Adapting to climate change in European forests – results of the MOTIVE project

Joanne Fitzgerald and Marcus Lindner (editors)

MOTIVE

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MOTIVE

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Preface

Adaptation to climate change is a subject which is gaining traction in recent years as an important challenge since, even if emissions are stabilised in the near future, the climate will change and adaptation will be necessary. With adaptation we seek to reduce vulnerability and increase resilience to changes in climate. Long term strategies designed to cope with climate change are necessarily underpinned by high quality science-based information. In Europe, the forest resource which covers 38% of total land area in EU-27 countries must form part of any holistic adaptation strategy. Forests not only provide wood products but also a range of ecosystem goods and services such as water catchment protection, biodiversity, erosion protection, recreation and tourism. Climate change impacts on forests are already noticeable with increases in productivity in some areas, and increased mortality or changes in species distributions at other locations. Natural disturbance regimes are also changing with significant implications for forest dynamics.

The project MOdels for AdapTIVE forest Management (MOTIVE) was a large-scale integrated project in the 7th Framework Programme of the EU that evaluated the consequences of Climate Change for European forests and explored potential adaptive management strategies. The project was coordinated by the Forest Research Institute of Baden-Württemberg (FVA, Freiburg). The scientific coordinator was Marc Hanewinkel (formerly with FVA, now based at the Swiss Federal Research Institute, WSL). MOTIVE involved 20 partners from 14 European countries with a budget of 9 million euro. The project focused on a wide range of forest types in different bioclimatic zones under various intensities of forest management.

This booklet provides an overview of major research activities and achievements of MOTIVE. It represents the state of the art in science-based information on adaptation of European forests to climate change. Topics covered include: Information on climate change projections for Europe with emphasis on implications for forest management; shifts in potential tree species ranges based on climate projections; genetic adaptation of tree species to climate change; mapping of disturbance risks to European forests with focus on wind, fire and bark beetles; decision support tools for adaptive forest management; and the MOTIVE toolbox which aims to allow users to select adaptive management actions and optimize management plans. We also look at the types of decision making approaches and their implications for adapting forest management to climate change. A special section describing the ten case study forests is included. Each of the case studies have contrasting environments for forest management, ranging from Finland and Sweden in the North to Spain and Portugal in the South, from Wales in the West to Bulgaria and Romania in the East. A wide range of forest types, management regimes and climates are covered. It is hoped that this will give insight into the challenges which climate change presents, and inform the reader as to the various potential responses around Europe.

Chapter I: Overview

Marc Hanewinkel and Joanne Fitzgerald

It is very likely climate change will cause a 2°C rise in mean global temperature by 2100 – and without drastic policy change, mean temperature may rise between 3 and 6°C in Europe. As forests cover a significant area of Europe, climate change represents a serious challenge. Changes in growth, drought-induced mortality and species distributions have already been observed at various European locations.

The project MOdels for AdapTIVE forest Management (MOTIVE) was a large-scale integrated project in the 7th Framework Programme of the EU which was set up to evaluate the consequences of Climate Change for European forests and evaluate various adaptation methods. The changing environmental conditions affect tree growth and productivity of forests. Moreover, natural disturbance regimes are changing as well with significant implications on forest dynamics. Past experiences about the local and site-specific suitability of species are no longer valid and this calls for an adaptation of present forest management strategies.

MOTIVE developed and evaluated strategies that can adapt forest management practices to balance multiple objectives under changing environmental conditions. The evaluation of different adaptive management systems took place within a scenario analysis and a regional landscape framework. The most important bioclimatic regions were covered within ten regional cases-studies reaching from Northern Boreal forest types (Finland) to Southern Mediterranean forests (Portugal, Spain) and from Western Atlantic (Wales) to Eastern Continental and Mediterranean (Romania, Bulgaria). This allowed the project to capture major differences in forest conditions. Forests across Europe are not only growing under different climatic conditions, management history as well as past and present socio-economic circumstances are also diverse and lead to variable objectives in forest management.

The consortium developed a common understanding of the behaviour of standard decision makers reaching from a "no change manager" to the "forward looking adaptive manager" and formalized the decision-making process using a Bayesian update approach. Such an approach is crucial to depict how decision makers may deal with the increasing uncertainty when managing forests under changing climatic conditions. Furthermore it is important to show the consequences of not adapting to climate change by simply continuing a "business-as-usual" strategy compared to an adaptive management approach. Based on the Bayesian update approach we were able to show that, while forest managers may be inclined to rely on observed forest variables to infer climate change and impacts, observation of climate state, e.g. temperature or precipitation is superior for updating beliefs and supporting decision-making.

An array of models (empirical as well as hybrid and process-based models) were employed in the analysis. Models were improved, for example regarding the simulation of disturbances under a changing climate, and further developed to model adaptive forest management regimes. Within a European knowledge transfer, models were adapted to the regional conditions in the case studies in countries where no model-base was available so far. Thus, the process-based model LandClim is now available for further research projects to partners in Romania, while the hybrid model PICUS has been adapted to coppice forests in Bulgaria.

The work on adaptation strategies in the case study regions brought many improvements and new developments. For example, a new cutting-edge optimization algorithm was integrated into a complex mechanistic model for Mediterranean forests and helped adding economic aspects to the simulations in the Catalonian case study. An empirical growth model was adapted to the conditions of Southwest Germany in the Black Forest case study. It was completed by a climate sensitive growth function and a storm module was included in the model.

Besides the regional studies the MOTIVE consortium also worked on the European level. It developed insights into major trends for important climate parameters, growth, productivity and political developments. Based on a European species distribution model, a group of MOTIVE researchers was able to show that climate change may have severe economic impacts. Increasing temperatures and a change of the precipitation regime may lead to a decrease of the area of mesic, cold- and humidity- adapted species like Norway spruce that are assumed to move northwards and lose large fractions of their growing space. These productive species that nowadays are the backbone of the timber industry in many European countries may be replaced by more drought-adapted but far less productive species like Mediterranean oaks that – under an extreme climate scenario – may take up to 60% of the total forest area in Europe. Such a drastic change in species distribution may lead to a decrease of the value of forest land in the range of a couple of hundred billions of Euros.

Answers to a questionnaire that was distributed to forests owners across Europe from Sweden to Portugal showed that the awareness of climate change is a crucial factor for adapting to climate change. The results of the questionnaire showed that there is a clear decrease in the belief of forest owners in adverse effects of climate change to forests from Portugal over Germany to Sweden. So far it has not been much recognized that there are distinct differences in the perception of climate change and that the application of adaptation measures essentially depends on having personally observed climate change. This is an important insight, because it underlines how important knowledge and information is in determining the adaptive capacity of the forest sector to respond to climate change.

The scientific work in MOTIVE was firmly based on participatory involvement of local and regional stakeholders and decision makers. These were instrumental in steering the model improvements and simulation studies in the case studies. A group of practitioners that formed the stakeholder advisory board accompanied the work of MOTIVE and formed a network that regularly met the scientists. The project also invested a lot of efforts into outreach to decision makers and politicians.

Many peer-reviewed and other scientific publications have already been published based on MOTIVE results. Further information about the project and its products can be found on the project web pages at www.motive-project.net.

Chapter II: Climate Change Scenarios to 2100 and Implications for Forest Management

Niklaus E. Zimmermann, Dirk R. Schmatz and Achilleas Psomas

Introduction

The global climate is currently warming and this trend is expected to continue towards an even warmer world, associated partly with drastic shifts in precipitation regimes (IPCC 2007). The global temperature has been warming by ca. 0.6°C (±0.2°C) during the 20th century (IPCC 2001), but the land areas have shown a higher increase in temperature within the same period. Here, we report on the current state of the art in climate model projections for Europe, with an outlook to the soon available 5th IPCC assessment report.

It is challenging to project how the climate might look like in 50–100 years, a duration that is relevant for forest management. In climatology many models are used in ensemble mode to generate possible climate futures. Each model and each simulation can be considered one possible representation of how the climate might evolve during the 21st century. For forest management and decision-making, we have to live with the fact that no exact forecast is possible. Rather, we have to implement our planning based on projected trends including their uncertainty. The periodic reports by the Intergovernmental Panel on Climate Change (IPCC) summarize the state of the art of how scientists see the development of the future climate and the associated impacts on ecosystems, economy and society. Now, the 5th assessment report is approaching, and some comparisons to the last two reports are already possible. The 3rd Assessment Report (IPCC 2001) had assumed that the global climate might be warming by 1.4–5.9°C, with no probabilities given for different increases, and with extreme scenarios projecting even far higher temperature increases. The 4th assessment report (IPCC 2007) provided a more narrow range of the likely future climate stating that temperatures will likely be between 2.0 and 4.5°C warmer than during the 1961–1990 period (with a likelihood of 66%). It also said that temperature increases by more than 4.5°C cannot be excluded (see Rogelj et al. 2012), but that the most likely temperature increase by 2100 is 3.0°C. First comparisons from global climate modeling studies for the 5th IPCC assessment report project an increase of 2.4–4.9°C as medians from three different scenarios of radiative forcing (following different emission scenarios that are similar to those used in earlier reports). A fourth scenario is added that assumes a more rigorous and rapid reduction of greenhouse gases than was ever used before, predicting a median temperature increase of only 1.1°C during the 21st century. Overall, the model simulations for the 5th IPCC assessment report expect that the likelihood of having global temperature increase exceeding 4.9°C is 14%, thus also likely, but that the most likely warming scenario at the global scale is still 3.0°C. Thus, in general, the newest scenarios do project similar average warming trends as we have seen in the 4th IPCC assessment report, although some scenarios point to somewhat higher warming trends than were calculated for the 4th report (see Rogelj et al. 2012). Figure 1 shows global climate data simulations for the 4th and 5th assessment report.

The global climate is simulated using so-called general circulation models (GCM), which project the climate future on physics-based processes and first-principles. For regional applications such as e.g. Europe, such GCM model output has a too coarse spatial resolution, usually in the range of 1°–2.5° Lat/Lon per model cell. In order to obtain more realistic climate projections at a regional to local scale, two types of downscaling are often combined. First, so-called regional climate models (RCM) are calculated to certain larger regions of the World (e.g. all or parts of Europe). These models contain the same physical mechanisms as the GCMs, are fed by GCM output, and simulate the climate development within the study region by using GCMs data as boundary input to the study region. The output of these models is at high temporal and moderate spatial resolution, ranging typically between 5–50 km per cell. This is a much better spatial representation of the climate in regions and the output is somewhat sensitive to mountains and their effects on the climate system, though often the output is still too coarse for management and decision-making. Therefore, a further statistics-based downscaling procedure is applied (Pielke and Wilby 2012) in order to scale the output from RCMs to finer spatial resolution ranging from e.g. 100 m to 1 km, which can be considered well-suited for management applications.

Climate projections for the MOTIVE project

For the MOTIVE project, we have used five different RCMs driven by four different GCMs resulting in six GCM/RCM combinations in order to study the impact of likely climate changes on forest species and ecosystems. Table 1 gives an overview of the models used, which originate mostly from the ENSEMBLES EU project, using GCM runs that were calculated for the 4th IPCC assessment report (IPCC 2007).

We downscaled basic RCM output variables such as monthly temperature and precipitation to finer spatial resolution, typically to 1 km or 100 m cell size. The method used can be called the “anomaly-approach”, where we scale the deviation of the future compared to current climate from coarser to finer resolution. This is an efficient method, since anomalies do not depend much on altitudinal lapse rates. Once downscaled, the anomalies are added to an existing high-resolution climate map such as those available from Worldclim (Hijmans et al. 2005) or from national mapping campaigns (e.g. Zimmermann and Kienast 1999). The most important step here is to generate anomalies appropriately. First, we need to know the reference period of the high-resolution climate maps. Worldclim is mapping e.g. average monthly values of the 1950–2000 period. Next, we generate the monthly climate anomalies for given periods in the future. To calculate the anomaly of each projected future

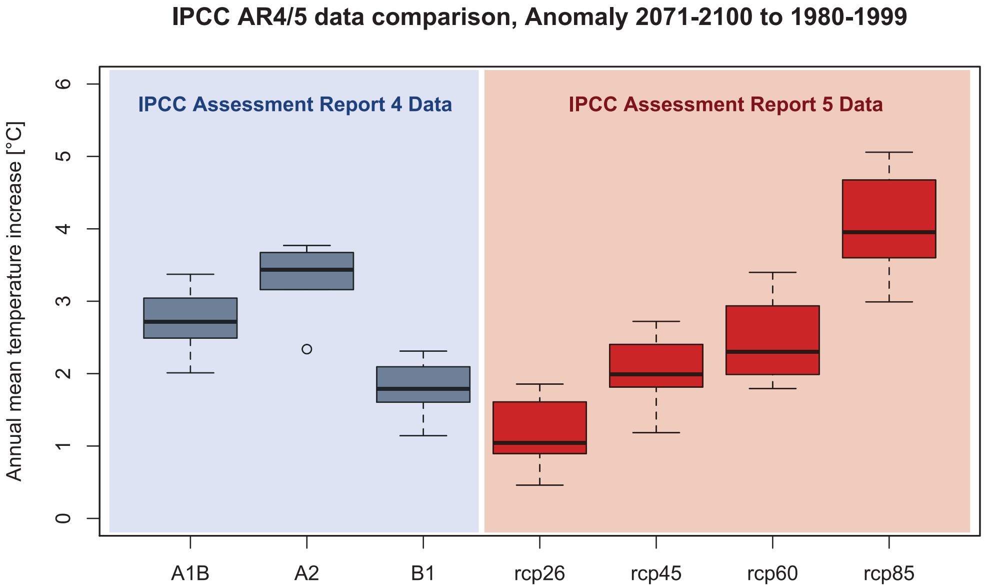

Figure 1. Comparison of global circulation model (GCM) simulations for the 4th (steelblue) and the 5th (maroon) IPCC assessment report (AR). It indicates the larger spread of possible climate futures projected with AR5 data, compared to AR4, despite simulating the same global mean climate.

Table 1. Climate models used to assess the impact of climate change on forest ecosystems and tree species ranges in the MANFRED project. RCM models are labeled in bold face, while the GCMs used to feed the RCMs are in normal font.

Model **RCM**/GCM	Scenario:	**A1B**	**A2**	**B1**	**B2**
CLM/ECHAM5, run by MPI		x	x	x	–
RACMO2/ECHAM5, run by KNMI		x	–	–	–
HADRN3/HadCM3, run by HC		x	–	–	–
HIRHAM3/Arpège, run by DMI		x	–	–	–
RCA30/CCSM3, run by SMHI		x	x	–	x
RCA30/ECHAM5, run by SMHI		x	x	x	–

climate month of any RCM relative to the current climate, we use the simulated time series outputs for the re-analysis period of 1950–2000 from each RCM. By this, we avoid the projection of modeled bias in RCMs should the recent past be wrong compared to climate station measurements. We are only interested in projecting the relative difference between simulated recent past and simulated futures. Once anomalies are generated, we interpolate these anomalies to the high resolution of existing climate maps such as Worldclim and add them to these maps to project the future climate changes to the representations of the existing climate.

