COST action FP0703 – ECHOES

Expected Climate change and Options for European silviculture

Country report

France

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Introduction

French forests encounter various biogeographical and institutional conditions; they have largely been modified along time by people and are today in Europe amongst the largest in comparison with other countries (see box 1). Since about four decades, changing growth conditions in the French forests have been highlighted for several reasons which themselves varied along time. Between the seventies and the eighties, some forest degradation signals appeared in France, for instance in North-Eastern mountains. They were attributed to air pollution but specific research studies showed also the major role of droughts around the year 1976. They encouraged forest policy makers to monitor quantitative forest resources and also forest health.

Interested in the historical origins of this decline, Becker (1987) initiated dendrochronology analyses, for fir first, then for several broadleaved and coniferous species. Surprisingly, he showed that annual rings were not reducing but, quite the reverse, had been increasing over the past century. Among the possible reasons for this productivity increase, the three main ones were nitrogen depositions, global warming, and a higher atmospheric concentration of carbon dioxide. Although the contributions of the two last factors were hardly known for the past, they illustrated the forest capacity to mitigate climate change.

Between 2001 and 2004, the research project CARBOFOR (Loustau [coordinator], 2004) aimed at analyzing this role, as its name renders. But it investigated further the way forests could be modified by climate change. The publication of maps displaying the shift, during the 21st century (cf. chapter 1.2.2.2), in the potential distribution of various forest ecological groups and main species under a moderate scenario (B2) struck many French foresters by the range of the phenomena. Its effect was all the stronger that it came after two other outstanding events: the 1999 windstorms that hit two thirds of the French forest area and felled about 8% of the growing stock; and the 2003 drought and heat that raged over a huge part of Europe and caused a large additional mortality, extensive forest fires and a significant growth reduction for the remaining trees.

As a result a new consciousness of possible impacts of climate change on French forests was born and led to various initiatives in order to answer the questions raised by forest managers, to initiate forest management adaptation and to identify the lacks of knowledge. In this perspective, strategic issues have been provided by several authors, in particular Roman-Amat (2007) who wrote a special report for both ministries in charge of agriculture and ecology. Such issues, including mitigation, have also been discussed in the frame of the participatory approach that has been decided in the environmental field by the French President in 2007, organized by the Ministry in charge of Sustainable Development and named “Grenelle de l’Environnement”[1].

Finally, forests have usually been managed according to predictions of future growth and a relative stability of the economic and environmental context. Past trends already invalidate such hypotheses; but the climate change still adds reasons to take explicitly changes, variability, opportunities, uncertainties and unknowns into account.

[1] This name comes from the agreements negotiated in 1968 between the French government and trade unions at the end of a troubled spring. The discussion was held in the Ministry of Employment, located in Paris in the so-called Grenelle street. This very participatory and open debate was quite unusual at that time and remains as a reference.

Box1: short description of French forests

Metropolitan France belongs to four biogeographical regions (Atlantic, mountainous, continental and Mediterranean). This diversity has to be taken into account when studying climate change impacts as well as when implementing adaptation and mitigation strategies.

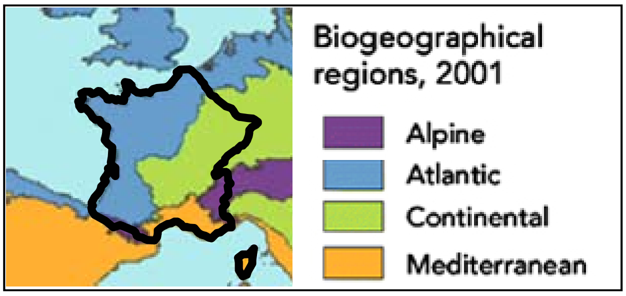

Figure 1 : Biogeographical regions of France (from European Environment Agency, 2001).

In metropolitan France, almost no natural forests are remaining. Most of wooded lands have been used more or less intensively by human beings since the recovery after the last ice-age. As a result, forests are either sub-natural or man-made. Sub-natural forests are generally more diverse (in species, ages and general structure) with longer life cycles.

French forests are amongst the largest in Europe,:

- their area is about 16 million hectares (ha) or 28% of the French territory;
- their growing stock is near to 2.3 billion cubic meters (m^3) of solid wood or about 160 m^3/ha;
- their current annual volume increment approximates 100 million m^3 of solid wood or 6 to 7 m^3/ha/year on average;
- the corresponding net carbon sink exceeds 80 million tons of carbon dioxide (CO_2) equivalents per year;
- roundwood removals for industrial and domestic energetic uses are estimated to be two thirds of the annual net increment; the remaining one third results in a rapidly increasing growing stock and explains the significant forest contribution to the annual carbon sink.

Beside its European part, France comprises also overseas territories with additional forest areas of more than 9 million hectares[2]. The most remarkable of them is French Guiana with 8 million hectares of tropical rainforests and approximately the same growing stock than Metropolitan French forests[3]. However, due to their very particular features compared with European regions, these overseas territories are not dealt with in the main part of this report.

French metropolitan forests are not only biogeographically diverse but also institutionally. Over one fourth of their area belongs to public institutions including the State and more than ten thousand communes. The other three quarters (or almost) are private, mainly non industrial ones, and distributed among 3.5 million owners; two thirds of these private owners are individual persons or households and more than fifty percent of them are retired. Since usually forestry is not the main activity of forest owners, forest policy plays an important role in order to stimulate sustainable forest management through regulations, incentives and technical assistance.

[2] Mayotte 5 000 ha, Réunion 84 000 ha, Wallis et Futuna 6 000 ha, Nouvelle Calédonie 717 000 ha, Polynésie française 105 000 ha, Guadeloupe 80 000 ha, Martinique 47 000 ha, Guyane 8 063 000 ha, Saint-Pierre-et-Miquelon 3 000 ha (from « Situation of the world forests 2005 », FAO/ECE).

[3] 2 822 million m^3 or 350 m^3/ha.

1. Impacts

Observed impacts are the basis of problem identification and understanding. They allow simulations in order to predict **expected impacts**. Forest monitoring is the best way to detect and study impacts; its improvement is thus a real challenge in order to better identify, understand and predict **climate change consequences**. Some impacts appear progressively according to trends and can be taken into account as they go along. But many consequences result from extreme events (such as storms, floods, droughts, outbreaks…) that cause crises; **crisis management** has thus to be implemented when the event has just occur; it has also to be anticipated long before it happens.

Following this rationale, this part deals successively with observed (past or present) French impacts, expected (future) impacts, impact monitoring and impact (crisis) management.

1.1. Observed impacts

In this section, described facts are probably linked with forcing by radiations and climate change but also with several other phenomena and particularly nitrogen depositions (cf. paragraph 1.1.2.4). One major challenge of research is thus to attribute these facts more precisely to their possible driving forces. Indeed, such attribution is necessary before the elaboration of models aiming at predicting future changes. It is still however unclear in many cases and this will be discussed whenever possible.

1.1.1. Observed climatic evolution

(Moisselin and al., 2002)

As climate change is a major driver of changes in forest stands, flora and fauna, it needs to be presented at first.

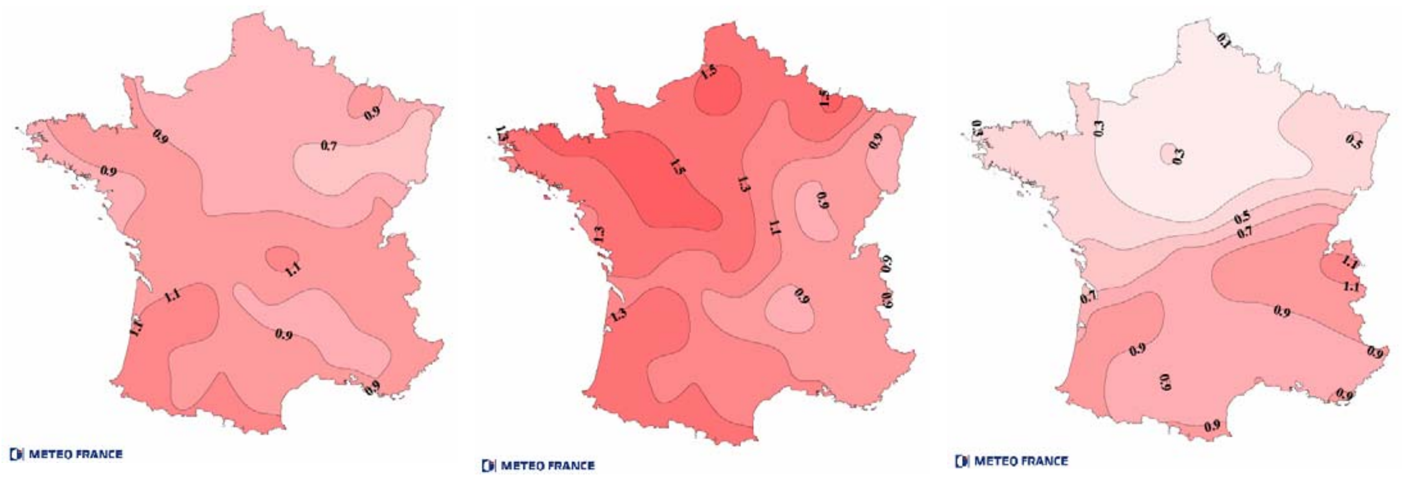

Figure 2 : Observed increase in °C of the average annual temperature (left), the minimal temperature (centre) and the maximal temperature (right) from 1901 to 2000 (source: Météo-France).[4]

In France, during the last century, the average temperature rise was between +0.7 and +1.1°C, which is higher than the international increase (+0.7°C). This increase corresponds

[4] http://imfrex.mediasfrance.org/web/resultats/index

to a climate shift toward North of an average 180 km. This rise more affects the minimal temperatures (+0.7 to 1.7°C, with an augmentation higher in summer) than the maximal ones (+0 to 1.3°C). The evolution was different between regions: +1.1°C in the South western regions, less for the others (see previous figure). There is a spectacular decrease of the daily amplitude (difference between maximal and minimal temperatures), mainly in Northern France.

Regarding precipitation, the average rainfall has been rising with a 0.5 to 1% per decade increase except, but not statistically significant, the Southern France. Some contrasts between North and South have appeared: the De Martonne index[5] shows some local dryness areas in Southern France whereas in North the both increase of rainfalls and temperatures leads to a more humid climate.

The seasonal contrasts are more important: summer warmed up more than winter, winter precipitations significantly raised up in one third of the cases whereas summer precipitation decreased not significantly.

1.1.2. Impacts on ecosystem dynamics and functioning

Impacts on ecosystem dynamics and functioning do not include the effects of extreme events that are dealt with further. They affect vegetation phenology and distribution, fauna phenology and distribution, and finally global productivity.

1.1.2.1. Vegetation phenology

As in the agricultural sector where long times series have been elaborated, for example for apple trees (Seguin, 2007) and grapes in vineyards, and have shown very significant changes as regards the harvest period (Chuine *et al.*, 2004), forest vegetation phenology is studied in the context of climate change and several interesting results have been produced. Contrary to other impacts on ecosystem dynamics and functioning which are influenced by global warming and by other environmental changes (like nitrogen depositions) climate change is the only factor which explains the observed phenological modifications.

A study of stands in the Renecofor network (level 2 plots of the European monitoring network) was recently carried out, over the period 1997-2006, in order to model the relationship between geographic and climatic parameters, and phenological phases (Lebourgeois and al., 2008). The modelling processes highlight the influence of climatic parameters like spring and autumn weather conditions (Turc potential evapo-transpiration[6] and/or temperature in March and October) on the phenological stages (bud burst, yellowing…). A 10 mm increase in potential evapotranspiration in March advances budbreak from 4 to 9 days depending on species. For temperature, a 1°C increase in March speeds up bud burst by 2 to 5 days.

A review on leaf unfolding dates variability in major forest trees shows that leaf unfolding has been advancing at a mean average rate of 2.9 days per decade since 1950 in tree species

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[5] De martonne index (mm/°C) = R/(T+10), with R the annual rainfall (mm) and T the average annual temperature (°C). The higher this index is, the more humid the climate is.

[6] For a relative humidity > 50% (monthly average), Turc potential evapo-transpiration (mm/month) = 0.40(T/(T+15))(Rg+50), with T the monthly average temperature (°C) and Rg the global solar radiation (cal/cm²/day).
For a relative humidity < 50% (monthly average), Turc potential evapo-transpiration (mm/month) = 0.40(T/(T+15))(Rg+50)(1+(50-Hr)/70), with Hr the relative atmospheric humidity (%).

from the temperate zone, with some species variation (CARBOFOR project, coordinated by Loustau, 2004). The observed changes in tree phenophases during the last decades show that leaf unfolding, growing season duration and leaf colouring have shifted in the last few decades to earlier dates than those previously observed.

There is an ongoing project in order to create a general database and to enlarge the network of phenological observations. This project concerns not only but mainly forestry ((Network of phenological observations for climate change impacts management, SIP-GECC). The data base has not been analysed yet.

