Towards adaptive **forest** management

François Lefèvre
Research Director
– INRA – Ecology of the Mediterranean Forests Research Unit.

Denis Loustau
Research Director – INRA-Bordeaux Sciences Agro – Atmosphere Plant Soil Interactions Joint Research Unit.

Benoît Marçais
Research Director – INRA-Université de Lorraine – Tree-microbe interactions Joint Research Unit.

Forests are sensitive to climate change. Observation networks, new genetic data and numerical simulations will give the opportunity to define forest change scenarios and to identify optimal conditions for adaptive forest management practices.

Forests will not be spared by climate change. While some effects have proven to be beneficial, climate change on the whole will probably cause significant damage. Since the first research programs aimed at understanding the effects of climate change began in the 1990's, the magnitude of current changes and their impacts have always been revised upward. However, it is the multiplication of extreme events, such as the series of storms and droughts that occurred in early 2000s, which raised awareness of the need to act quickly.

It has also become evident that adaptive strategies for forests will require flexibility over time. These measures need to be considered as dynamic processes rather than a means to reaching a stable equilibrium to adapt to local conditions in a given moment. Indeed, forests will be faced with climatic conditions that will continue to change over several decades, possibly over a century. To anticipate future climatic hazards, we need to be prepared to manage many uncertainties. This will require a thorough reexamination of models currently guiding forest management.

Forest dynamics

Forests are complex and diverse ecosystems, which vary depending on their climatic zones. Their functioning and dynamics are governed by a multitude of interacting organisms, which exhibit very different life cycles - from fungi to trees, insects or large herbivores. Forests actively impact their environment, affecting temperature changes, precipitation, soil, wind, and even influence atmospheric water vapor pressure.

It is important to stress that current forests only offer 'snapshots' of these more or less rapid dynamics. Some forests are changing quickly, for example those subjected to fire or mountain forests dating from major reforestation actions in the nineteenth century, or even riparian forests where cycles governing colonization, maturation and extinction are subject to flooding. Forests, which we consider to be stable, are also experiencing their own slower dynamics. Climate change may have cascading effects that will modify these dynamics. Milder winters and drier summers have, for example, favored the massive outbreak of the mountain pine beetle, a small insect which colonized the North American continent moving from west to east, progressively adapting itself to different species of pine trees. As a result, pine trees died which in turn facilitated the spread of forest fires, and effectively caused the destruction of entire sections of forests. In a more general sense, climate change and the spread of forest pests and diseases have modified both the number and the nature of enemies which pose a threat to forests. The distribution areas of certain pests have become significantly larger, either due to decreased constraints on their winter survival, or to improved breeding conditions during the warmer seasons.

The most well documented case is that of the pine processionary moth, but there exist a number of other examples such as oak ink disease and the red band needle blight afflicting laricio pines, both of which are caused by pathogenic fungi.

While parasites generally tend to strive in warmer temperatures, this is not always the case. The growth of the fungus Chalara fraxinea is in fact slowing due to increasingly hotter summers occurring in some parts of Europe, such as for example, in Slovenia or the Po valley in Italy. This could be a hopeful sign that this epidemic affecting ash trees in temperate forests could be alleviated in warmer regions.

More than the gradual change in global temperatures, it is the recurrence of extreme events, such as droughts and severe storms that will play a decisive role in the future of forests. The impacts of drought have prolonged effects that can last for several years and it is often the cumulative effects resulting from several successive dry years that have serious consequences. In the Southern Alps, for example, the drought that occurred in 2003 and its impacts over the following years resulted in the massive dieback of fir trees. On Mount Ventoux, the fir trees that died are those that benefited from good conditions when they were young, initially growing in soil with high water content.


Ph. Riou Nivert, DSF

Pine trees infested with Diplodia pinea, *a fungus which strives in drought conditions and which has become major threat in southwestern Europe.*

Such a finding suggests that, despite their vitality, these fir trees were less acclimatized to drought than neighboring trees that survived. Such a relationship, however, between the vitality of young trees and latter stage mortality, has not been found in other forests where different mechanisms occur. As this example illustrates, it is often difficult to identify the causes of tree dieback, which are multifactorial processes with intervening physicochemical (abiotic) and parasitic (biotic) factors.