The development of climate anomalies was done by (a) first averaging the monthly time series of minimum (Tmin), average (Tave), maximum (Tmax) temperature and precipitation (Prcp) over the period of 1951–2000 for each RCM run used, since these represent the same base period of Worldclim maps. Then we used monthly RCM outputs to calculate monthly anomalies relative to the 1950–2000 period means per month. We developed monthly anomalies: (a) by subtracting current from future climate for temperatures, and (b) by dividing future by current climate for precipitation. The latter results in ratios of change, which avoids negative precipitation values that could else result after downscaling if the difference method is used. All climate anomalies are first calculated at the spatial resolution of the RCM output, and is then scaled the medium resolution of 1 km by a bilinear interpolation (and in a second interpolation step to 100 m if necessary). Figure 2 illustrates the projected climate change trend from the six used RCM simulations by the example of the annual and seasonal (summer and winter half) means, and by the uncertainty in projected summer climates.

For temperature, we observe a general warming trend in the range of 1.1 to 4.1 °C, with least warming in the winter half in Atlantic regions (+1.5°C), and highest warming in the Boreal North (winter; +4°C) and Mediterranean South (summer; +3.5°C). The Alps generally face higher warming trends than the surrounding mainland, specifically in the winter months. The uncertainty among the six models is lowest in Southwestern Europe, increases towards North and East, and is highest in Eastern Europe. For precipitation, the trends show a similar and even clearer segregation between North and South. Winters are projected to become significantly wetter in Northern Europe (+30%), and to a lesser degree also in Central Europe (+15%), while Southern Europe is projected to become slightly drier (-15%). Summers are projected to become significantly drier in Southern Europe (-35%), and to a lesser degree also in Central Europe (-20%), while Northern Europe is projected to become slightly wetter (+20%). The uncertainty among the six models is highest in the (sub-) Mediterranean regions, in the Alps and in the far North of Europe.

General implication for forest management

For forest management, the projected climate anomalies may require specific actions to avoid significant loss in timber value. Least changes are likely required for (the far) Northern Europe. Here, the evaporative demand of a warming climate is balanced by higher precipitations both in winter and summer. Forest productivity can be expected to increase, and more thermophilic species may soon find suitable habitats in this region.

For Central Europe, the projections are still quite unclear. While there is a general warming trend projected, the models disagree as to the magnitude of warming, and whether precipitation will increase or decrease. But even if no changes in total precipitation amount will occur, there are likely to be two effects relevant to forest management. First, evaporative demands due to warmer temperatures can likely not be fully balanced, specifically because

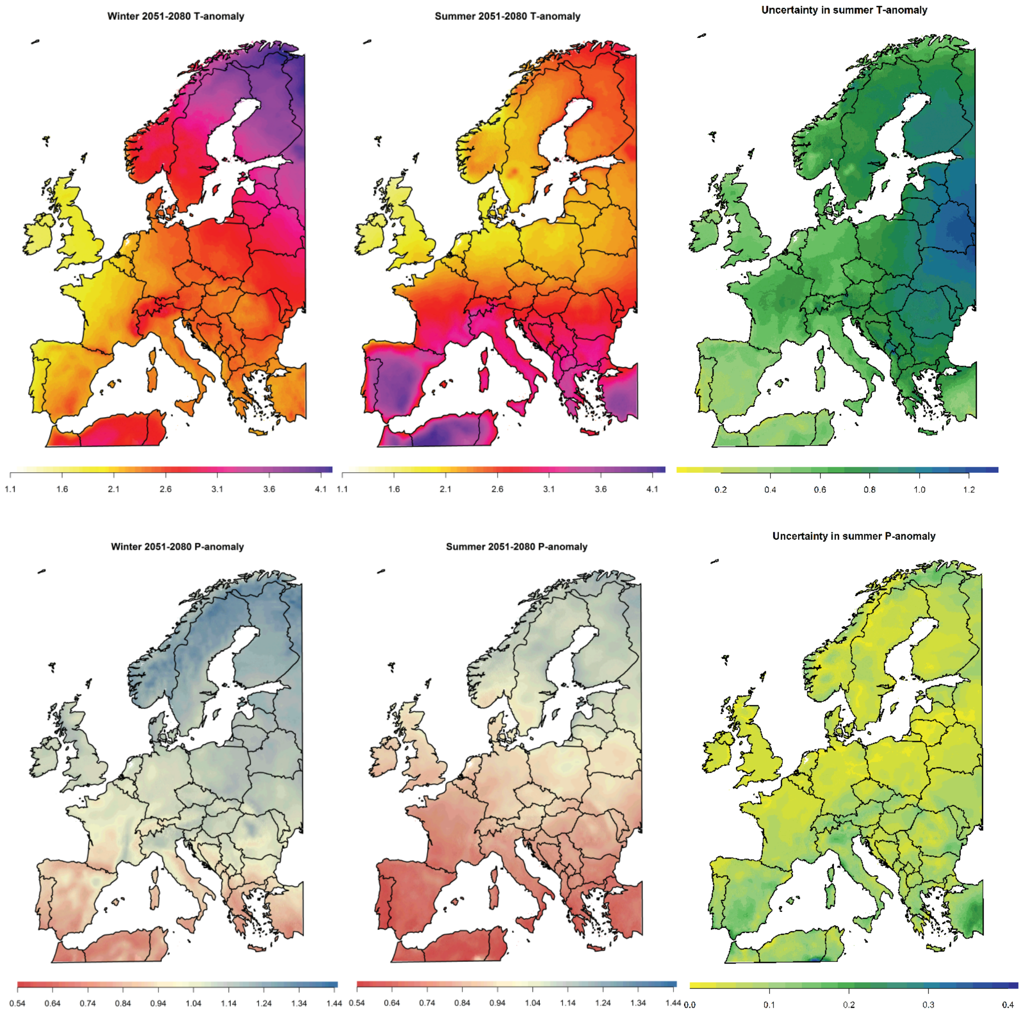

Figure 2. Climate anomalies for the A1B scenario by 2080 (deviations of the 2051–2080 period from the current, i.e. 1961–1990 climate) averaged over the six RCM models used to assess the impact of climate change on forest ecosystems and tree species ranges in the MOTIVE project. Top row: Anomalies for winter and summer temperature (in °C), and uncertainty (in °C) of summer temperature among all 6 RCMs used; Second row: Anomalies for winter and summer precipitation (in % compared to current), and uncertainty (in %) of summer precipitation among all 6 RCMs used.

summers become slightly drier, the result will be a net water loss for tree growth; the general tendency is a climate seasonality shift towards a more Mediterranean-type climate, away from a summer maximum and winter minimum in rainfall towards two rainfall peaks in spring and fall, with comparably dry summers. In some regions (especially towards the Atlantic coast), this trend is less pronounced, and both the changes in rainfall and in temperature are dampened by the proximity to the ocean.

Most severe changes with negative consequences for timber production can be expected for the Mediterranean region and its neighboring areas in Southern Europe. Here, precipitation is decreasing both in summer and winter, and temperatures are increasing in both seasons more (winter) or less (summer). This will result in much drier growth conditions, and is likely to have severe effects on the already water-limited forests. Only (and not shown in figures), the temporal variability for this region is specifically high with regards to rainfall, so that we may still expect some wet years in-between very dry years. This may mean that natural forest regeneration may still be possible.

While the general climate trends are still uncertain, as seen from the uncertainty maps originating from 6 RCM models, projections of climate extremes are even more difficult to make or to foresee. Several models, and even more so the deviation among models, are projecting that both the climate variability and the uncertainty of projections will become larger towards the end of the 21st century. In general, we can expect that both temperature and precipitation extremes will increase. This has the consequence that forest management becomes more difficult, because a larger range of possible conditions will need to be considered in the planning and decision-making.

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Chapter III: Future ranges in European tree species

Niklaus E. Zimmermann, Signe Normand, Peter B. Pearman and Achilleas Psomas

Introduction

Climate is a major driver of plant and tree distribution, while soil variables or inter-species competition are often considered to primarily drive their local abundance. The climate constraints to species ranges are generally accepted. Therefore, a changing climate is especially relevant to long-lived plants such as trees or shrubs, as these take many years to reach maturity and, given their long life and stationary nature, they are especially vulnerable to rapid changes in climatic conditions. In addition, forest management typically encompasses many decades, partly even reaching to the end of the 21st century, which illustrates the challenge to manage such organisms successfully at such long planning periods. This calls for careful and adaptive management strategies and for a good understanding of the uncertainties related to the expected changes and their impacts on trees and forest ecosystems.

Many approaches exist to project the impact of climate change on trees and forests. Most of these approaches can either only be applied to comparably small regions or too few species, or they need to be run at very coarse spatial resolutions in order to cover larger areas such as Europe. The following five basic approaches can be distinguished: (1) biogeochemistry models, (2) population dynamic models with competition (3) demographic models of single species; (4) phenological models of single species; and (5) species distribution models. The model types 1–4 are usually more process-oriented than type 5, and therefore contain biological realism in what they project under climate change. Their general limitation is usually in that they are not capable of simulating the future fate of species at large spatial extent (such as Europe) and simultaneously at a comparably fine spatial resolution (such as ≤1km grids) that is useful for forest management. Several of these approaches (3,4) lack the capacity to include competition among species, while almost all approaches (except few models of type 1–3) actually include seed dispersal and thus can provide insight into natural migration rates following climate and land use change.

Species distribution models (SDM) of the last approach (5) are most often used to project climate change effects on the suitability of an area for a given set of species. This represents a comparative method that relates the observed distribution of a species to the environment (such as climate, topography, soils), and calibrates statistically the ranges of species as a function of these environmental predictors. The method is capable of simulating large spatial extents (such as Europe) at a fine spatial resolution (≤1km), and once calibrated, it can be rapidly applied to changing environmental conditions. It thus provides useful information for forest and conservation managers in their decisions to cope with global change. However, it is important to also consider the limitations that go with this approach. First, the method is not dynamic, and only provides information of habitat suitability under future environmental conditions. It therefore cannot foresee by when a species naturally will invade an area. Although, several novel approaches have now been developed to combine SDMs with realistic migration simulations (e.g. Meier et al. 2012). Second, the method is not based on physiological first-principles, and thus is an empirical, not a mechanistic approach. It is therefore not fully reliable when projecting to very novel climatic conditions that cannot be observed today. This limitation is, however, valid for several of the above-mentioned 5 approaches.

Species distribution modeling

In the following, we present SDM simulations, often also referred to as climate envelope models (CEM), for major tree species in European in order to assess what the consequences of climate change on the habitat suitability of these tree species might be. We compiled data for 38 tree species at a total of >6,000 inventory plots. We then compiled a series of climate maps under current and potential future climate from downscaled RCM models for future climates (see Chapter 2). Additionally, we compiled some topographic variables that additionally may influence the spatial patterns of trees. Prior to selecting the variables, we executed a variable importance analysis for each tree species separately. This was done in order to adjust the variable selection to those that have a strong effect on the range dynamics of the species. We refrained from using all possible climate variables on order to avoid too high correlations per species, and in order to keep control over the number of variables we maximally allowed entering the models.

We selected predictor variables from the following groups of environmental predictors: (1) temperature – either degree days with a 5.56°C threshold or minimum temperature of the coldest month; (2) precipitation – we computed seasonal means and selected among those per species; (3) moisture index (difference between potential evapotranspiration and precipitation) – we computed this index for spring (March–May) and summer (June-August) and selected one of the two according to its predictive power; (4) potential global radiation – we computed winter or annual mean radiation values and selected according to predictive power; (5) slope angle in degree – we added this variable, if it was among the top 5 uncorrelated variables for a given species. By this we allowed to simulate habitat suitability based on predictors that are (a) relevant for a given species, (b) not highly correlated, and (c) we did not include too many variables into models, which might cause problems in a non-analogue climate due to changes in correlation among current to future climate variables. Winter and spring conditions were generally speaking more important for Mediterranean trees, while summer conditions were more powerful predictors for Central and Northern European trees.

Results

Potential future climate was taken from six different RCMs (see chapter 1), providing a range of potential climate futures. The use of several RCM models provides the mean trend that can be expected from climate change impacts on trees, and it allows us to derive a measure of uncertainty associated with the projection of these trends (Thuiller et al. 2009). Several statistical models were used, since the choice of a specific model has been shown to significantly contribute to uncertainty in projections. Therefore, given the use of six statistical models and six future climate model runs, we model 36 different possible futures per species and time slice. This allows for assessing the projection uncertainty from both the variability in climate models and the variability originating from the choice of statistical methods (see Figure 1).

We optimized each statistical model following procedures described in Thuiller et al. (2009) and where feasible, we maximized kappa to select a threshold to split probabilistic projections of species presences into simulated presence and absence values. We therefore had one presence/absence map per climate model/statistical model combination available. We then built ensembles of these model projections and classified these as follows: (1) a species is unlikely to find a suitable habitat if less than 30% of the projections indicated presence of a species; (2) a species is moderately likely, associated with high uncertainty, if 30–60% of the projections suggested that the species is there; (3) a species is most likely present with rather low uncertainty under projected climates if in >60% of the 36 model projections presence of a species is simulated to occur. Such as simple classification avoids an over-interpretation of the results from the simple model approach.

Figures 1 and 2 illustrate the potential future range shift in two species, namely *Picea abies* (L.) Karst. (Norway spruce), which is a species of Central to Northern origin, and *Quercus ilex* L. (holm oak), which is a species of Mediterranean origin. The first species (as a common Central to Northern European species) is expected to lose much terrain at low altitudes and in Central Europe, and will retract to higher altitudes and latitudes following climate change. Currently, Norway spruce is planted at lower altitudes than it would naturally occur. Obviously, these lower altitudes are still within the fundamental niche of the species now, and the distribution model under current climate does include these areas as suitable habitats. However, much of this area will soon become unsuitable. This is specifically visible for the simulations of the 2051–2080 period, where for Norway spruce clearly only higher elevations and latitudes are projected to remain suitable. Larger parts at low altitudes and Central Europe become unsuitable or remain only suitable with high uncertainty. This uncertainty arises from highly contradicting projections by both climate and SDM model combinations.

