that of the neighbouring countries, together with the consistent growing tendency in recent years, indicates that in the coming years there will be an increase in apparent timber consumption in our country, which will need to be covered either through an increase in national production or through imports.

9.1.2.3. Other goods and services produced in forests

Carbon sequestration

Forests act as elements that uptake CO_2, the main gas that contributes to the greenhouse effect and to the global warming of the planet. CO_2 sequestration in forests and in derived forestry products constitute a fundamental element of the carbon cycle. In the year 2004, Spanish forests (considering only forest lands) accumulate a total of 2,050 million tons of CO_2, with an annual net increase in sequestration equivalent to 40 million tons (Montero *et al*. 2002, 2004). This figure is equivalent to approximately 10% of the total CO_2 released into the atmosphere in Spain in 2002 (Anonymous 2004).

Protection against erosion and control of the hydric cycle

Hydric erosion is the main agent of desertification in Spain. In Spain, about 18.2% of the territory has erosion losses greater than 50 tm/ha /year (Anonymous 2000). Hydric erosion causes the loss of fertile soils in areas in which these are necessary for the maintenance of the biological potential of the territory, and the subsequent accumulation of these materials in other areas, with consequences that are often catastrophic (floodings...). Of all the possible types of cover in the territory, forests are the most efficient protectors, favouring the regulation of water quality, preventing floods and prolonging the life of reservoirs.

Conservation of biodiversity. Protected natural areas

In Spain, over 12 and a half million hectares of land have been included in the Red Natura 2000 network, either as *sites of community importance* or *Areas of special protection for birds.* In these territories, the regulations oblige the necessary measures and mechanisms to be included in the management process in order to guarantee the conservation of biodiversity. Over 70% of the territory included in the Red Natura (around 9 million hectares) are classified as forest land, which indicates that forests constitute the most important element of the territory with regard to the conservation of biodiversity. The non-use environmental assets (protection and conservation of biodiversity) are valued in 1,220 million Euros per year (Anonymous 2003).

Recreational use and landscape

Forests are a basic element of the landscape, and an area for leisure and expansion of the population. The management system of Spain's forests includes the controlled and rational enjoyment thereof, compatible with traditional uses. One of the basic tools for reaching this objective was the creation and maintenance of concentration zones (recreational areas, camp sites and refuges) and information centres and nature schools, facilities that help the citizens to approach and understand nature, and to become integrated into the forest environment. The recreational and landscape use of the forest was valued, with the use of contingency valuation methods, at 640 million Euros per year (Anonymous 2003).

9.1.3. Economic valuation of the different products and services obtained from forests

Table 9.3 presents the total annual value and per hectare assigned to the different products and services obtained from forest lands. These figures are an underestimation, as livestock farming production was not considered, and only the value of the net carbon uptaked annually by forests (without considering that uptaked in non forested lands, or assigning a value to the carbon accumulated.

Table 9.3. *Valuation of services and products.*

Service or product	Annual value (10^6 €)	Annual value (€/ha)
Timber	800	30.45
Non-timber forestry products	400	15.22
Annual net Carbon sequestration	220	8.37
Environmental assets (protection, conservation)	1220	46.45
Recreational use and landscape	640	24.36
TOTAL	**3280**	**124.85**

* (only forest lands, using as a reference value 5.5 €/t CO_2)

9.1.4. Public investment in the forestry sector

Public investment in the forestry sector was 20% of total public investment in the environment, reaching a value of over 820 million Euros in 2002 (ASEMFO 2002). Public investment in the forestry sector is mainly implemented by the regional Autonomy Administrations (580 million €) and Central Administration (240 million €). The regional administrations finance both actions on forested land, the management of which they control (normally publicly owned) and grants for intervention in privately owned forests. Investments by the Central Administration of the State focus both on the maintenance of integrated services (protection against forest fires and toxic agents, Nature Database), the management of National Parks and co-funded actions with the Regional Autonomies (FEOGA, complementary measures by the CAP).

Considering Spain's Forest Area, the average investment per hectare and year, financed through public funds, is estimated at 31.53 €.

Table 9.4. S*ummary Forestation Programme on Agricultural Land (1994-1999)(Anonymous 2003)*

AID FOR FORESTRY	
Dossiers opened after implementation of work	34 981
Subsidisable area	451120 ha
Total cost (FEOGA+State)	608 10^6 €
Average area per beneficiary	12.9 ha
Average cost forestation	1348 €/ha
FORESTED AREAS MAINTENANCE SUBSIDIES	
Number of beneficiaries with application accepted	34 697
Subsidisable area	439923 ha
Total Subsidisable cost	421 10^6 €

The main investment in forestry in Spain in recent years has involved the Forestry Programme on Agricultural Land, implemented as a measure accompanying the CAP, within the framework of community regulation 2080/92. This action, mainly financed by community funds, involved an average investment between 1994 and 1999, of over 200 million Euros. The main result of this plan was an increase by 450,000 ha in national forest area. Table 9.4 summarises the results of the programme for the period 1994-1999.

9.1.5. Production-investment balance in forests

Considering the annual valuation of the products, goods and services produced by one hectare of Spanish forest land in one year, estimated at 124.85 €, and the assigned public investments, estimated at 31.53 € / hectare/year, we obtain a clearly positive balance, of over 90 € / hectare/year. Considering that this valuation did not include forest livestock production, or valuation of accumulated carbon (only the net carbon uptaked each year was considered), and in view of the result obtained, we can conclude that the maintenance, management and sustainable use of forests is clearly a positive activity for society.

9.2. SENSITIVITY TO PRESENT CLIMATE

For the main forest species, those defining landscape and complementing rural economies, Climate Change is not a recent phenomenon. Some species of *Pinus* or *Quercus* originated millions of years ago, and have therefore survived climate fluctuations. Due to their longevity, the change occurs in their cycles, which is why they have necessarily survived the extreme values of the last few centuries. Phyto-geographycal studies show how lineages located in glacial refuges on the Iberian Peninsula had sufficient genetic variation to adapt to the change. Under conditions of warming in the Holocene, forest species rose up the mountainside or were displaced northwards as the glacial ice caps retreated. This is the case of white oaks, one of the best studied groups in Europe (Petit *et al*. 2002).

Adult trees are capable of resisting intense environmental stress, but they are more sensitive when the forest is being regenerated. This requires continuous success in several successive ecological processes, from pollination to the establishment of seedlings. Many of these processes are quite unknown in forest species, which must be situated in a disturbance regime that creates differential opportunities for the co-existence of several tree species, a generalised situation in our country.

Climate Change is not the only factor forest species are faced with. Sensitivity to present climate is greater due to environment retreat. Many forests are unable to recover lost areas. The effect of degradation is more intense in territories with abrupt topography, with a profile of rejuvenated soils and with erosion problems resulting from the lack of plant cover, or in climates unfavourable for regeneration due to the lack of rainfall. Among other processes, we can highlight the overexploitation of aquifers, which has eliminated the water table close to the surface and brought numerous populations close to extinction, including cork oak, Holm oak or gall oak forests, affected by drought, and unique forest, such as the population of *Pinus sylvestris* in Coca (Segovia), located among the *Pinus pinaster* forests thanks to the presence in the past of an accessible water table. The severe reduction of this population has severely affected the reproductive system of an anemophilous and alogamous species (Robledo Arnuncio *et al* 2004). The latest regenerative event of the population occurred almost one century ago, and a population adapted to the temperature characteristics of the Northern Plateau, more severe than on the slopes of the Guadarrama mountains, is on the verge of disappearing.

The capacity to adapt to environmental changes is associated, in the short term, with greater phenotypical plasticity; this is higher in species of over five hundred years of life span (*Pinus nigra, P. canariensis, P. sylvestris, Quercus ilex* or *Q. petraea*) and with vast distribution ranges. Population variability is high therein, as the genetic flow prevents disruptive selection and speciation. Natural selection is quite inefficient because the environment is heterogeneous and the variation component within the populations is much greater than that existing between populations. In species with a higher evolutionary level, such as oaks and Holm oaks, we can expect greater intrapopulation genetic diversity, especially if they are indifferent to edaphic factors, because they resist greater environmental heterogeneity in space and time. In heliophilous species, like pines, variability is lower, because they colonise empty spaces and only acquire permanence on rustic land, where the poor soil prevents Holm oaks and oaks from successfully rooting, and conifers therefore have an advantage over them due to their higher growth rate.

In the short term, the sensitivity of forest species will depend on their capacity for dispersal and on the genetic variability at the heart of their populations. Man has eliminated them or fragmented their distribution area or has degraded their habitat. The time of response has been shortened, because the most suitable land is destined for agriculture and there is much more land suitable for pioneer species. In dry, open and contrasted habitats, extreme climate values are harsher, and species disseminated by the wind are more easily dispersed. Frequently fruiting species facilitate coincidence with favourable years for regeneration, but greater longevity allows for the appearance of favourable events in species which concentrates regeneration events in particular years.

As with other causes, sensitivity to present climate is related to the demography of the populations and with recent reproduction events of sexual origin that have been subjected to the selective pressure of the environment. Certain processes favour genetic diversity, in the characters affected by climate change, such as leaf overheating, to which pines are less vulnerable than broadleaf species, due to the presence of needles and a more efficient cooling system. It is assumed that when more than one species appears in a place, this is due to spatial diversity and to the temporal fluctuation of climatic variables. This situation favours the occupation of existing niches by populations with high plasticity and interspecific diversity. Competition in the ecotone between strains of different ecological significance is responsible for higher diversity values, when compared with those of more homogeneous territories.

Another positive aspect to consider, which characterises the last half century, is reforestation and the abandonment of traditional agro-pastoral practices, which are extensive and marginal. Forests have recovered vast areas, which allows the species to show much of their potential for adaptation, because the demographic increase in individuals.