The question of how rapidly these changes take place is all the more important for the different components within the forest ecosystem (trees, fungi, insects) as their reaction times vary. For example Diplodia pinea, a parasitic fungus of pines, which strives in drought conditions and high summer

Forest biomass, a renewable energy source

The term 'biomass' refers to the total mass of biological material derived from living organisms, plant or animal. In France, biomass is the primary source of renewable energy, well ahead of wind turbines, photovoltaics or geothermal systems. Today it is consumed mainly by private individuals for wood heating. In the framework of a French policy aimed at developing renewable energy by 2020, one of the main biomass resources could come from forests; it would be much more widely used over the next several years for central and industrial wood heating systems. Indeed, today, only half of the annual production is used in materials and energy sectors.

However, increased use of forest biomass raises two difficulties. The first is in its collection, as French forests (16.3 million hectares, or 30 percent of the territory) are frequently the property of private owners with surfaces often too small to lead to any profitable activity, wood energy being only one of several possible applications. One of the challenges is therefore determining the best way to exploit the French forests. The other difficulty is the environmental agenda. It will be essential to integrate all of the environmental issues in the use of biomass in order to maintain equilibrium within ecosystems. This will be possible notably by putting in place forest management strategies combining two objectives: adaptation to climate change and mitigation of if its negative effects. Research will provide tools to guide this decision to allow local decision makers to optimize forest management while considering multiple environmental issues.

Caroline Rantien, ADEME

temperatures, was once considered to be a minor disease and has become, in less than 20 years, one of the major health problems that pine forests face today.

Adaptations and their limits

Over the next century, the fate of forests will depend on, above all else, their capacity for adaptation to climate change: physiological resistance, genetic diversity and evolution of forest stands, migration to more favorable environments, both altitudinal and latitudinal, and forestry practices. Plasticity and biodiversity in forests are considered to be strong assets, but we do not yet know how or to what extent these two parameters will allow tree populations to adapt to such rapid changes. Climatic conditions for the current distribution range for a tree species will change much more rapidly than the rate of their spontaneous migration. Therefore, the capacity for spontaneous migration will likely not be sufficient to maintain all of the ecosystems and their biodiversity in the same climate. It is adaptation to new climatic conditions that will determine their persistence.

It is here that forestry - a set of practices and methods aimed at improving growth management, maintenance and forest exploitation - can intervene. A first planned adaptive method is to increase biodiversity, particularly in European forests, characterized by relatively few species compared to other temperate areas. Certain parasites, which strive with climate changes, will limit the options available to forest managers. Caused by two fungi, the red band needle blight led to the suspension of laricio pine plantations in Great Britain and has limited its use in western France. In some cases, this may justify considering the use of exotic forest species.

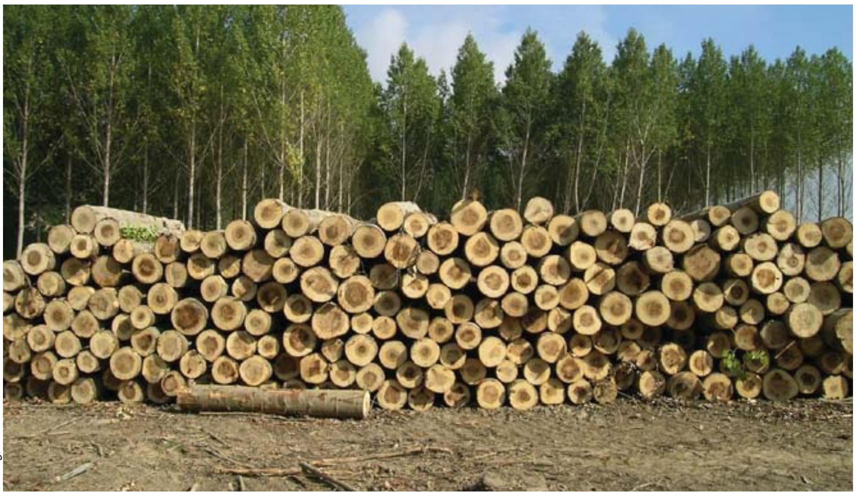
Another planned adaptive measure aims at promoting genetic evolution within specific forest species. Foresters have for many years resorted to the practice of transplantation, which has provided valuable indications related to the speed of possible genetic changes. They found that the Monterey Pine, Pinus radiata, is able to survive, to flourish and reproduce in environments that are very different from its native range (the California coast), demonstrating a high potential for adaptation following several generations during which time the varieties had been improved. Another example concerns the spruce provenances transplanted from Germany to Norway at the beginning of the twentieth century. Trees from Germany were poorly adapted to the cold Nordic climate: they entered dormancy three weeks later than local trees rendering them more vulnerable to early frost. Some trees nevertheless survived and the cycles of their offspring synchronized with those of indigenous trees. Several processes contributed to this rapid evolution: the selection of more resistant trees, the effects of the environment on gene expression and pollen contribution of indigenous trees for reproduction. It is therefore important to avoid the rapid and systematic eradication of the trees that survive massive dieback. These surviving trees are the product of intensive selection pressure, which promotes the evolution of new genetic resources, when it does not lead to the complete disappearance of the population. Naturally, limits to adaptive potential exist. In many regions, adaptive capacities are not sufficient to maintain forests in their current state. Nonetheless, it is important to exploit these evolutionary changes wherever they occur.

