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# The Influence of Climate Change on European Forests and the Forest Sector

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*Climate change resulting from fossil fuel emissions could create adverse conditions for the forest sector if policy to mitigate the effects of climate change is not actively implemented*

## What is climate change?

The Earth's temperature is mainly driven by the greenhouse effect. Without natural gases, which keep the energy originating from the sun and the centre of the earth close to the surface, the mean temperature at the Earth's surface would not be the current approximate 15 °C, but -19 °C.

Changes in the atmospheric concentrations of greenhouse gases (GHGs) and aerosols, as well as in land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. Natural factors (solar irradiance and volcanic aerosols) have only made a small contribution to global change over the last century. However, it is highly likely that most of the warming observed over the past 150 years can be attributed to human activities, in particular to GHG emissions, such as carbon dioxide (as well as methane, nitrous oxide, chlorofluorocarbons and hydrochlorofluorocarbons) via the burning of fossil fuels (Figure 2).

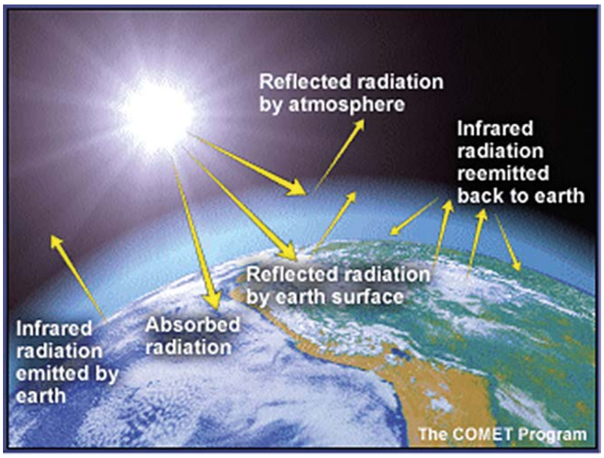


Figure 1. The greenhouse effect. Source: the COMET program.

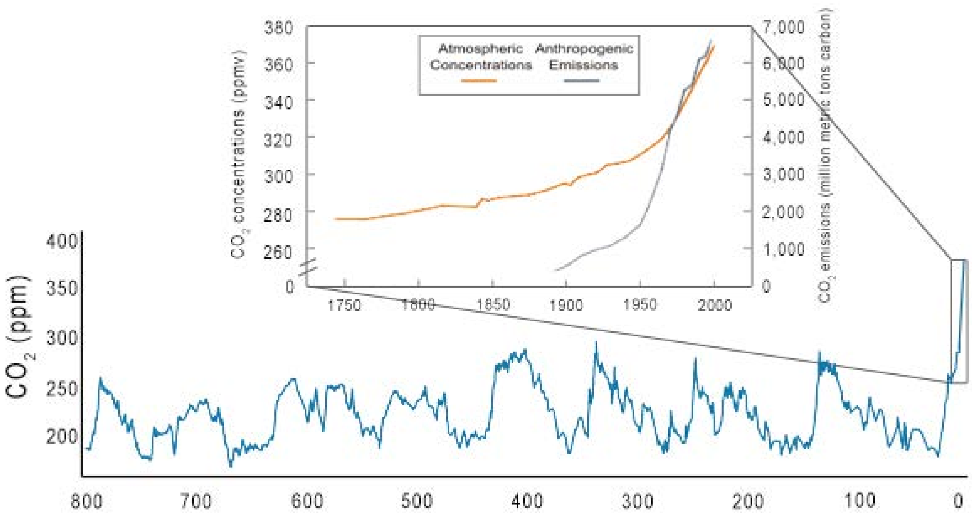


Figure 2: Evolution of $CO_2$ concentration aver the last 800,000 years and anthropic emissions of $CO_2$ over the last 150 years. Modified from Oak Ridge National Library, Carbon Dioxide Information Analysis Center and Hansen et al. 2008.

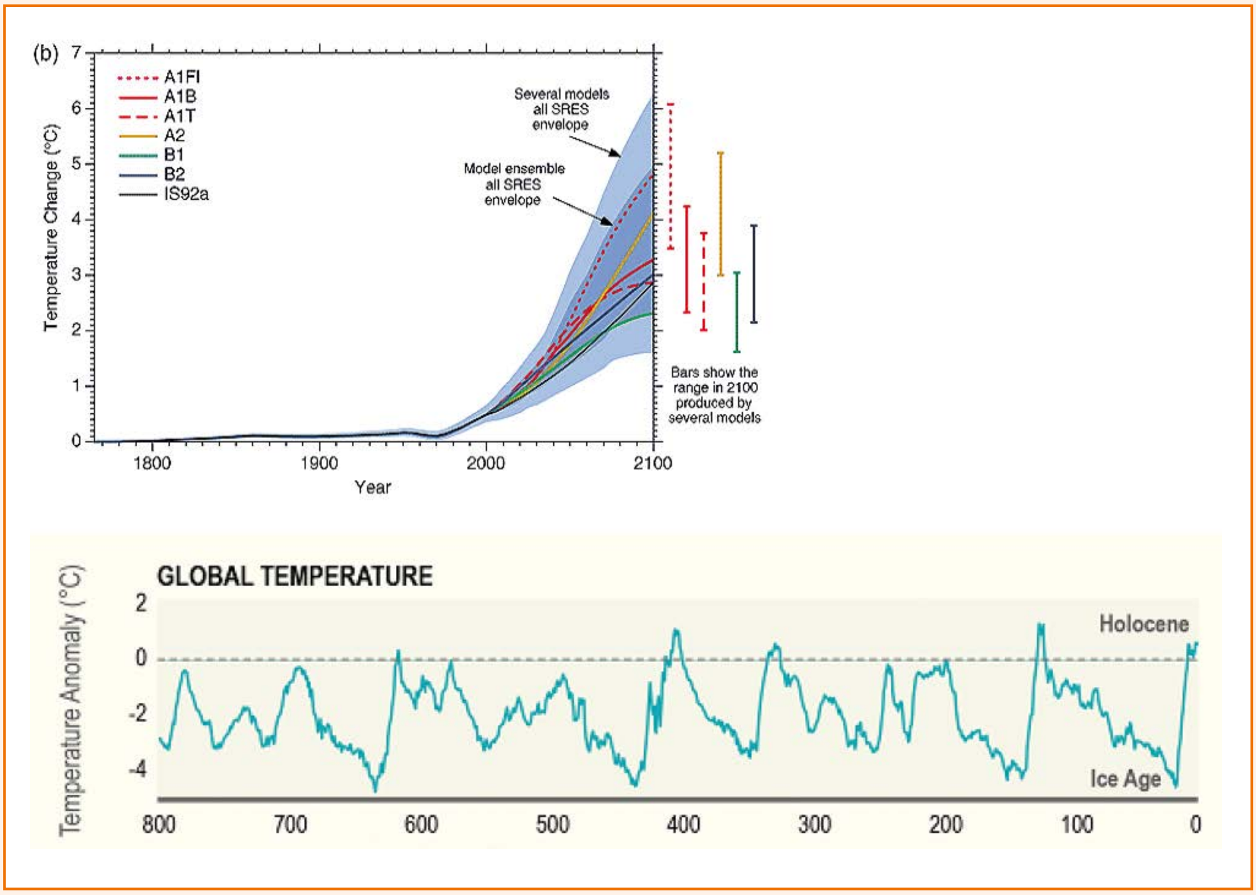


Figure 3. Evolution of mean temperature changes at the Earth's surface over the last 800,000 years and forecasts for the next century using fossil fuel emissions scenarios. In the past ices ages the temperature decreased of 4 degrees in thousands of year. The forecasted changes if green house gases emissions are not reduced is an increase of up to 6 degrees in one century. Source: IPCC 2007 (top) and Hansen et al. 2008 (bottom).