9.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

9.3.1. Forest pests and diseases

The foreseeable impact of Climate Change has a particular effect on forest ecosystems, both directly and through the different elements that comprise this universe, and among these, pests and diseases could play a relative role in the fragmentation of forest areas, along with the process by which species become rarer and the simplification of the biodiversity inherent to these spaces, leading, in extreme cases, to the disappearance of the vegetation. Change, simplification and risk of disappearance are foreseeable consequences in the short and medium term.

Pests and diseases are inherent to forest ecosystems. As another element of the trophic network, they contribute, in an endemic or epidemic manner, to the rejuvenation and dynamics of the existing vegetation. They are occasionally a key element in the succession of plant formations and a good indicator of climatic variability: The poikilothermia inherent to most arthropods makes them adjusted bioindicators of climate and variations thereof. The importance of pests and diseases in a scenario of CC should therefore be considered from two radically different perspectives:

- Their presence or absence as early warning indicators of climatic variations in the environment.
- The impact associated with the damage they cause, an element that accelerates the rupture of the plant-system balance and which often camouflages other agents that initiate this imbalance (in this case, climatic variation).

Increased temperatures and the consequent lengthening of the optimum periods for the development of pests and diseases can 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 movement of imagoes can be advanced by one month as a result of the temperature increase, and can be prolonged throughout the autumn. Defoliators such as *Diprion pini* can habitually develop two cycles, or the pine caterpillar can increase the area susceptible to colonisation, on being able to rise in altitude in warmer winters, and colonise in a natural way of *Pinus silvestris* forests which have heretofore escaped impact.

In all these cases, the insects are only mere indicators of climate conditions, and the impact they have only serves to camouflage the role played by these precursor agents. Along with this, the capacity of the plants subjected to hydric and thermal stress to resist the attack, is undermined.

But the greatest threat is undoubtedly posed by the pests and diseases exogenous to the environment, the so-called *alien species* or quarantine organisms. The combination of these species, the undesired result of international trade, host species lacking mechanisms for adaptation or for mitigating the impact, and optimum climatology for the development of the pathogen, lead to exponential damage being caused, against which the vegetation has practically no defence. The development of *Lymantria dispar* in North America, the presence of scolitid fauna and other aloctonous perforators in any forest system, or the development of syndromes such as *dieback* in the Southwest of Europe or *Sudden oak death* in North America, with interaction among fungi such as *Phythopthora*, *Bothryosphaeria*, bacteria such as *Brennia*, scolitids and the impact of continuous hydric deficit and heat waves that prevent recovery of the soil's hydric reserves, presents a panorama which, at best will involve the substitution of some forest species by others, better adapted to the new conditions, or at worst, the progressive fragmentation and disappearance of certain forest species. The worrying situation of *Abies alba* in some parts of the Pyrenees or of *Quercus suber* in the Southwest of the Iberian Peninsula, could be an indicator of this complex process.

9.3.2. The average life of evergreens will be shortened in the future

Leaf renovation, which can be represented by the average life of the leaf, is very much associated with temperature. It has been observed, in the case of evergreen trees, like the Holm oak or the pine, that a temperature increase can accelerate their leaf dynamics, reducing the duration of the leaves on the crowns, which accelerates even more in the case of drought conditions. The average life of Holm oak leaves is 2.8 years in Montseny (north-east Spain), where mean temperature is 10º C, with 700 mm annual rainfall, and 1.7 years in Seville (south Spain), where mean annual temperature is18.8º C with 535 mm annual rainfall (Gracia *et al*. 2001). These observations are also valid for fine roots which last on average little more than 100 days in the Prades Holm oak forest and which disappear in conditions of drought (López *et al*. 1997, 1998, 2000, 2001a, 2001b). Leaves and fine roots therefore require important amounts of mobile carbon for renovation. If climate change causes temperature increases, we deduce that the renovation of leaves and fine roots will accelerate. Furthermore, in the case of deciduous trees, (such as beeches and oaks), the duration of the leaves will increase: they advance sprouting time and retard the moment when the leaves are shed, which is seen in a longer growing season and therefore a longer production period. Although if these species are faced with more accentuated summer drought periods due to climate change, things may go badly for them (McClaugherty *et al*. 1982, 1984). It must be kept in mind that the leaves of deciduous trees are generally less sclerophyllous and more sensitive to water loss than those of a hard-leafed evergreen like the Holm oak and that they might therefore have less resistance to water loss during a prolonged episode of hydric stress.

The impact of climate change upon leaf duration and the derived physiological effects were evaluated on 147 plots of evergreen species from the Catalonia Ecology and Forest Inventory (Gracia *et al*. 1992, 2000). The mean value of the variable for the 147 plots analysed was 2.6 years, most of the values being between 2 and 3 years and only in some sites, all of these in mountains of the Pyrenees, Puertos de Beceite or Montseny, with values of over three years. In the year 2040, the predicted distribution in the results of the simulations changes notably, with a resulting mean value of 1.9 years, which represents a reduction of 27% of the leaf life span. This reduction of leaf life is reflected in an increase in litterfall production, which varies from 205 g of C $m^{-2}\cdot year^{-1}$ at present to values of 377 g of C $m^{-2}\cdot year^{-1}$ in the year 2040. This increase by almost 80% in the organic matter reaching the ground affects respiration rates. By total respiration, understanding here the sum of the autotrophic respiration of the trees (maintenance respiration plus growth respiration invested in the formation of new tree tissue) plus the heterotrophic respiration coming mainly from the decomposition of soil organic matter. The amount of carbon returned into the atmosphere annually by forests in Catalonia is, on average 1462 g of C $m^{-2}\cdot year^{-1}$ and this value increases to 2307 g of C $m^{-2}\cdot year^{-1}$ in the year 2040, which is an increase of 70% in relation to present values.

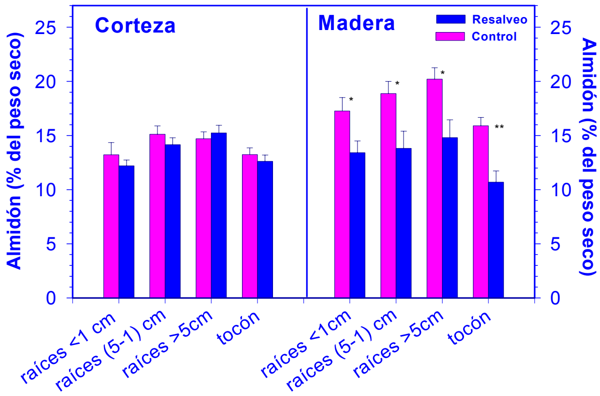

Fig. 9.2. *Percentage of starch in different fractions of the root system of the Holm oaks in control and thinned plots, measured one year after thinning. The percentage of starch in the wood of the thinned plots is five per cent less than the control plots. The difference is due to the starch mobilised following the treatments. In absolute terms, this percentage represents around 10 tons of carbon which is mobilised after thinning. This result shows the importance of mobile carbon reserves in trees.*

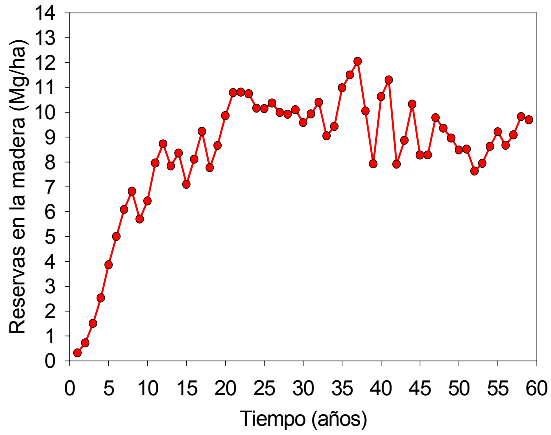

Fig. 9.3. *The mobilisation of starch after thinning or a fire or any other disturbance must be compensated for by the carbon fixed by photosynthesis. When large amounts are mobilised, like in the aforementioned thinning experiment, the tree may take a considerable amount of time to replace the reserve. During all this time, the plant may be sensitive to other disturbances that it cannot resist due to the lack of reserves of mobile carbon. The recovery of the ten tons mobilised after thinning requires an approximate time of 20 to 25 years, as shown in the graph.*

9.3.3. The greater consumption of mobile carbohydrates with increase the vulnerability of forest ecosystems

New shoots are formed through the mobilisation of considerable amounts of reserve carbohydrates stored in the subterranean structures (Breda *et al*. 1995). Starch represents over 95% of reserve carbon. Figure 9.2 shows the starch content in the bark and wood of the subterranean structures.

Starch represents around 15% of the biomass in the stump and the roots and does not undergo any significant changes after thinning (Gracia *et al*. 1994, 1996, 1999a). In the woody tissues, starch represents between 15 and 20 per cent of belowground biomass, which is equivalent to 21.2 Mg/ha. Of this amount accumulated in belowground biomass one year after thinning, in the treatment referred to in figure 9.2, 6.1 Mg/ha had been mobilised, which is around 30% of the reserves accumulated by the roots.

In the mobilisation of this considerable amount of reserve carbon lies the capacity of the Holm oak to regenerate the structures that have been altered by a disturbance. This consumption of reserves, however, leaves the tree in a temporary state of precariousness, on preventing it from dealing with disturbances that occur too frequently. It is therefor pertinent to establish the time needed by the plant to bring reserves back to the levels existing previous to thinning. Figure 9.3 shows the evolution of the reserve starch in the wood of the subterranean biomass. These results show that the time needed to accumulate the 6.1 Mg/ha mobilised after thinning is around 20 years. This result coincides with the time that traditionally elapses between the two successive cuttings to produce charcoal in the traditional use of these Holm oak forests, which would justify, in terms of the tree's physiology, a certain empirical optimisation of the traditional use of these forests. The increased summer drought in Mediterranean environments predicted by the climate change models will contribute to increasing the consumption of reserve carbohydrates, thus increasing the vulnerability of many forest species to adverse episodes (Aussenac and Granier 1988, Ball *et al.* 1987, Brix and Mitchell 1986, Jarvis 1998).