For holm Oak, the picture is very different. This evergreen species is adapted to dry and warm climates and withstands the repeated climate extremes by growing slowly and

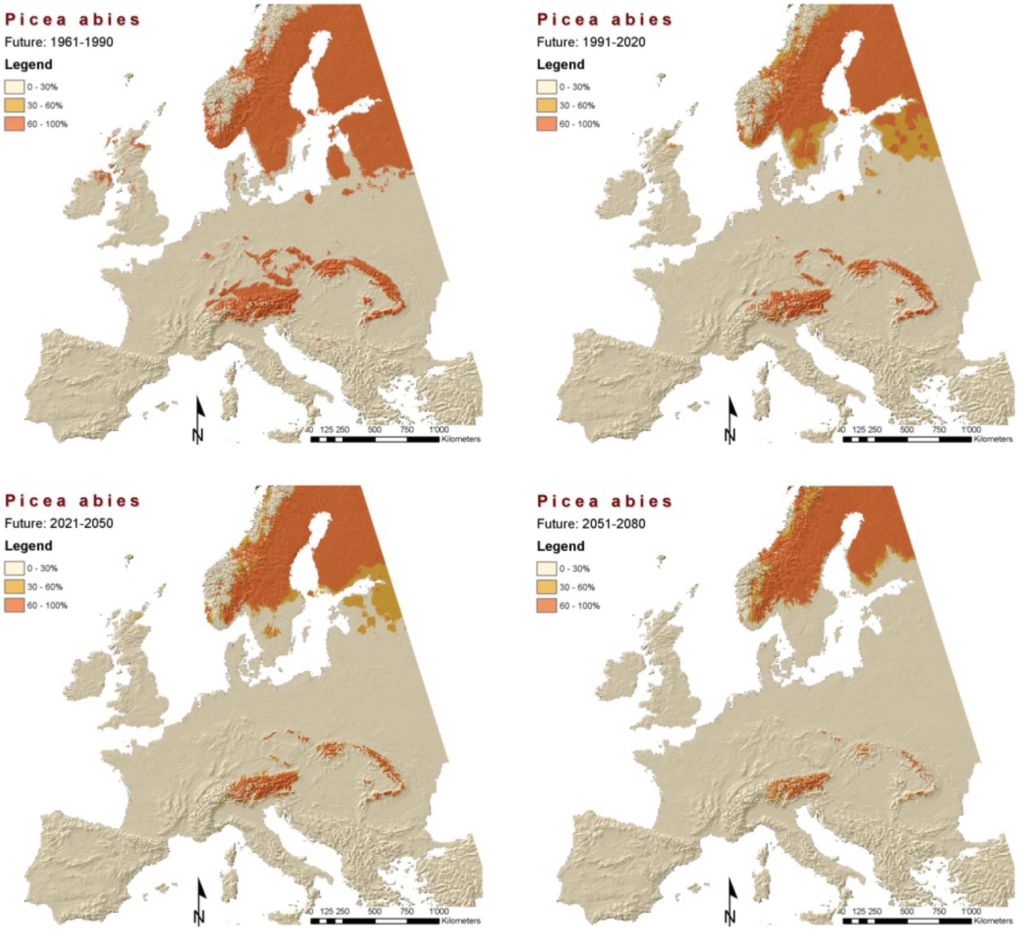

Figure 1. Ensemble projected change in habitat suitability for Norway spruce (*Picea abies*) in Europe following climate change in response to 6 RCM climate models using the A1B scenario and calibrated from 6 statistical models. The legend gives the agreement for simulating suitable habitat among all climate model x statistical model combinations from current (top) to the 2051–2080 period.

investing nonstructural carbon into leaves, bark and roots to avoid drought damages, but does so at the cost of a slow maximum growth. The species is projected to extend its range considerably towards the North. E.g. these models project suitable habitats along the Southern Atlantic coast of France, where the species has been observed to naturally extend its range from initial populations recently.

All 38 tree species have been simulated for Europe, and only two species are displayed here. A more complete set of species can be checked out and downloaded from a dedicated website[1]. It becomes obvious that mostly the more drought-tolerant species such as Sessile

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[1] http://www.wsl.ch/lud/motive

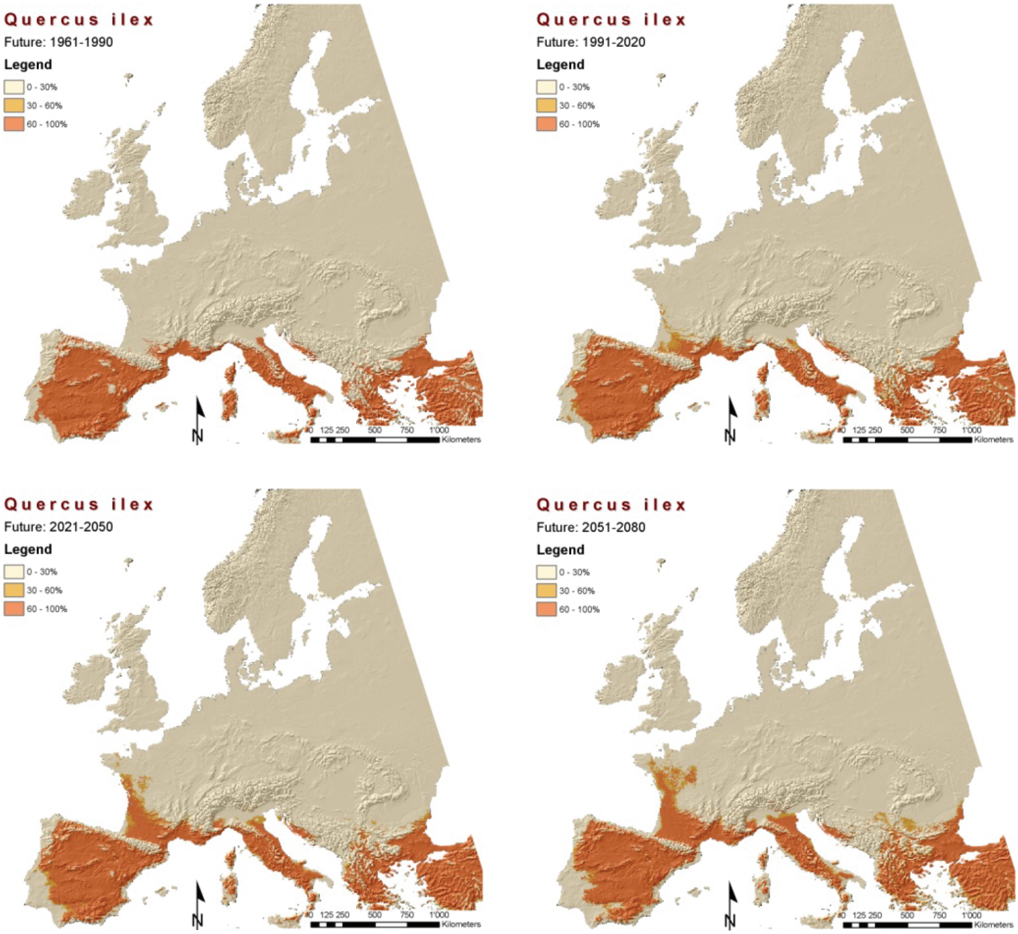

Figure 2. Ensemble projected change in habitat suitability for *Quercus ilex* in Europe following climate change in response to 6 RCM climate models using the A1B scenario and calibrated from 6 statistical models. The legend gives the agreement for simulating suitable habitat among all climate model x statistical model combinations from current (top) to the 2051–2080 period.

oak (*Quercus petraea*), pubescent oak (*Quercus pubescens*), or Scots pine (*Pinus sylvestris*) can be expected to become more abundant at lower altitudes throughout Europe, while other species such as beech (*Fagus sylvatica*), Sycamore maple (*Acer pseudoplatanus*), lime (*Tilia*), elm (*Ulmus*) or silver fir (*Abies alba*) are likely further reduced in their ranges similar to Norway spruce. Species from (Sub-) Mediterranean regions such as holm oak (*Quercus ilex*), hop hornbeam (*Ostrya carpinifolia*) or cork oak (*Quercus suber*) are expected to extend their ranges to the North, but these species will not reach the areas currently suitable for beech or spruce by the end of the 21st century. Different pine species are also expected to extend their ranges quite considerably. However, they will likely not extend to very fertile soils either, and some of the species like e.g. Scots pine (*P. sylvestris*) might face indirect threats

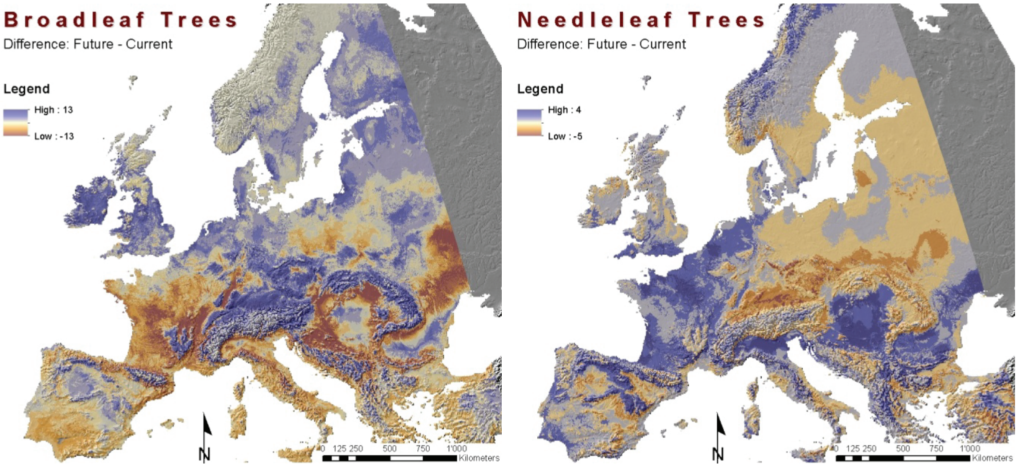

Figure 3. Changes in plant functional type composition from single species habitat suitability changes following climate change. The two panels indicate to what degree broadleaf (left panel) and needleleaf (right panel) tree species are expected to increase (blue) or decrease (red) in numbers. The results represent ensemble SDM simulations from six climate scenario (A1B) simulations and six statistical models.

from insects and other pest outbreaks, rather than direct threats from climate change alone. In summary, the projected range shifts will affect the forest structure quite considerably. Among all species modeled, we can expect a shift in plant functional types in Europe between now and the end of the 21st century (see Figure 3).

Discussion and conclusions

Such changes will affect the functioning of forest ecosystems and the services we can expect these ecosystems to provide. One study (Hanewinkel et al. 2013) found a likely severe loss in timber value resulting from such tree species habitat suitability shifts for most of Europe, except for most of Northern Europe. This is due to a loss in suitability for valuable timber trees such as Norway spruce or beech at the cost of less valuable trees with slower growth potential, such as sessile or pedunculate oak.

How reliable are such model projections? The displayed maps only represent the habitat suitability by a certain time period (e.g. 2051–2080), but do not predict that a species will disappear or invade as rapidly as displayed by the suitability maps. The response of species will in most cases be much slower (see Meier et al. 2009 for examples and related discussions). If climate is simply shifting its means, and no climatic extremes occur, then most likely the natural re-adjustment of species ranges will take considerable time, ranging from Centuries to Millennia. However, there are two reasons that may explain faster responses. First, although only minor range shifts have been observed in trees so far, we can expect an acceleration in the range shift response to ongoing climate change in the near future. Until now, the degree of warming has not clearly exceeded the natural range of variability a tree species experiences at any given location. This range will be exceeded in most locations by 2050 due to an increasing warming trend. On the other hand, most scenarios project more frequent climatic extremes, and an increase in climate variability, resulting in even more severe extremes. Such extremes have been shown to affect species ranges (Zimmermann et al. 2009), and they will cause severe effects specifically at the rear edge, where climate is hot and becoming drier in Central and Southern European summers. This means it is likely that the northward movement will naturally occur at a steady pace with smaller forward leaps, while the contraction at the rear edge of species ranges may occur in more acute events following climatic extremes and the subsequent pest outbreaks.

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Chapter IV: Adaptive potential - a partial insurance against climate change risks

Jean-Baptiste Lamy, Sylvain Delzon and Antoine Kremer

To exploit natural adaptation to climate: a weapon to cope with climate change

Adaptation of forests to climate change can occur via inherent processes or may be triggered by measures instigated by humans. The rationale for considering inherent physiological processes comes from the evidence that tree populations have undergone profound genetic changes during the natural warming after the last glaciations facilitating their adaptation to changing climate (Petit et al., 2008). Provenance refers to the specific geographical location that marks the natural origin of a tree. Natural selection by evolution has adapted each provenance to its local environment, hence, there are genetic differences between different provenances of the same tree species. In provenance testing, seed is collected from several provenances and planted for comparison in random replicated experiments at various forest locations. (Figure 1). Since provenance tests were first installed by forest practitioners, results accumulated showing substantial population divergence for almost any adaptive trait that has been investigated so far. During the past decade, the evolutionary historical trajectories during the Holocene (our current interglacial climate period) have been reconstructed for most of the European tree species, providing some clues about the rates of evolutionary changes. A prevailing view resulting from combined genetic and historical investigations is that adaptation can occur at rapid time scales – even contemporary time scales- provided that there is enough genetic variation. The issue of future adaptation to on-going climate change can therefore also be thought of in evolutionary terms.

The fate of extant (or living) tree populations undergoing severe environmental changes is related to their adaptive potential. Practitioners are seeking studies which imitate climate change so they may evaluate adaptive potential that would guide their management options. Evolutionary scientists are attempting to identify ecological and genetic drivers or processes contributing to the adaptive potential.

Adaptive potential of a tree population can be defined as its capacity to respond to a given environmental change, by modifying its own genetic composition and/or by modifying its phenotypic expression. In more scientific terms, adaptive potential is the sum of the changes due to genetic adaptation[1] and changes due to phenotypic plasticity[2].

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[1] Genetic adaptation is shaped by evolutionary forces as natural selection, genetic drift, migration, type of mating and recombination.

[2] Phenotypic plasticity is the capacity of an organism to change its phenotype in response to a change in environment.

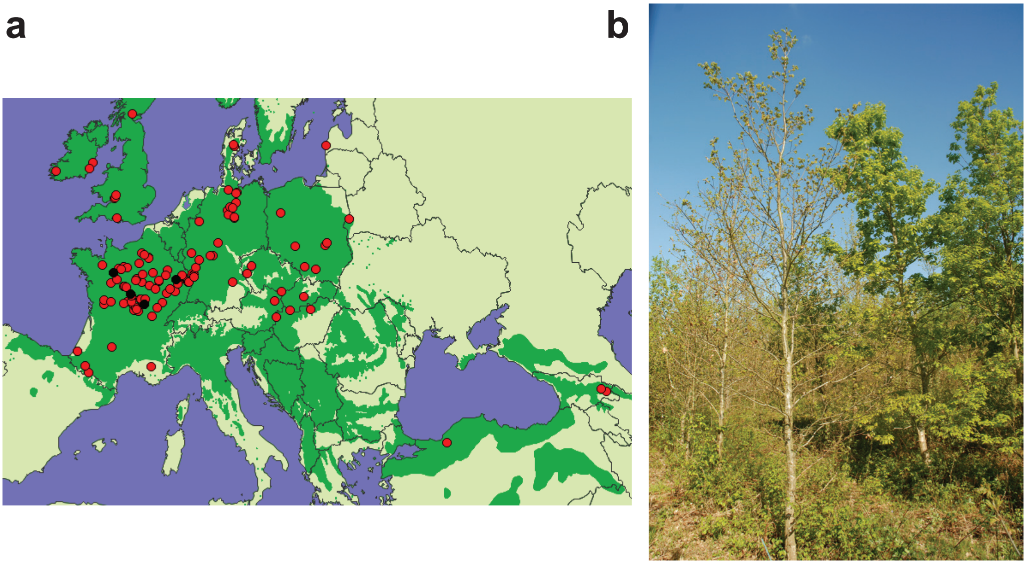

Figure 1. Illustration of provenance tests concept (a). The green background represents the distribution area of *Quercus petraea*. Black dots represent the planting site, where the performance of each provenance, red dots, is tested in the same environment (provenance test). For example, if provenances have different heights in their native environment; such differences could be due to genetic or to environmental properties. If differences in height between provenances are conserved in the planting site (provenance test), it means differences in height are genetic. Illustration of genetic difference for a phenological trait (b). On the left side, defoliated trees (beginning of bud burst) are from a french provenance (bertanges) and, on the right, foliated trees (end of bud burst and leaf elongation) are from an austrian provenance (klostermarienberg).