In August 2012, $CO_2$ concentrations exceeded 392 ppm, an increase of roughly 25% since 1959 when modern measurements begun.

As this phenomena is human driven, human beings can also decide to stop the process by reducing or halting the use of fossil resources. This is why climate forecasting is very uncertain and why it is necessary to use many different scenarios representing future human activities in order to forecast future greenhouse gas emissions.

## How do we observe and forecast climate change?

As previously mentioned, the main driver for climate change is the concentration of greenhouse gases in the atmosphere, but the main consequences affecting human activities are related to more common climatic variables such as temperature and precipitations. To forecast the future climate in a given region, scientists use computer software which can calculate the effects of increasing concentrations of Green House Gases in the atmosphere using global atmosphere circulation models and regional climate models. These models are calibrated using past data and different scenarios of population growth, economic growth and fossil fuel consumption, resulting in different Green House Gases emissions for each scenario (from A1F1 high emission to B2 low emission scenario).

## A temperature increase unique in speed and intensity since the existence of humanity

IPCC (Intergovernmental Panel on Climate Change) scientists have been able to use climatic data from 1850 to the present time and have concluded that the global average temperature has increased by 0.8 °C since 1900 and that the actual warming rate is 0.2 °C per decade. It was found that the average global land surface temperature for August 2012 was the second warmest for August.

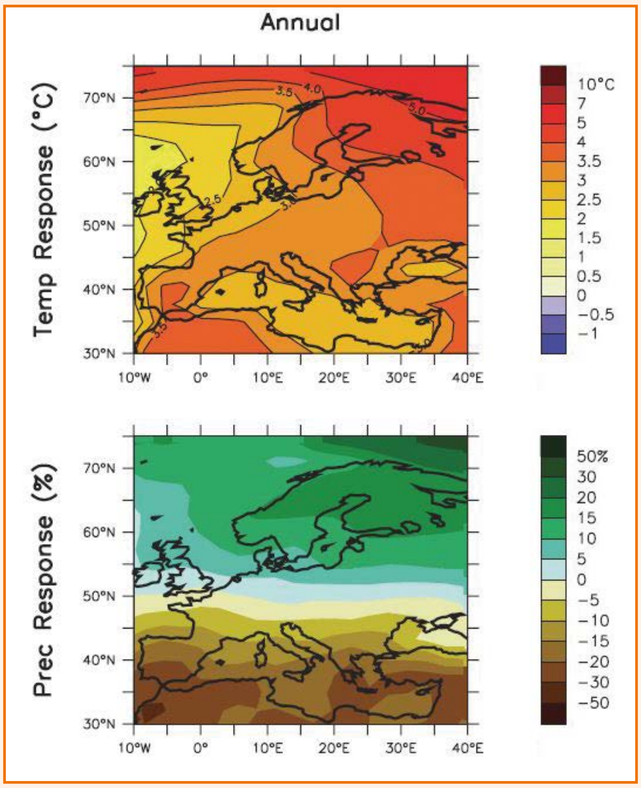


Figure 4. Temperature and precipitation changes over Europe by 2100, based on a set of 21 global models in the MMD for the A1B scenario. (Source: Christensen et al., 2007)

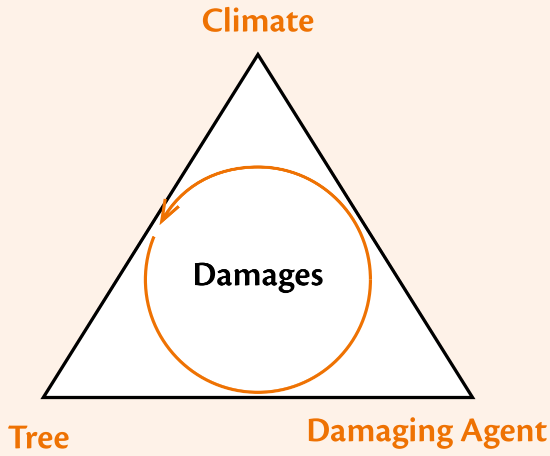


Figure 5. Plant disease triangle.

If the observed global warming is unique in speed and intensity, the climate forecast for the 21st century is still very uncertain and will depend on human activities and the corresponding emissions scenario used. But all climate experts claim that the probability of the B1 scenario occurring is now very low and that at the moment our society is following the A1F1 trend. In terms of the forest sector, it is also important to notice that not all European regions will be affected with the same intensity, as shown in Figure 4.

## Changes in mean precipitation

As temperature increases, wind regimes and the moisture holding capacity of air changes. According to predictions using model this results in a decrease in precipitation in southern areas and continental Europe and an increase in northern Europe.

## Increase in sea level

As the temperature increases, the ice on the continents melts and the water in the ocean dilates, resulting in an increase in sea level that is estimated to rise by 1m in one century.

## More frequent extreme events

Another effect of rising temperatures is an increase in global atmospheric turbulence and in extreme events.

It is very likely that events such as heat waves, heavy precipitation, storms, floods and droughts, will become more frequent. Even if weather forecast models still cannot provide accurate information about these changes on a regional level, some main trends can be identified.

Intense storms capable of damaging forests will become more frequent and their trajectory will move further north and eastwards.

Summer droughts (days without rain) are expected to become more frequent and more intense, especially in southern and central Europe, due to the combined effects of rising temperatures and a decrease in summer precipitation

Intense rainfall may also become more frequent, causing soil erosion and a decrease in water supply for trees throughout the year; these phenomena will be accentuated in areas where soil water capacity is low.