A challenge for forestry

All of these examples confirm that it will be necessary to take an adaptive approach to forest management based on continuous adjustment of tested practices. This adaptive management will allow us to build on previous

A Bosc, INRA

Sensors placed at top of a 55 m tower located in a forest in French Guiana. They allow for the measurement of carbon dioxide fluxes, in order to assess if the ecosystem gains or loses carbon over time.



P. Frey, INRA

Forest biomass is a source of energy, but fragmentation of French metropolitan forests, three-quarters of which are privately owned, makes its use difficult.

advances in research, such as developing technology for measuring environmental variables. For example, we know today how to detect subtle changes in climatic variables (temperature, humidity or light radiation), as well as concentrations of carbon dioxide and air pollutants (ozone levels and nitrogen deposits).

Organized networks of standardized and integrated observation infrastructures covering the greater part of the continents allow us to continuously monitor the biogeochemical functioning of forests with a resolution of 30 minutes. Sensors on aircrafts and satellites complement these observation networks and offer global coverage. Data collected by these networks are used to model the impacts of climate change and to organize more accurate monitoring of terrestrial ecosystems. Infrastructures in Europe such as ICOS (Integrated Carbon Observation System) and ANAEE (Analysis and Experimentation on Ecosystems), and NEON (National Ecological Observatory Network) in the United States, were designed for this purpose. Through the use of robust calculation power, these infrastructures focus on revealing the current extent of ecological disruptions and anticipating the most critical situations.

Mathematical models are used to simulate the current and future role of forests in the carbon cycle. On the global scale, forests contain nearly 50 percent of carbon stored in terrestrial ecosystems. Any variation of this stock would change the atmospheric concentration of carbon dioxide. Tropical deforestation and changes in land use release carbon. Conversely, the renewal of the vegetative cover of one part of deforested surfaces combined with the plantation of trees temporarily trap carbon in the biomass. Undisturbed tropical forests, as well as temperate and boreal forests which are currently expanding, accumulate carbon. The net combined result of these phenomena corresponds today to a fixation of 4.4 gigatons of carbon dioxide per year, or roughly 15 percent of the release of fossil carbon in the atmosphere. Consequently, the reduction of net carbon dioxide emissions will largely depend on our ability to restrict deforestation. With regard to the soils that also store carbon, it is not known if climate change will alter their organic matter composition, which effectively determines their storage capacity.

Models capable of integrating adaptive processes, interactions between various actors and even silvicultural operations are currently developed. The most likely scenarios, on local and global scales, will soon be available to foresters and policy makers.

Dynamic models

Modeling will also benefit from important methodological progress, notably new genomic tools which provide access to detailed information about a species' genetic diversity. Such information is of key importance to understand the current dynamics of species as well as their past evolution. The advent of high-throughput sequencing (NGS, Next Generation Sequencing technologies) also offers new perspectives. In theory, NGS technologies provide access to the full genome information of any organism and no longer only for a limited number of model species. The genome of fungi and other poorly understood microorganisms could thus be characterized. This will be the case, for example, for agents responsible for emerging diseases, notably ash dieback.

Innovation, however, does not only mean new technologies, analysis methods or numeric simulations. Forests adaptation to climate change will necessitate the use of new anticipatory practices and support systems. Adaptive forestry will allow forests to evolve taking into account ecological and socio-economic constraints. Every aspect of this evolution will be based on future scenarios and no longer on what we know from past experience.

References

A. Cheaib *et al.*, *Climate change impacts on tree ranges : model intercomparison facilitates understanding and quantification of uncertainty*, Ecology Letters, vol. 15, pp. 533-544, 2012.
J. Stenlid *et al.*, *Emerging diseases in european forest ecosystems and responses in society*, Forests, vol. 2, pp. 486–504, 2011.