Moreover, some data that have not been collected in order to study climate change may be used for that new purpose. For example, some specific data have existed since 1979 for 50 clones of Douglas fir (*Pseudostuga menziesii*) and controlled crosses (Bastien, personal communication). The date of controlled crosses is linked to a particular stage of female flowers. The date of the first controlled crosses (most early clone) varies a lot but the date of the last one (latest clone) is less variable and can be used as a reference. It becomes earlier and earlier. During this 24-year period, the dates of the last controlled crosses have been occurring 17-18 days earlier (see Figure 1). This analysis should be improved in order to show in particular the clone effect, but similar observations exist also for larch (*Larix decidua*).

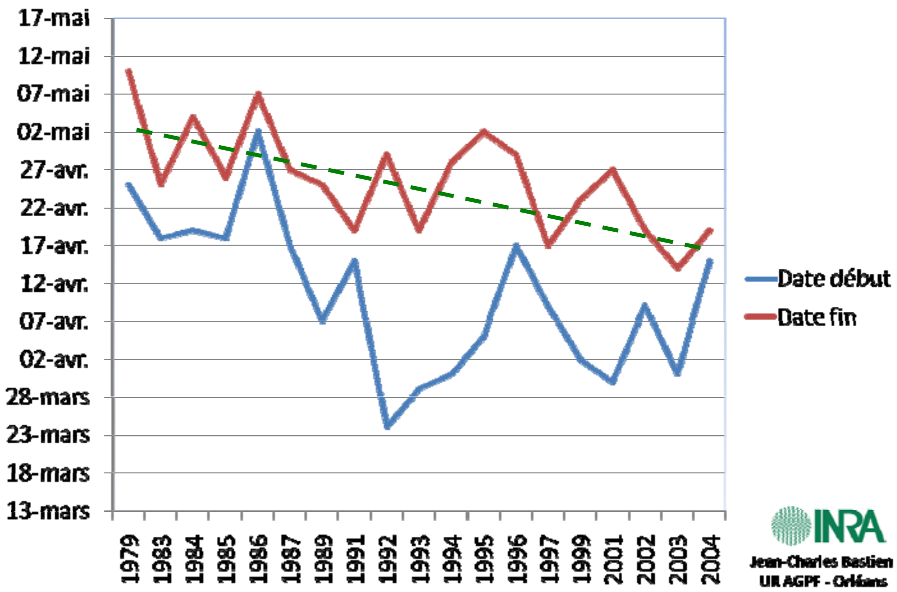


Figure 3 : Dates of controlled crosses in March, April or May for Douglas fir. In blue (below) the date for the earlier clone; in red (above) the date for the latest clone; in green the general trend for these last controlled crosses (BASTIEN JC, INRA, personal communication).

Other data could certainly be used, regarding for example crop frequency of acorns or beech nuts and its consequences on natural regeneration, but they have not been synthesised yet.

1.1.2.2. Vegetation distribution area

With climate warming, vegetation is supposed to shift towards the North and upwards. Regarding the temperature increase, that has been experienced until now in a rather short period, mainly for some three decades, shifts upwards have certainly been easier to observe and characterize.

Many empirical observations are carried out at the ranges of different species distribution areas . Some diebacks are noted for example for beech (*Fagus Sylvatica*) at Chizé (Central West), Douglas fir (*Pseudostuga menziesii*) in the Black Mountain (South), Scots pine (*Pinus sylvestris*) in the Mediterranean Alps… Their reasons are not totally elucidated but climate change could be a major factor.

The altitudinal distributions of 171 forest plant species have been compared between 1905 and 1985 and 1986 and 2005 along the entire elevation range (0 to 2600 meters above sea level) in France, and more particularly in Western Alps, Northern Pyrenees, Massif Central, Western Jura mountains, Vosges mountains, and Corsican range (Lenoir *et al*., 2008). These comparisons showed that climate warming has resulted in a significant upward shift in species optimum elevation averaging 29 meters per decade. The shift is larger for species restricted to mountain habitats and for grassy species, which are characterized by faster population turnover. Their study shows that climate change affects the spatial core of the distributional range of plant species, in addition to their distributional margins, as previously reported. In the same way, Vennetier (2005) noticed an upward shift of 150 m for Aleppo Pine (*Pinus halepensis*) in the Sainte Baume Massif (Mediterranean mountain) for the last century.

According to Dupouey and *al.* (2005), global warming effects on vegetation range remains small compared with other major evolutions that are affecting the forest environment: acid rains, nitrogen depositions, increase of the growing stock, natural and man-made afforestation, intensification of silvicultural practices, voluntary or chance introduction of new species… All those factors have certainly played together a greater role than global warming for vegetation dynamic. For example, nitrogen inputs are favourable for ocaeanic species and nitrogen depositions (from agriculture, industries and transportations) are moving by wind from West to East and thus from low elevation areas to mountain barriers. This fact could explain, at least partly, the upward shift of vegetation in the French mountains.

1.1.2.3. Insects, parasites, pathogens

Due to global warming, more generations of parasites per year are observed, with a development toward the North of the distribution area of the species. For example, during 2003 drought, bark beetles like *Ips typographus* and *Pityokteines curvidens* realized one more generation leading to important disasters (Nageleisen 2004, OFEFP 2005; quoted by Candau, 2008). Other species need several years to realize one whole life cycle but for some ones, their life cycle is now shorter, only one year, which also leads to pullulations and important disasters (Battisti and al. 2000; quoted by Candau, 2008).

One of the most famous examples[7] is the processionary caterpillar (*Thaumetopoea pityocampa*) which has moved upward in the Alps (49.7 m/decade significant upward shift), the Pyrenees and the Massif Central. It also has progressed toward the North during the last 30 years (27.1 km/decade in the Paris Basin, with a maximum 55.6 km/decade-speed for 1994-2004 period) (see Figure 4). It has been proven that the larvas are able to surviving in winter because of the minimal temperature rise. Nevertheless, the 2003 high temperatures led to a death increase of processionary caterpillar's eggs.

[7] http://www.inra.fr/layout/set/print/presse/la_chenille_processionnaire_du_pin_remonte_vers_le_nord_a_la_vitesse_moyenne_de_55_6_km_par_decade

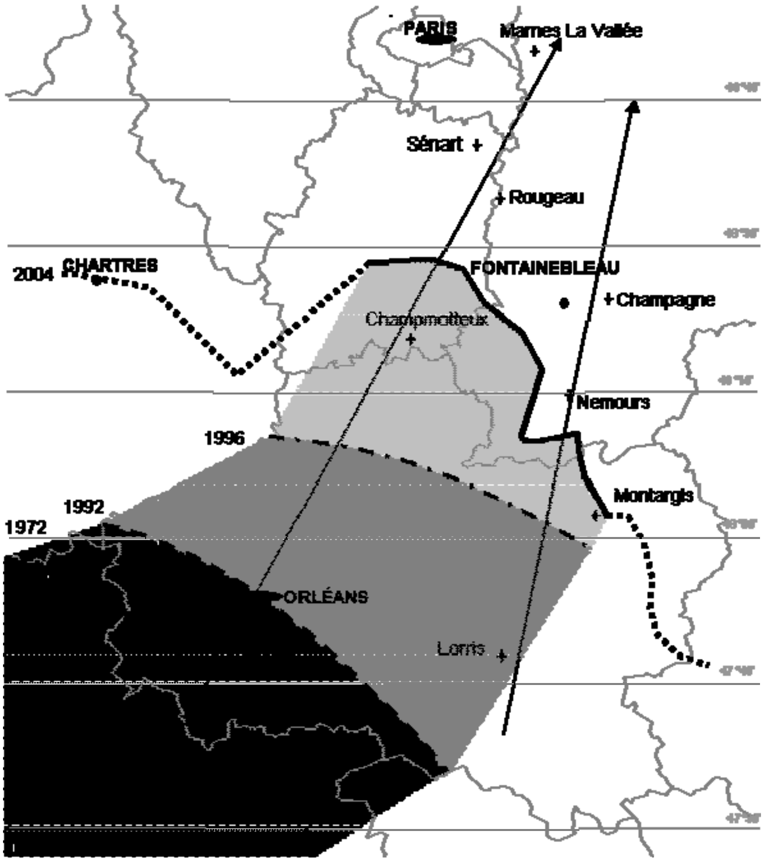


Figure 4 : Shift of the processionary caterpillar's distribution area toward North during the last 30 years, in the Paris Basin.

There are also observations about invading species like butterflies[8]: Small monarch of Africa (*Danaus chrysippus*), Brown Pelargoniums (*Cacyreus marchalli*) a geraniums and crane's bill parasite, *Cameraria ohridella* a common horse chestnut parasite (*Aesculus hippocastanum*). All these butterflies come from North Africa and are now in Southern France (Lhonoré and Bouget, 2003).

Concerning pathogens, the comparison between observations made in the seventies (Lanier and al., 1976; quoted by Marçais and Desprez-Loustau, 2007) and the more recent Forest Health Department's database shows a development of diseases caused by thermophilous pathogens (e.g. favoured by high temperatures). Marçais and Desprez-Loustau (2007) pointed out different pathogens like red band needle blight (*Dothistroma septospora*), chestnut canker (*Cryphonectria parasitica*), chestnut and oak ink (*Phytophthora cinnamomi*). Another example is oak oïdium (*Erisiphe alphitoïdes*) which has been developing for the last 15 years in South-western France, following mild winters.

1.1.2.4. Global productivity

During the period when acid rains were studied (1986), a French researcher, Michel Becker, had analysed tree rings in order to find the historical origins of this forest decline. However, contrary to his expectations, he found a general increase of ring width since the end of the nineteenth century, and thus a productivity increase (Peyron, 2007). The same result was obtained in Germany and has been confirmed then for many species in many parts of Europe. This increase is today partly attributed to climate change (through warming and carbon dioxide fertilisation) but probably mainly to nitrogen depositions from agriculture and

[8] http://www.cemagref.fr/Informations/Actualites/Actu/chgmt_climat/invasion-insectes1.htm

transportation.

For oceanic and continental forests, Bontemps (2006) noticed also an increase of forest productivity, particularly in the Northern oak stands with a twofold increase. Like Becker, Bontemps attributes this evolution mainly to nitrogen depositions. Indeed, between 1940 and 1980, temperature and precipitations were stable whereas productivity increased, thus global warming cannot explain the evolution of productivity. Since productivity increased more in Eastern than in Western France, and more in the North than in the South, since emissions are more numerous in Northern France and because winds are mainly oriented from West to East, nitrogen depositions could have been a major driver until now. However, in the future, the role of warming and carbon dioxide concentration could be larger (see paragraph 1.2.2.4).

Regarding Mediterranean and mountainous Mediterranean forests, in the Sainte Baume Massif, Vennetier (2005) pointed out an increase of the radial and height growth for Aleppo pine (*Pinus halepensis*) which is a typical Mediterranean species, whereas Scots pine (*Pinus sylvestris*), a species more mountainous, strongly decreased (see Figure 5) during the last century. Nowadays, when the two species are together in the same stand, the Aleppo pine has a real better productivity than Scots pine.

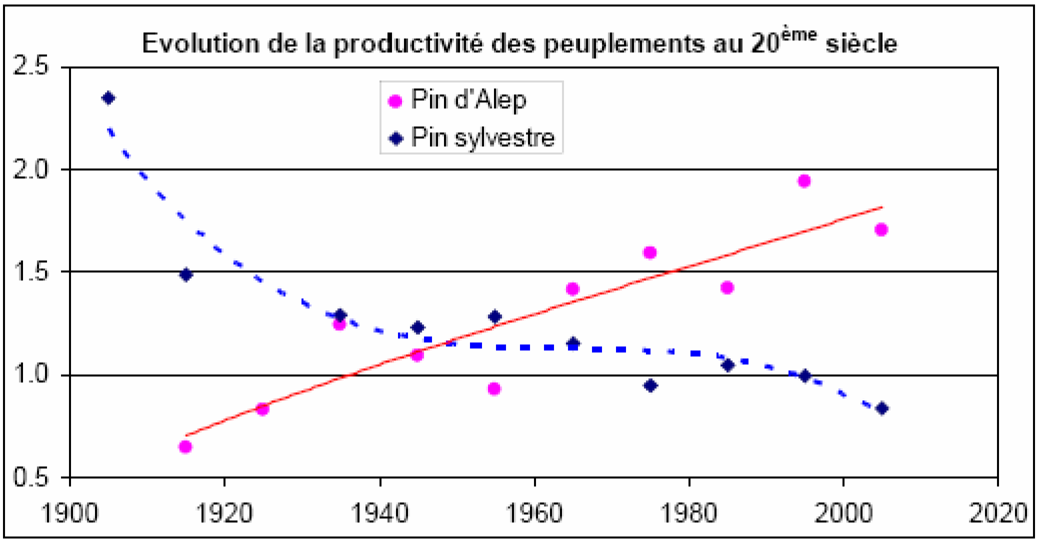


Figure 5 : Evolution of productivity index for average stands of Aleppo pine (around 400 m of altitude, in pink circles and red line) and Scots pine (around 1100 m of altitude, in blue diamonds and curve) during the 20th century.

1.1.3. Disturbances and extreme events

There were a lot of disturbances and extreme events in France: drought in 1976, 1989-90 and 2003, forest fires particularly during some dry years, windstorms in 1982, 1987, 1990, 1999 and 2009. But it is important to remind that there is not statistically-proved increase of the number and intensity of windstorms in France (Moisselin and Dubuisson, 2006). Only the major of them are discussed here.