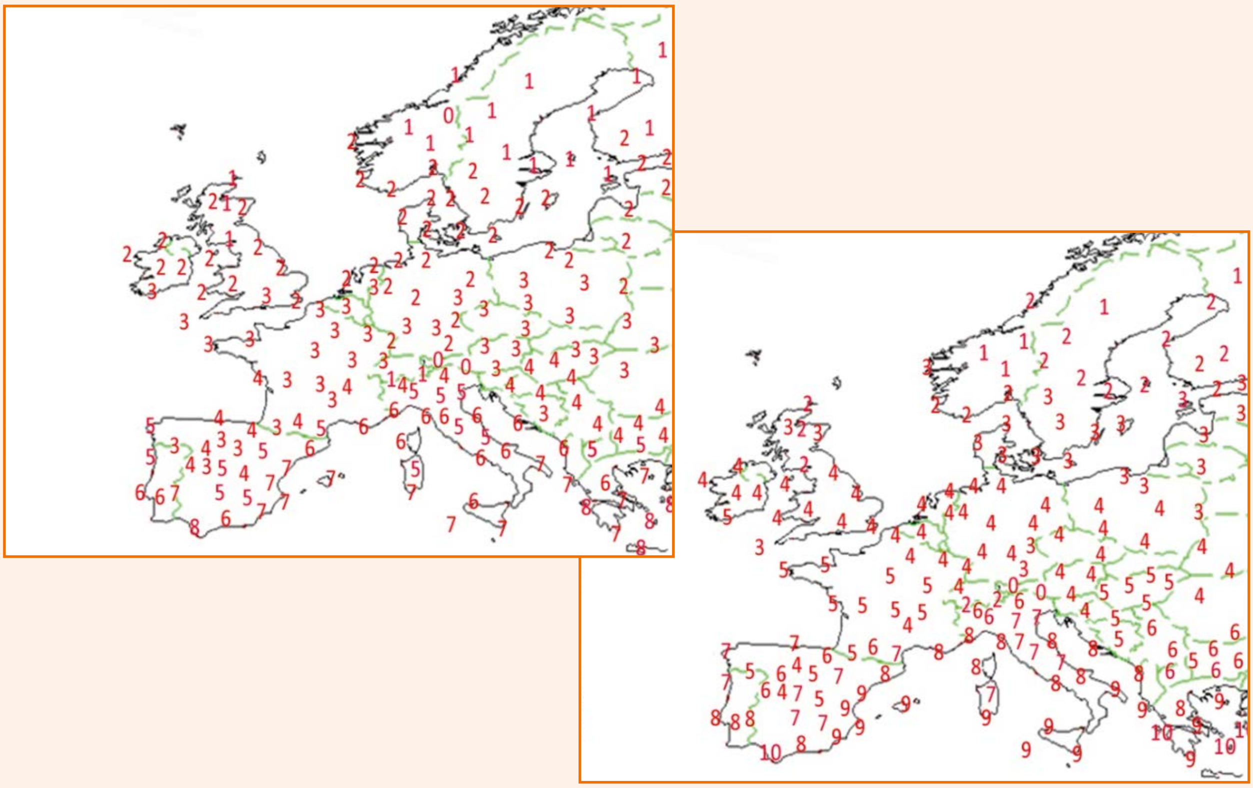

Figure 6. Simulation of the development of spruce bark beetle (*Ips typographus*) in Fennoscandia depending on: a) current climate parameters and b) the impact of a 3°C increase in mean temperature, 1,2,3... n – number of produced generations per year (Modified from http://www.finessi.info/ISTO/index.php?prjpage=99).

## The geography of climate change: regional consequences

Climate change will not affect all of Europe with the same intensity. Alongside mean climatic values, it is also important to take into consideration the changes that will occur throughout the year and extreme events (Table 1.).

## Mountainous areas

Mountainous regions (Alps, Pyrenees, Carpathians) are currently undergoing specific changes. European mountainous regions may experience somewhat higher increases in temperature compared to the surrounding regions (Lindner et al., 2010). During the last century, for instance, the temperature has already increased by twice the global average in the Alps (about +1.5 °C). In the Swiss Alps, an increase of 2 °C is expected in autumn, winter and spring, and 3 °C in summer by 2050. Moreover, the duration of snow cover is expected to decrease by several weeks for every 1 °C temperature increase in the Alps (Christensen et al., 2007).

## How will climate change affect forests?

### Biotic risk will increase

Many insects and fungi are damaging forests and killing trees (eating leaves, boring into wood, causing decay, etc.). Over the generations, trees adapt in order to survive and cope with these damaging agents. Yet with climate change, this equilibrium could be disturbed and epidemic situations may arise. For example, in Canada, a certain insect has benefited from the warmer climate by breeding more quickly and in less than ten years it is killing more than 16 million hectares of trees on the west coast. It is therefore important to anticipate the effect of climate change on living damaging agents.

Any changes to the balance of the three factors in the above triangle could cause a massive outbreak of pests and/or diseases. Climate change will affect all three parts of the plant-disease triangle in various ways.

For example, the Pine wood nematode is confined to zones where mean July temperatures do not exceed 20 °C. However, if nothing is done to limit climate change, it is likely that with increasing temperatures this pine infecting worm will move further north, thus potentially impacting all pines in Europe.

**Table 1. Projected regional climate change impacts on forests.**

| | BOREAL ZONE | TEMPERATE OCEANIC ZONE |
|---|---|---|
| COUNTRIES | Sweden, Finland, Norway | Belgium, Czech Republic, Denmark, France, Germany, Ireland, Luxemburg, the Netherlands, the United Kingdom |
| CLIMATE CHANGE | 3.5–5 °C temperature increase , higher in winter (4–7°C) than in summer (3–4°C).<br>Increases in yearly precipitation up to 40%.<br>Wetter winters. | 2–3.5 °C annual mean temperature increase.<br>Summers likely to be drier and hotter.<br>More damaging extreme events, such as storms, floods and droughts. |
| POTENTIONAL IMPACTS | Prolongation of the growing season.<br>Enhancement of soil organic matter decomposition, increase in nitrogen supply and thereby increase in growth, timber yield and accumulation of carbon in the biomass. | Positive impact on forest growth in northern and western parts.<br>Negative impact in southern and eastern parts.<br>Reduction in the number of tree species.<br>More harmful consequences of extreme events (storms, insects, pathogens).<br>Extension of range and increase in mass outbreaks of pests. |
| INSECT DAMAGE | Northward expansions of nun moth (*Lymantria monacha*) and gypsy moth<br>Range expansion and increased frequencies of mass propagation of *Neodiprion sertifer* and *Ips typographus.*<br>Pronounced expansion of less cold-tolerant species *Operophtera brumata* into north-eastern into areas previously dominated by *Epirrita autumnata* outbreaks.<br>Expansion of *E. autumnata* into the region in which it exhibits regular outbreaks into the coldest and most continental areas. | Rise in incidence of mass outbreaks of pest species.<br>Enhancement of bark beetle development due to prolonged and warmer vegetation periods, through the establishment of additional generations and multiplying population densities.<br>Range expansions and range shifts for pest insects such as *Lymantria dispar, Lymantria monacha* and *Thaumetopoea pityocampa.* |
| DISEASE DAMAGE | Spread of fungal diseases, such as *Heterobasidion parviporum* and *Heterobasidion annosum*, due to longer growing seasons and higher temperatures. | Expansion of highly termophilic, mediterranean pathogen species, such as charcoal disease, *Biscogniauxia mediterranea* or chestnut blight due to the temperature increase associated with drought.<br>Development of fungal diseases present in a latent form in large areas (e.g., *B. mediterranea, Diplodia pinea*) as a result of a decrease in precipitation, as endophytes may turn to pathogens in drought stressed trees.<br>Drought is also a main trigger for infections caused by root diseases, such as *Armillaria spp.* on conifers and Collybia fusipes, on oaks.<br>Rising summer temperatures will be beneficial for another subspecies of *Melampsora* and the root rot *Heterobasidion annosum.*<br>Intensification of *Dothistroma*, the needle blight on pines, during moist spring or summer periods or decrease with precipitation deficits. |