9.3.4. The hydric reserve of forest soils will be reduced, hindering recovery after episodes of summer drought

The water content in the soil of a forest varies greatly, from values close to zero during summer drought to maximum values during periods of more or less abundant and continuous rainfall. According to the analyses conducted in the aforementioned 147 forest plots, the hydric reserve in the soils of Catalonia's forests (averaged throughout the year) is 32 mm. The temperature increase and the greater evaporation demand of the atmosphere around 2040 will reduce this annual mean value of the reserve to 24 mm, which represents a decrease of 25% of the present water content in forest soils (Gracia *et al*. 2001, 2002).

In those sites in which the forest avails of sufficient water to compensate for the greater hydric demand associated with the temperature increase and potential evapotranspiration, an increase in forest production can be predicted. Although, in places with a hydric deficit, which represent many of Spain's forest ecosystems, we can expect big changes, ranging from reduced tree density to changes in species distribution. In extreme cases, areas currently occupied by forests could be substituted by shrubland, and areas currently occupied by shrubland might be exposed to the impact of intense erosion.

This is why it is important to anticipate the changes we are exposed to and the possible role of adaptive management aimed at redirecting or, channelling, or at least optimising the response by our forests to climate change.

9.3.5. Our forests will become net emitters of carbon in the second half of this century

The maps in figure 9.4, which show the net production of European forest ecosystems, and the maps in figures 9.5 and 9.6, referring to the Iberian Peninsula, represent an attempt to explore the effects of climate change on some variables considered to be particularly sensitive, with the use of the model GOTILWA+ (Gracia *et al.* 1997, 1999b, 2001, Kramer *et al.* 2002, Mohren 1999, Mohren et al. 1997, 2000). These were obtained with the use of a 10 x 10 minute pixel. The climate of each pixel corresponds to that estimated by HadCM3 model, using socioeconomic scenario A2 (Carter *et al.* 2000, IPCC 2001 Watson 2001). The results of figure 9.5 represent the net production of the ecosystem in European forests in the years 1990 2020 2050 and 2080.

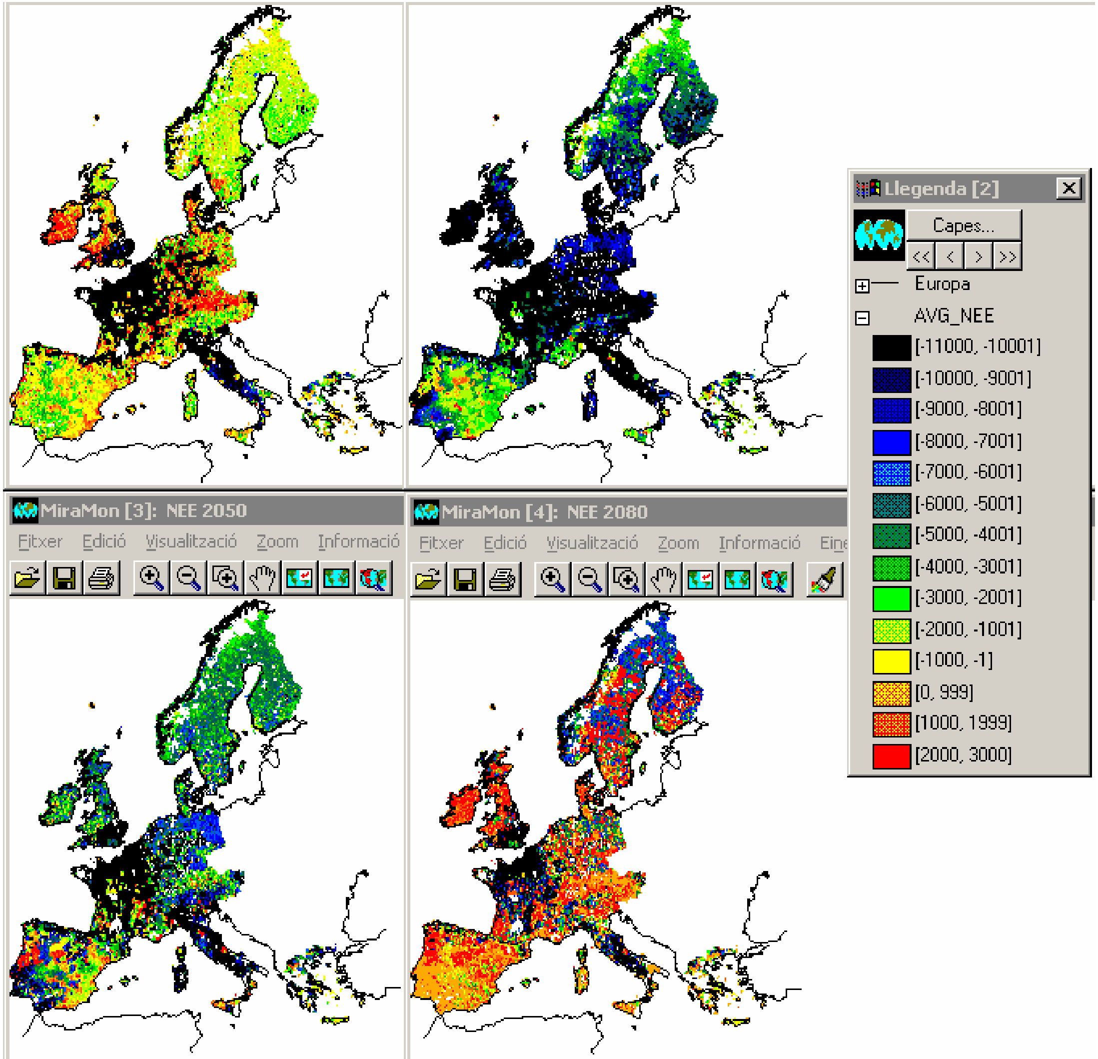

Fig. 9.4. *Estimation of net Production of the ecosystem in European forests. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scocioeconomic scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minutes x 10 minutes pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). The results show that on the Iberian Peninsula, the sink effect of forests can undergo a transitory increase for a few decades, but towards the second half of the present century, forests will invert their role as sinks and become net emitters of carbon into the atmosphere.*

The results are eloquent and generally coincide with the patterns predicted by other models (Aubinet *et al.* 1998, Ceulemans and Mousseau 1994, Epron and Dreyer 1993a, 1993b, Medlyn and Dewar 1996, Medlyn and Jarvis 1997). In spite of the fact that on the Iberian Peninsula, the sink effect of forests may undergo a transitory increase for a few decades, in the second half of this century, they will invert the role they play as sinks and become net emitters of carbon into the atmosphere. With regard to water reserves in the soil, the results of figure 9.6 show that on the Iberian Peninsula, the groundwater reserves progressively diminish in the summer months. The lack of water in the soil in summer constitutes a serious risk for the survival of some forests.

9.4. MOST VULNERABLE AREAS

Populations whose southern limit is located in the high parts of mountain ranges will be the most affected, in particular if they coexist with more thermophilic species or if they have little genetic variability. In general, the so-called restricted area origin, recorded by Martín *et al* (1998), due both to being outside the main distribution area and to problems of genetic derivation, to their susceptibility to natural disturbance or to human intervention, are more vulnerable. These dangers will be determinant if they are associated with changes in rainfall regime.

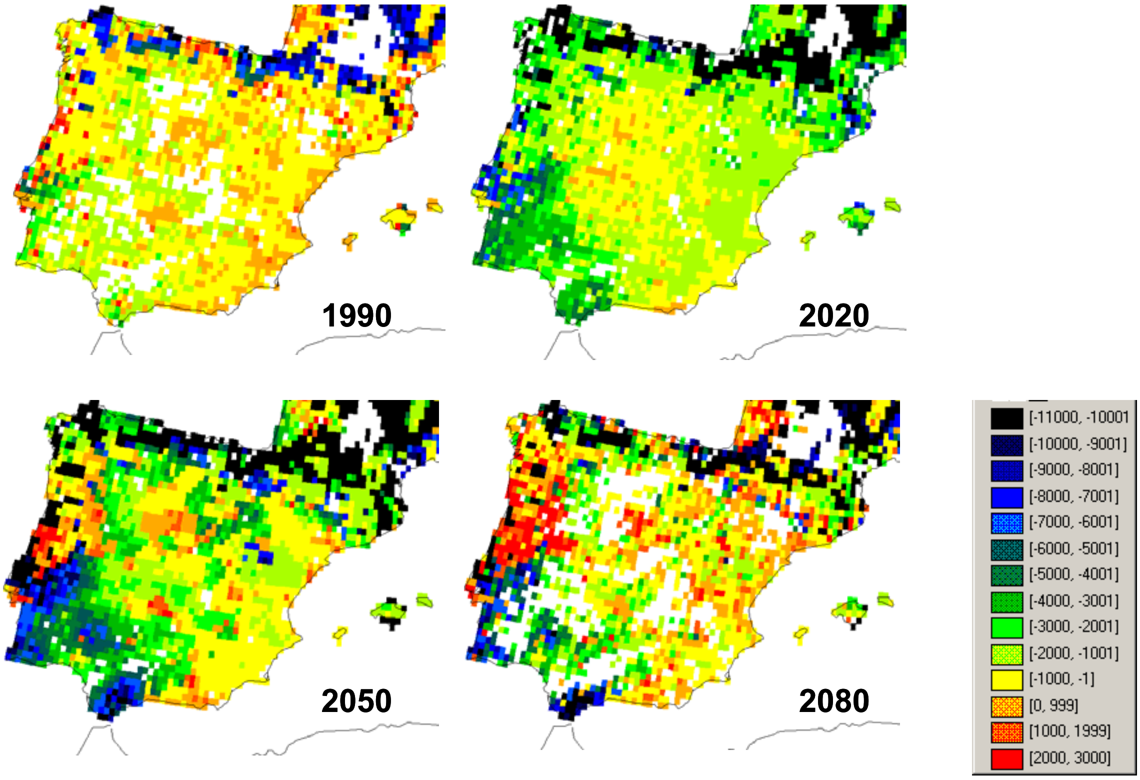

Fig. 9.5. *Estimation of net Production of the ecosystem in forests on the Iberian Peninsula. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scocioeconomic scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minute x 10 minute pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). See figure 9.11.*

On the Iberian Peninsula, the forest area, not necessarily with trees, appears as a continuum crossing all the mountain ranges, generally interconnected by corridors. There is an acceptable change of these acting in many situations as corridors for rustic species such as conifers of the genus *Pinus*. A temperature increase and irregular rainfall will reduce the frequency of situations favourable for the establishment and consolidation of trees. Less capacity to accumulate reserves is also associated with greater vulnerability to disturbance (fires, pests, diseases), as the trees cannot handle renovation processes.