1.1.3.1. 1999 and 2009 windstorms

At the end of 1999, two windstorms struck France, one in the North (Lothar on December 26th) and one in the South (Martin on December 27th and 28th). They felled about 170 million cubic meters, approximately three French annual harvests. Immediately after them and during the first semester of year 2000, a scientific expertise (Birot and al., 2000) was carried out in order to answer two main questions: how to explain the level of the observed impacts? What are the scientific and technical backgrounds in order to rebuild the forests? This expertise was followed by a research program, coordinated by ECOFOR and supported by the Ministry in charge of Agriculture and the Ministry in charge of Sustainable Development, INRA and CEMAGREF. All the studies dealt with forest, wind and the different risks (economic, pathologic, biologic diversity…).

On 24th of January 2009, a violent storm Klaus struck the South-West of France less than 10 years after Martin and produced more damages in Aquitaine than Martin (40 million cubic meters, mainly of maritime pine [*Pinus pinaster*]). Over 230 000 ha of forests were affected with at least 40% of the trees bowled over or broken.

Even if windstorms frequency has increased during the last 30 years in comparison with the previous decades, there is no general trend at the century level: the storm activity simply became the same now than at the beginning of the 20th century (Birot and *al*., 2000). With the great interdecade variability and the short statistic series, it is impossible to deduce now an increase of the phenomenon and to link it to the climate change. But, at the same time, the standing volume per hectare has considerably increased, thus forest is more vulnerable to this kind of event.

1.1.3.2. 2003 drought and heat

- ***Impact on oceanic and continental forests : example of oak***

During or just after the drought, mortalities were observed because of physiologic constraints on non favourable forest sites. That is the case, for example, of pubescent oak (*Quercus pubescens*) deaths on South sides in the Prealps. The year after, in 2004, a second step of mortality was observed in several regions (Lorraine, Centre, Midi-Pyrénées…) because of insect outbreaks (*Agrilus biguttatus*, *Scolytus intricatus* in particular). These two steps were followed three-four years later by another wave of mortality induced by a complex mix of biotic and non biotic factors (Nageleisen, 2008). After 1976 drought, the oak diebacks were observed until mid eighties.

Particularly for common oak (*Quercus robur*), many dieback observations are in fact the result of the succession of various climatic constraints (soil saturations on 1999, 2000 and 2001 springs, dryness on 2003, 2004 and 2005 summers) and insect outbreaks (2005 defoliation because of caterpillars). In addition, those phenomena occurred mainly in overcrowded stands (over-accumulated volume per hectare). As a consequence, it is hard to analyze the most important original factor.

- ***Impact on Mediterranean forests***[9] *(Vennetier, 2005*)

In Mediterranean region, tree growth begins at the end of the winter, so the 2003 summer dryness did not seriously affect growth for this year. The immediate symptoms were a loss of needles and leaves (30 to 80% for Aleppo and Scots pines [*Pinus halepensis* and *Pinus sylvestris*]), a desiccation of roots for all the trees and twigs for deciduous trees. One to three years later, needles and leaves size decreased (30 to 40% for Scots pine), growth also decreased. Some diebacks were observed especially for Scots pine at low altitude. Past droughts experience showed that these effects could persist during 3 to 7 years. All these phenomena were exacerbated by other dryness, less important, from 2004 to 2006.

[9] http://www.cemagref.fr/Informations/Actualites/Actu/chgmt_climat/index.htm

The REFORME project (coordinated by Guiot J., CNRS) highlighted also the drought influence on phenology. For Aleppo pine, with the 2003 heat wave, there was a reduction from 30 to 60% of needles size, of formed needles number, of annual shoot length on branches and fructification. The polycyclism disappeared almost entirely after 3 years of drought. The utilized model BILHY showed a wood production loss, about 30%.

Brushwood and garigue were also concerned by an intensive dieback. Even typical Mediterranean species, like rosemary (*Rosmarinus officinalis*) and kermes oak (*Quercus coccifera*) died on bad soils.

In conclusion, for Mediterranean forests, the global warming will have several consequences: decrease of the productivity, forest dieback and increased forest fire risk because of huge dry biomass (leaves, needles, branches…) (see figure below).

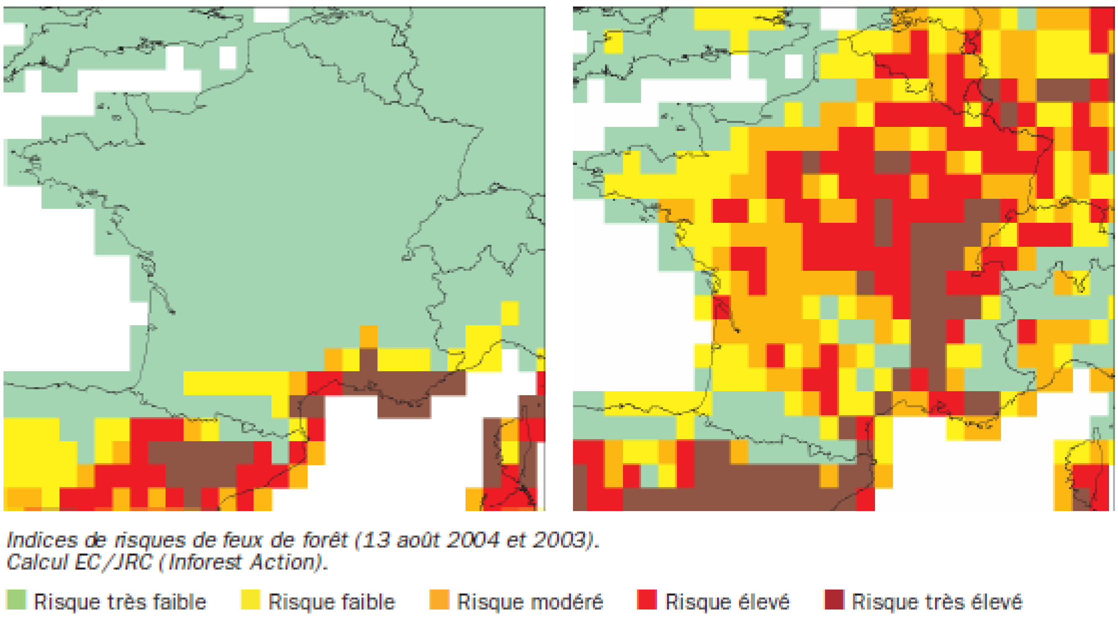


Figure 6 : Expansion of the area with a forest fire risk between a “normal” summer (2004, left) and a dry and heat summer (2003, right): in green very low risk, in yellow low risk, in orange moderate risk, in red high risk and in brown very high risk.

1.1.3.3. Impact cost

The Ministry in charge of Sustainable Development has initiated an interministerial task force in order to analyse "Climate change impacts, adaptation and associated costs in France". The will is to highlight climate change impacts on some important sectors such as health, agriculture-forests-water resources, construction and transportations, energy, tourism, natural risks and insurance, land use and biodiversity. The work is in progress, particularly in the forest sector with a project led by FCBA in link with the University of Paris Ouest Nanterre La Défense. The objectives of this study are to assess the (i) direct costs (and benefits) of impacts of climate change on forests and industries, and (ii) the costs and benefits of adaptation measures.

In the past, analyses have been made in order to value losses and costs due to storms (after 1999 storms) and to drought and heat (after 2003 drought and heat). Although these approaches concerned only two specific aspects, they could be useful in order to value the impacts of climate change both for their methodology and their results. The losses associated with 1999 windstorms and 2003 drought and heat in France were estimated to be respectively about 6 million Euros and 1 million Euros for forest owners, insurance companies and French government (Birot, Peyron, 2009).

1.2. Expected impacts

Past and recent impacts are mainly based on observations. Models could only help in attributing them partly to climate change. On the contrary, expected impacts are mainly based on several kinds of models: Global Circulation (climatic) Models (GCM) on a worldwide scale; regional climatic models that realize a downscaling of the previous models in order to take into account local factors influencing local climate; vegetation models that represent vegetation behaviour, including forest impacts in climate evolution; other models according to the objectives and the needs, concerning for example fauna. Moreover, all these models depend on 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 of the international panel on climate change: SRES-IPCC).

1.2.1. Expected climatic evolution

The expected climatic evolution is determined by two French models: IPSL-CM4 of the Pierre-Simon Laplace Institute and CNRM-CM3 of the National Center of Weather Research (Météo-France) whose atmospheric part is the Arpège-climat model. These models are more or less accuracy (respectively 50 and 160 km for the two models) and with some differences. They are just utilized in order to give the great climatic trends.

Mediterranean climate, defined by a water balance below -350 mm per year, would concern, at the end of the 21st century, 60 to 80 % of the French territory, depending on the GHG emissions scenarios (respectively B2 and A2). The main climatic forecasts are summed-up in the tables below.

Table 1 : French climatic forecasts for the end of the 21st century, depending on GHG emissions scenarios (Planton, 2004), in comparison with current situation.

	Scenario B2	**Scenario A2**
Average annual temperatures	+ 2 to 2.5°C	+ 3 to 3.5°C
Winter rainfalls	Increase of about 25% of the days with rainfall over 10 mm	
Summer rainfalls	General decrease (more important for A2)	
Heat-wave periods	7 days/year with maximal temperature over 35°C	14 days/year with maximal temperature over 35°C
Summer dryness	+ 4 dried days/year	+ 9 dried days/year

Table 2 : Expected evolution of temperatures and rainfalls in France, between 1960-1989 period and 2070-2099 ones, depending on GHG emissions scenarios (Planton, 2004).

	Temperatures (+)			**Rainfalls**		
	Annual	**Winter**	**Summer**	**Annual**	**Winter**	**Summer**
Scenario B2	+ 2 to 2.5°C	+ 1.5 to 2°C	+ 2.5 to 3.5°C	-5 to 0%	0 to +10%	-25 to -5%
Scenario A2	+ 3 to 3.5°C	+ 2.5 to 3°C	+ 4 to 5°C	-10 to 0%	+5 to +20%	-35 to -20%

Like observed evolution, there will be differences between regions (see Annex 1 for the detailed forecast with scenarios A2 and B2):

- number of consecutive dried days would increase more in South-West and windstorms frequency more in North,

- in Mediterranean region (and also in South-West), summer temperatures rise and spring rainfalls decrease would be more important than in other regions, with higher frequencies of dried periods and strong rains,
- the worse degradation of water balance would concern first the Alps, then mainly Mediterranean and South-Western regions for 2050-2080 period.

These models are quite good at the national scale. However, as they show some important differences between regions, it would be interesting to have more local climate forecasts, in order to anticipate the expected local impacts and the adaptive strategy to adopt. But the current models can not be used for that purpose.

1.2.2. Impacts on ecosystem dynamics and functioning

1.2.2.1. Vegetation phenology

If changes in phenology remain linear with global warming, CARBOFOR project (coordinated by Loustau, 2004) estimated, using present trends and based on scenario B2, that leaf unfolding should advance on average at a rate of 5.4 to 10.8 days per decade over the period 2000-2050. Thus, by 2050, leaf unfolding of forest trees could occur on average 27 to 54 days earlier than currently. A few species, with chilling requirements, would be delayed by warming climate. However, the dual action of temperature on phenology (i.e. the action of cool temperature to break dormancy followed by the action of warmer temperature promoting cell growth during quiescence) should lead to a non linear response of phenological change to warming.

1.2.2.2. Vegetation distribution area

The CARBOFOR project (coordinated by Loustau, 2004) modelled the geographical distribution of main forest species groups based on scenario B2 (IPCC-SRES, 2001). That was elaborated with automated classification techniques and multivariate models in two main steps: modelling of the vegetation distribution areas with current climate then modelling of potential vegetation distribution taking into account expected climate at the end of the 21st century with Météo France's ARPEGE-Climat model (based on scenario B2). Within expected climate conditions at the end of the 21st century, models show that the Mediterranean species group could eventually occupy the entire Southern half of France whereas the temperate oceanic species group could replace temperate continental vegetation. The potential area for alpine species group could be restricted to topmost areas in the Alps and Pyrenees. Most vulnerable species are those at their southernmost limit such as Scots pine (*Pinus silvestris*) and Beech (*Fagus silvatica*). The case of the beech, which could disappear from western and central areas of France, is illustrative. Conversely, holm oak (*Quercus ilex*) and maritime pine (*Pinus pinaster*) could have a dramatic increase of their French range.

This approach is based on statistical "niche" models. These models take into account the actual species distributions and the current conditions in order to determine the future potential vegetation pattern in expected conditions. But they do not take into account biological processes such as genetics, competition and evolutionary history. An alternative is "process-based" modelling, which aims to predict species distributions based on resource allocation, demography or competition. They are theoretically more robust than niche models, but require much more ecological knowledge and data (Thuiller, 2007).

Table 3 : Proportion in France of the distribution area of 7 species groups for current situation and for the end of 21st century depending on GHG emissions scenarios (CARBOFOR, 2004).