Measuring adaptive potential: response and transfer functions

Adaptive potential in tree species is assessed by monitoring the same provenance in different ecological settings (see Figure 1), for instance by planting a "northern" provenance more in a "southern" provenance test location. This approach is relevant in the context of climate change especially if environmental changes over spatial gradient can mimic future climate changes.

Adaptive potential is, then, described by a response and/or transfer function. The response function describes the provenance's performance along a climatic gradient, indeed data is needed from several provenances tests (>6) with the same populations in each. These experiments are laborious, costly, and only available for some valuable species as pine, Norway spruce or beech. For the majority of tree species, there are few provenance experiments with many provenances tested.

A valuable alternative strategy is to use a transfer function i.e. the provenance's performance (or standardized proxy) is described along a transfer distance (see below). This method relies more on assessing contrasts between populations at the same site, rather than contrasts

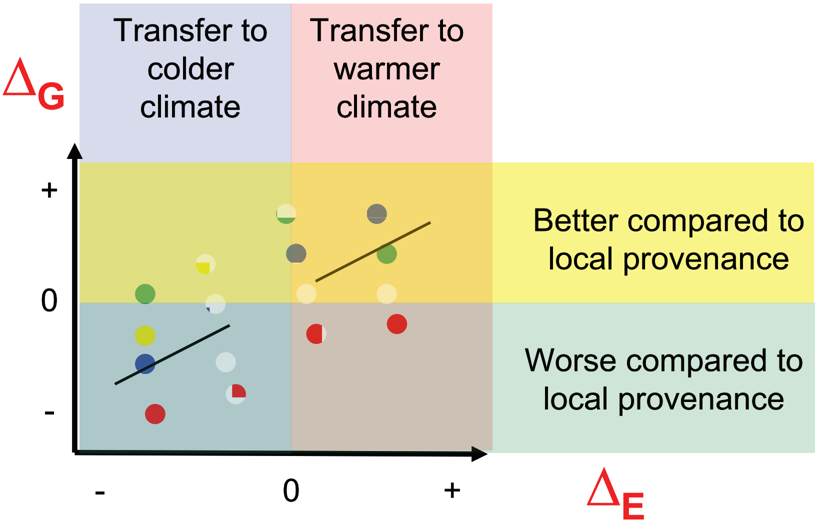

Figure 2. Illustration of the construction of species transfer function. The x axis (Δ_E, the unit is the same as the climatic variable) represents the difference between the mean of a given climatic variable at the test site (provenance test) and the mean of the same climatic variable at origin of the provenance. The y axis (Δ_G, the unit is the same as the measured trait) represents the difference between the performance of foreign provenance and the performance of local provenance. It is also possible to represent the performance of populations without any standardization.

between same populations at different sites. Here, we present a statistic free approach to illustrate this concept.

For each population the transfer distance (Δ_E, see Figure 2) was calculated as the difference between the mean of a given climatic variable (usually temperature) at the testing site (provenance test) and the mean of the same climatic variable at origin of the provenance. When temperature is used as the climatic variable, negative values on the x axis can therefore represent transfer to warmer climates ($\Delta_E < 0$), while positive values indicate transfer to cooler climates ($\Delta_E > 0$). Each population performance was also standardized by the local population performance (Δ_G, see Figure 2). A negative value of Δ_G means that populations performed less well compared to the local population and positive values mean that the foreign population outperformed the local population. A species response function with a positive slope, as it is illustrated in Figure 2, means a transferred provenance in a warmer climate could increase provenance performance when compared with local provenance.

Re-analysis of old *Quercus petraea* provenance tests

Almost all available provenances tests were not designed to mimic climate change. However, the comparison between the transfer distance realized in four French provenance tests (with

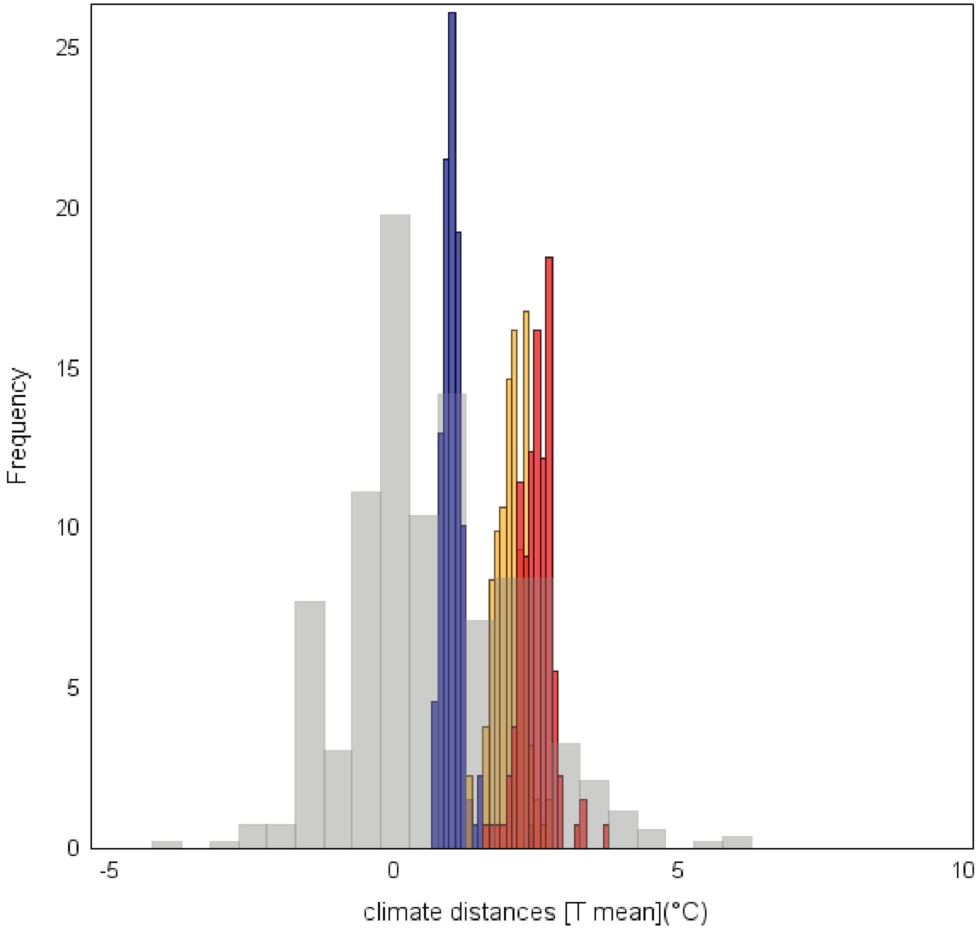

Figure 3. Comparison between transfer distances (light grey histogram) realized on four French provenance tests and the expected climate change at the provenance origins (blue histogram: expected warming over 2011–2040, yellow histogram: expected warming over 2011–2070, red histogram: expected warming over 2011–2100).

more than 100 provenances tested) on *Quercus petraea* and the expected climatic change at the provenance origin showed that provenance tests are valuable tools for prediction about provenance performance in the climate change context.

Figure 3 shows how the transfer distances realized in the French provenance tests overlap the expected climatic change at the provenance origins, however, only the transfer to warmer climates are useful (transfer distance > 0). For example, a Western German provenance planted in a Northern French test location simulates a rise in temperature of 1.5 °C, Such an increase in temperature is expected in Germany by 2040. Using the described strategy for old data from *Quercus petraea*, we adjusted a species transfer function (see Figure 4).

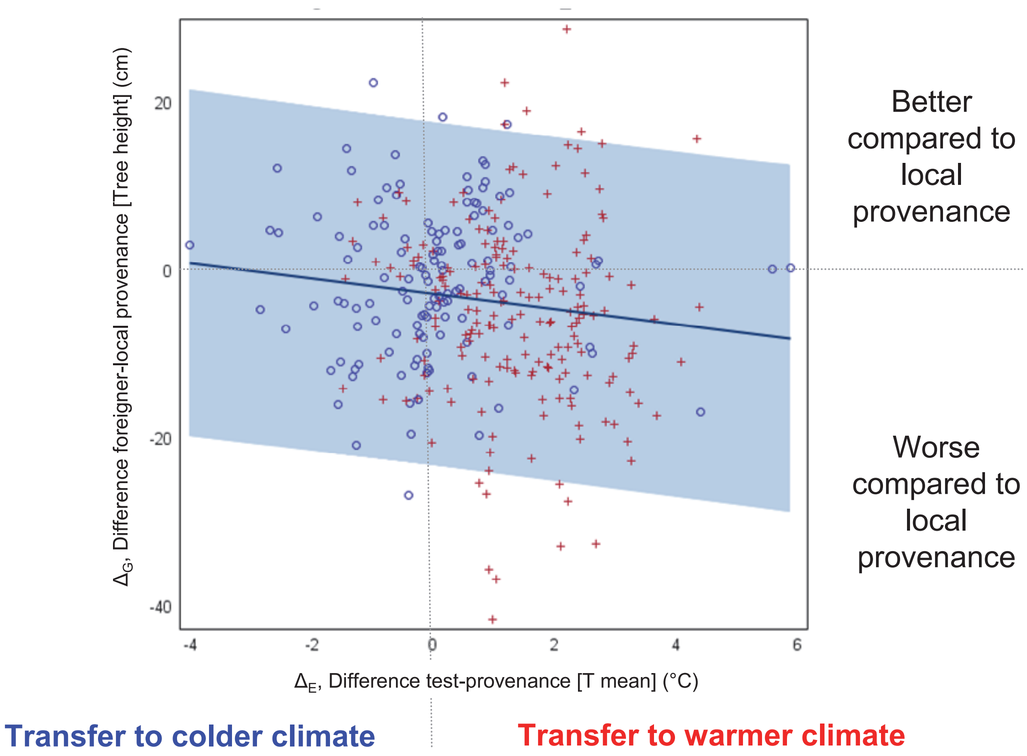

Figure 4. *Quercus petraea* transfer function for tree height at 4 years old along, adjusted on 124 populations replicated in 4 provenance tests. The x axis is the transfer distance and the y axis is the standardized performance of provenances in each provenance test (for more explanations see text). The blue line (regression line) is the expected deviation of a provenance comparing to a local provenance after a given transfer distance, the associated blue area represents the confidence interval for the prediction. Thin grey lines symbolized the 0 values on x and y axis.

As seen in Figure 4, most populations show positive transfer distances, meaning that they were moved on average towards warmer climates. The y axis is the difference in height between the transferred population and the local population (at the site where the test is established). All populations above the 0 on the y axis are taller than local populations. The transfer function has a negative slope, suggesting that on average transfer to warmer climates is likely to reduce the tree height. An increase of 1°C in the mean annual temperature decreased tree height by 12.3 cm at 10 years old. However there was a very large population variation around the mean response. At least 8 populations (see populations above the confidence interval) actually will grow better than the local population when they are transferred to warmer climates.

Such approaches, in order to accelerate forest adaptation, are under evaluation in North-America, and future seed transfer guidelines will take in account such considerations. In contrast European countries are just starting such work despite large numbers of provenance trials and an old tradition in forest science. These genetic approaches coupled with adaptive management strategies could buffer or maintain sustainable levels of forest productivity and ecosystem health.

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Chapter V: Mapping the risk to European forests with a changing climate

Barry Gardiner, Mart-Jan Schelhaas and Bruce Nicoll

Background

Insects and diseases, storm damage, wildfires, drought, and herbivore grazing are the main agents affecting forests within Europe although their importance varies by region. The level of damage is increasing at the same time that European forests are being asked to provide an increasing range of ecosystem services and therefore understanding the impact of forest management and the changing climate on forest disturbance is one of the big current challenges for forest science.

European Forest Disturbance

The primary abiotic damage in Europe is due to wind and fire and the primary biotic damage is due to bark beetles. However, these damage agents are quite localised so wind tends to be more important in Western and Northern Europe and fire more important in the Mediterranean region, and beetle damage is important in Atlantic temperate, Alpine and Mediterranean forests, whereas mountain and boreal forests are more affected by fungi and wildlife. The economic consequences of this damage to forests can be profound: for example fire caused €5 billion of damage in Greece in 2007 and €0.8 billion in Portugal in 2005, and wind caused €6 and €1 billion in France in 1999 and 2009, respectively, and €2.4 billion in Sweden in 2005.

The overall increase in European damage levels appears to be due primarily to an increase in the forest growing stock together with changes in climate and land management (Figure 1). Such changes are expected to continue in future. For example, wind damage is predicted to increase by at least a factor of 2 by the end of the century and extend further east across the continent. In addition, warmer and drier summers will increase fire risk. For example, in France the high levels of forest fire danger currently limited to the Mediterranean area, will extend to the western part of France by 2040 and to most of the country by 2060. Global warming is expected to enhance the winter survival of bark beetles triggering increases in population abundance and risk of outbreaks.

European forests will, therefore, be under increasing threat from a range of existing and new damaging agents and it is important to be able to predict the level of risk now and into the future. Furthermore, because major damage events and outbreaks of pests and diseases can affect large areas and many countries such calculations need to be carried out from the regional to the European scale.

Modelling Disturbance at the Landscape to European Scale

It is now possible to work at regional to European scales without losing sight of the detailed mechanisms controlling tree damage which operate at the tree scale or lower. This is because of recent developments in computer science, complex system modelling and artificial intelligence. However, high-resolution modelling of risk to forests from different hazards at the European scale presents serious challenges. In particular there are requirements for detailed data on forest structure (species mixture, tree height, diameter, spacing, ground vegetation, etc.) and site (soil type, elevation, climate, etc.) and to have available models that are able to calculate risk across Europe for the range of site types, forest species, forest management regimes and climate that occur. For illustration, we present here modelling of the risk of wind damage and bark beetle attacks across Europe.