Debilitation resulting from a lack of adjustment to the new climate conditions will provide greater trophic availability to pests and, which will do their job as indicators of the decomposition cycle of organic matter. If global warming is associated with increased aridity, a greater proliferation of insects is to be expected, due to the greater sensitivity of fungi and other micro-organisms to dry periods. The lack of vigour in the present plant populations over a large area will allow for noteworthy increases in pathogen populations. Disturbances will accelerate change in present populations, which will be renovated by new produced plants more adapted to the new situation, or will be substituted by other, more thermophilic species with a better resistance to aridity. This is the case of the substitution of *Pinus pinaster* by *Pinus halepensis* in the inland mountains of Valencia, or of the substitution of the cork oak or the gall oak by the Holm oak.

9.4.1. Mountain top areas

If the distribution area covers the top area of the mountain ranges, the forest having no natural limits – like in most of the eastern ranges or those in the South of the Peninsula, with the exception of Sierra Nevada – an altitudinal rise will not be possible following a temperature increase. The few spots of *Abies pinsapo* are threatened. Also affected will be the populations of *Pinus sylvestris* in the Sierra de Baza range, those of *Pinus nigra* in the Betic ranges or those of *Pinus uncinata* in the Sierra de Gúdar range. In all these cases, the populations indicated have few individuals and are therefore more sensitive to change and are endangered, in particular, in Andalucia, due to the low genetic variability, caused by problems related to genetic derivations associated with historic human intervention.

9.4.2. Xeric environments

Global warming associated with changes in rainfall regime could lead to the disappearance of trees in territories at their limits of adaptation to drought, giving way to formations of herbaceous species associated with sporadic rainfall. One example with economic effects, due to being one of the most typical non-timber products of Mediterranean forests, can be found in populations of *Pinus pinea* in the sanded soils of the Northern Plateau, but can be extended to other areas. This pine generates a large seed that is dispersed by animals, as opposed to other species with winged seeds. The interannual variation of pine kernel production in the province of Valladolid over 40 years shows a continuous decrease in the moving average of the last 20 years (figure 9.7.) This tendency is accentuated in pine forests with lower pine production, which become incapable of guaranteeing species reproduction (Gordo 2004). In spite of its adaptation to warmer areas with intense summer drought, the natural regeneration of the umbrella pine is compromised. Under the current climatic tendencies (figure 9.8), it will become increasingly difficult for a good harvest to coincide with favourable environmental conditions in successive years in order to permit the establishment of seedlings and the survival thereof in the early stages. A good harvest saturates the predators that act as dispersers, and has sufficient genetic variability to express a potential for adaptation capable of resisting the new conditions. Retreat in area will occur in spite of adaptation to very poor environments which require very open forest. This interpretation is based on the fact that it is a pine whose spherical crown is the result of adaptation to conditions of development in intense sunlight, with no lateral competition from other trees. This morphology is the result of the lack of vigour of the apical meristems of the trunk and the main branches, as this growth pattern allows the number of codominant axis to be maximised. Only branches of a certain thickness are capable of sustaining cones with a weight of 0.3 kg (Mutke *et al.* 2004).

The availability of records of production in a characteristical area of the species enabled us to establish the factors that determine the magnitude of the harvests; and establish a model that accounts for 75% of variation and shows tendencies towards a warmer, drier climate (Gordo 2004). The most determinant climatic variable with regard to the size of the harvests corresponds to the sum of rainfall from January to May (P5F, figure 9.8) of the year in which the female estrobilous were produced and pollinated. The follow-up, based on data from the Valladolid meteorological station, shows a tendency towards reduced rainfall in this period by 15 mm per decade. The decrease in related to the appearance of smaller harvests, which reduce the genetic base of the new produced plants exposed to higher summer temperatures. The species is vulnerable in the more arid parts of its current distribution, and will be associated with less extreme environmental conditions, such as areas with a water table that ensures a water supply that produces a consistent harvest size.

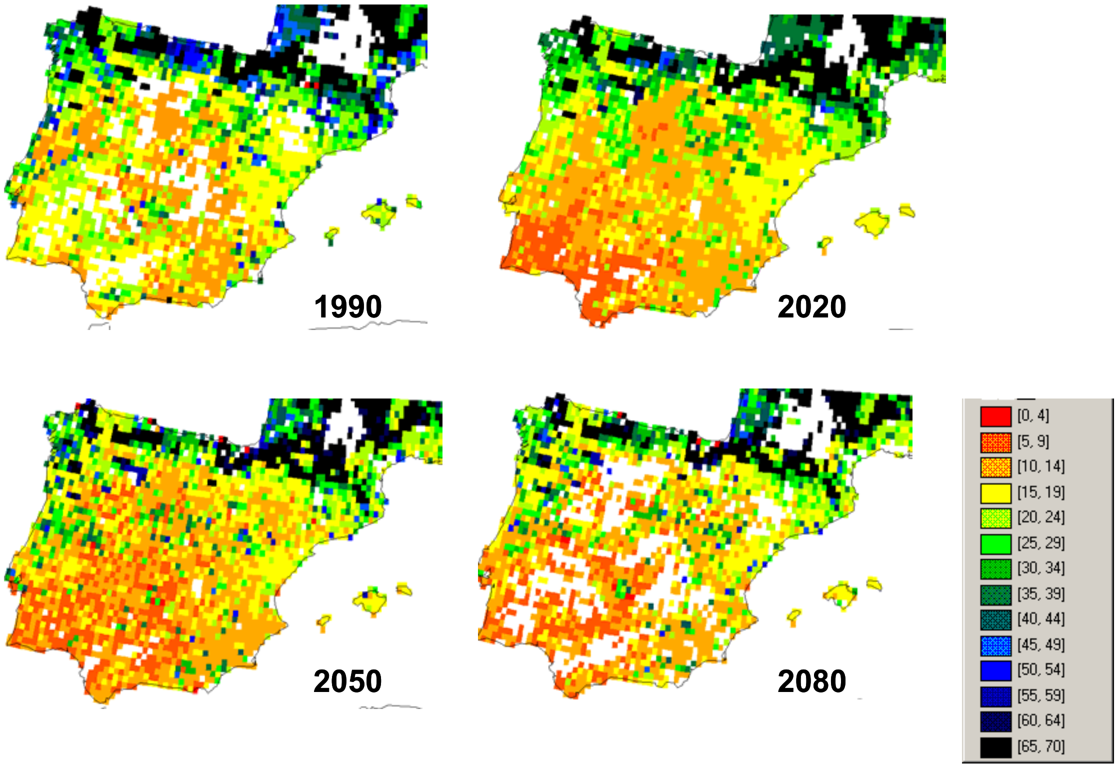

Fig. 9.6. *Estimate of average groundwater reserve in summer months in the forests of the Iberian Peninsula. The maps show the situation in the years 1990 2020 2050 and 2080. In the ATEAM project, GOTILWA+ model is being used to simulate the growth of European forests under the different scenarios of climate change defined by the IPCC. The maps of the figure were obtained using a 10 minutes x 10 minutes pixel. The climate of each pixel corresponds to that estimated by the HadCM3 model using socioeconomic scenario A2 (IPCC 2001). The results show that on the Iberian Peninsula, groundwater reserves progressively diminish. The lack of groundwater during summer constitutes a serious threat for the survival of some forests.*

9.4.3. Riparian forests

Riparian forests constitute one of the systems most affected by anthropic action, and have been drastically fragmented, with a reduction of their variability –as a result of man using the clonal capacity of their species as an exclusive form of reproduction- to the detriment of the sexual system. The construction of reservoirs, the regulation of river courses, the establishment of rockfills or the transformation of the riverbanks for crops or forests such as poplar groves, has fragmented the alignment of these forests and has reduced to a minimum their spontaneous manifestations, leading to the extinction of very unique ecological corridors. Forests of*Alnus* sp., *Populus* spp., *Fraxinus* spp., *Ulmus* spp. and *Tamarix* spp. are formations associated with the existence of a more or less permanent phreatic layer. An increase in mean temperatures will be linked with an increase in evaporation demand, which will require greater regularity of the phreatic layer. Changes in the rainfall regime will increase the torrentiality of our water courses, making them more irregular. A more spontaneous nature of the water table could cause a change in the riparian vegetation, increasing the vulnerability of most of the trees that use the phreatic waters. In the case of elm forests, the danger of extinction due to global change is greater due to the appearance of Dutch elm disease. This disease seriously affected the size of its populations at the end of the last century. The rapid spread of the fungus was aided by the low diversity of the species, both in Spain and in other European countries. The domestication of this species as a result of its extensive use in clonal form by the Romans (Gil *et al* 2004), shows the need to avail of high levels of genetic diversity in order to respond to disturbances. There is a need to take measures to ensure the maintenance of their adaptive potential.