Group	Main species	Colour	Current %	2100 % (B2)	2100 % (A2)
Continental plain	*Pinus sylvestris, Fagus silvatica*		22.4	3.2	1.2
Centre plain	*Quercus robur, Castanea sativa, Carpinus betulus*		35.6	17.4	16.4
Oceanic plain	*Pinus pinaster*		17.2	45.9	30.8
Mediterranean	*Quercus ilex*		9.1	28.1	47.9
Subalpine	*Pinus cembra*		5.2	2.3	1.0
Mountain	*Larix decidua*		4.1	3.0	2.4
Mountain-hill	*Abies alba*		6.3	0.1	0.3

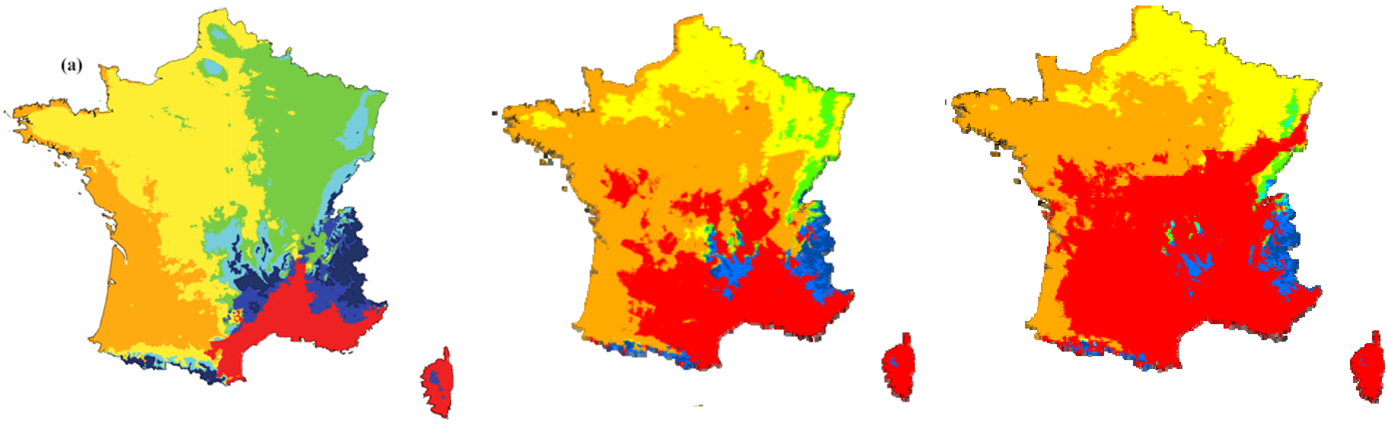


Figure 7 : Evolution of the distribution area of 7 species groups: current situation (left), modelling for the end of 21st century with scenario B2 (centre) and scenario A2 (right) (see the previous table for the colours; source: CARBOFOR, INRA).

Another project, named "Quantifying the effects of global environmental change on terrestrial plant diversity" (Qdiv, coordinated by Leadley P.[10]), is still in progress. Its main objective is to develop quantitative estimates of changes in plant community structure, spatial distribution and diversity in France that could occur due to climate and atmospheric CO_2 concentration changes. This work will be based on a combination of observations, experiments and mathematical modelling.

1.2.2.3. Insects, parasites, pathogens

Climate change impacts on forest pathogens (CARBOFOR, 2004) are mainly an extension of geographical area for species limited by low temperature or soil freezing. For oïdium species, the predicted warming would increase annual infections frequency from 10 to 50-70%. For poplar rusts (polycyclic species), a 1°C increase in mean air temperature leads to an 11-day advancement in the initial infection dates and a 33% increase in the proportion of infected tissues at the end of the growing season. But the evolution of rainfalls (decrease during growing season) will have different consequences on species depending on their biology. The two examples below (oak ink and chestnut canker) illustrate this difference of impact.

[10] www.qdiv.u-psud.fr

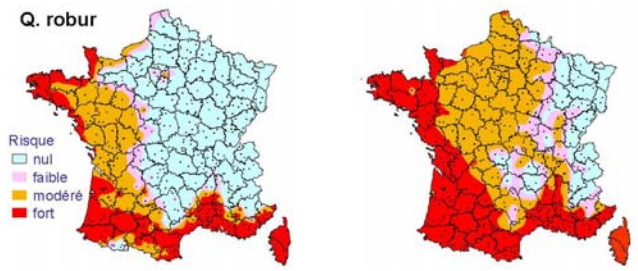


Figure 8 : Example of the risk of presence of oak ink (*Phytophthora cinnamomi*), on the left 1968-2008 situation, on the right 2068-2098 forecast with scenario B2 (blue: no risk; pink: low risk; orange: moderate risk; red: high risk) (source: INRA).

Chestnut canker (*Cryphonectria parasitica*), contrary to oak ink, would be in regression even if chestnut is more sensitive because of water stress. In fact, the rise of the temperatures during its growing season would be too high and not favourable to the development of this pathogen (Desprez-Loustau and al., 2007).

The past climate warming was less than the expected one for the next decades. Thus, for Candau (2008), **the expected modification for the insect distribution area** and phenology could be more important in the future. But, in the state of our knowledge, we cannot forecast insect population evolution and their impact on the forest ecosystems. Indeed, on one hand, the direct effects of warming, already observed (better winter survival, shift toward altitude and North of the distribution area, modification of the phenology), could probably be enhanced. But, in the other hand, indirect effects, like phenological de-synchronization between parasite and host plant, will be more difficult to detect and to analyse.

1.2.2.4. Global productivity

2 main trends could be observed for the growth and productivity of the stands (Roman-Amat, 2007; CARBOFOR project, 2004):

- an increase where the current temperature is the main limiting factor (particularly in North-East and in mountain), this increase is the consequence of growing season extension and photosynthesis improvement because of atmospheric CO_2 rise, on condition that water and nitrogen will not be limiting;
- a decrease because of water constraints, especially on soils with low water reserve, firstly in South-Western then a shift toward North and East; with the worse modelled scenarios, wood production and harvest could be strongly diminished for a large South part of France.

At the national level, these two trends will lead to a global increase of the annual growth until 2050, then to a decrease. Higher frequency of extreme events (dryness, forest fires…) should have a negative influence on future productivity.

Specifically for the Mediterranean forests, some growing vegetation modelling were carried out in the REFORME project (Response of the French Mediterranean forests to climatic changes; Guiot, coordinator, and al., 2007), based on B2 scenario. The comparison between evergreen oak (*Quercus ilex*) and Aleppo pine (*Pinus halepensis*) showed that both species arrive at a maximum of growth during the first decade of the 21st century, with a three times stronger productivity for Aleppo pine. Then, drought becoming more important, the species see their productivity diminishing till the end of the 21st century, of 28% for oak and 8% for pine. Pine seems to better resist to water stress. Due to fertilisation effect by CO_2 which increases the water utilisation efficiency, both species seem to resist quite well to water stress (with productivity slightly increased). A statistical approach carried out in parallel showed the importance of the delayed effect of extremes during the previous years. By degrading the health state of the tree and by subsequent defoliation, they are able to exponentially cumulate with several successive events. This delayed effect has therefore the potentiality to attenuate the fertilisation effect by CO_2. Finally Aleppo pine, likely by its capacity to early close its stomata, seems to better resist than evergreen oak.

Vennetier (2005) also simulated the evolution of Scots pine (*Pinus sylvestris*) and Aleppo pine (*Pinus halepensis*) in Sainte Baume Massif (South-eastern part of France). Scots pine, more mountainous species, is more sensitive to global warming (see Figure 9).

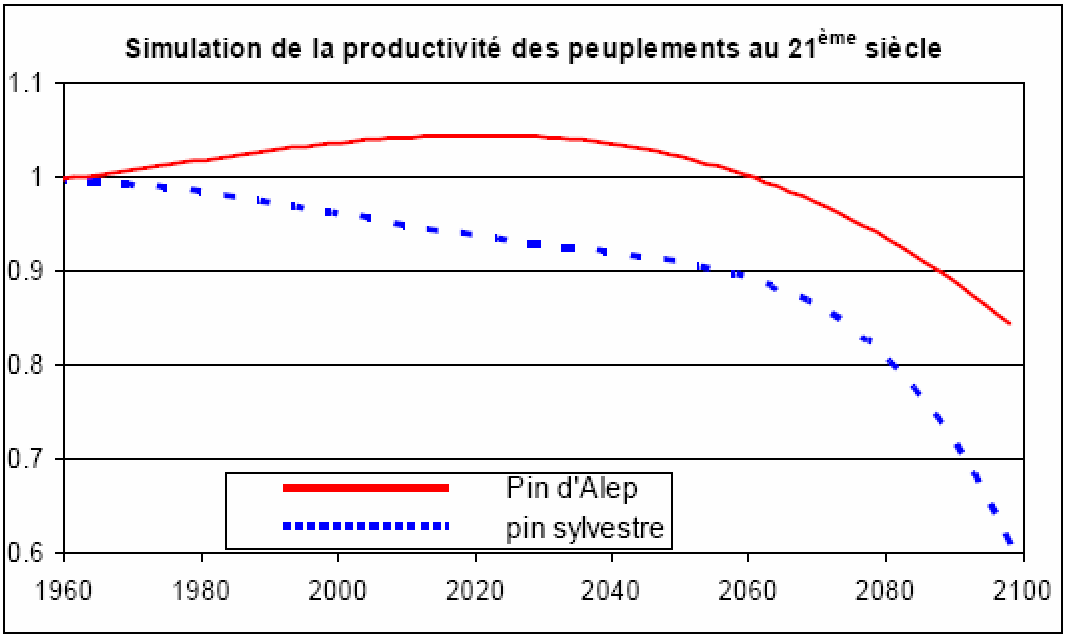


Figure 9 : Simulated evolution of the productivity for Aleppo pine (red line) and, a more mountainous species, Scots pine (blue line), during the 21st century in Sainte Baume Massif, without taking into account extreme events (Vennetier, 2005).

1.2.3. Disturbances and extreme events

Two projects are in progress in order to study extreme events influence, particularly drought, on forest ecosystems and main forestry species:

- DRYADE project (coordinated by Bréda N.): Forest vulnerability face to climate changes, from tree to bioclimatic areas[11];
- DROUGHT project (coordinated by Guiot J.): Mediterranean ecosystems face increasing droughts vulnerability assessment.

Vennetier (2005) points out also the influence of the dryness in increasing the forest fire risk because of the dry biomass (leaves, needles, branches…) after a heat wave (cf. chapter 1.1.3.2). In Mediterranean and southern temperate forests, the duration of high fire risk period will be extended because of climate change (CARBOFOR, 2004). The ongoing land abandonment and the increase in urban areas, and peri-urban forest areas where ignition frequency is highest, will increase together the fire risk in southern, mostly unmanaged, forest ecosystems as it has already been observed since the 1970. Under changing climate, fire return interval might decrease from 72 to 62 years for Mediterranean forests and from 20 years to 16 years for scrublands. In turn, increased fire frequencies curb forest extension in southern Europe and lead to domination by fast growing shrubs or resprouting species.

[11] www.inra.fr/dryade

1.2.4. Future impact cost

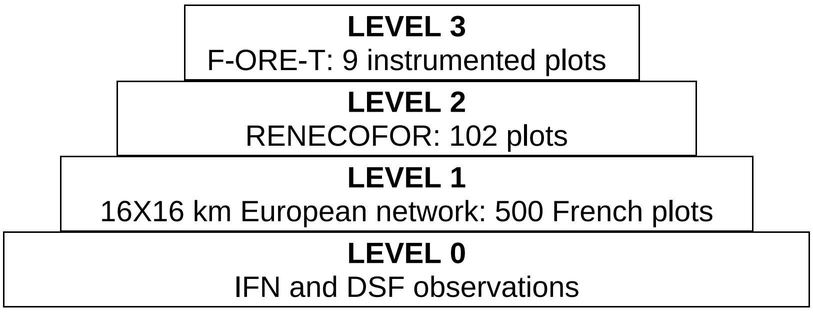
As previously said (cf. chapter 1.1.3.3), the Ministry in charge of Sustainable Development has initiated an interministerial task force in order to analyse "Climate change impacts, adaptation and associated costs in France". The work is in progress, particularly in the forest sector with a project led by FCBA in link with the University of Paris Ouest Nanterre La Défense. The objectives of this study are to assess the (i) direct costs (and benefits) of impacts of climate change on forests and industries, and (ii) the costs and benefits of adaptation measures at time horizons of 2030, 2050 and 2100.

1.3. Impact monitoring

1.3.1. Usual monitoring system/network

As in many other countries, the first forest monitoring network in France was the National Forest Inventory (IFN). It was created in 1958 and effectively implemented all over France during the sixties and the seventies. Later on, it was very useful to account for carbon sequestration, together with the national Land Survey (TERUTI). At the end of the seventies and the beginning of the eighties, deteriorations of forest health were observed in many sites (see introduction and paragraph 1.1.2.4). These events induced the implementation of monitoring system of forest health at the national and European levels (1986 regulation).

As a result, the current permanent forest monitoring network can be represented by the graph below:



7 of the 9 sites of F-ORE-T network (Survey for Environment Research on Forest Ecosystem Functioning) are located in metropolitan France (the 2 others are in French Guiana and in Côte d'Ivoire). They represent the different kinds of French forests: plain, Mediterranean, artificial and tropical forests. Functioning and quantification of carbon fluxes are determined, with nutrient balances[12]. Those data were utilized in CARBOFOR project (2004).