Mapping of wind damage risk for Europe

To map wind damage risk across Europe requires knowledge of the current and future wind climates, information on the forest stands (tree species, tree diameter and height, stocking), and soil type and rooting depth. In this study we used high resolution wind climate data for the past and future climate that is available at 25 km resolution from the EU ENSEMBLES project (Figure 2). Information on the forest structure was obtained from the Synthetic European Forest Structure Database, which has a resolution of 1 km and is based on a species distribution map of Europe and a collection of National Forest Inventory (NFI) measurements. The FAO soil map that was used to construct the species map was also used to assign soil type and rooting depth. The stand and soil data described above were used as inputs to the wind risk model ForestGALES2.3, which calculates the critical wind required to damage a stand. The output from the ForestGALES model run is shown in Figure 3. Only areas where the land cover is more than 10% forest are shown. From this figure it can be seen that there are areas of Central Europe, southern Sweden, Southern Finland and Estonia which have the lowest critical wind speeds. If the critical wind speeds are combined with the wind climate from Figure 2 it is possible to calculate a probability of damage for the whole of Europe and data on future wind climates allows the future risk to be calculated.

Mapping of bark beetle risk for Europe

Tools are not currently available that allow mapping of the risk of bark beetle outbreaks across Europe. However, scientists at BOKU University in Vienna performed a large number of simulations with the PICUS forest growth model, covering a wide range of stand and climatic conditions in Austria. These simulations were then used to construct

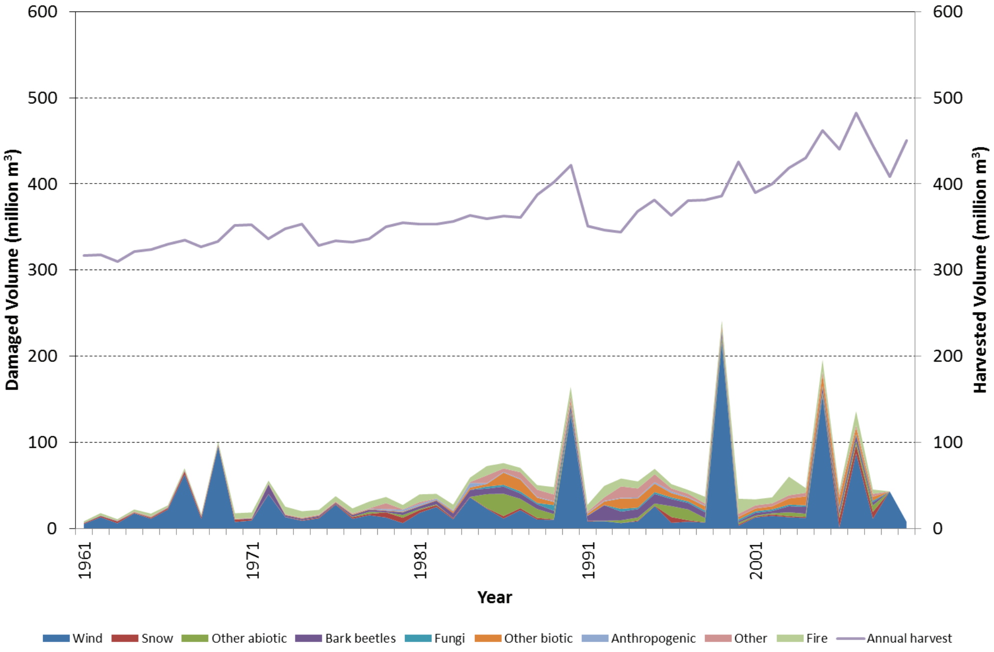

Figure 1. Damage levels, causes of damage and annual harvest rate for European forests (1961–2010).

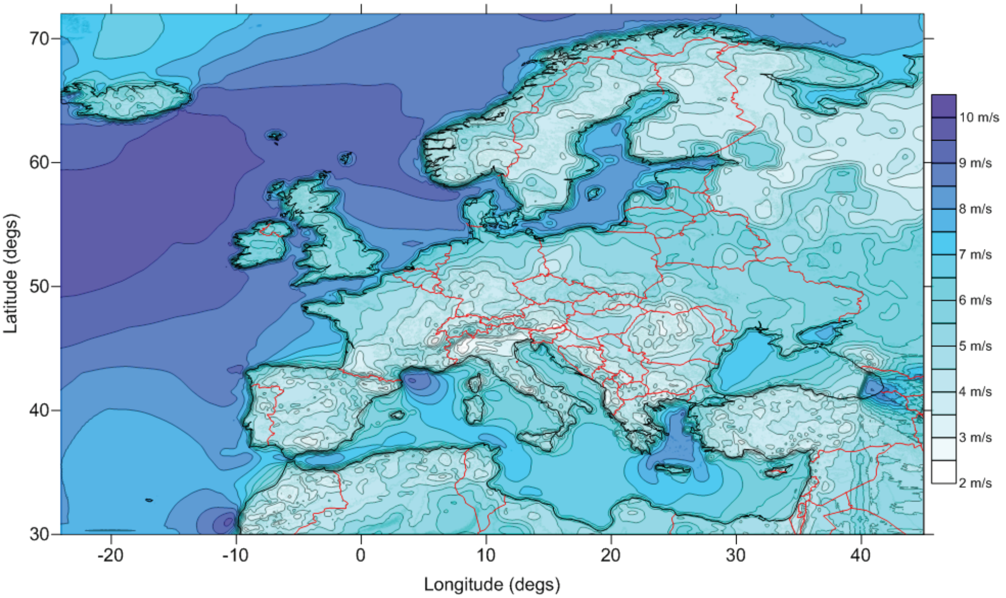

Figure 2. Estimated Weibull A values for current conditions (1991–2010) from ENSEMBLES data. (Darker colours represent areas of stronger annual winds).

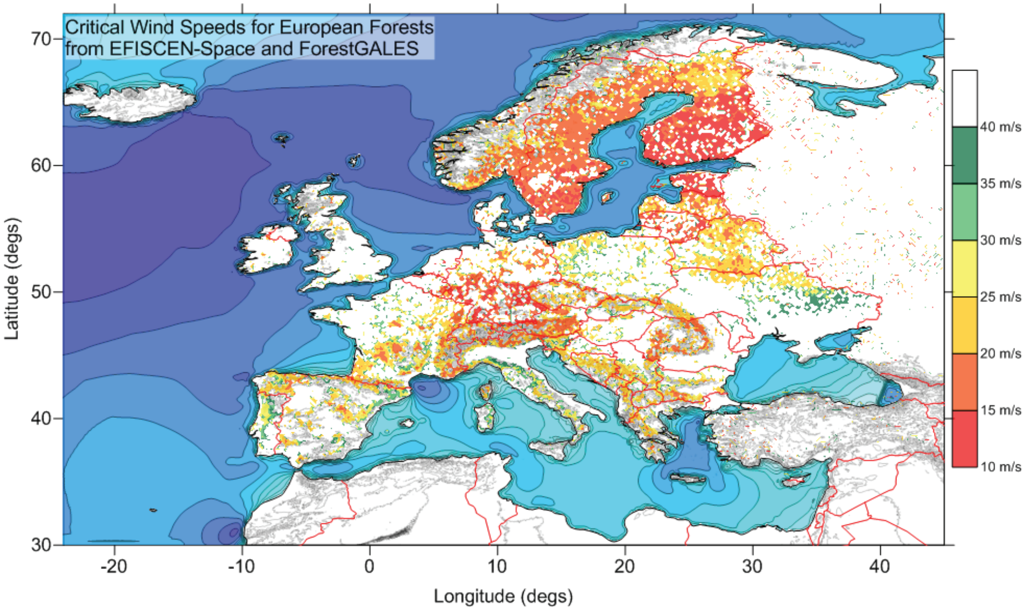

Figure 3. Critical wind speeds to cause damage to forests stands across Europe. Only areas with forest cover of more than 10% are displayed. The sea areas show the same wind climate information as are displayed in Figure 2.

a regression model that predicts the chance of bark beetle infestation based on average annual temperature, total annual precipitation, stand age, stand density and the percentage of the host tree within a stand. If a stand is infested the damage level is then predicted as a function of average annual temperature, total annual precipitation and host tree percentage.

We applied this regression model to the whole of Europe, using the Synthetic European Forest Structure Database (see above) and WorldClim data focussing on spruce. Stand age was estimated from height and soil type, based on yield tables. Climate data were derived from the WorldClim database, as average annual temperature and average annual precipitation. Stand risk was quantified for each cohort in the forest structure database as the product of total volume of spruce, the chance of infestation and the fraction of the stand damaged. The resulting map (Figure 4) gives the endemic risk of bark beetle infestation, so it ignores increased risk due to build-up of the population in previous years, for example due to wind-throw events. Furthermore, this reflects the average long-term weather conditions. As can be seen from the map Central Europe and Southern Sweden are major areas at risk of bark beetles on spruce, which corresponds well with observed damage outbreaks. Although spruce is also found in more northerly areas it is too cold at these latitudes for bark beetles although this could change in the future with a changing climate.

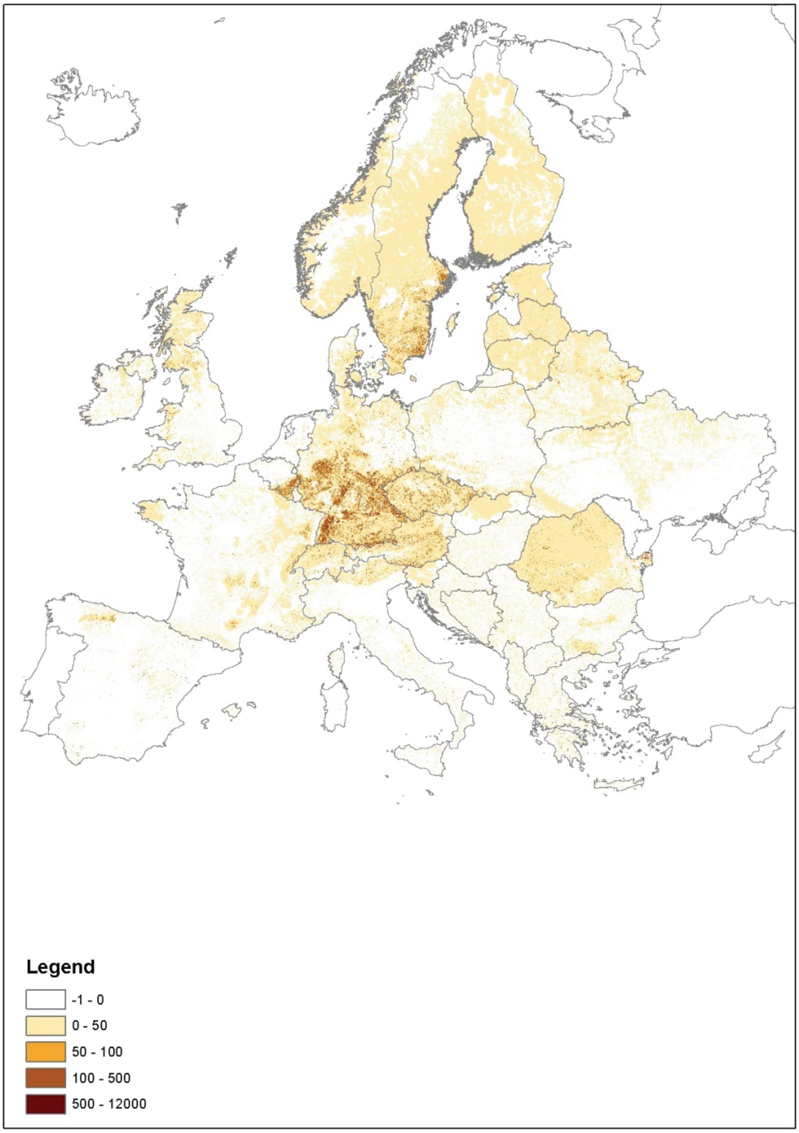

Figure 4. Endemic bark beetle risk for average weather conditions, expressed in m^3 per pixel.

Summary and Conclusions

We have shown that it is possible in a preliminary way to calculate the risk for wind damage and bark beetle attack across the whole of Europe. Such calculations require extensive data sets on European forest condition, and information on the current and future climate. In addition these maps can only be created by models that are able to work across the whole range of forest and site conditions that exist within Europe. The use of informed decisions on how to adjust these models when data are not available for a particular species or site is also an important requirement. Therefore, these maps have to be treated with caution and we emphasise that at this stage they only demonstrate the possibilities for the future and give some indication of the most vulnerable areas of Europe to these hazards.

With improved data on European forests and soils such as is becoming available from remote sensing it will become possible in the future to put higher confidence in the outputs from such simulations. At the same time it is important that work continues to extend the existing risk models for different damage agents and to start building models for other important hazards such as forest fires for which at present only locally applicable models are available.

Chapter VI: Adaptive forest management - overview of the MOTIVE Case Studies

Harald Bugmann and Antoni Trasobares

Forest managers have a long tradition of adapting their silvicultural practices to new insights gained upon past experience. Anthropogenic climate change, however, is proceeding at a magnitude and speed that is unprecedented in the history of human civilization, and forests will likely be out of phase with climate over the coming decades to centuries. Thus, information on the likely future development of the drivers of forest dynamics, such as climate, and the resulting impacts on ecosystem properties and ecosystem services must be taken into account in forest decision making already now, rather than in hindsight only. This means that a pro-active, forward-looking approach is needed for managing forests.

The forest models developed in the MOTIVE project are thus essential for projecting future forest dynamics to support current-day decision making. The 'decision space' of potential forest management actions was determined by using the MOTIVE forest models for simulating a wide range of management practices, including current practices as well as adaptive, forward-looking management regimes. For each case study region, this was done for a set of forest stands in the framework of a set of specific management objectives that aimed at maximizing the goods and services from the stands, while minimizing risks. Also, a range of climate scenarios was taken into account.

The goals of these analyses were as follows: (1) to assess the likely changes of forest stand dynamics and of the provision of relevant ecosystem goods and services for the major European forest ecosystems; (2) to assess the utility of adaptive vs. conventional management regimes for maintaining the provisioning of forest ecosystem goods and services; and (3) to allow for cross-case study comparisons of the results regarding the effects of adaptive management.

In a first step, pilot studies were conducted to assess the concept of adaptive management underlying MOTIVE (Figure 1), showing that it was appropriate and efficient. These first results were already consolidated for some case studies but incomplete for others.

In a second step, refined simulation studies were conducted, again on a per-case study basis, yielding significant and novel scientific results on (1) climate change impacts on forest ecosystem goods and services, and (2) the identification of the most suitable management strategies. Generally, the interactions between forest management (both current and adaptive strategies) and climate change were elucidated, and the effects on the provisioning of a given set of targeted ecosystem goods and services were analyzed through time. The following chapters will present exemplary results from all the case studies.