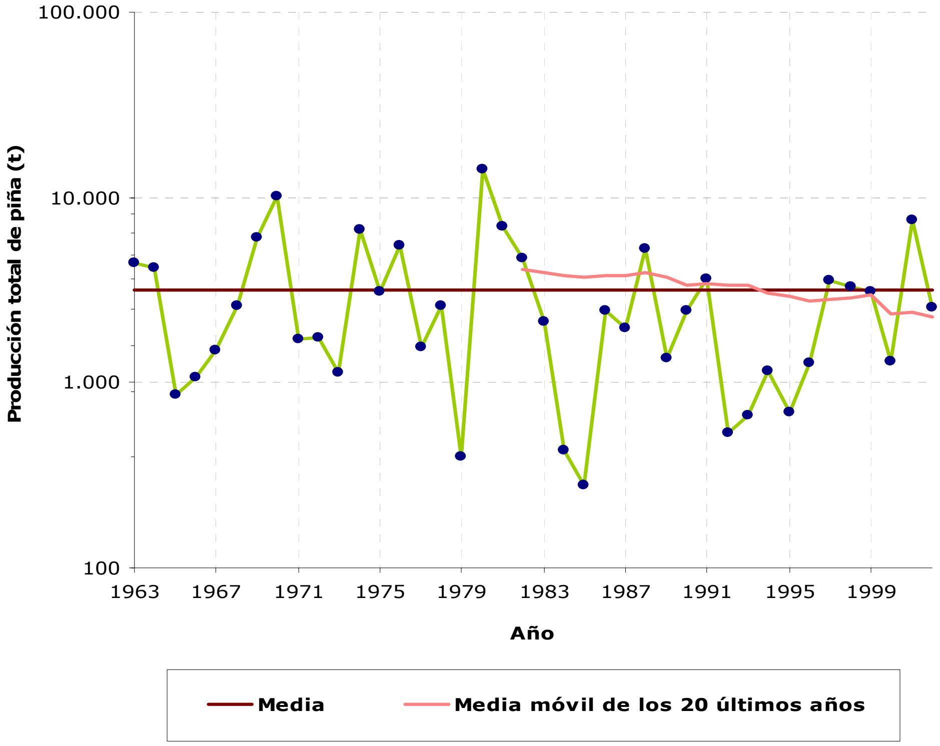

Fig. 9.7. *Irregularity of pine kernel harvests (tons) of Pinus pinea in public forests in public forests in the province of Valladolid, which presents a continuous decrease in the moving average in the last 20 years. Source: Gordo 2004.*

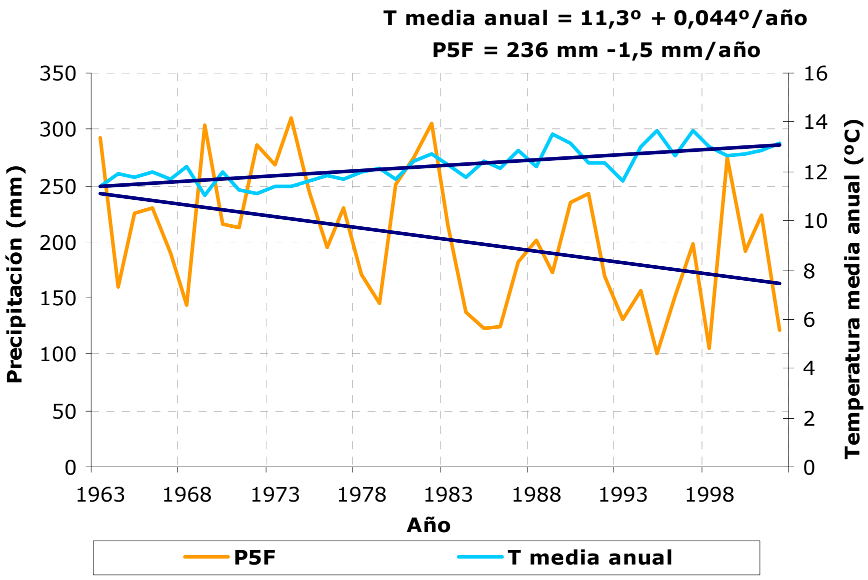

Fig. 9.8. *Evolution of annual mean temperature and of rainfall in the five months previous to flowering of Pinus pinea L in the Valladolid observatory. Source: Gordo 2004*

9.5. MAIN ADAPTATIONAL OPTIONS

9.5.1. Selective thinning of coppices and transformation into tall forest: an effective treatment for improving the response of forests to climate change

Many Mediterranean forest species are resprouting ones and some, like the Holm oak, develop large lignotubers in which the belowground biomass is accumulated, while the aerial fraction is burnt or cut more often. These differences cause a predominance of belowground biomass (over 50% of total biomass) over aboveground biomass (Canadell *et al*. 1997, 1999).. When the treatment of these forests is abandoned, the forest grows very slowly, because the high density of small-diameter trees leads to a situation very close to stagnation (Djema *et al.* 1994, Rodà *et al.* 1999, 2003, Hilbert and Canadell 1995, Sabaté 1993, Sabaté *et al*. 1992, 1994, 1995).

Fig. 9.9. *Experimental thinned plot in the Prades Holm oak forest. The reduced tree density of the stands modifies the water and carbon balance of the forest and has enables some of the possible effects that analogous environmental changes caused by climate change can cause in Mediterranean forests. More explanation in the text.*

In field experiments conducted in Holm oak forests in the mountains of Tarragona it was shown that in these conditions, the biomass accumulated causes, at this time of year, respiration to be greater than gross primary production, thus giving rise to negative net production rates (Albeza *et al*. 1996, Djema 1995). In order to survive, the trees deal with these conditions by using a fraction of the reserve mobile carbon.

If the unfavourable period is prolonged, reserves can be used up, first causing the destruction of the fine roots and defoliation and the subsequent death of the trees. The reduced aboveground biomass caused by the thinning treatment profoundly affects the water and carbon balances of the forest (Tello *et al*. 1994). Reduced leaf area considerably improves the hydric state of the remaining trees. The transpiration rate measures per unit of ground in the experimental treatment in Prades was around 400 kg·m^{-2} ·year^{-1} in all the plots, regardless of the density of the trees, which indicates an increase in the transpiration rate of the trees (transpiration per leaf area unit) in the thinned plots, which reduces the death rate during unfavourable periods.

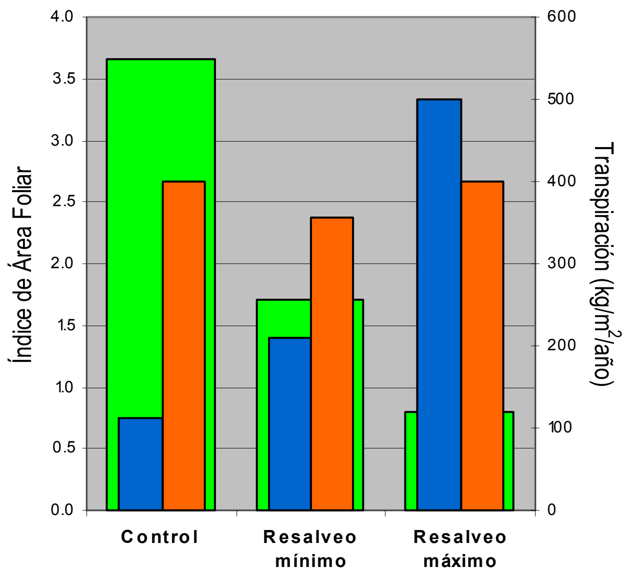

***Fig. 9.10**. The response by the Prades Holm oak forest to different thinning intensities (see figure 9.9) highlights the primordial role played by water in the response of the forest to structural or environmental changes and allows some of the responses that might be expected within the framework of climate change to be anticipated. The reduction of the leaf area index (green) according to the intensity of the treatment does not affect the transpiration rate per unit of ground area (orange, kg·m^{-2} de soil·year^{-1}). The reduced leaf index is compensated for by an increase in transpiration rate per unit of leaf area (blue, kg·m^{-2} of leaf·year^{-1}). The result, which has profound repercussions for the physiology of the trees, highlights the fact that water limitations restricts the growth of Mediterranean forests, and this, in turn, conditions all the responses of Mediterranean forests to climate change.*

9.5.2. Adaptive management: how to optimise the response of forests to climate change

The role of management in controlling the response of forests to climate change was studied in depth in the SilviStrat project. Succinctly, the project adopts three climatic scenarios basically corresponding to present conditions and two climate change scenarios predicted by the two general atmospheric circulation models (ECHAM4 and HadCM2). The growth of the forest is analysed combining these scenarios with alternative management scenarios. The objective is to establish the role of management in the different climate scenarios. The definition of management scenarios is based on the common management regime applied in each region. Using this base, the value of two variables is increased or reduced in a determined proportion: the period of time that elapses between two interventions and the intensity of these. Reducing the thinning interval, thinning frequency is increased, which involves greater intervention in the forest. The intensity of the intervention is defined according to the uncut proportion of the basal area at the moment of thinning. A parallel analysis was conducted of the effects of selective logging of the bigger or smaller trees or a combination of different diameters.

In the case of Mediterranean forest, we analysed the effects on Prades Holm oak forests (Tarragona) and Puechabon (Montpellier, France) and the Scots pine forest in Montesquiu (Barcelona). The results discussed here analyse the effect of increasing or decreasing by 33% the time interval between thinning interventions. The base interval upon which the 33 per cent variation was applied was, in accordance with the opinion of the managers 15 years in the pine forest and 20 years in the Holm oak forest. Analogously, the thinning intensity, expressed as the percentage of the basal area of the trees extracted, increased and decreased by a value of 30 per cent with regard to the habitual practices which are specific for each forests species.

With regard to management, it is clear that the effect of removing more or less basal area is much greater than that of modifying the intervals between successive thinnings. In the future climate scenarios (ECHAM4 and HadCM2), temperature rises and mean rainfall remains more or less constant, while the variability of this increases. In these scenarios, boreal and temperate forests present a positive response: there is an increase, albeit slight, in carbon accumulated in the soil, in the same way in which annual production increases, and therefore, carbon accumulated in biomass. In Mediterranean conditions, however, in which water is the most important limiting factor, the opposite effects can be seen. Analysis of the results show that the response of forests to temperature increase depends very much upon water availability. In conditions in which potential evapotranspiration is lower than rainfall, the temperature rise causes an increase in growth rate and in the carbon stored in the system. To the contrary, in forests in which potential evapotranspiration exceeds precipitation, the temperature increase tends to reduce the amount of carbon stored in the different compartments of the forest.