For level 2, meteorological, dendrometric and dendrochronologic parameters are assessed. Atmospheric inputs are also assessed for only 27 plots and soil solutions for 17. Some new objectives are set up for this network and particularly to study forest ecosystems evolution under climate change.

For level 1, in an European perspective and since 1989, some permanent plots have been set up. 20 trees per plot are assessed every year in order to study forestry health.

[12] www.gip-ecofor.org/f-ore-t

For level 0, IFN (National Forest Inventory) carries out permanent survey on more than 7.000 temporary plots a year (one plot per 2000 ha of forest). Dendrological, ecological (plants and soil) and environmental data are collected using remote sensing techniques and field measurement. At last, all these networks are completed by non systematic observations realized by DSF (Forest Health Department).

Regarding biodiversity, the National Museum (Muséum National d'Histoire Naturelle, MNHN) coordinates a national network, with regional sub-networks. The aim is to follow the state of nature condition by observation of biodiversity indicators groups: birds, butterflies, bats and coming soon plants and amphibians. Most of the observations are carried out by voluntary naturalists' networks, utilizing simple scientific protocols[13].

1.3.2. Specific monitoring system/network

The network of phenological observations for climate change impacts management (SIP-GECC), coordinated by Chuine I. (CNRS) was created in order to:

- have a national database of phenological observations realised in France since 1880,
- pursue phenological observations of a set of species selected on the basis of existing historical data as well as their socio-economic importance,
- use phenological data for fundamental and applied research, especially climate evolution.

This national network is regionally detailed, with for example a survey in the regions of Nord-Pas-de-Calais and Picardie (Northern France). It is also completed by a survey of the phenological phases of some specific species open to the amateurs[14].

More specifically, due to their synoptic and monitoring capacities, Earth observation satellites could be used in **assessment and evaluation of drought effects in forest ecosystems** (Deshayes and al., 2006). Indeed, airborne and space borne sensors represent an unique source of information for monitoring forest response to the 2003 drought at local to regional scale: most of forest canopy anomalies can be detected from space. This capability has proved to be extremely useful for monitoring forest seasonal and inter-annual activity. The anomalies of vegetation activity, as seen from a vegetation index or water stress index, could be detected almost in near-real time. This capability can be extended to following years in order to analyze the forest response to drought in the long term.

Roman-Amat (2007) suggested creating a common working group between Forest Health Department and National Forest Inventory in order to enhance the forest health survey by implementing survey protocols with complementary expertise from these two organizations.

1.4. Impact management

For most of the recent extreme events (1999 windstorms, 2003 droughts and forest fires), the impacts were both managed by French State (Ministry of Agriculture) and each organization involved in forest management (see detailed example below). As these last events were unprecedented because of their importance, national and international scientific expertises were rapidly carried out: Birot and al. (2000) after windstorms, impact of drought and heat on forests coordinated by ECOFOR in 2003. These expertises led to publications in professional

[13] www2.mnhn.fr/vigie-nature
[14] www.obs-saisons.fr

and scientific newspapers. 2-3 years later, some guidelines were also published in order to summarize the main lessons of crisis management and the way to avoid one other or, at least, to diminish the potential impacts (ONF’s guide on salvage management, guide on diebacks management in progress…).

In order to detail one example, after the 1999 windstorms, the French government published a relief program for French forests on January 12, 2000 that was later supplemented with a variety of measures tailored to meet specific problems. To encourage operators to log the fallen timber, one set of measures was designed to clear and improve access roads, provide pre-financing for the purpose of removing timber, train loggers and subsidise machinery purchases. A second group of measures, designed to maximise value of huge quantities of timber to be harvested very rapidly, was implemented to encourage industries and forest operators to store wood, to delay felling of intact stands, to move timber outside the devastated areas, as well as to promote the use of wood. The third group of measures focussed on protecting and reconstituting damaged forests with phytosanitary means, prevention of intensified forest fires risk, incentives in favour of land restructuring as a prelude to reforestation, clearing of damaged plots and reforestation operations themselves. Special terms were applied to land tax, income tax, wealth tax and VAT. Finally, the government also set up various accompanying measures such as damage assessment by aerial photography, assignment of additional staff to field organisations, special aid for state forests and establishment of a think tank to explore forest insurance issues.

After this event, ONF (French Forest Service) developed a methodology to manage this kind of crisis and set up a crisis management system which includes 3 steps (Mortier and Bartet, 2004): (i) a monitoring system out of crisis period, (ii) a deployment of the plan in case of crisis, (iii) an experience analysis after the crisis.

2. Adaptation

2.1. Forest vulnerability to climate change

Adaptation to climate change aims at reducing the vulnerability of natural or human systems and at exploiting beneficial opportunities. In France, these two views are present but harmful impacts are more emphasized than positive effects. This can be explained in several ways.

The main positive impact of climate change on French forestry is an increase of productivity. However, the observed increase of forest productivity is not only due to climate change but also and probably mainly to other reasons such as nitrogen depositions (see paragraph 1.1.2.4). For the future, this increase is expected to go on until 2050 with a relative bigger effect of climate change and smaller effect of nitrogen depositions; after 2050, ecological constraints and extreme events could reverse this trend. There is thus the consciousness that this effect is temporary.

How can the increase of productivity benefit to the forest-based sector? For the moment, it has increased the gap between the net increment of the growing stock and the removals, but has not been used in a beneficial way. Would adaptation allow changing this situation? It is probably possible to improve the harvest rate of the French forest resources (at Urmatt, on the 19th of May 2009, the French President announced measures to be taken in order to develop the use of wood) but such action is usually considered to be in another framework than climate change and to depend mainly on the economical context: growth rate and energy price.

One factor could improve this situation and depends on climate change: the contribution of forestry to the carbon cycle. A larger roundwood harvest could both take profit of an increased productivity and take part in the long term mitigation of climate change. But for forest owners, it is not yet clear how it could actually be integrated in the economic flows and decisional processes. Moreover, this contribution depends on the possibility to adapt forestry to harmful effects of climate change that are in all minds.

Consequently, the reduction of future impacts of climate change is a major challenge for French forest owners, managers and policy makers. It requires to better assess the actual vulnerability of forests to climate change and to develop adaptation methods that are not available at the moment.

Forests have been considered vulnerable since the last 3 extreme events (1999 windstorms, 2003 drought and heat, 2009 windstorms). The actual vulnerability of French forests to climate change is supposed to be rather high because France will be concerned by significant changes (see paragraph 1.2.1) with more dryness and because most of these forests is relatively productive with economic interests at stake.

This vulnerability is nevertheless not well-known because only few research studies have been led on it until now: CARBOFOR project shows how the potential range of species could shift along time but it uses static methods and ignores ecological processes. There are then several different socioeconomic and climatic scenarios for the future and a pessimistic scenario, issued for example from A2, should lead to very different adaptation measures than a less negative one, based on B2. In addition, oaks (*Quercus petraea* and *Quercus robur*) cover about one third of the French forest area and are long lived trees (especially *Quercus petraea*) with rotation periods of more than 100 years and up to 240 years. Such a length of time shows how vulnerable to climate change the French forests could be.

As a result, this feeling of vulnerability led to multiple actions in the field of forestry and climate change: a contribution to the National strategy of adaptation, a special chapter of the National Forest Program, two ministerial reports dedicated to climate change, a contribution to the global environmental participatory approach of "Grenelle de l'Environnement"…

2.2. General adaptation strategy and policy

A general strategy for adaptation to climate change has been published in 2007 by the **ONERC, National Observatory on the Effects of Climate Change**. This organization was created in 2001 and is attached to the Ministry in charge of Sustainable Development (Ministry of Environment, Energy, Sustainable Management and Seas, MEEDDM). Its job is to collect and to disseminate information (studies and researches) about change and climatic extreme events risks linked to climate toward general public and local administrations. It can recommend measures for prevention and adaptation in order to limit climate change risks.

All those recommendations are compiled in its strategy and concern both some industrial and agricultural sectors (agriculture, energy and industry, transport, building, tourism, banks and insurances) and some different areas (towns, littoral and sea, mountains, forests). Regarding forests, the recommendations are very global specifications: local choice and mix of species, maintenance and development of edges, strong and early thinning in order to decrease the water competition and to increase stand stability… This strategy highlights that researches and studies on forest adaptation are needed because of the numerous questions.

This strategy for adaptation to climate change is currently completed by another **national strategy for sustainable management** of MEEDDM's General Sustainable Management Commission (Commission Générale du Développement Durable, CGDD). This strategy is based on the "Grenelle de l'environnement" reflexion (cf. following paragraph). The final version should be defined soon. The first version determines 9 challenges, the first concerns climate change and non-polluting energy. To face this challenge, one of the objectives is to prepare the local territories' adaptation to climate change and their participation to mitigation. Two recommendations concern the forests: to develop bioenergy from forests, to take into account climate change and its consequences in forest management in order to preserve biodiversity and productive capacity.

Some regional policies are also developed in several French regions in the framework of climate action plans "plan climat". Some of those plans, such as in Aquitaine region, include a specific component on forests with adaptation measures.

2.3. Forest adaptation measures

2.3.1. Political level

Following international and European commitments (Rio de Janeiro in 1992, Lisbon in 1998 and Vienna in 2003), French government set up a **National Forest Programme (PFN)**. Forestry community, wood-based industry and Environmental Non-Governmental Organisations (ENGO) are represented in the PFN. They determined the main lines which are used after to define the French forestry policy. The main PFN's objective is to keep on improving the sustainable forest management.

The programme defined for the 2006-2015 period takes into account climate change as a major issue. It recommends improving R&D on this subject about impacts and adaptation (silviculture, planting…). It also proposes to enhance forest wood-based sector contribution to climate change mitigation and to develop wood energy and wood as friendly environment material.

Concerning biodiversity, the National Strategy for Biodiversity (SNB), defined in agreement with the Convention on Biological Diversity (CDB, signed in Rio in 1992), is declined in several management plans whose one is dedicated to the forests. This plan was established in relation with the PFN's strategy concerning biodiversity. The joint strategy is to promote a sustainable forest management which associates wood production and biodiversity improvement. More precisely, the objective is to preserve ordinary and specific biodiversity taking into account forest ecosystems evolution under climate change. One of the main propositions is to analyze relations between climate change and biodiversity, in order to improve protection measures and to assess their effects on biodiversity. Some other propositions concern training for forest owners and managers, development of forest certification…

On July 2007, the French government launched the "**Grenelle de l'Environnement**" process[15]. Some working groups, with representatives from the State, local authorities, NGOs, employers and employees associations, were defined: climate change and energy, biodiversity and natural resources, environment and health, production and consummation, competitiveness and employment. Some general propositions were elaborated. From November 2007 to January 2008, the "**Assises de la Forêt**" defined more precisely propositions for forest and wood-based industry. 20 measures were proposed to harvest more timber and better (the annual harvest, which represents nowadays only 2 thirds of the biological growth estimated about 100 Mm^3/year, should be increased by +12 Mm^3 in 2012 and +20 Mm^3 in 2020).

These works were partially based on 2 reports: the first one ordered by the Ministry of Agriculture to Bourgau, Lerat and Cailmail (2007), the second one ordered to Roman-Amat by the 2 Ministries of Agriculture and Environment and achieved on December 2007. 32 propositions are defined in this last report (Roman-Amat, 2007) compiled in 5 themes: R&D, risks, production, biodiversity and governance. 2 levels of priority are distinguished: propositions to be active before or after 2010.

The second proposition consists in **giving GIP-ECOFOR the national responsibility for coordinating all the researches about forest adaptation to climate change**. This mission has been effective since September 2008.

Moreover, the fourth proposition is to create in 2008 2 joint technological networks (Réseau Mixte Technologique RMT), which includes both research and development organizations and training centres. The first one should concern forest sites and the second one genetic variability of forest trees. A third one should be prepared about modelling and silvicultures. In fact, only **one global RMT, called AFORCE** (Adaptation of Forests to Climate Change) led by the Forest Development Institute (IDF), was created in August 2008 after the agreement of Ministry of Agriculture. 11 partners are involved, with GIP-ECOFOR. 5 themes are covered: (i) forest sites, (ii) factors of stand vulnerability, (iii) development and conservation of gene pool, (iv) growth and silviculture, (v) economic consequences on forest production. Its main objectives are: (i) publication of guidelines and other documents, (ii) structuring and transfer of information to professional people, (iii) organisation of scientific and technical networks concerning silviculture evolution, forest sites, species strategy and provenance choice.

[15] www.legrenelle-environnement.gouv.fr

Concerning gene pool, the **Forest Gene Resources Commission (CRGF)**, formed by scientists, private and public forest managers, representatives of ENGOs, defined a general strategy to preserve and utilize forest gene pool diversity in order to improve forests' adaptive ability to climate change. Its main recommendations are (CRGF, 2008):

- to maintain a long term gene diversity through silviculture,
- to promote progressive processes to let natural adaptation stands',
- to give graded solutions depending on geographical scale of diebacks.