| | TEMPERATE CONTINENTAL ZONE | MEDITERRANEAN ZONE |
|---|---|---|
| COUNTRIES | Austria, Bulgaria, Croatia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Serbia, Slovakia, Slovenia. | Cyprus, Greece, Italy, Malta, Portugal, Spain. |
| CLIMATE CHANGE | 3–4.5 °C annual mean temperature increase.<br>Up to 10% annual mean precipitation increase mainly in winter<br>Summer precipitation decline in most of the region (up to 10%). | 3–4 °C annual mean temperatures increase.<br>Annual precipitations decrease: up to 20% of current annual precipitation.<br>Changes in frequency, intensity, and duration of extreme events. |
| POTENTIONAL IMPACTS | Decrease in forest productivity at sites vulnerable to water stress.<br>Milder winters reducing winter hardening in trees, causing increased vulnerability of trees to frost.<br>More pronounced abiotic disturbances (forest fires, wind throws, drought, etc.)<br>Altitudinal shifts, outbreaks and development of additional generations in certain pest insects. | Decline in growth and biomass production.<br>Replacement of tree species.<br>Prolonged drought periods, more hot days, heat waves, heavy precipitation events and fewer cold days.<br>Frequent fires.<br>Distributional shift in insects.<br>More virulent thermophilic pathogen species.<br>Acceleration of desertification in dry areas. |
| INSECT DAMAGE | Range shift and rising outbreaks of certain pest insects caused by temperature increase impacting population dynamics and distribution of exothermic organisms.<br>Northward expansion of distribution areas of *Lymantria monacha* and *Lymantria dispar.* | Water stress of eucalypt trees plays a crucial role in the colonisation success, larval survival and growth of the phloem-boring beetle *Phoracantha semipunctata.*<br>Southern restrictions in distribution of *Lymantria dispar* and *Lymantria monacha.*<br>Pest species profit from climate change in case of altitudinal expansion or dislocation of the distribution range, especially when coupled with host switching (i.e., *Thaumetopoea pityocampa*).<br>Heat stress during summer responsible for a northward move for the nun moth (*Lymantria monacha*).<br>Sensitive reaction of the gypsy moth (*Lymantria dispar*) to rising winter temperatures, as diapause requirements may not be satisfied any more. |
| DISEASE DAMAGE | Predisposition of host trees to root diseases, such as *Armillaria spp,* due to reductions in summer precipitation resulting in drought-stress in forests.<br>Increased incidence of decay caused by *Heterobasidion spp* due to high temperatures and xeric conditions<br>High risk of severe outbreaks of fungal pathogens which sporulate and germinate during warm and moist periods (extended periods of precipitation combined with intermediate temperature (15°- 20°C) are optimal for infections of pines by *Dothistroma* needle blight). | Increase in virulence of highly thermophilic pathogen species.<br>Rapid development of *Biscogniauxia mediterranea* on *Quercus spp.* and *Diplodia pinea* on *Pinus spp.* in the case of water stressed host trees, causing sudden dieback.<br>Increase in will promote outbreaks of various pathogenic fungi, such as the Dutch elm disease, Ophiostoma ulmi, poplar rusts, or the chestnut blight, due to temperature increase and summer droughts.<br>Spread of *Heterobasidion abietinum,* together with the root disease *Armillaria spp.* Resulting from summer drought<br>Spread of *Phytophthora cinnamomi* on oaks due to long periods of high temperature interspersing with short intervals of heavy precipitation. |

### Forest pests are benefiting from warmer climates in Europe

The effects of climate change on insect populations could either be direct, through the influence that weather may have on the insect's physiology and behaviour, or indirect, through physiological effects on their host plants, competitors and natural enemies.

- The population dynamics of many forest pest species depend highly on temperature. As a consequence of climatic change, rising temperatures, will lead to increased frequencies and intensities of insect-pest outbreaks.
- Mild winters promote larval survival and higher numbers of adults, resulting in heavier defoliation in the next generation of larvae.
- For herbivores which have more than two broods or generations per year, a rise in temperature will provide more time for the development of additional generations at the beginning and the end of the growing season.
- The geographical ranges of many insect species will expand to higher latitudes and elevations.
- Increases in atmospheric $CO_2$ may considerably alter insect herbivore-plant interactions indirectly, primarily through effects on plant growth and development.
- Climate change may alter the interactions between herbivores and their natural enemies, leading to changes in levels of the natural control and dynamics of the herbivore.

### Diseases will also benefit from climate change, due to water deficits and higher temperatures

Diseases comprise pathogenic fungi that can cause decay in any part of living trees (leaves, trunks, roots, etc.) or even kill them. The main consequences of climate change for diseases are as follows:

- The temperature will impact plant diseases through either the host crop plant or the pathogen.
- Higher temperatures will accelerate the life cycle of many pathogenic fungi, which could spread over shorter time periods and consequently increasing the risk of infection.
- More generations of pathogens will be produced within a given time span
- If a generation of a particular disease lasts longer, it will be able to infect plants at a later growth stage than at present.
- More frequent and extreme precipitation events could result in more and longer periods of favourable conditions for pathogen development.
- The expression of resistance genes and their efficacy in the host plants could decrease.
- Because of low genetic variation, plantations of monocultures or single clones may be affected by new or adapted strains in the pathogen population.

## Abiotic risk

### More frequent fire events

In the 21st century climate change is likely to increase the risk of wild fire in the Mediterranean region, as well as in other parts of Europe (Dury et al., 2011). Figure 8 shows the burned area in the Mediterranean region during the 1961-2100 period.

Simulations have been carried out using the CARAIB model for the 21st century. Results show that fire frequency and intensity increase significantly in central Europe(up to 60°N) and in western France, Poland, Romania, central Russia and the Ukraine, etc..... Authors have suggested that the risk of wild fire may increase almost everywhere in Europe (except in Scandinavia and northern Russia) and that most countries may have to face an increase in fire damages (Dury et al., 2011).

Forest fires will become an even larger threat to Mediterranean forestry and human well-being in rural areas (Moriondo et al., 2006). Frequent fires can increase soil erosion and reduce plant regeneration, while in dry areas desertification may accelerate (Certini, 2005).

### More damaging storms

In the period 1950–2000, an annual average of 35 million $m^3$ of wood was damaged by disturbances (i.e., 8% of total fellings in Europe); storms were responsible for 53% of the total damage, while fire was responsible for 16%. Storms will tend to be accompanied by heavier rainfall leading to more saturated soils and an increased risk of wind damage (EFI).