Table 9.5. *Carbon in aerial biomass (CAB, Mg/ha), carbon in soil (CS, Mg/ha), yield over a 100-year period (Y, Mg/ha) and fraction of available water not used by forest (WY, mm/year) in the PRADES Holm oak forest. The tables show the results of each variable under the three climate scenarios explored in the SilviStrat project in the nine management combinations defined in the management matrix. Ref represents the current management practices, ∇ and Δ represent the decrease and increase, respectively, in the management components (thinning interval and thinning intensity) discussed in the text.*

Thinning intensity

	Thinning interval	CRU			ECHAM			HadCM2		
		∇	ref	Δ	∇	ref	Δ	∇	ref	Δ
CAB	∇	34.9	31.0	27.3	39.3	35.3	31.9	38.0	36.0	31.1
	ref	35.5	33.2	29.1	40.7	35.6	32.5	41.7	38.5	34.8
	Δ	35.2	32.8	30.1	39.5	38.4	33.7	42.7	38.9	35.6
CS	∇	74.2	73.4	73.4	78.9	79.2	77.7	89.2	87.8	81.2
	ref	74.0	73.6	71.5	78.8	81.6	81.6	87.8	86.3	86.9
	Δ	74.7	75.1	74.7	80.0	77.9	79.4	88.4	90.5	90.0
Y	∇	76.6	102.8	124.4	105.1	126.1	172.6	137.4	149.4	200.4
	ref	71.6	86.9	109.9	92.6	106.6	110.8	118.5	48.3	143.6
	Δ	62.6	82.1	93.8	79.6	103.4	95.3	120.2	100.6	116.0
WY	∇	170.2	171.5	172.7	149.4	149.6	149.2	182.7	184.0	188.9
	ref	169.8	170.9	173.9	149.0	149.2	148.8	183.0	184.6	183.6
	Δ	169.7	171.3	170.7	148.4	149.7	148.1	183.1	182.2	182.6

Figures 9.11 and 9.12 summarise the results obtained from the analysis of 7 different species in 17 different sites throughout Europe. Growth was simulated under three climate scenarios and all cases of the aforementioned management matrix were applied. The baseline management corresponds to the current management system so that, in each particular case, the common practice is reproduced. Increasing thinning intensity and/or reducing thinning interval, leads to more severe management strategies (1 to 4) and, to the contrary, reducing thinning intensity and/or increasing thinning interval leads to more severe management strategies (6 to 9). A joint analysis of the capacity of forest management techniques to modify the response of European forests to climate change, conducted within the framework of the SilviStrat project, highlights the fact that the different management alternatives have hardly any effect when these are applied to European forests in restrictive growth conditions, represented by Mediterranean sites on one hand, limited by hydric deficit, and on the other, boreal forests, limited by low temperatures (figure 9.12).

***Table 9.6.** Carbon in aerial biomass (CAB, Mg/ha), carbon in soil (CS, Mg/ha), yield over a 100-year period (Y, Mg/ha) and fraction of available water not used by the forest (WY, mm/year) in the pine forest of Pinus sylvestris in Montesquiu (Barcelona). The tables show the results of each variable under the three climate scenarios explored in the SilviStrat project in the nine management combinations defined in the management matrix. Ref represents present management practices, ∇ and Δ represent the respective decrease and increase in the management components (thinning interval and thinning intensity) discussed in the text.*

Thinning intensity

Thinning interval		CRU			ECHAM			HadCM2		
		∇	ref	Δ	∇	ref	Δ	∇	ref	Δ
CAB	∇	64.4	60.1	47.8	51.2	48.8	42.4	60.8	58.6	48.1
	ref	67.9	61.4	51.0	54.3	51.5	43.3	64.7	58.5	50.1
	Δ	70.0	63.8	55.3	57.6	52.9	51.5	65.3	61.5	53.1
CS	∇	47.7	46.7	46.3	43.4	43.0	41.7	51.3	50.3	48.4
	ref	47.4	47.2	46.3	42.9	42.5	41.5	50.6	50.0	48.4
	Δ	47.6	46.9	46.1	42.5	43.2	41.0	51.2	51.1	49.4
Y	∇	188.7	244.7	298.9	10.3	69.2	145.5	112.2	159.0	342.8
	ref	158.7	192.7	268.3	0.0	22.0	142.4	75.9	166.4	248.1
	Δ	105.1	191.6	237.6	0.4	0.0	121.4	36.7	11.7	115.9
WY	∇	449.3	450.8	454.9	348.8	349.9	352.6	364.3	366.7	369.2
	ref	448.1	449.8	453.7	350.5	351.6	354.2	365.8	366.4	369.8
	Δ	447.3	450.9	453.0	350.4	349.8	352.8	365.9	366.9	370.5

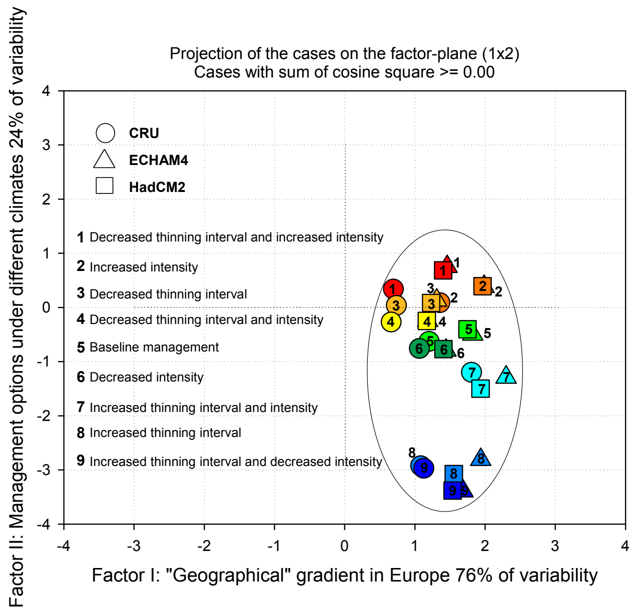

***Fig. 9.11.** Example of a complete set of simulations of the beech forest in Fabrikschleichach, Germany. The baseline management corresponds to the current management system so that, in each case, the habitual practice is applied. Increasing thinning intensity and/or decreasing thinning interval leads to more severe management strategies (1 to 4) and, to the contrary, reducing thinning intensity and/or increasing the thinning interval leads to more severe management strategies (6 to 9). These management strategies are explored under three different climate scenarios: CRU, ECHAM4 and HadCM2.*

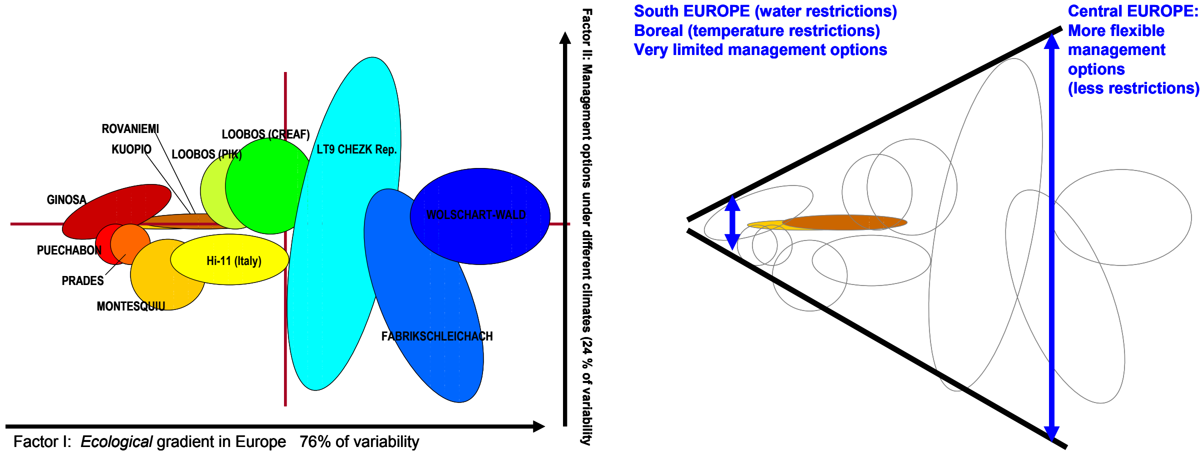

Fig. 9.12. *A joint analysis of forest management techniques to modify the response of European forests to climate change, conducted within the framework of the SilviStrat project, highlights the fact that the different management alternatives have hardly any effect when these are applied to European forests in restrictive growth conditions (represented by Mediterranean sites on one hand, limited by hydric deficit, and on the other, boreal forests, limited by low temperatures). To the contrary, the same management alternatives applied to central European forests present much more differentiated responses.*

9.5.3. Other adaptational options

The fact that practically 50% of the composition of wood is carbon witnesses the ease with which this is sequestered through accumulation in trees. Among the techniques involved are those that improve the productivity of the season, such as controlling the water table, or the recovery of this when it has descended due to agricultural use. Reducing the thinning interval, in particular of species with short rotations such as poplars, eucalyptus or *Pinus radiata,* will enable noteworthy increases to be obtained, due to the very short periods which contrast with those of Iberian species, as these trees represent the highest percentage of timber felled yearly. A similar action would involve the establishment of forest reserves with Iberian mountain conifers such as *Pinus sylvestris*, which currently are cutted much younger in relation to their natural longevity.

With the use of genetic improvement, we should promote, in the more productive species, the use of forest materials of selective reproduction, such as genotypes, origins or species that are more efficient in the formation of wood. Likewise, in other tree species, we should consider the use of material with carbon storage patterns altered towards location in the root systems, for example, the use of *Quercus pyrenaica*, given its capacity for root resprouting, which is an adaptation that enables subterranean biomass to be increased.