2.3.2. Management level

2.3.2.1. Public forests

For public forests (around 4 million ha in metropolitan France), the French Forest Service (ONF) reacted early in 1994 by the active participation to national and local surveys and proposes now a global strategy (Office National des Forêts, 2009). Some guidelines were defined (Legay and Mortier, 2006), trying to anticipate changes without excessive haste and to take advantage of ecosystem plasticity and resilience. They concern national and local directives for management planning, silviculture, biodiversity and soil protection:

1. **Develop monitoring systems and remote sensing techniques** to detect emerging risks and quickly react to crises.
2. **Actively participate to research programs** on impact assessment, adaptation and mitigation.
3. **Management planning strategy**: disseminate national and regional directives and orientations; recommend site-species combinations; use adapted species/provenances/material; preserve and enhance genetic diversity of autochthonous and acclimated species; make a wise use of exotic species, based on observed adaptation and performance in field trials.
4. **Management planning**: identify stands at risk; replace them progressively, starting by the most vulnerable situations (common oak [*Quercus robur*], Norway spruce [*Picea abies*]) ; for species choice, discriminate between dynamics in young stage and long-term site adaptation, and prevent the extension of non-adapted species by inappropriate silviculture (e.g. spread of Silver fir [*Abies alba*] at low elevation sites due to uneven-aged forestry); adapt target-diameters to market demands and risks (health, quality degradation).
5. **Silviculture**: take into account increased growth in silvicultural prescriptions, e.g. by faster reaching the target-diameters; in even-aged stands, fully apply silvicultural guidelines, to enhance resilience with young, intensively thinned and mixed stands; decrease growing stock in old, overcrowded stands; use natural regeneration as often as possible (species adapted to site and future climate, enough seed-trees); in uneven-aged stands, apply the recommended growing stock (basal area) and use the same target-diameter as in even-aged stands; restore the forest-wildlife equilibrium, to prevent adapted species to disappear due to deer browsing…
6. **Biodiversity**: create a network of dead trees, old stands (beyond the recommended rotation age), and senescent stands.
7. **Insure soil protection**: avoid compaction by forest machines (use of designated skid trails, development of cable logging…), and maintain fertility (do not export all logging residues, apply liming where necessary).
8. **Develop a crisis management culture** (to face decline, pests, fires, windthrow), and improve it with returns on experience.

The ONF's strategy highlights also the need for closer cooperation with research institutions. In this regard, joint R&D operations are favoured between ONF, INRA, AgroParisTech and Cemagref, in order to carry out studies and researches on forest adaptation and to disseminate results directly to the forest managers. Eleven main concerns and needs for forest managers are listed:

- localized information on climate change,
- new protocols for site description, adapted to changing environmental conditions,
- for species choice, assessment of species autecology, productivity and vulnerability,
- provenance and species tests, especially including drought-resistant material,
- influence of climate on wood quality,
- monitoring systems of forest ecosystems functioning and health,
- growth and yield models taking into account climate and soils variables,
- economics of silviculture under risk,
- relationships between biodiversity and climate change (management of protected species and areas, use of mixtures to enhance resilience and resistance),
- silvicultural guidelines to reduce drought stress,
- improvement in crisis diagnosis and management.

2.3.2.2. Private forests

The **Société Forestière de la Caisse des Dépôts (SFCDC)** is in charge of forests belonging to institutional investors (237 000 ha in France). It has formulated new management rules promoting fast growing species and shorter rotations (Piermont, 2007). This new scheme was instituted in 2006 on the basis of climate forecasts, but also takes on board market trends, customers and society expectations. An ongoing review of this scheme is planned every three years. It is founded on several principles:

- adaptation and reversibility: taking into account the existing uncertainties concerning climate forecasts;
- reference date 2050: because of various climate scenarios after 2050 regarding the summer dryness (the most important factor for forestry stands); this reference date introduces a dichotomy between fast- and slow-growing species, with a preference in the latter case, for uneven-aged, mixed species stands;
- shorter turnaround times with fast-growing species, to be more reactive and decrease the risk (storm, fire…);
- list of transition species which are able to thrive with current and expected climates (the first list which can evolve includes maritime, laricio and Scots pines, Douglas fir, Atlas cedar and Nordmann fir for coniferous species; lime, locust tree and Norway maple for deciduous species[16]);
- priority on water soil reserve criterion because of the expected summer dryness, in link with the decrease of stand density in order to reduce leaf area index.

Finally, the other criteria that form the basis of the SFCDC's silvicultural practices, aside from the climate change aspect, are maintained: expectations of owner/customers, consideration of market factors, profitability, sustainable management, stand diagnoses, consideration of current adaptiveness of species to sites, etc.

4 new orientations were recently added by SFCDC[17]:

- a more regional approach to take into consideration local specificities of climate change;
- a risk cartography and their possible mitigation by forest massif;
- to complete the list of transition species and to enhance stand diversification;
- to pay more attention to forest soil (water reserve) and to avoid soil compaction during logging operations.

[16] *Pinus pinaster, Pinus nigra subsp. laricio var. corsicana, Pinus sylvestris, Pseudotsuga menziesii, Cedrus atlantica, Abies nordmanniana, Tilla sp., Robinia pseudacacia, Acer platanoides*

[17] http://www.forets-et-climat.fr/

More generally for private forests (around 12 million ha in France), the Regional Forest Owners' Centres (Centres Régionaux de la Propriété Forestière CRPF), public institutions created to guide and develop forest management in privately owned forests, have regional "climate change correspondents". They transmit global information and advice to their colleagues and to private owners.

Long term experimental and demonstration sites networks are also set up to test new tree species and management alternatives for adaptation or mitigation purposes. An example of such approach is the 4-years R&D project **CLIMAQ**[18] conducted by CRPF Aquitaine with INRA, FCBA and private forest managers. It concerns potential productive species like black locust (*Robinia pseudacacia*), taeda pine (*Pinus taeda*), eucalyptus (*Eucalyptus sp.*) that could complement maritime pine (*Pinus pinaster*) in the changing climatic conditions context and market demands.

2.4. Research studies as regards forest adaptation

Most of research projects dealing with climate change impacts (current or expected) give some direct and practical advice for forest adaptation. The guidelines previously quoted for ONF and SFCDC are some examples. For instance, from the climate forecast and various modelling, CARBOFOR project (Loustau, 2004) led to recommendations. Where climate change effects are beneficial to forest functions, in northern temperate, continental and boreal forests, the results suggest that optimising forest management should aim at reducing the effects of limiting factors, for instance through fertilisation. Conversely, where detrimental effects of the future climate are expected through increased water deficit, e.g. in southern temperate and Mediterranean forests, enhancing the ecosystems resistance to drought and fire using species substitution, understory control, site preparation and reductions in the maximal value of leaf area index could be appropriate strategies to adopt. Since climate change is provoking a continuous -but not monotonous- change in site productivity, the forest management must be revised dynamically along its life course. At the southern margin of geographical areas, a management aiming at an optimal adaptation of forests should be considered, favouring, for example, multi-age and mixed forest stands including pre-existing species and their southern variants and maximising the intra-specific diversity.

The institution in charge of private forestry (CNPPF) has developed general information of forest owners on the physical bases of climate change, on the present and actual effects and on possible future effects. Then many questions have been raised ("*what must I plant?*"...) and their answers have still to be elaborated by the scientists. All these questions were compiled in 5 thematic sheets published in a professional newspaper (Riou-Nivert, 2008):

- stand management: how to diagnose stands to know their potential? do we have to develop new silvicultures and what kind? do we have to get techniques for stand establishment in progress?
- forest reproductive material: how to choose the species? what about genetic improvement and conservation of genetic resources?…
- forest sites: how to take into account water balance? how to determine the sites which present higher risks for the strands in regard to climate change? what is precise species autecology?…;

[18] http://www.crpfaquitaine.fr/infos.php#57

- risk management: how to take into account the direct and indirect effects of climate change (dryness, hot wave, storm, fire, disease…) in silvicultural management? how to manage the risks?
- wood production and harvest: what are the quantitative and qualitative evolutions of harvest?

Specific researches are carried out in order to answer these questions:

- predictive mapping for forest sites, using three main ecological factors (soil nutrient content, soil moisture and bioclimate which integrates temperature and water balance) (Gegout and al., 2008); in Champagne-Ardenne (North-Eastern France) forest managers took also into account climate change in their forest sites types and they defined new guides (Gaudin, 2007);
- the DRYADE project (cf. chapter 1.1.3.2), in progress, will lead to recommendations for forest managers to take into account the drought and its consequences on forest diebacks, threw an anticipating management plan (species and varieties, objectives, stand resilience improvement) or an attenuation of constraints (adapted silviculture, fight against diseases and parasites);
- within the scientific platform about the “maritime pine of the future”, which gathers together FCBA, INRA, CRPF and ONF in Aquitaine, genetic improvements of maritime pine (*Pinus pinaster*) are carried out; one of the new criterion for this improvement is the adaptation of current or new varieties to dryness (Alazard, 2006).

With all the uncertainties concerning climate forecast, natural species adaptiveness and forest inertia, forest owners and managers are still prudent by implementing “no regret” or reversible strategies (shorter turnaround times, mix of species…). Strategies to manage uncertainties are needed and should be based on various scenarios more or less pessimistic. They would explore all the possible futures, by analyzing and evaluating all the possible actions at different scales and mainly at local scale to be more adapted (Legay and al., in press). As long as deterministic techniques are no more entirely appropriate and decision methods under uncertainty are not yet tailored to forest management, the feeling of vulnerability will still be reinforced.

3. Mitigation

Forest-based sector is particularly promoted by French foresters as an important tool to mitigate climate change. For example, a report published in 2003 on its competitiveness as a challenge for sustainable development (Juillot, 2003) began by a chapter on carbon sequestration. Moreover, during the French Presidency of the Council of the European Union (second semester 2008), an international conference have been organized in Nancy by the Ministry in charge of Agriculture on forest mitigation[19].

Forest mitigation is highly dependent on the climate-energy policy at the international level, and on the energy markets. It means that, as for future impacts and adaptation, many uncertainties are at stake. It also depends on forest adaptation.

As forest carbon sequestration has become a new ecosystem service, there is a possible conflict with other forest functions if it used very intensively.

3.1. Carbon accounts

3.1.1. Kyoto Protocol and French position

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change[20]. The Kyoto Protocol was adopted in Kyoto, Japan, on 11th December 1997 and entered into force on 16th February 2005. 184 Parties of the Convention have ratified its Protocol to date. The detailed rules for the implementation of the Protocol were adopted in Marrakech in 2001 (COP 7), and are called the "Marrakech Accords."

The major feature of the Kyoto Protocol is that it sets binding targets for 37 industrialized countries and the European community for reducing greenhouse gas (GHG) emissions by 5.2% against 1990 levels over the five-year period 2008-2012. Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations (countries listed in Annex 1 of Kyoto protocol, like France) under the principle of "common but differentiated responsibilities". The Annex 1 parties are required to submit annually a national inventory report (NIR) and common reporting format (CRF) tables comprising data from the base year up to two years before the year of submission.

The 15 countries of European Union (before the 2 last enlargements) established a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms. European Union has to reduce by 8% its GHG emission for the 2008-2012 period. Within this scheme, every involved country has different objectives taking into account its specific situation (economic growing perspectives, repartition between the various kinds of energy, industries…). For instance, **France has to maintain its emissions at the 1990 level**, and not to decrease them by 8%.

Forests, through growth of trees and an increase in soil carbon, contain a large part of the carbon stored on land. Forests present a significant global carbon stock. Thus several articles of the Kyoto Protocol make provisions for the inclusion of land use, land-use change

[19] The title of this conference was: "The European Forest-Based Sector: Bio-Responses to Address New Climate and Energy Challenges?"

[20] http://unfccc.int

and forestry activities (LULUCF) by parties as part of their efforts to implement the Kyoto Protocol and contribute to the mitigation of climate change. In this way, Annex I parties, including France, shall implement and/or further elaborate policies and measures to protect and enhance sinks and reservoirs of greenhouse gases, promote sustainable forest management, afforestation and reforestation and sustainable forms of agriculture.

Annex I Parties must report emissions by sources and removals by sinks of GHGs resulting from LULUCF activities, in accordance with Article 3, paragraphs 3 and 4 (Chaudron et al, 2005). **Under Article 3.3 of the Kyoto Protocol**, Parties decided that net changes in GHG emissions by sources and removals by sinks through direct human-induced LULUCF activities, limited to afforestation, reforestation and deforestation that occurred since 1990, can be used to meet Parties' emission reduction commitments. **Under Article 3.4** of the Kyoto Protocol, parties may elect additional human-induced activities related to LULUCF specifically, forest management, cropland management, grazing land management and revegetation, to be included in their accounting of anthropogenic GHG emissions and removals for the first commitment period. Upon election, this decision by a party, like France, is fixed for the first commitment period. The changes in carbon stock and GHG emissions relating to LULUCF activities under Article 3, paragraphs 3 and 4 must be reported for each year of the commitment period, beginning with the start of the commitment period, or with the start of the activity, whichever is later. When LULUCF activities under Articles 3.3 and 3.4 result in a net removal of GHGs, an Annex I party can issue removal units (RMUs) on the basis of these activities as part of meeting its commitment under Article 3.1.