Three factors determining forest stability will be affected by climate change leading to increased damages:

1. A change in wind regimes with higher wind speed and different trajectories
2. A change in water regimes with more rain in winter during the storm period
3. A change in soil frost regimes in Nordic countries

### More frequent extreme events, such as drought and flooding

Extreme flooding events are expected to occur more frequently as a consequence of climate change. While the number of rainy days is projected to decrease, the number of days with heavy rainfall events is projected to increase. This change will lead to more extreme flooding events damaging forest during summer, especially in the Mediterranean or mountainous regions.

Rising temperatures and the projected decrease in rainfall will magnify the risk of drought, increasing mortality in areas where tree species are not drought tolerant enough. In this case, dying trees should be replaced by more adapted species resulting in a new landscape, changing the main tree species distribution all over Europe.

## Climate change consequences for forest cycles

### Changes in growth rates

According to past data from the end of the 20th century the rate of tree growth is increasing all over Europe, due to the fertilising effect of rising $CO_2$ concentrations in the atmosphere. In the following decades, when precipitation decreases, water will be the limiting factor (around 2030–2050 in many European regions) and forest tree growth is therefore expected to slow down in the southern half of Europe. In the long run, climate change may only have a positive impact on growth in northern countries where frost limits the length of the growing period; with less and less frost, the duration of the growing period will increase.


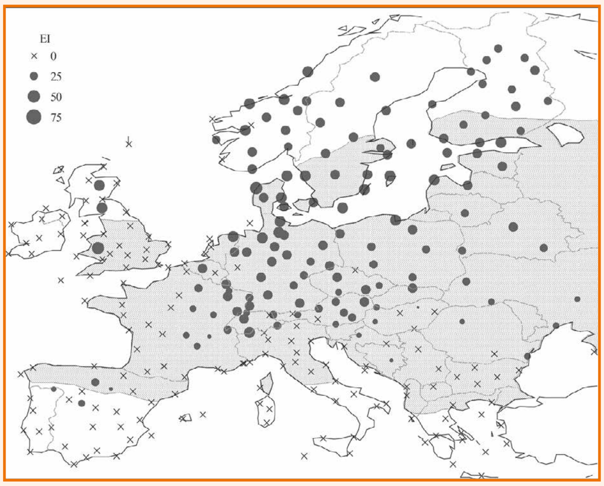



Figure 7. Climate change and range shifts in insect defoliators nun moth. A model study with 3 climate change scenarios showing that the more green house effect gases will be emitted, the more the insect will find good living conditions in Nordic area. (Source: Vanhanen et al., 2007).

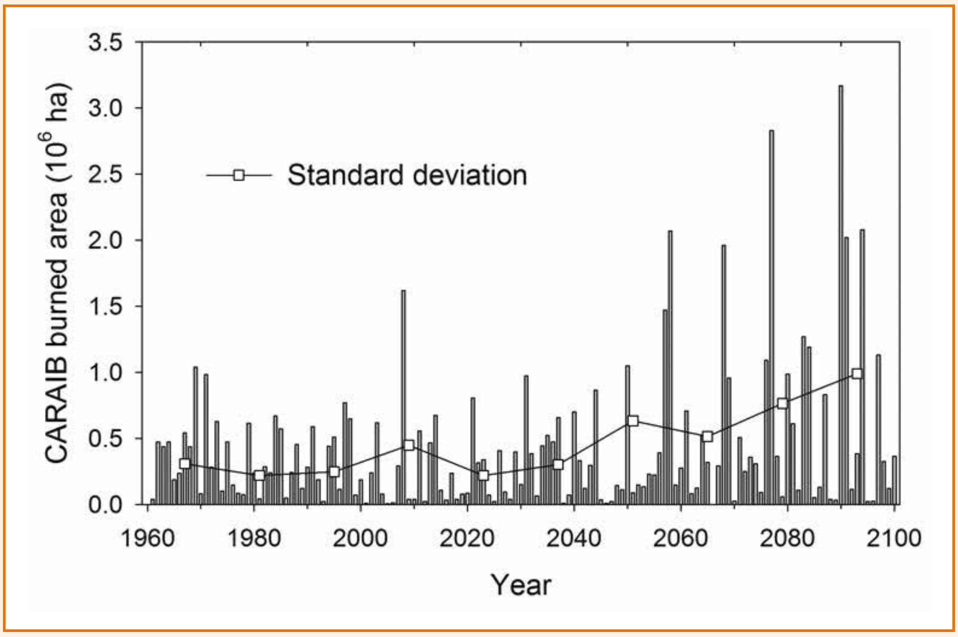


Figure 8. Projected wildfire areas in Europe under a scenario with intermediate green house effect gases emission. Source: Dury et al. 2011.

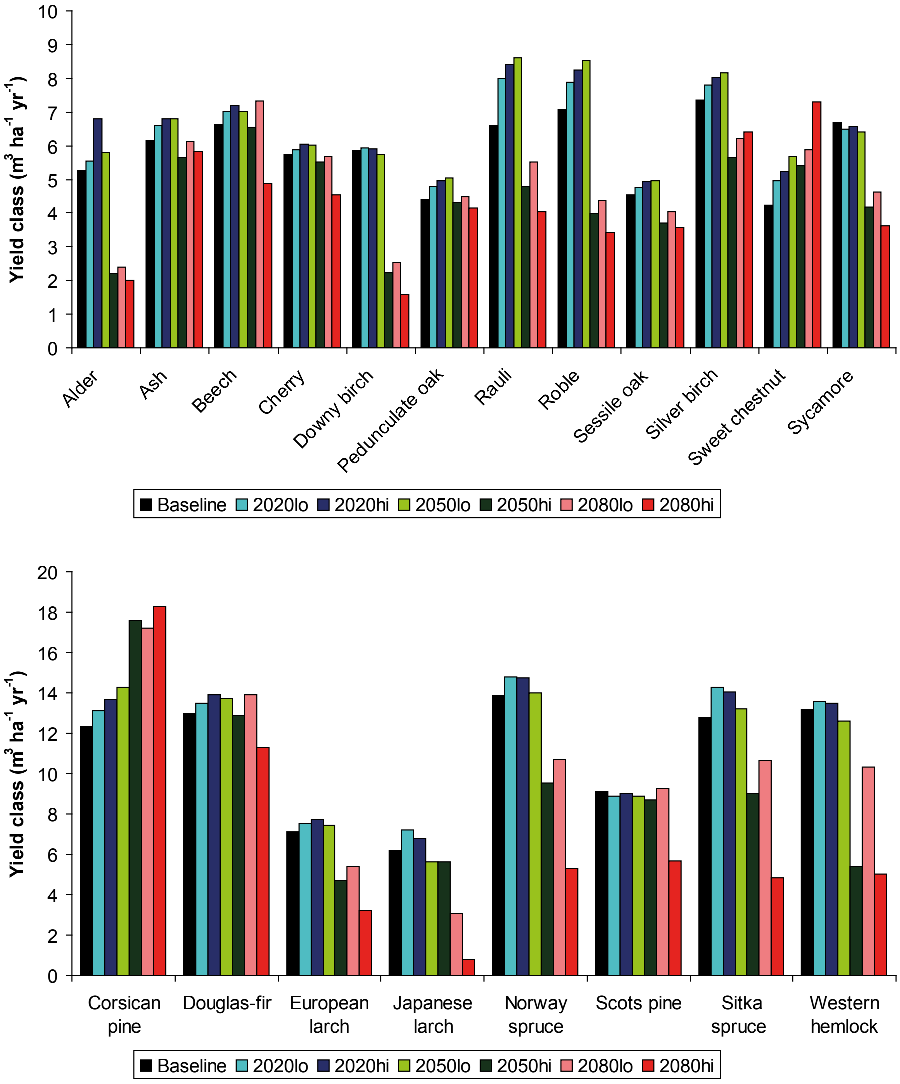


Figure 9. Changes in yields of broadleaves (upper) and conifer (lower) under different GHG emission scenarios in the UK (lo: low emissions, hi: high emission). Source: Gardiner, 2011.