The recovery of large areas of degraded and treeless land by reforestation constitutes a priority action. To this end, species and origins must be chosen that are suitable for reforestation. Against the transformation to shrublansds of forest systems, planting rustic and heliophilous trees allows for horizontal stratification, which produced the biggest accumulations of biomass. Improvement of the original situation requires the subsequent application of forestry techniques in order to control the tree density of the forest and to prevent catastrophic disturbances such as forest fires, pests and diseases. These actions can be extended to existing forests.

Finally, the use of timber as raw material for the manufacture of products or for structural use in civil construction, constitutes another option for reducing the effects of climate change. Timber with heartwood or tannins in the case of pines, in particular *Pinus canariensis*, should be promoted, as they provide products with life cycles of great durability and high aesthetic quality. Additionally, in the manufacturing process, apart from being a naturally renewable product, wood consumes less energy than other materials such as bricks, glass, steel, aluminium or plastic. In this sense, we can highlight the use of cork, as opposed to other increasingly used alternatives, like plastic derivatives.

9.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

The Forestry Sector as a generator of goods and environmental wealth influences the industries associated with commercial production. The ecological, recreational and landscape functions associated to these systems, and related to the leisure activities of urban societies and rural tourism, will be subjected to changes that are not easy to assess. Landscape is a subjective concept and the one we observe today is a product of our culture.

9.6.1. Timber industry

This sector supplies several industrial sectors such as timber, playwood, pulp or paper and furniture. Timber, because of its local nature, could be the worst hit, particularly that depending on Iberian mountain species, such as the Scots pine (*Pinus sylvestris*) or the beech (*Fagus sylvatica*), the use of which is very great at present. In the remaining sectors, a high percentage of the raw material consumed comes from fast-growing species, located on the Cantabrian coast or in clonal plantations in areas with a supplemental water supply. A deficit of these products would be compensated by imports, as a result of the little value given to these unmannufactured products and the important added value obtained in the transformation process.

9.6.2. Effects on hunting

Hunting is currently an essential element of much of the country's socioeconomy. As the main species involved are herbivores, this sector as a whole will probably not be greatly affected by climate change, but certain changes can be expected in the behaviour and distribution of numerous species subjected to hunting, with the consequent repercussions at regional level.

Specifically, there could be certain effects of climate change resulting from several different processes:

- Changes in the distribution areas of hunted species, according to direct ecological demand.
- Changes in the distribution areas of hunted species, according to changes in the structure of the ecosystems this inhabits.
- Changes in the aetiology of hunted species, especially in the case of migratory ones.

The first factor mentioned would have a direct effect, depending on hydric availability and temperature regimes, generally causing the spread of the species most associated with Mediterranean environments (for example, the moruna partridge) at the expense of those associated with Atlantic environments (for example, the pardilla partridge). Locally, especially with animal groups at their "range limit", this could lead to the disappearance of certain types of game in the area, decisively affecting biodiversity through the extinction of subspecies or varieties, as might have been the case of the stag in the cork oak of the Sub-Betic ranges.

Another series of influences might lie in the foreseeable changes in the structure of the ecosystems inhabited by the hunted species. In the last few decades, the general abandonment of practices typical of the traditional agricultural system, seen in the increase in forest area to the detriment of pastures and shrublands, is causing a notable increase in big game species, with small game species becoming rarer, except in areas with intensive agricultural activity. The limitations that the new climate regime could exercise over the re-colonisation of open spaces by trees or with regard to preventing closed tree canopies from becoming established in Mediterranean areas, could contribute to attenuating or inverting this tendency, thus favouring the small game associated with open structures.

The final series of changes refers to changes resulting from general climatic variation in the migratory regimes of numerous species. Certain bird species, that previously spent barely three months, during summer, on the Peninsula, such as quail, will progressively increase the length of their stay, even remaining in some of the warmer areas, as has been seen for the quail in some places in Andalucia. To the contrary, there may be a reduction of summertime migratory individuals associated with wetlands, due to their becoming rarer. With regard to wintertime migratory species, there may also be a downward tendency, but this will be intensely conditioned by changes occurring in their countries of origin. Lastly, we can expect changes that are difficult to predict in general migratory patterns, such as the abandonment of the traditional routes of pigeons in the Pyrenees and the North of the Iberian Peninsula, probably attributable to the frequency of early autumn storms in these areas.

9.6.3. Effects upon mycology

The changes to be expected in activities related to mushroom collecting will also be associated with direct changes in temperature and hydric regimes and with changes in the forest ecosystems where these activities are carried out. The most likely effect will probably involve variations in hydric availability in autumn, which will reduce the vital area of numerous species associated with rainy autumns. We must not, however, underestimate the possible effect of temperature regimes, especially because of the irregularity of these: brusque and out-of-season cold spells at the beginning of autumn are limiting the fruiting period in much of the North of such valued species as *Amanita cesarea*, whereas warm phases in autumn, winter and spring favour the rapid decomposition of many of the bodies generated and the rapid colonisation by parasites that devalue the product. In general, if the changes are sufficiently gradual, and if there is a certain continuity in the forests, we can expect the main groups to migrate northwards or in altitude, in search of conditions more similar to those currently existing in their distribution ranges.

9.6.4. Effects upon the cork sector

Influences in this field may, in turn, be variable, depending on the aspects considered.

- Distribution and condition of cork oak forests.
- Repercussions in the exploitation process.
- Commercial characteristics of the product.

The greatest influence will necessarily be exercised by the first of these three points, specifically because of the possible reduction of the existing cork oak forest area, which will drastically reduce the saleable stock of the product. We cannot ignore the death rate of cork oaks which, at the time, in 1995, was attributed to the complex episode known as the “seca” (dieback), and which has continued to act with surprising virulence over all these years in certain areas of cork oak forest in Cadiz, causing the death of big extensions of forest. Apart from this influence, we must also highlight the possible reduction of the exploitation season, conditioned by the last rains of spring and by the cessation of vegetative activity in summertime. Finally, the market tendency of the product will involve a general decrease in available sizes, which could involve increased peeling periods in some areas.

9.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

The series of results we have commented upon highlights some possible adverse consequences of climate change in forest ecosystems. There is obviously a degree of uncertainty associated with the complex analyses required to explore the effects of a complex change in itself, of which we do not yet avail of any details, in systems in turn as complex as forest ecosystems the biology of which is the result of interactions between numerous processes.

We need tools to help us to refine the analyses and in this sense, the administrations involved should make a big effort to compile and update the necessary databases. A paradigmatic example is the lack of information on the belowground biomass of our forests. We have seen that, in some cases, this biomass is greater than the aerial biomass, and therefore makes a crucial contribution to carbon balances. Hardly any information, however, is available on the biomass in the belowground compartment of our forests, and even less on the dynamics thereof. But, contrary to what should be expected, there are very few chances of finding funds for a competitive research project, aimed at extensively quantifying the belowground biomass of forests.

Another example of unsatisfied requirements involve forest inventories. The traditional design of national forest inventories aimed at quantifying *commercial timber stocks,* without considering the role of the remaining components (leaves, branches, bark, coarse roots, fine roots) which have been grotesquely termed “forest trash” by some uninformed technicians, should give way to designs based on a more modern concept of the forest as an ecosystem in which timber production is giving way, in some cases, to other alternative services, such as the frequently mentioned role played by forests, ,as a carbon sinks.

9.7.1. Biomass expansion factors

On building up national inventories of the carbon accumulated in forests, there is an obvious need to avail of values of the so-called biomass expansion factors.

Given that the objective of most forest inventories mainly involves determining trunk volume or biomass, in order to extend these measurements to other important components of the carbon balance of forests, such as roots, branches, leaves, litter or soil carbon, the so-called biomass expansion factors (BEF) have been adopted. The values currently used often involve another source of uncertainty and possible error, as, unfortunately, the databases containing extensive measurements of the aforementioned tree components are very scarce (FAO 2000, 2001). Apart from this problem, the transformation of data on biomass into carbon values also requires attention, as carbon proportion can vary among the different components of the tree or among different species.

The detail used to sample the 10,644 plots of the Ecological Forest Inventory of Catalonia (IEFC)(Gracia *et al*. 1992, 2000) has provided information on the biomass of the different tree components of the 95 species sampled. The resulting database (http://www.creaf.uab.es/iefc), with over two million records, represents the most comprehensive image of forests in the Mediterranean region.

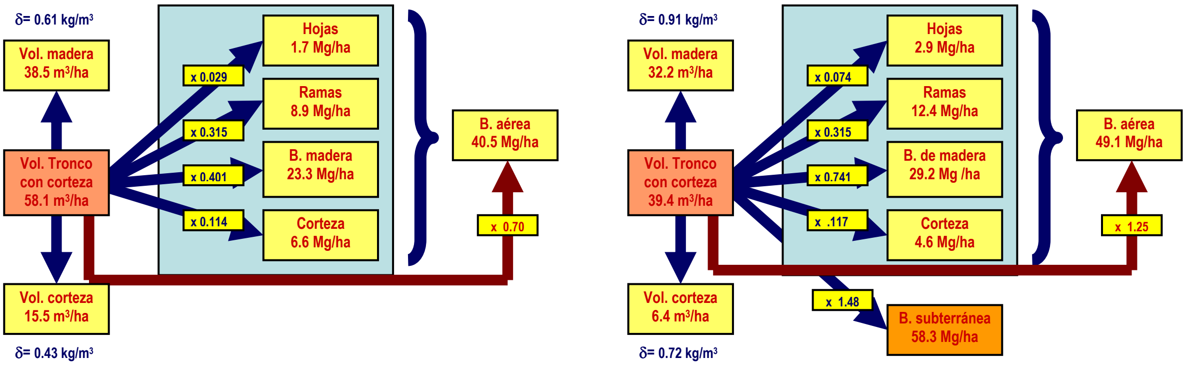

Fig. 9.13. *Components of the biomass expansion factors of he species: Quercus ilex (ileft) and Pinus halepensis (right). The data are based on the analysis of 1,666 Holm oak plots and 2,045 Aleppo pine plots. The most frequent variable in forest inventories is the volume of the trunk with bark and its two components: the volume of wood and the volume of bark. The specific densities of wood and bark enable biomass to be calculated. The biomass of the remaining components of the tree can be calculated by multiplying the volume of the trunk by the corresponding factors of each fraction. Multiplying the volume of the trunk with bark by factor 1.25 of the Holm oak (or 0.70 for the Aleppo pine) the total aerial biomass of the tree can be estimated, which is the basis for estimating carbon.*

This database was used to determine the biomass expansion factors of the main species. Figure 9.13 summarised the values of each one of the components intervening in the determination of the biomass expansion factors in the case of the Holm oak and the Aleppo pine. An estimate of the value of the aerial biomass expansion factor (ABEF) of the main species on the Peninsula can be consulted in Sabaté *et al* (submitted).