3.1.2. French carbon account

In France, the GHG emission reporting is led by a non-profit association Citepa. For the forestry part, it centralizes results obtained from the various observation networks. The results are provided to the UNFCCC which publishes the data for France on its website[21]. If we take into account forestland remaining forest plus all other lands (cropland, grassland, wetland, settlement and other) converted to forest, we obtain the net emission for the French forest sector, detailed in the table below. For the first period of Kyoto protocol (2008-2012), the Marrakech agreement allows for France a carbon credit with an upper limit of 3.2 Mt CO_2 per year, under the condition that the forest carbon stocks keep on increasing.

Table 4 : GHG emissions results for French forest sector in Gg CO_2[22]. Negative emissions correspond to sequestration.

Year	1990	1995	2000	2005	2006
Gg CO_2	- 60 561	- 66 822	- 69 570	- 79 930	- 84 016

Some discussions are still in progress in order to eventually take into account carbon stock into harvested wood products. For example, the Carbostock project (Deroubaix and al., 2008) defined a methodology to quantify the variations of carbon stocks in wood products within IPCC's rules. The study analyzed five stocks or pools of carbon downstream of forest in wood chain and paper sector: housing, furniture, packaging, energy, pulp and paper. For each sector, the stocks were identified (intermediate technical stocks and final in service stocks) then quantified with three different approaches defined by IPCC: stock change, production or atmospheric flows approaches. The quantification varies with the utilized approach from -4.709 to +452 Gg CO_2/year (respectively stock change and atmospheric flux methods). The approach which will be finally accepted depends on international political choices.

[21] http://unfccc.int then GHG data/GHG data UNFCCC/flexible queries
[22] http://unfccc.int then GHG data/GHG data UNFCCC/flexible queries

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

One of the major “French mitigation actors” was the **Interministerial Mission on Greenhouse Effect** (Mission Interministérielle de l'Effet de Serre, MIES[23]). Created in 1992 and attached to Prime Minister, the MIES had in charge the coordination of the French actions to face the climate change, at national, European and international scales. This mission was to elaborate, update and implement all those policy measures. The MIES was recently replaced by the Department of Global Warming Fighting (Département de Lutte Contre l'Effet de Serre, DLCES) in the Ministry in charge of Sustainable Development (MEEDDM-CGDD).

The MIES defined in 2004 the **“Plan Climat”** (Climate plan) which is the governmental plan of actions to reach at least the Kyoto protocol’s objectives. This plan gathers together all the mitigation measures in very economic sectors and for every-day life, in order to decrease by 54 Mt equivalent CO_2 per year until 2010. This plan is optimistic and has more ambitious objectives than Kyoto protocol. The “Plan Climat” proposes some easy and actual actions for every-day life, to motivate everybody by a sort of citizen’s movement. 8 major orientations have been defined:

- national advertising campaign about climate change,
- sustainable transport,
- eco-building,
- industry, energy and wastes,
- sustainable agriculture and forests,
- sustainable air-conditioning,
- local climate plans and exemplary State,
- research and forecast beyond 2010.

Regarding forest-based sector, the main action of the “Plan Climat” is to promote and develop the use of biomass like biofuel, wood-energy but also wood for building. The forests are considered as a carbon sink.

In 2006, The Ministries of Industry and Ecology ordered to a working group led by C. de Boissieu (2006) **a report called “Division by four of the French greenhouse gases (GHG) emissions for 2050”**. As the title suggests, the objective is to reduce by a factor 4 the French GHG emissions (from 140 Mt of carbon in 1990 to 38 Mt/year in 2050) in order to limit atmospheric CO_2 concentration to 450 ppm which seems to be the most realistic objective taking into account the current concentration (382 ppm) and the annual increase (+2 ppm/year). This objective was fixed by a law, adopted in 2005, defining the French orientations regarding energy policy. The reports details the national strategy and the technical recommendations to reach it and points out the social dimension of this strategy (citizens’ behavior). Concerning forest and wood-based industry, the recommendations are mostly the same than “Plan Climat”’s ones.

Recently, among the 9 challenges defined in the first version of the on-going national strategy for sustainable management (SNDD, cf. chapter 2.2), one concerns the adaptive capacity of local territories and their contribution to mitigation. More precisely, one objective is to promote carbon catchments by forests and the use of wood.

In link with these general plans, the “**Grenelle de l’Environnement” then the “Assises de la Forêt”** process determined more specific and actual objectives for forest and wood-based industry in order to adapt forest to climate change, as written in chapter 2.3.1, but also to

[23] http://www.effet-de-serre.gouv.fr

mitigate it. The increase of annual harvest (by +21 Mm^3 in 2020 with a current harvest of about 60 Mm^3/year) is the first one. To promote local use of wood (as a renewable material and energy), to improve the certification (FSC and PEFC) particularly for wood in public buildings (from 2010, 100% of the wood bought by French State will have to be certified), to oblige certification for imported wood, to promote wood as a friendly-environment material for building, to adapt the building norms to wood material… are some of the particular objectives regarding wood as an eco-material. Other objectives concern also the use of wood as energy in order to improve it, but with the priority given to wood as material before energy.

As previously written (cf. paragraph 2.2), some regional policies are also developed in several French regions in the framework of climate action plans "plan climat". Some of those plans such as in Aquitaine region include a specific component on forests with adaptation measures and also contribution to mitigation strategies through support to bioenergy systems, voluntary carbon markets and use of wood in construction.

3.3. Forestry as a source of bio-energy

Promotion of forestry as a source of bio-energy is one of the major actions proposed by the various political processes and strategies. As a result, many national and local projects have been carrying out for several years. We quoted here after some of the most important ones.

French Environment and Energy Management Agency (ADEME[24]) led **from 2000 to 2006 a wood-energy program**. Its objectives were:

- to maintain to 8 Mtoe (ton oil equivalent) the domestic consumption of wood energy (mainly firelog),
- to improve by 10% the energy efficiency and environmental performance of individual boilers (for the most efficient boilers, tax rebates also exist),
- to set 1000 collective and industrial boilers for a global power of 1000 MW, by improving the technology and organizing the supplying market.

At the end of 2006, 1880 boilers were actually set up for a total power of 675 MW. So a new program from 2007 to 2010 was launched with a larger scope, as it concerns bioenergy in general (wood, straw, bioenergy farming…), but with almost the same objectives for wood energy. The current goal is the substitution of 80 mtoe/year of fossil fuel by diverse renewable energies and particularly green chips. Only over-1MW boilers are now concerned.

A complementary program of National Federation of French Forestry Districts (FNCOFOR), called "1000 boilers for rural area", was launched to gather small-scale boilers in rural districts. Within this program, a wood-supplying local plan was elaborated and tested in 2007-2008 and will be set up in 2009.

Other really important programs are those concerning electricity production and cogeneration. A law defining the French orientations regarding the energy policy was adopted in 2005 and plans until 2010:

- electricity production from renewable resources has to reach 21% of French electricity consumption,
- use of renewable energy is a priority and has to increase by 50% for the heat production.

Investments for electricity production from biomass are planned at a national level. They will have to represent 1000 MW in 2010 and 2000 MW in 2015. Within this scheme, 2 calls for project were launched by **the Ministry of Industry (Commission for the Regulation of Energy, CRE)**: the first one in 2004 and the second in 2006. 22 new biomass power stations

[24] http://www.ademe.fr

were accepted and should use 1 Mt of green chips and 250 mt of other wood chips. A third call for project was launched at the beginning of 2009, the results will be known later on.

With all these projects, a major question is the wood-energy availability. So, at the request of the Ministry of Agriculture, CEMAGREF, in 2006 and 2007, performed a study about **forestry biomass availability for new industrial energy uses** going forward into 2010 through 2020 (Ginisty and al., 2007; Vallet and al., 2008). The study aims at estimating at the national level the quantities of wood biomass that it may be possible to take from forests, in addition to current fellings of timber, while remaining within a context of sustainable management and a rational exploitation of forestry resources. CEMAGREF developed a method of diagnostics of standing plantations, investigated through French National Forestry Inventory's (NFI) data in comparison with the silvicultural scenarios recommended by guides in this field. Woods from coppices, first thinnings and tree-tops are among the forestry management compartments for which the study has provided estimates. Theoretical estimated additional availability of energy and pulp woods is over 17 Mm^3/year, although this estimate should be qualified by giving consideration to the assumption adopted by the method. By extension, available timber for manufacturing purposes is quantified per region, per tree species and accessibility class. The estimate of theoretical timber availability for production and manufacturing purposes is about 11.5 Mm^3/year. This work is continuing in 2008 and 2009 with French NFI and French Forest Service (ONF) in order to use data from the new NFI's inventory method, implemented since 2005. This should result in a better estimate of the availability of timber on the basis of more up-to-date information, and hence take into consideration the effects of the 1999 storms.

But the increase of wood harvest might have consequences on forest biodiversity, particularly the insect biodiversity linked to dead wood. ECOFOR coordinated in 2008 an expertise, **"Biomass and Biodiversity" (Bio2**), in order to answer the question how to harvest more and better. To leave some free-harvest areas in high biodiversity zones, to leave some dead wood in forests, to conserve soil physical and chemical properties during logging operations… are some of the main advices of this scientific expertise (Landmann and al., in press). A new program (Biomadi) is going to complete the lack of scientific knowledge of this first expertise.

3.4. Research studies on mitigation

During 1999, a concerted French initiative led to **the research program "Management and Impacts of Climate Change"** ("Gestion et Impacts du Changement Climatique", GICC). GICC is essentially managed by the Ministry in charge of Sustainable Development (MEEDDM[25]) in close collaboration with the ADEME and ONERC. The GICC's mission is to promote and develop scientific research on identifying national "Impacts of Climate Change" and associated physical mechanisms. The main objective, downstream, is to provide sound scientific arguments in order to participate in the tuning of adaptive tools and techniques. This will allow policy and decision makers from the public sector to optimize strategies for prevention and mitigation of those impacts.

CARBOFOR (Loustau and al., 2004), supported by GICC program, was one of the first research projects which gave data of carbon stocks and fluxes in forests (biomass and soil). The response of different forest canopies to environmental and biophysical determinants, using information produced from the French network of Flux sites where CO_2 and H_2O fluxes have been monitored since 1996, was analyzed. The behaviours of the various canopies considered in terms of energy, water and carbon exchanges are weakly dependent on

[25] http://www.environnement.gouv.fr

species but strongly affected by climate and canopy structure. In particular, the Leaf Area Index (LAI), standing biomass, canopy height and vertical structure and stem density are influencing the canopy behaviour to a considerable extend. The Gross Primary Production (GPP) ranged from 1000 to 2500 $gC.m^{-2}.an^{-1}$ (10 to 25 $tC.ha^{-1}.an^{-1}$). The Ecosystem Respiration (RE) was the main cause of interannual and between-sites variations in Net Ecosystem Exchange (NEE) at least for wet years: low values of NEE corresponded to high values of RE. RE includes autotrophic and heterotrophic components. Their determinants are numerous and their respective influence is difficult to partition and quantify. The harvest and regeneration practices such as coppicing or clearcutting determines age structure of forest stands, their LAI and standing biomass, which affects profoundly ecosystem functioning and its interannual variability.

Forestry practices should optimize carbon storage by forest and wood-based sector and promote greenhouse gas emissions reduction. How this can be done is the question raised by the Association France Forêts, a grouping of public and private forestry management entities. The Association asked the INRA-AgroParisTech's Laboratory for Study of Forestry and Wood resources (Laboratoire d'Etude des Ressources Forêt-Bois) to answer this question (Robert and al., 2008).

Their analytical work relies on chains of models (Vallet, 2005; Robert and al., 2008) developed to simulate the impact of various silvicultures on carbon storage in standing trees and wood products, as well as on changes in levels of greenhouse gas emissions when wood substitutes other materials or energies. Based on simulations of regular high forests of common oak (*Quercus robur*), beech (*Fagus sylvatica*), Laricio pine (*Pinus nigra subsp. laricio var. corsicana*) and Douglas fir (*Pseudostuga menziesii*) in France, it is demonstrated that growing seedling forests on agricultural soil or grass lands enables carbon storage whatever the forestry management. Carbon stored in the biomass is higher in high fertility soils and dense tree stands.

The quantity of carbon stored in wood products is relatively small, compared to the quantity of carbon stored in forests themselves. Two major factors positively influence carbon sink in wood products. The first is the volume increase of the products themselves, and the second is the extension of their average lifetime. The silvicultural management scenarios which are favourable to increasing carbon sink in wood products are those enabling the production of large quantities of wood, a substantial portion of which can be used for building or furniture. The substitution of building materials and fossil fuels by wood in most cases leads to a reduction in the greenhouse gases emission. This effect increases when the wood products themselves are recycled. The highest substitution effect, under current technology, is obtained in stands with the highest production of quality wood. In even-aged oak high forests, the scenarios leading to the highest substitution effect are:

- in low fertility stands, the one with large target diameter (>70cm, similar to current practices);
- in high fertility stands, the one with medium target diameter (nearly 50 cm).

These latter conclusions highlight that one possibility to use forest and wood sector to limit global GHG emissions can be the use of smaller timbers from shorter rotations. One hypothesis of the work is the certainty of production. In an uncertain environment (storm, drought hazards), the conclusions might lead a higher reduction of revolution period.