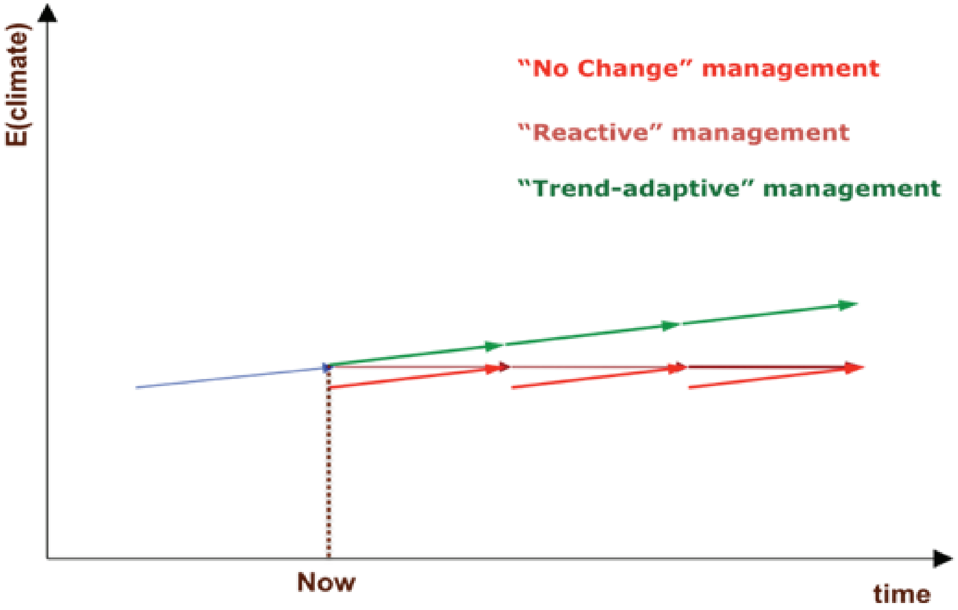

Figure 1. Concept of adaptive management underlying MOTIVE. The blue arrow represents the past provisioning of ecosystem services (E) from a forest stand. "*No Change*" management repeats past treatments, not integrating the knowledge about recent changes in E. "*Reactive*" management capitalizes on past changes in E by modifying the management such that higher levels of E are expected for the future. "*Trend-adaptive*" management incorporates scenario-based knowledge regarding future likely changes in E as may be induced by climate change, and adapts current management to anticipated future changes of abiotic and biotic conditions. Sub-types of "trend-adaptive management can be distinguished depending on the incorporation of uncertainty, but these are not shown here. Figure redrawn from Bredahl Jacobsen et al. (2010), where additional details may be found.

As a prerequisite for the robust application of the MOTIVE forest models under a wide range of scenarios of climate and management practices, they were significantly improved and further developed to allow for a better representation of the ecological processes underlying forest dynamics and an advanced evaluation of adaptive management strategies (e.g., improving climate sensitivity, more accurate calculation of ecosystem goods and services).

Examples of model improvements are the refinement of the species suitability model used in the Welsh case study, a more realistic module for ungulate browsing introduced for the Austrian case study, the coppice management module that proved to be essential for the Bulgarian case study, or a novel bark beetle module developed for the German case study.

Innovative methods and tools were implemented for the optimization of adaptive management at both the stand level (e.g., simulation-optimization approaches in the Finnish and Spanish

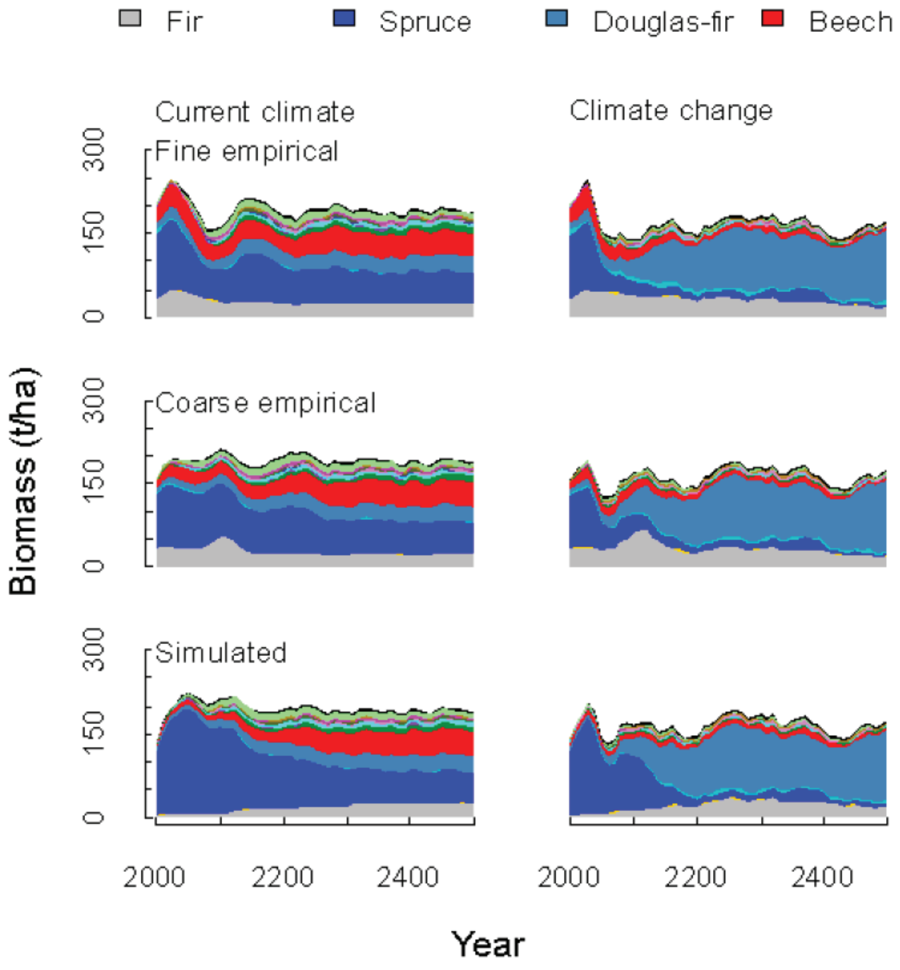

Figure 2. Effect of different kinds of initialization data for the Black Forest case study, demonstrating that the nature of the initialization data used for starting the model in the year 2000 dictate the short-term (decades) development of the forest both under current climate (left column) and under a changed climate (right column). The two top rows are based on measured initialization data, albeit at different spatial resolution; the bottom row is based on an assumed equilibrium state between climate and forest properties (so-called "spin-up" run of the model). From Temperli et al. (2013).

case studies) and the landscape level (e.g., landscape level optimization developed for the Finnish case study).

These methods and tools were developed in close interaction with key stakeholders in the case studies and thus they should be of practical relevance.

Below, we highlight three different challenges that researchers were faced with in the context of adaptive management in MOTIVE, and how they solved them.

First, it is not trivial to answer the question whether "conventional" management may suffice in the face of climate change, or whether a truly forward-looking, adaptive approach is superior. In the Welsh case study, several management approaches were set up for investigation including: 1) a business-as-usual approach; and 2) an adaptive species-diversification approach. Simulations showed that decision-maker 1 could be facing worse results in terms of the provision of ecosystem goods and services and the aversion of risks by postponing adaptation. The diversification management approach resulted in much closer trajectories (i.e. less uncertainty) between climate model variants than BAU. BAU management had possibility of higher economic returns but also of much lower returns.

This example highlights the importance of a key question in the current discussion on adaptive forest management, and shows that it can be answered by systems analysis: under which circumstances and at what point in time is it most beneficial to adapt?

Second, severe environmental limitations, e.g. by drought in Mediterranean countries, may call for specific adaptation measures. The results obtained for Mediterranean Catalonia, where a multi-objective stand-level optimization for *P. sylvestris* forests was developed and applied, and for Mediterranean Portugal, where cork oak management was simulated, clearly illustrate the effects of severe drought and suggest management strategies for adapting to this driving factor. These case studies are excellent examples of a 'live laboratory' of phenomena that will emerge in other parts of Europe in the coming decades.

Third, when implementing a given adaptive management regime (e.g., for even-aged management) at the landscape level, its effect and efficiency may be highly conditioned by the initial state of the forest, as expressed e.g. via the diameter distribution of the set of stands that compose the landscape (Figure 2). This is particularly pronounced in landscapes that are composed of many stands of similar ages, resulting from land-use legacies such as increased afforestation in the late 19th century or after the Second World War. Thus, the most appropriate management of forests does not only depend on the likely future trajectories of climate, the most limiting abiotic factors, and the specific ecosystem goods and services that are demanded by society, but also by the legacies of past uses of the landscape, thus sometimes strongly reducing the "manoeuvering space" of current and future management.

Overall, the results presented here demonstrate that the MOTIVE project has achieved robust simulation results of climate change impacts on stand dynamics and key ecosystem goods and services for the major European forest ecosystems, including approaches for adaptive management to alleviate negative consequences of climate change.

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Case Study Introduction

The following pages summarise the results from the case studies in MOTIVE.

The chief climate change challenge for each case study is presented and selected adaptive management options are introduced. Climate graphs characterize current and future projected climate conditions for the case study region. They display mean monthly temperature and precipitation for baseline 1961-1990, and the highest, medium and lowest projections for 2070-2099. The baseline climate data was from the Climate Research Unit at University of East Anglia, whereas 2070-2099 projections were derived from four regional climate models from the ENSEMBLES EU project namely: CLM/ECHAM5, run by Max Planck Institute for Meteorology; RACMO2/ECHAM5, run by KNMI - The Royal Netherlands Meteorological Institute); HADRN3/HadCM3, run by the Hadley Centre at the UK Meteorological Office; and HIRHAM3/Arpège, run by DMI - The Danish Climate Centre at the Danish Meteorological Institute.

This chapter is based on the work of many researchers of MOTIVE, including

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Black Forest, Germany: Christian Temperli and Che Elkin; ETH, Switzerland; Alfons Bieling, FVA, Freiburg.

Montafon Valley, Austria: Michael Maroschek, Werner Rammer and Manfred Lexer; BOKU, Austria;

Portugal – Chamusca case study

Case study forest area: 51,339 ha

Forest goods and services:
Non wood products: cork, pine nuts, mushrooms
Wood products: pulpwood, wood biomass
Services: grazing, hunting , fishing
Non market services: carbon stock, forest protection, habitat conservation

Ownership: 98.7% private, 1.3% public

Special local conditions:
40 landowners hold 72% of the area in large scale properties (>500 ha)
Most owners have properties <1ha
Most stands leased by pulp/paper industry

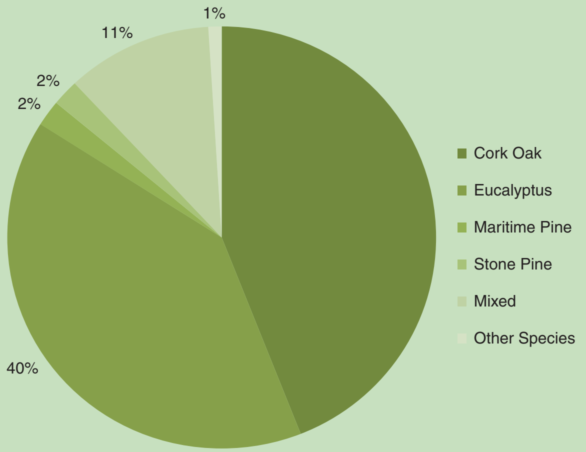
Stakeholders

ACHAR is the main forest owners' association. It has direct access to all local, regional and national stakeholders (both public and private) and is directly involved in preparation of management plans.

Management and governance issues

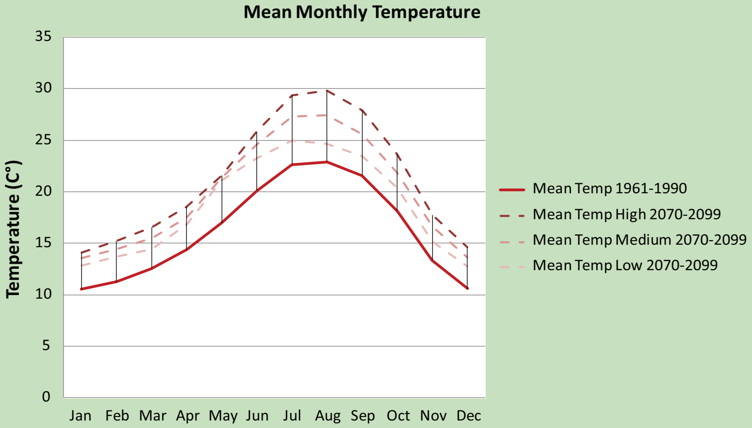
The Chamusca case study management area is under the Regional Forest Plan for Ribatejo (PROF), a regional planning tool that aims to promote sustainable forestry according to national forest policy guidelines.
Main decisions are undertaken by forest owners. ACHAR is also responsible for the development of collaborative forest management planning for five areas that group several individual properties (Forest Intervention Zones – ZIF).

Proportion of Species – Chamusca



Climate change challenge

Forest fires are already the main threat in the Chamusca region and they are expected to increase as future climate will be characterized by dryer summers and longer fire seasons.



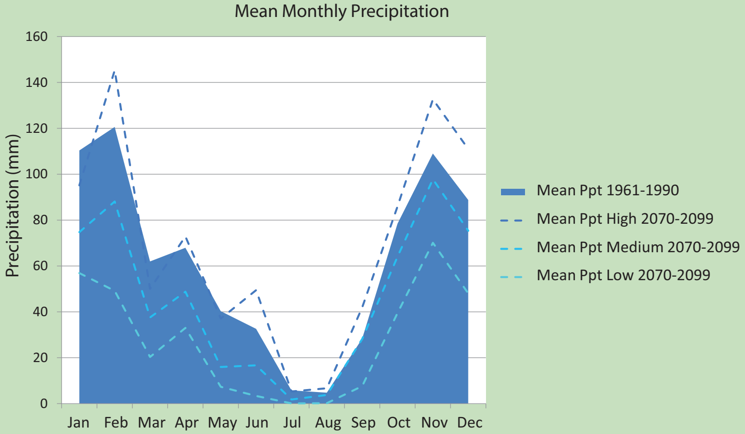



Photo: Susana Barreiro.

Under changing climate, the growth of forests will decrease, especially in the driest parts of the country. For example, the growth of eucalyptus plantations will be reduced.

Even the cork oak which is quite well adapted to dry conditions will suffer from more frequent and severe droughts in this region. In sites with lower water-holding capacity it may be expected that there will be a reduction in tree and cork growth, and an increase in tree mortality.


Photo: Brigite Botequim.


Photo: Juan Guerra.

Forest fires are already the main threat in the Mediterranean basin and they are expected to increase as the future climate will be characterized by drier summers and therefore longer fire seasons.

In order to minimize the impact of climate change on cork oak production, the stand density (traditionally low in the area due to silvopastoral management) may be increased to offset the reduction in growth. Due to silvopastoral management and/or by doing understory cleanings, fire risk will not increase significantly.

Photo: Joana Amaral Paulo.

Photo: Joana Amaral Paulo.

Proper management (e.g. thinning, pruning, understory management) will be particularly important to increase resistance of forest landscapes to forest fires. For example, thinned stands with large trees are more resistant than very dense stands. Another important measure is to reduce understory biomass.

Photo: Joana Amaral Paulo.