9.8. DETECTING THE CHANGE

9.8.1. Pests as bioindicators of climate variations

The presence of endemic pests and diseases is closely associated with certain forest formations: defoliators such as *Tortrix viridana* are associated with the genus *Quercus*, and they usually hatch coinciding with the development in spring of the buds of the host species. The modification of the plant's annual phenological cycle can influence the presence and abundance of this species, as well as its concurrence and competition with other defoliators, in relation to which its biological cycle is slightly advanced, such as *Lymantria dispar* or *Catocala* sp.

In the same way, certain perforating insects (species of the genus *Ips* in conifers) require the maintenance of certain moisture levels in the decaying wood in which they develop their larval and feeding galleries. The rapid desiccation of the plant material prevents these from being detected by the imagoes, hindering development.

9.9. IMPLICATIONS FOR POLICIES

9.9.1. Forest management based on the promotion of intra- and inter-specific diversity.

In general terms, forestry has traditionally been identified with the activity aimed at the establishment, conservation and commercial exploitation of forests. This may therefore appear to be unimportant from the environmental point of view, but the current objective of forestry management, without renouncing the commercial use, lies in the need for human intervention in order to maintain or re-establish the functional efficiency of existing managed forests.

According to the permanent forest theory, it is the forest that should establish the degree of intervention for the forestry manager, and not the other way round. This means that man's objectives should not prevail over the demands of the forest. This way of understanding the forest and the management thereof considers the forest as the subject of forest exploitation, and not the object.

Furthermore, the consideration owed to the forest as a space of public use, due to vital role it plays as a provider of goods and services of public interest, is not sufficient reason to defend the abandonment or non-use of forests, or non-intervention therein. If it is necessary to give priority to the long-term interests over the more immediate commercial ones, it is also true that the persistent and preconceived hostility towards the application of forestry techniques as the only way to manage the forest, with some claiming that non-use is the most efficient form of conservation, makes no sense, because, apart from not being based on coherent and realistic scientific arguments, it may not be legitimate or comprehensible in the technical sense, as it does not permit the forest microcosm to be observed as it really is, sometimes different from what we would like it to be.

It is at the meeting point between the maintenance and improvement of the biological functioning of forest systems, and the exploitation of the goods produced, commercial or not, where forestry management finds its place.

If, as has been previously mentioned, it is the ecological conditions that impose the type of management to be applied to a forest, then it is obvious that if these specific conditions were to change, there should also be a change in the type of management applied. The general idea is quite easy to take in, but in practice, climate-forest management relations operate within a broad context, which has not been quantified. With regard to vegetation, a significant climate change is considered to have occurred when conditions change in relation to quantity to the extent that the effects thereof cause modifications in the life/survival strategy of forest species, with a possible change in the dynamics and composition of the forest flora. This is when the existing vegetation, adapted to the previous climate, finds it difficult to survive in the new climatic conditions.

There are numerous studies of climate change, but few of them consider the phytological significance of these changes, which is the most interesting aspect with regard to designing strategies for mitigating the effects of the changes. Knowledge of vegetation and study of past climate allow the basic conditions to be identified. There is a certain degree of uncertainty, however, in relation to the characteristics of the final climate to which the present apparent changes have led or might be leading.

In general, the change tendency appears to indicate greater aridity resulting from a temperature increase and reduced rainfall. This tendency or change, when it occurs, is considered to be harmful to the vegetation in areas with a Mediterranean arid or semiarid climates. To the contrary, in areas in which thermopluviometric variations have no limiting effects, vegetation could be favoured, and there might be a consequent increase in productivity and even in diversity.

9.9.2. Promoting forestry interventions capable of mitigating the change

During the last drought that lasted from 1994 to 1995, numerous visual observations of forests were made in an attempt to establish relationships between the degree of mortality of the trees through drought and the type of forestry treatment being applied. On specific occasions, there appeared to exist certain cause-effect relationships, which rarely stood up to greater generalisation (Fernández and Montero 1993). Generalist studies that establish tendencies, generally weak ones, between forest density at a given moment and its response to a possible and not very well-determined climate change, are indicative and useful for establishing future behaviour patterns, but they certainly do not guarantee a quantified cause-effect relationship, not even within a broad interval of forest density responding to a quantified climate oscillation or change in similar terms.

It would seem that climate change does not yet involve a large-scale change in biological vocations (Allué 1995a, b). Only in some sites, with arid and semiarid climates, might there be any warnings of future climate. These cases might justify the initiation of forestry treatment aimed at absorbing the effects of climate change.

In order to design forestry actions, the application of which can be justified, there must be evidence that a climate change has occurred and that this will persist in the future and is considered to be incompatible with the existence of the present vegetation. Furthermore, we must also consider, where possible, the preservation of species of special interest, helping them, during a transitory period, to accelerate their adaptation, for example, by changing vegetative regeneration to sexual regeneration, modifying densities in proportion to the change occurred, etc. If the amount, persistence and/or speed of the change do not allow the vegetation to readapt to the new climatic conditions, forestry management alone will not be able to absorb the change process without incorporation large amounts of energy, such as irrigation, fertilisation and other types of protection, as is done in agriculture. In our opinion, the techniques for buffering the effects of this or of other processes should have a temporal horizon limited to the period of time that these effects last, the causes of which should be combated with the use of other types of measures.

To end with, in our opinion, uncertainties for the future can be dealt with, provided that we are aware that we will always have certain doubts. Management of forest systems could serve as a tool for transitorily absorbing the effects of the change. Reducing the tree sensitivity by selective thinning of trees could attenuate the effects of drought for short periods of time. If the change were to persist, it would become necessary to apply more complex forestry techniques, including the spatial-temporal programming of the forests, adapting intervention to determined moments of the life cycle of the species to be maintained or protected from the effects of the new climatology.

If the change is permanent and remains stable over time, it will become necessary to define a new type of forestry management adapted to the new climatic conditions and to the new evolutionary dynamics of the plant communities that have been established as a consequence of the changes. As always there will be a need to apply a type of forestry management appropriate to an ecological environment, accompanying and helping, on occasions, the evolution of the natural vegetation and not attempting to absorb the influence of natural factors affecting this environment.

9.10. MAIN RESEARCH NEEDS

9.10.1. Priority lines of research for learning of climate change and absorbing the effects thereof on forest systems

A. Basic aspects

- Quantification, structure and dynamics of the carbon accumulated in forest formations and shrublands. Aerial and root parts and carbon in the soil.
- Measurement of photosynthesis and carbon flow in forest systems.
- Models simulating biomass growth in forest systems, with particular emphasis on models of processes.

- Current carbon balance in the main forest systems and the possible influence of climate change therein. Consequences for forest management.
- Identification of the main eco-physiological factors limiting the natural regeneration of forests.
- Influence of climate change on vegetation displacement and modifications in plant cover.
- Evaluation of the adaptational variation among origins.
- Effects of climate change on forests. Design of indicators for detecting climate change for the establishment of early warning systems.

B. Applied aspects

- Experimental methods for estimating the aerial and root biomass of the main forest species, for rapid valuation as carbon sinks. Adaptation to the National Forest Inventory.
- Quantification of biomass expansion factors for the main forest species. Application to the National Forest Inventory.
- Development of methodologies for estimating biomass in shrublands and underbrush.
- Optimisation of management practices aimed at promoting the efficiency of forests as carbon sinks. Carbon forestry management.
- Application of forestry techniques for mitigating the effects of climate change in forests.
- Study for the partial substitution of construction materials obtained from highly pollutant processes by other, renewable natural resources.
- Estimation of the average life of the different forest products and the valuation of these as temporary carbon stores.
- Economic possibilities for energy use of forest waste (remains of cortas and others).
- Development of cultivo techniques and selection of species and clones for the creation of biomass for energy production.
- Agro-forestry cultivo techniques (agricultural crops interspersed among broadleaf plantations) as an instrument to satisfy the requirements of the Kyoto protocol.
- Study of the factors limiting the use of the forestry flexibility mechanisms established in the Kyoto Protocol. Emissions trading, MDL AND AC projects. Socioeconomic valuation, methodology and credit allocation.

9.10.2. Identification of future integrated projects.

The 2004-2007 National Scientific Research, Development and Technological Innovation Plan includes additional priority lines in the National Programme of Agroalimentarias Resources and Technologies, aimed at facilitating and promoting the contribution of the Agricultural Sector to reducing greenhouse gasses.

These research lines should be jointly studied by groups of researchers and experts from the Ministries of Education and Science; Environment; Agriculture, Fisheries and Foodstuffs; Industry and Technology, etc. The purpose is to define joint projects, consistent with regard to content and committed in relation to funding; thus, the Scientific Community will work towards solving specific problems that have been well identified by the specialists in charge of economic policies and management of energy resources.

The big electricity companies, or big consumers of energy should necessarily participate with the Scientific Community and with the Administrations involved.

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