4. Conclusion

Observed impacts until now are linked with forcing by radiations and climate change but also with several other phenomena such as nitrogen depositions. For instance, the latter one has played a greater role in the observed increase of forest growth and productivity. But climate change will become the predominant parameter of evolution in the future if we consider the climate forecasts (increase of average temperature and dryness periods…) whatever green house gases emission scenario. Nevertheless there are still many uncertainties concerning climate evolution: what will it be exactly? Moreover, strong differences exist between the scenarios and their local modelled effects should be more precise.

A French reference concerning impact is the CARBOFOR project and its maps of the future ecological range for the major forest species (at the end of the 21st century). Forest owners and managers, and all forest professionals in general, became aware of climate change potential impacts. But they are based on statistical niche models which do not take into account biological factors such as competition and evolutionary history, and thus natural adaptive capacity of species and forests.

Face to those uncertainties, forest owners and managers adopt a "no regret" strategy for adaptation. They have still many questions about the way to evolve stand management, forest sites, plant material… As a result, actual actions for adaptation have concerned few forests until now, despite numerous political processes at national ("Grenelle de l'environnement", "Assises de la forêt"…) or regional levels ("plans climat").

As for adaptation strategy, the political processes regarding mitigation are numerous. One of the most important objective is to increase the annual wood harvest (+12 million m^3 in 2012 and +20 million m^3 in 2020), since only two thirds of the annual biological growth are harvested, for energy and construction purposes. Based on a report ordered to Puech (2009), a recent speech of French President N. Sarkozy insisted on that point with the idea to multiply by 10 the use of wood in construction.

On the other hand, the green house mitigation by forests could be jeopardized in the future if the climate change impacts are too strong and extreme events too frequent, by changing forests from carbon sink to carbon source as it happened with 2003 drought or successive storms in 1999 and 2009. To keep this mitigation role, the forest adaptation is really important by a forest management preventing the risks of storm, dryness, outbreak and fire. And this one depends mostly on research in link with climate change impacts but also on investment capacity and willingness of forest owners. Adaptation strategy is an evolving process to take into account new knowledge form these studies and surveys.

Before the end of the COST Action ECHOES, this French report will be up-dated in particular with the results of the numerous on-going projects.

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Annex 1

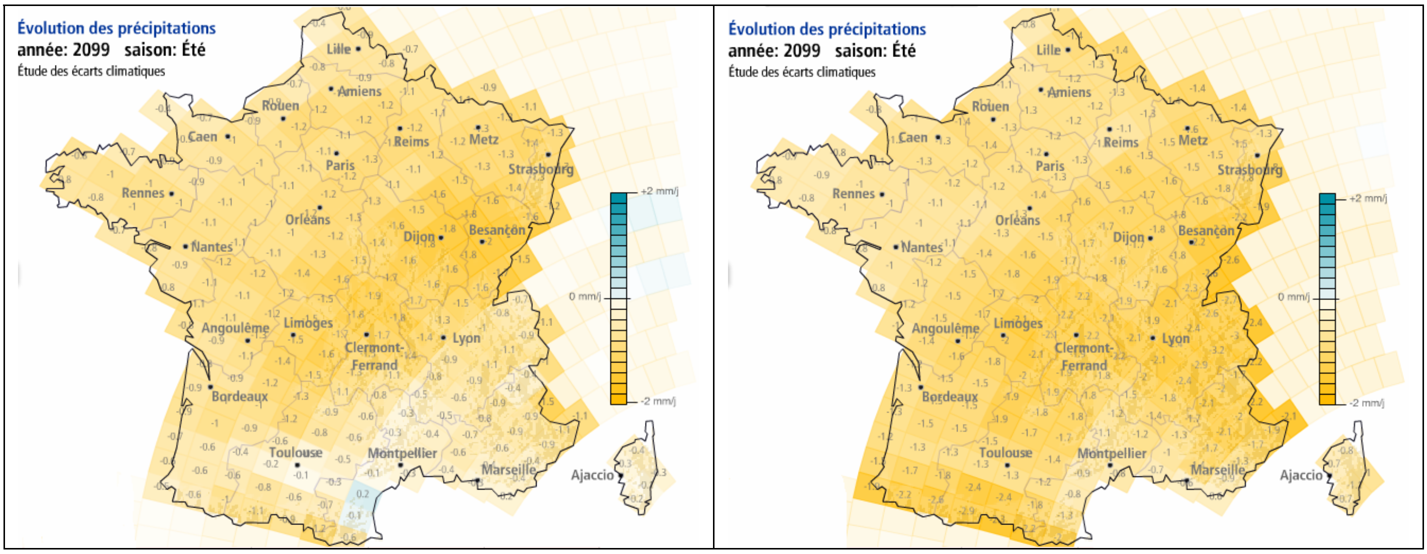

Figure 10 : Estimated evolutions for the summer rainfall (in °mm/day) between the current climate and the end of the 21st century based on scenarios B2 (left) and A2 (right) (source: (http://climat.meteofrance.com/chgt_climat/simulateur/).

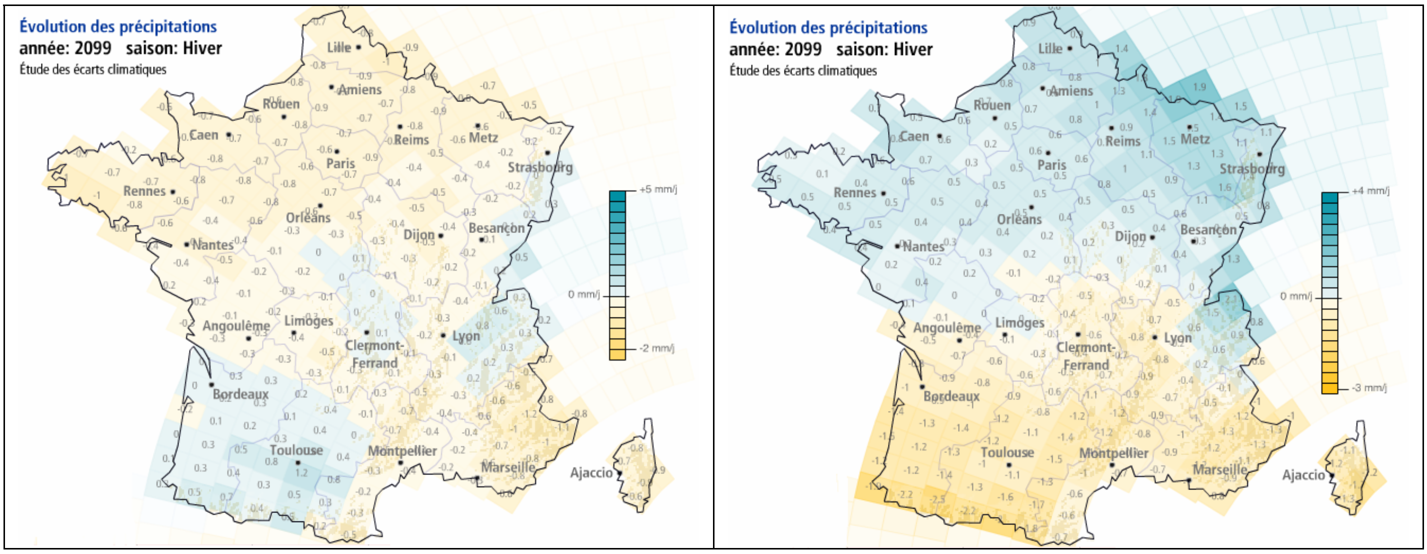

Figure 11 : Estimated evolutions for the winter rainfall (in °mm/day) between the current climate and the end of the 21st century based on scenarios B2 (left) and A2 (right) (source: (http://climat.meteofrance.com/chgt_climat/simulateur/).

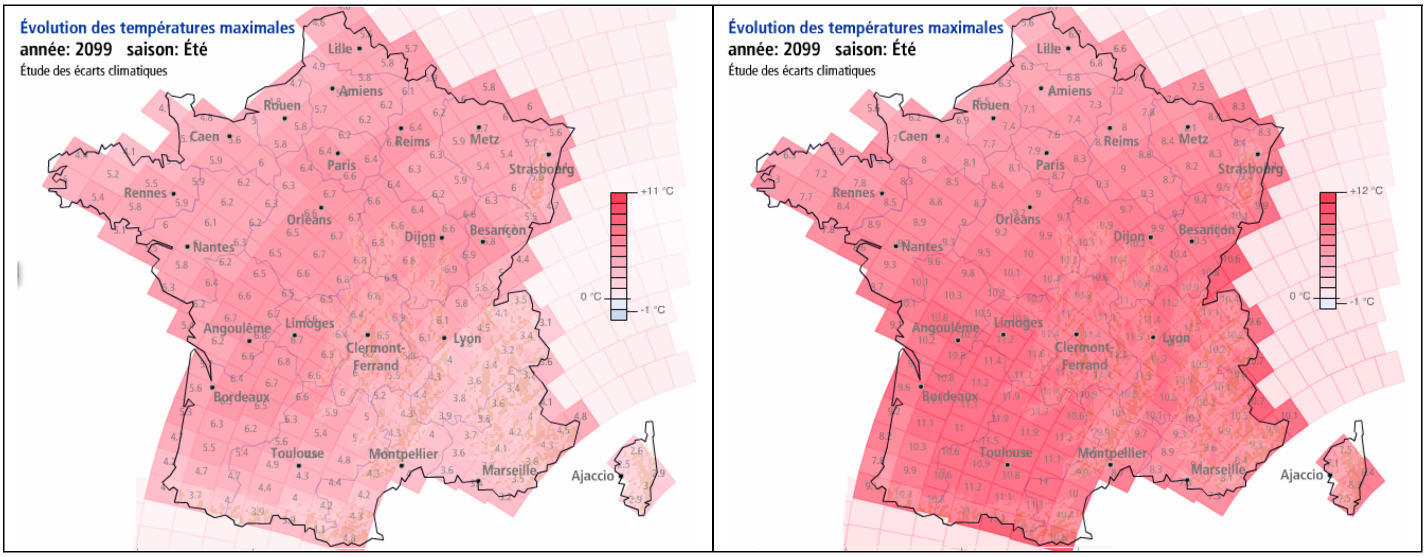

Figure 12 : Estimated evolutions for the maximal summer temperature (in °C) between the current climate and the end of the 21st century based on scenarios B2 (left) and A2 (right) (source: (http://climat.meteofrance.com/chgt_climat/simulateur/).

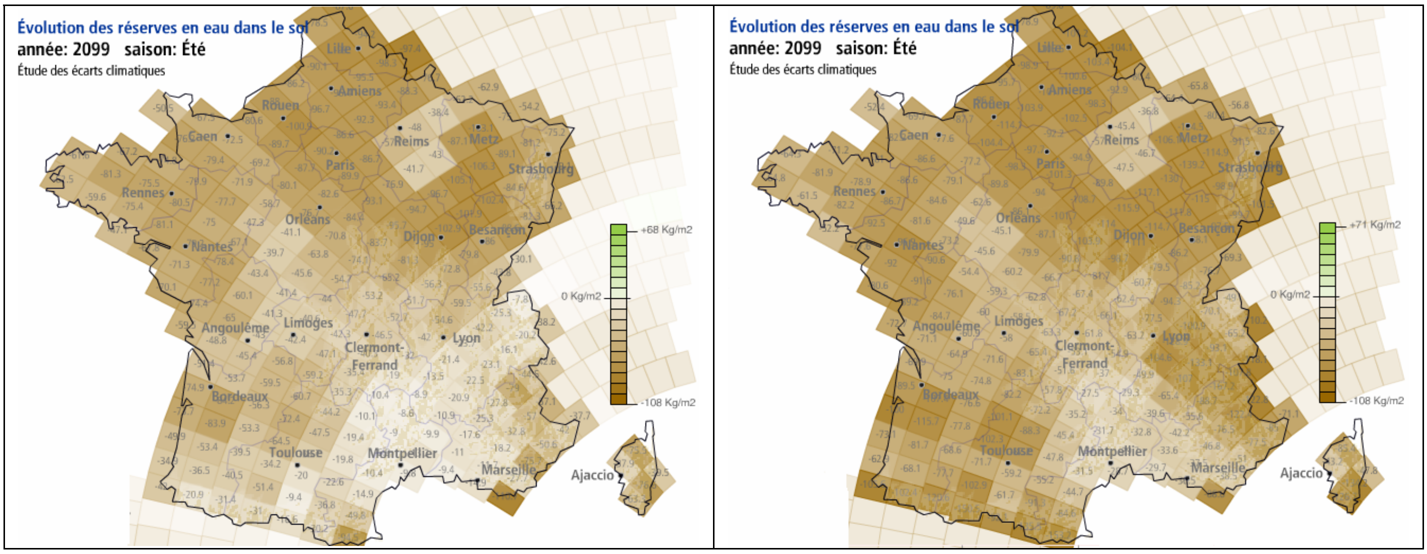

Figure 13 : Estimated evolutions for the summer soil water reserve (in kg/m²) between the current situation and the end of the 21st century based on scenarios B2 (left) and A2 (right) (source: (http://climat.meteofrance.com/chgt_climat/simulateur/).