In addition, forest managers may extend the debarking rotation period to more than 9 years in order to allow the increase of cork thickness as cork will grow more slowly due to the dryer climate.

Conclusion

With climate change an increase in aridity will cause a reduction in productivity of cork oak, however this can be mitigated by increasing stand density, extending the debarking rotation and adapting forest management to minimise fire risk.

Spain – Prades, Catalonia case study

Case study forest area: 2,460 ha	**Ownership: 90% private and 10% public in the Prades mountain, 100% public in the Natural Site of National Interest**
Forest goods and services: Tourism, recreation, conservation, small scale forestry, mushroom picking	**Special local conditions:** Large areas of the forest were coppiced for charcoal until the 1960s and now left unmanaged with high densities over 20,000 trees ha^{-1}.

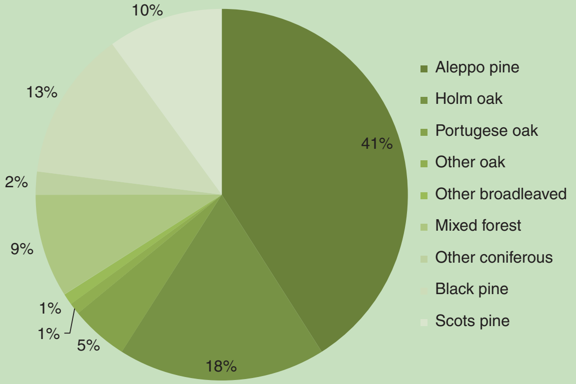
Stakeholders

Public forest managers, natural park management commission, cooperative of forest owners

Management and governance issues

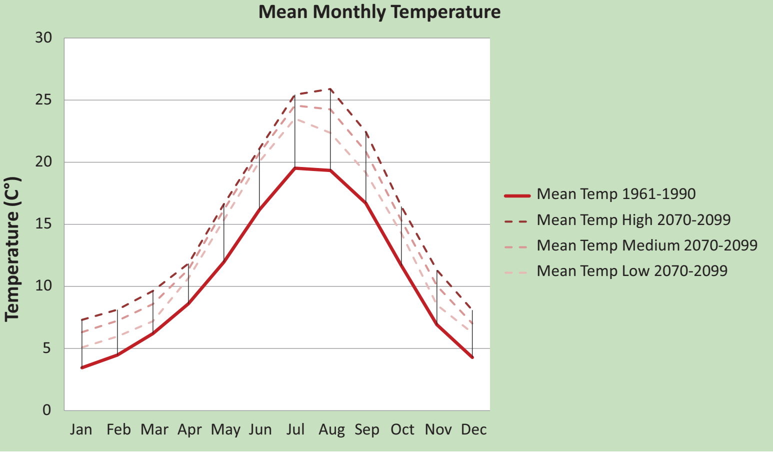
Poblet Natural Site of National Interest (NSNI) is a protected natural area. The case study is situated within the NSNI. As in many other parts of the Mediterranean, forest management activities have been abandoned due to low profitability. Today, the main management motivation is to maintain forest health and forest regeneration. The conservation and management of the forest is executed by a professional team of forest managers of the regional government (Generalitat de Catalunya). Because it is a protected area, they are supported by a management commission of stakeholders and experts. There is a long tradition of forest research in the area, which has certain interaction and effect on the forest management.

Proportion of species of Prades



Climate change challenge

Climate change in the region is revealing itself by rapid increase in aridity, and more frequent extreme events such as droughts. Such changes will drastically impact forest dynamics and as well as biotic and abiotic risks (forest fires). The level of these impacts and the adaptive capacity of forest ecosystems will affect the provision of relevant forest ecosystem goods and services.



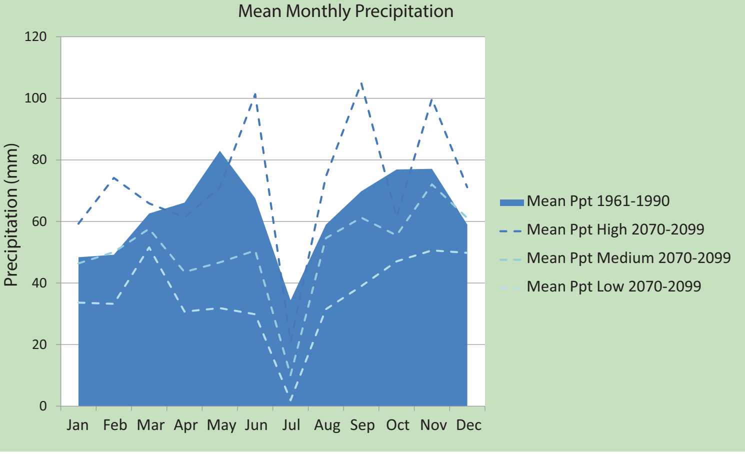


Photo: Michael Maroschek.

Most tree species occurring in the area are typical Mediterranean tree species which are medium to extremely drought resistant. It means that they have low risk of cavitation due to drought.

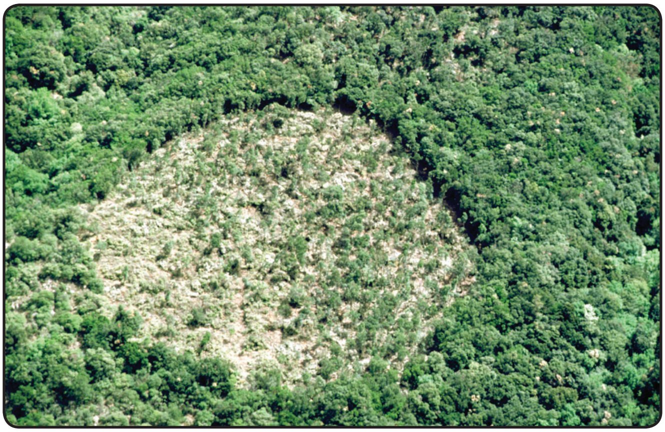
The most relevant climate feature in Prades is the high variability in precipitation from month to month or year to year. Future projections show an increased probability of drought periods linked to this variability. The increased occurrence of long dry spells represent a serious threat to forests in the area.

Even Mediterranean species can suffer carbon starvation due to dry spells, as they need to consume their mobile carbon reserves to overcome such periods. If too recurrent, mobile carbon reserves cannot be replenished in time, with vitality loss as a consequence. This may be the case for holm oak. EuroSiberian species like Scots pine, who find some of their southernmost distribution areas in these mountains are directly threatened by climate change. Scots pine has no possibility to migrate to higher elevations given that they occupy already the highest zone of this geographically isolated mountain.

Photo: Joanne Fitzgerald.

Tree species like holm oak that were perfectly adapted to the area in former time show decrease in vitality and even mortality due to recent long drought periods, which probably causes carbon starvation in the trees. Other species that were already at the edge of their distribution range, like *Pinus sylvestris* increasingly suffer from dieback due to drought stress. The general risk profile of all species changes because of increased fire risk.

The circular area is a thinned plot in the forest. The photo below shows that several years later, the thinned plots withstood drought much better than unthinned plots.



Photos: Carlos Gracia.

Simulations show that under climate change the current low management intensity leads to a decrease in biomass production. The reason is that the high stand density under this management in combination with increased drought stress leads to increased competition and mortality.

In general, managers are recommended to follow a more intensive management which reduces canopy density. The effect of this is a decrease of competition between trees, which means more water available per tree, less mortality, and better overall growth performance.

Conclusion

The main limitation for adaptive forest management is the cost. Forest management operations are expensive, and income from the forest is very limited. Increasing wood prices would be beneficial, as would be increasing income from mushroom permits. In general, ways must be explored to finance adaptive management, considering the potential of payments for ecosystem services (PES) and other economic instruments to internalize forest ecosystem services and non-wood forest products.

Bulgaria – Panagiurishte case study

Case study forest area: 6,584 ha

Forest goods and services:

Wood products: fire wood for local citizens, pulpwood, technology wood (for wood based panels). Non wood products: mushrooms, herbs, tourism. Services: grazing, hunting. Non market services: Protection against landslides and soil erosion.

Ownership: 93% public, 7% private

Special local conditions:

The Executive Forest Agency is responsible for forest management in all types of forest in Bulgaria, irrespective of ownership. It participates in the process of design and implementation of forest management plans together with the owners.

Stakeholders

State and municipal public bodies, green NGOs, local hunters and tourist companies, local farmers, all local householders for providing winter heating.

Management and governance issues

The forest regulatory framework applies to both public and private forests (there are no local or regional forest policies). However, differences in management of forests are evident in the case study with small private owners practicing clear-felling, while large state or municipal owners are concerned with converting coppice stands into broadleaves (high forest), which excludes clear-cutting. Maintenance of some black pine plantations to provide some softwood supply for the local economy is a traditional aim.

Proportion of species of Panagiurishte

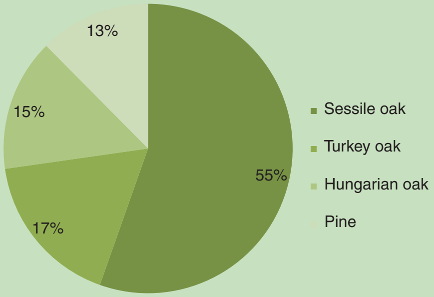
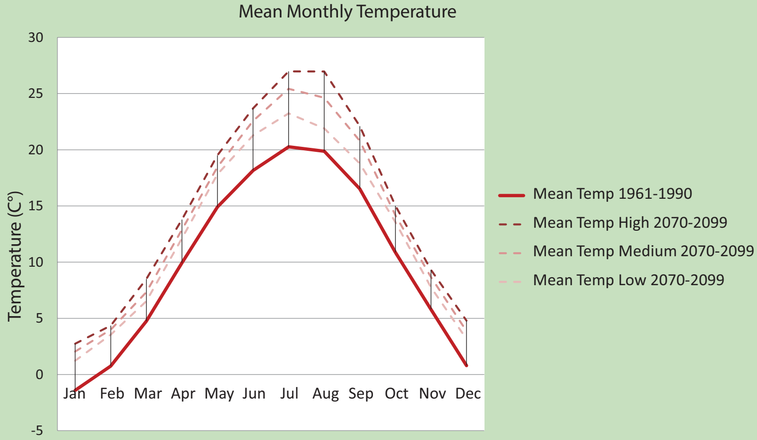


Photo: E.Rafailova.

Climate change challenge

Droughts and less favourable growing conditions will cause substantial decrease in mean annual increment of forest stands, a decrease in seed regeneration and increased fire risk.



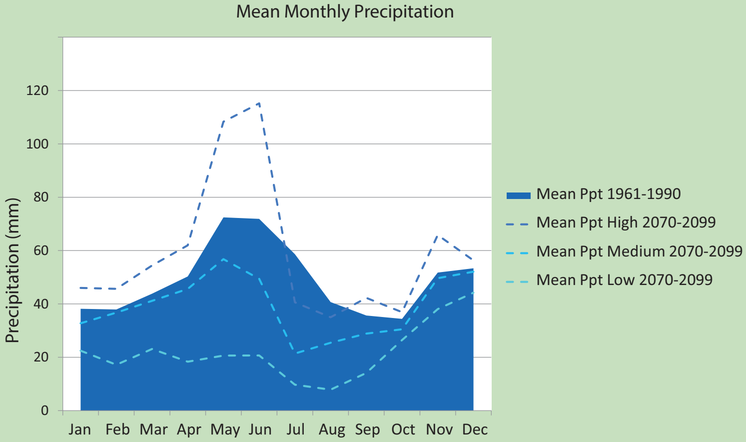


Table 1. Mid- to longterm tree species' sensitivities towards projected climate change for the three forest ecosystem processes. + increase, ~ no change, - decrease.

	growth		regeneration		mortality	
Tree species	2020–2050	2050–2100	2020–2050	2050–2100	2020–2050	2050–2100
Turkey oak –coppice	~	--	++	+	~	+
Turkey oak – high	-	---	~	-	~	-
Sessile oak – coppice	-	--	+	~	~	--
Sessile oak – high	--	---	-	---	-	---
Hungarian oak – coppice	-	--	+	+	~	-
Hungarian oak – high	-	---	~	--	-	--
Austrian pine	-	--	~	+	~	--
Flowering ash	~	-	~	+	~	-

Photo: Georgi Kostov.

Seed regeneration will become difficult for oak coppice stands as mature oak trees need favourable climate to produce acorns. Young seedlings are also more sensitive to drought stress. Warmer winters could lead to early blossoming and susceptibility to frost damage.

Fire risk is increased by reduced precipitation and longer dry periods. The presence of coniferous plantations which are not regularly thinned as well as abandoned agricultural land covered by tall grasses also increase fire risk.

Photo: Executive Forest Agency, Bulgaria.

Current management practices (business as usual; BAU) operate with the goal of converting existing coppice stands into high forest through natural regeneration. This would increase timber quality and productivity in the long-term.

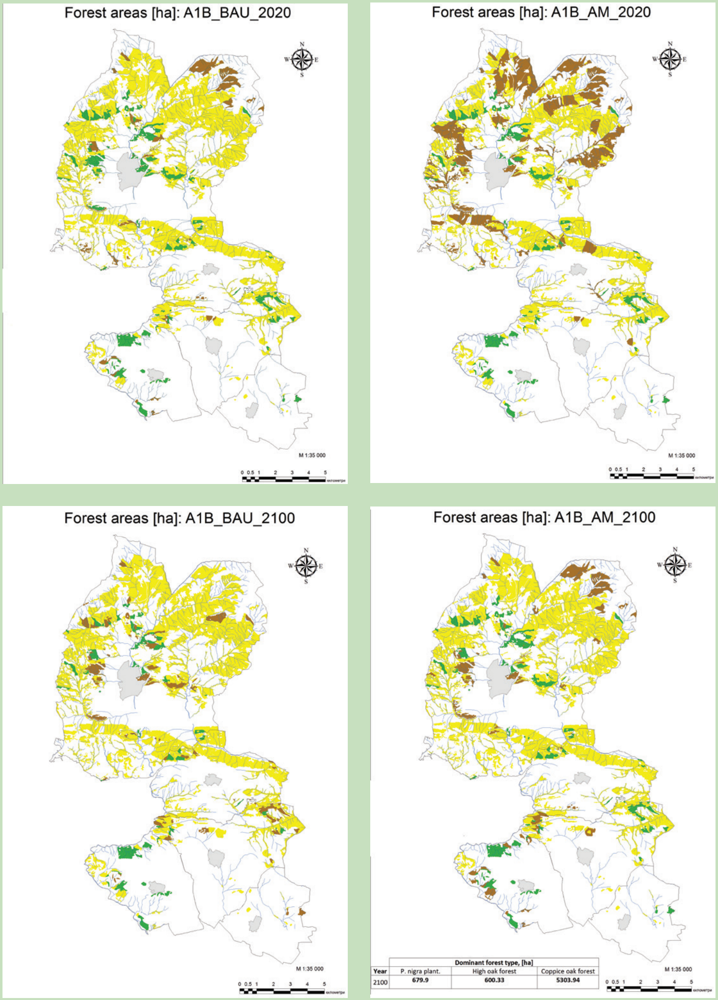
Using the PICUS model, under the BAU scenario for 2100, it was found that the mean Annual Increment of high oak was less than that of coppice oak. The main goal of transformation from coppice to high forest would not be reached with BAU management.