Locally, it is difficult to quantify the impact of climate change on forest tree growth, as it is very site and species specific. For some tree species, such as beech and pine, annual growth will be sensitive to an increase in maximum summer temperatures, while others, such as the sessile oak, will suffer more in dry and warm autumns affecting its growth in the long term. Obviously, a forest system with a long rotation length (of more than 50 years) will be affected more, accumulating adverse climate impacts on growth over many decades.

## Changes in species suitability

Gaining knowledge of how climate change will affect the growth potential and ecological suitability of individual tree species is essential for developing climate change adaptation strategies. As part of this process, different Ecological Site Classification (ESC) decision support systems have been developed to account for the effects of predicted climate change. ESC decision support systems have been designed to match key site factors with the ecological requirements of different tree species and produce suitability maps (Figure 10).

In Europe, the switch in species will also have consequences on the volume produced; it is forecasted that between 20 to 60% of European forest lands in 2100 will be suitable for Mediterranean oak forest type with low timber production and low economic return.

## Changes in phenology

All these irregularities in the weather regime will affect phenology (bud burst, flowering, leaf fall etc.). For many tree species $CO_2$ concentration and the warmer temperatures in winter can cause early growth rendering them more prone to frost damage, even if frost is becoming less frequent. In Europe, It has been observed that a change in mean temperature of 1 °C will induce an extension of the forest tree growing period per year, varying from 7 to 13 days according to the tree species and location.

Global warming has been shown to be one of the most serious threats to biodiversity. Forests are particularly sensitive to climate change, because the long life-span of trees does not allow them to adapt quickly to environmental changes

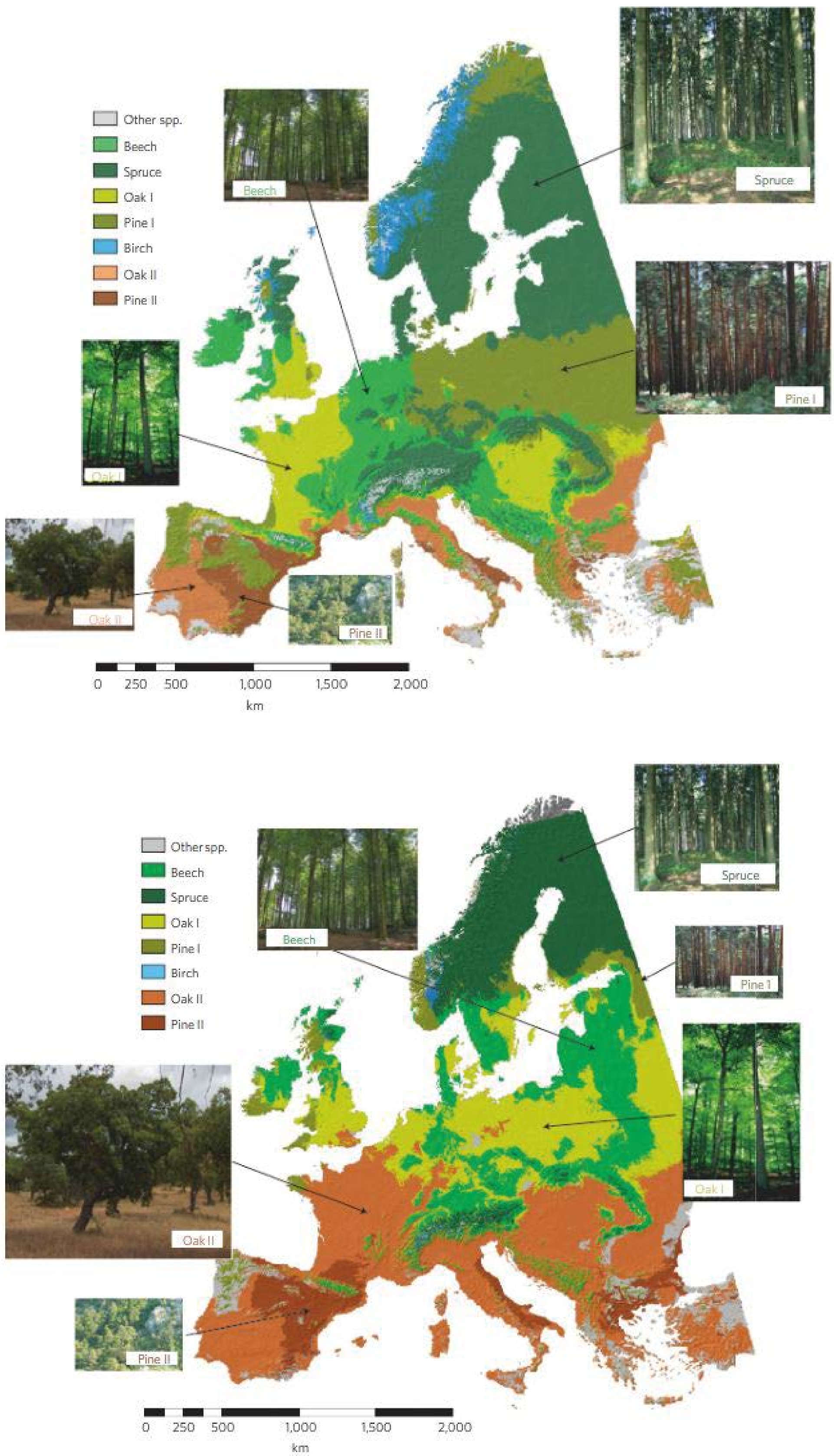


Figure 10. Ecological Site Classification for the distribution of main forest tree species with a moderate warming from 2000 to 2100 showing an extension of Mediterranean species. Source : Hanewinkel et al. 2012.

**Table 2. Impact of climate change factors on the growth of some forest species and on their wood quality in the UK. Source: Gardiner, B. 2011.**

| Climate Change / Species | Species | Direct Impact | Potential Impact on Timber Properties |
|---|---|---|---|
| Increased temperatures | Sitka spruce | Increased growth, lammas growth | Lower wood density, increased branchiness |
| | Scots pine | Increased growth, lammas growth | No impact on density, increased branchiness |
| | Oak | Increased growth, lammas growth | Higher density, increased branchiness |
| Drier summers | Sitka spruce | Earlier switch to latewood | Higher wood density, drought cracks, ring shake |
| | Scots pine | Reduced growth | Little impact on density |
| | Oak | Drought stress | Increased shake |
| Wetter winters | Sitka spruce | Shallower rooting and increased leaning | Compression wood, poorer form |
| | Scots pine | Increased leaning | Compression wood, poorer form and heavier branching |
| | Oak | Increased lean | Tension wood |
| Milder winters | Sitka spruce | Earlier flushing | Risk of frost damage |
| | Scots pine | Earlier flushing | Risk of frost damage, more blue stain |
| | Oak | Earlier flushing | Risk of frost damage, reduced vessel size |
| Increased storminess (?) | Sitka spruce | Increased wind damage, leader loss | Higher levels of compression wood, poorer stem form |
| | Scots pine | Increased wind damage, leader loss | Higher levels of compression wood, poorer stem form |
| | Oak | Increase lean | Higher levels of tension wood |
| Increased pest and disease | Sitka spruce | *Dendroctunus micans, Armillaria Heterobasidion* | Reduced growth rates |
| | Scots pine | *Dothistroma septosporum, Tomicus* | Reduced growth rate and increased mortality |
| | Oak | *Phytophthora, Amillaria* and *Biscogniauxia spp* | Reduced growth rate and increased mortality |

and not all species will benefit from the $CO_2$ fertiliser effect in the same way. The difference in species sensitivity will induce a rapid change within the forest landscape affecting ecosystem services (carbon storage, soil protection, etc.) and associated habitats which have been identified as areas of interest in terms of its biodiversity. The dynamics of this change will vary from region to region.

### Changes in wood quality

In addition to tree growth, overall wood quality may also be negatively affected as a result of irregular tree growth rate from one year to another and any damages caused to the trees. The wood supply for a given species and area may increase for a few decades when the species is in the northern part of its range, where conditions will be optimal. However, the trees that remaining in the southern range will find themselves in unfavourable conditions, affecting their growth and quality. These changes could occur in one century, the rotation length of many forest species.

## What changes are needed so that forests can adapt to climate change?

### What can foresters do?

With a short rotation system (trees harvested after less than 50 years), the main threat is to areas exposed to extreme events. Measures should therefore be taken to increase tree stability and prevent erosion. Recommendations for tree stability include wind risk mapping, management with few thinnings, appropriate site preparation and regeneration, and moderated stand height (i.e., shorter rotations). For other extreme events, fire prevention strategies must be extended further north and biotic risk management must be intensified, as forests will become more and more exposed.

For tree species with longer rotation lengths, even if mitigation measures are implemented actively, the speed and intensity of climate change is too fast for natural selection processes to be efficient. Foresters will have to favour genetic material that is better adapted to local situations (resistance to drought, pest and diseases, extreme events, etc.). For species with a long rotation length, the rotation, timber products and target species should be revised based on regional climate forecasts. Amidst so much uncertainty about the real intensity of climate change, the challenge for assisted migration (deliberately moving species or varieties adapted to the future climate to another region), species replacement or enrichment is to find silvicultural practices which will allow stands to cope with the current and future climate. Mixing tree species within stands or between stands is an option that can be considered in some cases, allowing species resilient to drought and biotic diseases to compensate for timber production loss arising from biotic or abiotic diseases.

In southern regions where draught will be the main issue, any means of improving water supply to trees should be considered; for example, reducing competition for soil water (decreasing tree density, weed control), improving soil water capacity (biochar application to soils), and selecting more drought tolerant genetic material.

All these changes to species and silviculture will have consequences on wood supply (timber quantity and quality, product size, growing stocks) and will have to be conducted regionally by wood producers and the wood sector in general, combining the most appropriate of the recommendations listed above.

### What policies should be supported?

Policies should anticipate climate change and any associated risk by:

- Accurately monitoring climate change impacts on forests.
- Actively preparing for more extreme events by producing forest contingency plans: fire, insects, drought, storms, pathogens, etc..
- Changing policy on the use of genetic material in forests taking into consideration the fact that local provenances are not always the best choices. Climate seems to be changing too quickly for the natural adaptation process of many tree species.
- Preparing the forest sector for changes in wood supply (quantity, quality, different tree species etc.).
- Supporting all mitigation action (i.e., stopping or reducing the emission of fossil carbon into the atmosphere by replacing fossil energy and plastic with renewable resources) and policies, nationally and internationally, to prevent climate change as much as possible and to reduce its impact on forests.

### What are the implications for research and forest sector activity in the next decade?

Reducing uncertainty about climate change on the regional level is the main output expected from climate scientists by forest managers. Furthermore, more knowledge on adaptive forest management is expected; this could be done by taking the following action:

- Integrate climate change scenarios in decision support tools (growth models, damaging agents, etc.).
- Improve knowledge of species/provenances/families tolerance to climate change, not only to mean climate parameters, but also to extreme ones to assess the resilience of genetic material used in forests and to recommend more appropriate ones.
- Improve knowledge about climate-driven risks and identifying certain climatic thresholds, so that they can be monitored properly and so that early warnings can be given.
- Improve ecosystem management recommendations to make them as resilient as possible; in particular focusing on site characteristics, forest structures and composition parameters.
- Start to develop innovative forest reconstitution schemes that will be applied in the aftermath of damaging events to cope with future climate scenarios.

## Conclusion

Climate change and change in climate variability bring significant risks to the environment and to life itself. The whole planet is likely to be affected. Practically all countries in the world, party to the United Nations Framework Convention on Climate Change (UNFCC, 1992), have recognized the need to take part in climate change adaptation and mitigation activities. In speed and amplitude, climate change is a phenomenon that has never previously been faced by humanity and which holds unseen challenges for all economic sectors. However, the uncertainty surrounding it is very high, including policy decisions and mathematical model errors. If we are able to implement policies to reduce green-house emissions and to keep climate change under control new opportunities for the forest sector may also be created. Policy-makers and managers in forestry should seriously take this into consideration, understanding that forestry can adapt to a moderate change in climate, but probably not to the more extreme emissions scenarios. Immediate and significant action is needed to limit the intensity of climate change and to prepare the forest sector for a new future climate.

## Literature


Ashton, M.S., Tyrrell, M.L., Spalding, D., Gentry, B. (Eds.). 2012. Managing Forest Carbon in a Changing Climate. Springer. 414 p. http://www.springer.com/life+sciences/forestry/book/978-94-007-2231-6

Battisti, A., Stastny, M., Netherer, S., Robinet, C., Schopf, A., Roques, A., Larsson, S. (2005). Expansion of geographic range in the pine processionary moth caused by increased winter temperatures. Ecological Applications 15, 2084–2096.

Bergot, M., Cloppet, E., Pérarnaud, V., Déqué, M., Marçais, B., Desprez-Loustau, M. (2004). Simulation of potential range expansion of oak disease caused by Phytophthora cinnamomi under climate change. Global Change Biology 10, 1539–1552.

Caldeira, M.C., Fernandez, V., Tome, J., Pereira, J.S. (2002). Positive effect of drought on longicorn borer larval survival and growth on eucalyptus trunks. Annals of Forest Science 59, 99–106.

Christensen et al. (2007). In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M-, Averyt, K. B., Tignor, M. and Miller, H. L. (eds). Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

Climate Change for Forests Policy-Makers. An approach for integrating climate change into national forest programmes in support of sustainable forest management. FAO, 2011. http://www.fao.org/docrep/015/i2429e/i2429e00.pdf

Desprez-Loustau, M., Marcais, B., Nageleisen, L., Piou, D., Vannini, A. (2006). Interactive effects of drought and pathogens in forest trees. Annals of Forest Science 63, 597–612.

Desprez-Loustau, M., Robin, C., Reynaud, G., Déqué, M., Badeau, V., Piou, D., Husson, C., Marcais, B. (2007). Simulating the effects of a climate-change scenario on the geographical range and activity of forest-pathogenic fungi. Canadian Journal of Plant Pathology 29, 101–120.

Dury, M., Hambuckers, A., Warnant, P., Henrot, A., Favre, E., Ouberdous, M. and François, L. (2011). Responses of European forest ecosystems to 21st century climate: assessing changes in interannual variability and fire intensity. iForest 4: 82–99.

Forest Management and Climate Change: a literature review. Forests and Climate Change Working Paper 10. FAO, 2012. http://www.fao.org/docrep/015/md012e/md012e00.pdf

Forest Management and Climate Change: Stakeholders perceptions. Forests and Climate Change Working Paper 11. FAO, 2012. http://www.fao.org/docrep/015/md510e/md510e00.pdf

Forests and Climate Change. Forestry Research Agency. Forestry Commission, UK. http://www.forestry.gov.uk/climatechange

Gardiner, B. (2011). Climate Change, Tree Growth and Timber Properties. http://www.forestry.gov.uk/pdf/CCTTFeb11_Barry_Gardiner_tree_growth_and_timber_properties.pdf/$FILE/CCTTFeb11_Barry_Gardiner_tree_growth_and_timber_properties.pdf

Hanewinkel, M., Cullmann, D. A., Schelhaas M-J., Nabuurs, G-J. and Zimmermann, N. E. (2012). Climate change may cause severe loss in the economic value of European forest land. Nature Climate Change.

Hanninen, H. (2006). Climate warming and the risk of frost damage to boreal forest trees: identification of critical ecophysiological traits. Tree Physiology 26, 889–898.

Hansen, J., Sato, M., Kharecha, P., Beerling, D., Berner, R., Masson-Delmotte, V., Pagani, M., Raymo, M., Royer. D.L., Zachos, J.C. (2008) Target atmospheric $CO_2$: Where should humanity aim? Open Atmos. Sci. J., 2, 217–231.

Hodar, J.A., Castro, J., Zamora, R. (2003). Pine processionary caterpillar *Thaumetopoea pityocampa* as a new threat for relict Mediterranean Scots pine forests under climatic warming. Biological Conservation 110, 123–129.

IPCC (2007). Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K. and Reisinger, A. (Eds.).

Jepsen, J.U., Hagen, S.B., Ims, R.A., Yoccoz, N.G. (2008). Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: evidence of a recent outbreak range expansion. The Journal of animal ecology 77, 257–264.

Karolewski, P., Grzebyta, J., Oleksyn, J., Giertych, M.J. (2007). Effects of temperature on larval survival rate and duration of development in *Lymantria monacha* (L.) on needles of *Pinus sylvestris* (L.) and in *L. dispar* (L.) on leaves of *Quercus robur* (L.). Polish Journal of Ecology 55, 595–600.

Kellomaki, S., Vaisanen, H., 1997. Modelling the dynamics of the forest ecosystem for climate change studies in the boreal conditions. Ecological Modelling 97, 121–140.

La Porta, N., Capretti, P., Thomsen, I.M., Kasanen, R., Hietala, A.M., Von Weissenberg, K. (2006). Forest pathogens with higher damage potential due to climate change in Europe. Symposium contribution: The Effects of Climate Change on Tree Diseases, 29 July – 2 August 2006, Québec, Qué.

Lindner M. et al (2008). Impacts of Climate Change on European Forests and Options for Adaptation, Report to the European Commission Directorate – General for Agricultural and Rural Development, contract nr. AGRI-2007-G4-06, European Commission.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolstrom, M., Lexer, M., Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. Forest Ecology and Management 259, 698–709.

Mattila, U., Nuutinen, T., (2007). Assessing the Incidence of Butt Rot in Norway Spruce in Southern Finland. Silva Fennica 41, 29–43.

Moore, B., Allard, G. 2009. Los impactos del cambio climático en la sanidad forestal. In: Documentos de trabajo sobre sanidad y bioseguridad forestal. FAO, 2009.

Moriondo, M., Good, P., Durao, R., Bindi, M., Giannakopoulos, C., Corte-Real, J., (2006). Potential impact of climate change on fire risk in the Mediterranean area. Climate Research 31, 85–95.

Ogaya, R., Penuelas, J., Martinez-Vilalta, J., Mangiron, M. (2003). Effect of drought on diameter increment of *Quercus ilex*, *Phillyrea latifolia*, and *Arbutus unedo* in a holm oak forest of NE Spain. Forest Ecology and Management 180, 175–184.

Penuelas, J., Boada, M., 2003. A global change-induced biome shift in the Montseny mountains (NE Spain). Global Change Biology 9, 131–140.

Puddu, A., Luisi, N., Capretti, P., Santini, A. (2003). Environmental factors related to damage by *Heterobasidion abietinum* in *Abies alba* forests in Southern Italy. Forest Ecology and Management 180, 37–44.

Resco De Dios, V., Fischer, C., Colinas, C. (2007). Climate change effects on Mediterranean forests and preventive measures. New Forests 33, 29–40.

Schutz, J.P., Gotz, M., Schmid, W.,Mandallaz, D. (2006). Vulnerability of spruce (*Picea abies*) and beech (*Fagus sylvatica*) forest stands to storms and consequences for silviculture. European Journal of Forest Research 125, 291–302.

Seppälä, R., Buck, A., Katila, P. (Eds.). 2009. Adaptation of forests and people to climate change. A global assessment report. IUFRO World Series Volume 22. Helsinki, Finland. 224 p.

Thuiller, W., Lavorel, S., Sykes, M.T., Arau' jo, M.B. (2006). Using niche-based modelling to assess the impact of climate change on tree functional diversity in Europe? Diversity and Distributions 12, 49–60.

Vanhanen, H., Veteli, T.O., Päivinen, S., Kellomäki, S., Niemelä, P. (2007). Climate change and range shifts in two insect defoliators: gypsy moth and nun moth – a model study. Silva Fennica 41, 621–638.

# The Influence of Climate Change on European Forests and the Forest Sector

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