Legend:

🟩 P. nigra plant.

🟫 High oak forest

🟨 Coppice oak forest



	Dominant forest type, [ha]		
Year	P. nigra plant.	High oak forest	Coppice oak forest
2100	**679.9**	**600.33**	**5303.94**

Modeled areas under high forest, coppice forest, and pine forest for BAU and AM scenarios in 2020 and 2100 using the PICUS model.

Adaptive management includes shortening the rotation age of coppice stands to facilitate conversion to high forest, and more intensive tending and thinning of young forest stands. This management promotes a greater area under high forest than the BAU scenario. However the long term modeled projection indicates that area-wide conversion to high forest will not occur because of time-lags and the underlying set of different sites, climatic conditions and management actions affecting regeneration processes.

Conclusion

Adaptive management activities may not be able to fully mitigate the negative consequences of climate change, still negative impacts as expected for BAU management will be attenuated under AM.

Romania – Frasin case study

Case study forest area: 10,500 ha

Forest goods and services:
Timber, fuel wood,
carbon sequestration, biodiversity,
non timber forest products, hunting grazing,
fishing, berries and mushrooms
tourism, conservation

Ownership: 60% public, 40% private

Special local conditions:
The restitution of forests to heirs of pre-war owners between 1991 and 2005 as well as privatisation of wood harvesting, transport and processing sectors had a big impact on the development of the forest sector and forest management.

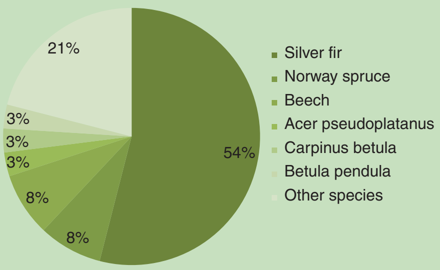
Stakeholders

Private forest owners associations (Association of Private Forest Owners of Romania and Association of Forest and Mountain Owners). There are also three trade associations which officially represent most of the forest logging and wood industry operators: The Association of Romanian Foresters (ASFOR) the Association of Romanian Furniture Producers (APMR) and the Association of Romanian Pulp and Paper Producers (ROMPAP)

Management and governance issues

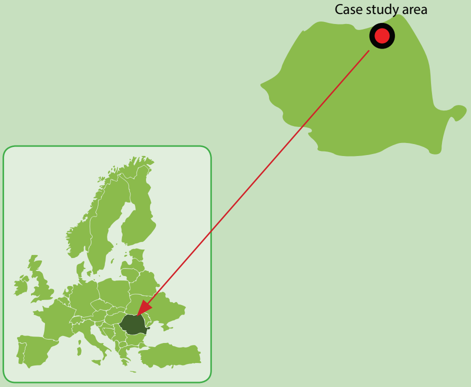
The same forest management legislative structure (Forest Code, 2008) is applied to private and public or communal forests. It outlines the rules regarding administration, forest management planning, forest regeneration, harvesting, protection and legality of timber harvesting and transportation.
The main principle of the Forest Code is that forest owners need to manage their forests via the agreed state administration. The main instrument for joint-decision making is the forest management plan. Without such a plan, private owners cannot harvest their forests.

Proportion of species of Frasin



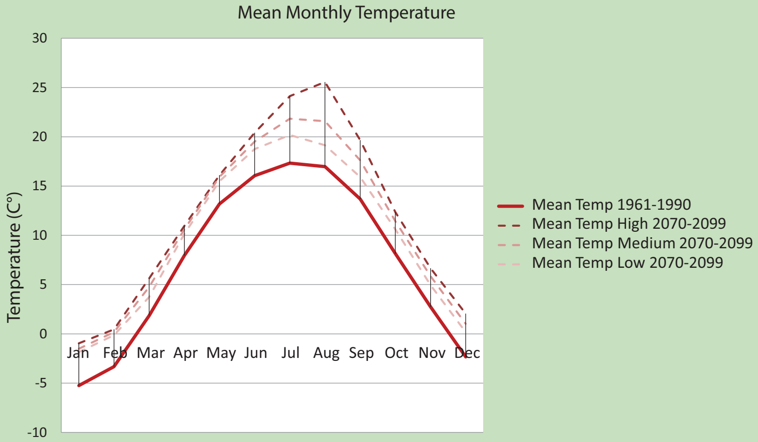
Aspect from an actual uneven-aged mixed stand in Frasin forest.

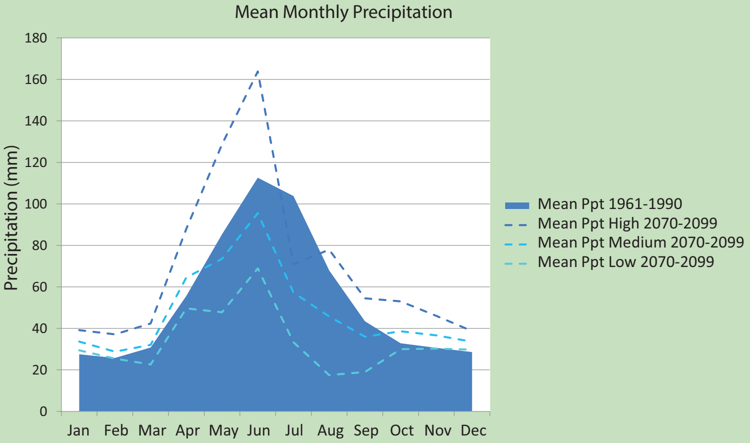
Photo: Gabriel Duduman



Climate change challenge

The current humid climate brings harsh winters and cool summers, and a moderate regime of air temperature fluctuations. The Frasin climate is predicted to be warmer and higher variations in temperature and rain regime are expected. The Norway-based spruce forests from Frasin will suffer more frequently from drought, insect damage (*Ips typographus*) and windthrow.





The predicted climate evolution will effect biomass volume and diversity of future forests. Depending on climate scenario used, Norway spruce may decline or even disappear while new species which are more thermophilic, such as larch, pine and maple may come to dominate in the future in the Frasin forests.

Photo: Mihai Leonard Duduman.

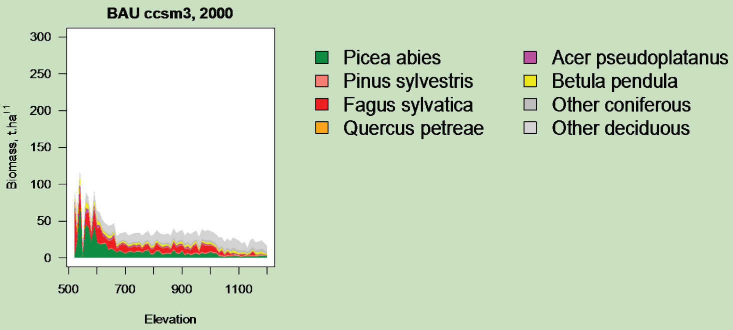
Photo: Mihai Leonard Duduman.

Natural drivers may lead to major disturbances in the forest ecosystem if nothing is changed in the current forest management approach. The difficulties encountered today by forest owners and managers to maintain economically viable forest management may encourage a trend towards unsustainable practices in future.

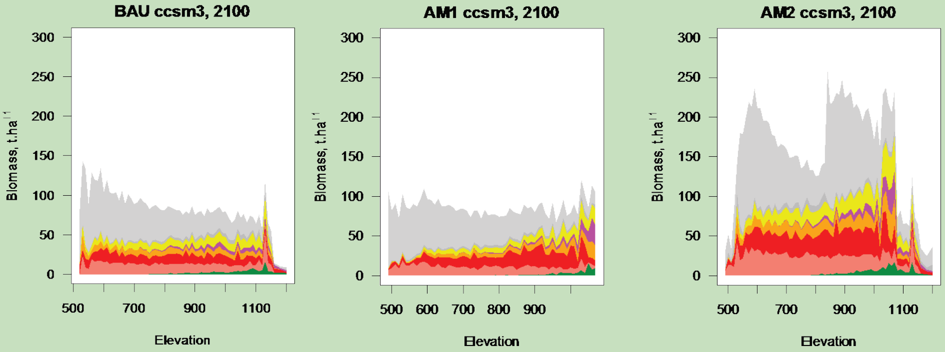
Photo: Olivier Bouriaud.

In case of disturbances, the projected temperature increase will become a handicap for Norway spruce regeneration. The photo shows a 15-year old windthrow.

There may be changes in the forest species composition as forest managers are looking at the regeneration of existing stands. Species diversity will increase, and Norway spruce will be less dominant. New forest species which are more thermophile, such as larch, pine and maple may come to dominate the Frasin forests. The share of broadleaves in general, and pioneer species in particular, is expected to increase at elevations higher than 600 m.



Growing stock in t ha-1 at different elevations in the year 2000 for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), beech (*Fagus sylvatica*), oak (*Quercus petreae*), Sycamore maple (*Acer pseudoplantus*), birch (*Betula pendula*) and other coniferous and deciduous species.



Growing stock in t ha^{-1} at different elevations for the year 2100. Three management strategies were used, BAU, AM1, AM2. Both adaptive management scenarios will produce higher timber volumes and higher biodiversity than BAU management. They are based on a strategy of saving water: more intense and more frequent thinning is combined with the reduction of the rotation length from 120 year (BAU) to 110 years (AM1) and to 100 years (AM2). The greater biomass predicted by AM2 is due to the intensive thinning proposed and also because a high share of the biomass is represented by pioneer species such as birch. This climate change scenario predicts that Norway spruce will only persist at higher elevations and will be replaced by Scots pine (*Pinus sylvestris*) at lower elevations.

Conclusion

Expected climate change will influence the species composition towards less coniferous trees. Adaptive management, which involves intensifying the harvests, will amplify this trend. This change in species may significantly affect forest owners' revenues. The forecasted species shift will impose a change in management practices. The climate has more influence on the species composition and forest standing biomass at this location than management practices.

Finland – North Karelia case study

Case study forest area: 1,520 ha

Forest goods and services:
Sustainable production of timber and energy biomass
Recreation, foraging for mushrooms and berries, hunting

Ownership: 100% Private

Special local conditions:
Free public access to the forests
Hunting rights belong to forest owner

Stakeholders

The Finnish Forest Centre (North Karelia regional unit) – an advisory and regulatory body
Nature Conservation Association
Hunting Association.

Management and governance issues

The forestry experts of the Regional Forest Management Associations have a major role in providing support and guidelines for forest owners with regard to silvicultural issues, timber trade, forest planning and implementation of practical forest management. In addition, the forestry experts of the Finnish Forest Centre and Forest companies help in these tasks.

Proportion of species of North Karelia

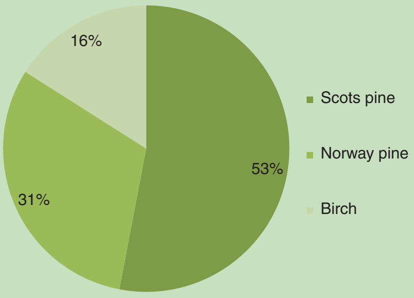
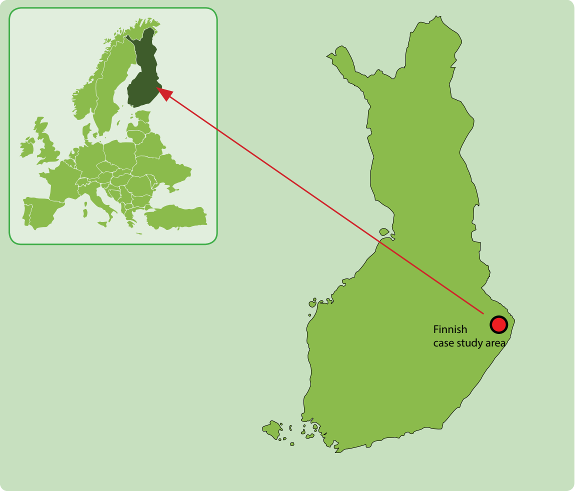
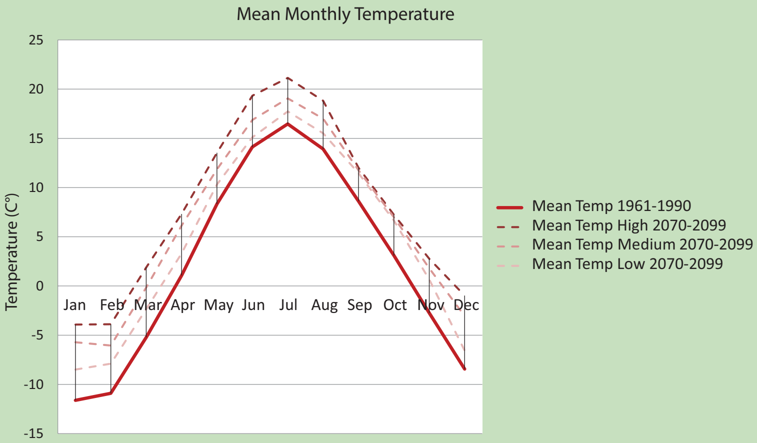


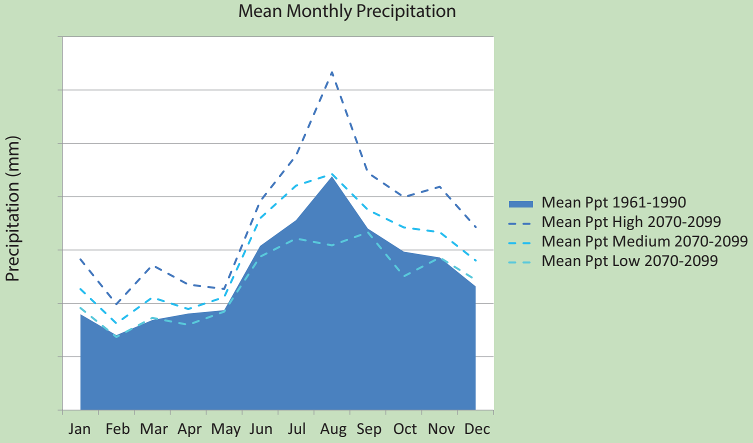
Photo: Michael den Herder



Climate change challenge

Due to changing climate, it is expected that the duration of frozen soil period will decrease significantly along with increase in annual mean temperature. Any increase in the frequency of strong winds during unfrozen soil period may increase the risk of wind and snow damages.


Mean Monthly Temperature


Mean Monthly Precipitation

Under changing climate, the growth of forests will in general increase significantly towards the end of this century, and in relative sense the most in Northern Finland. However, the growth of Norway spruce is expected to suffer from water stress especially in the southern Finland on sites with low water-holding capacity.

Photo: Michael den Herder.

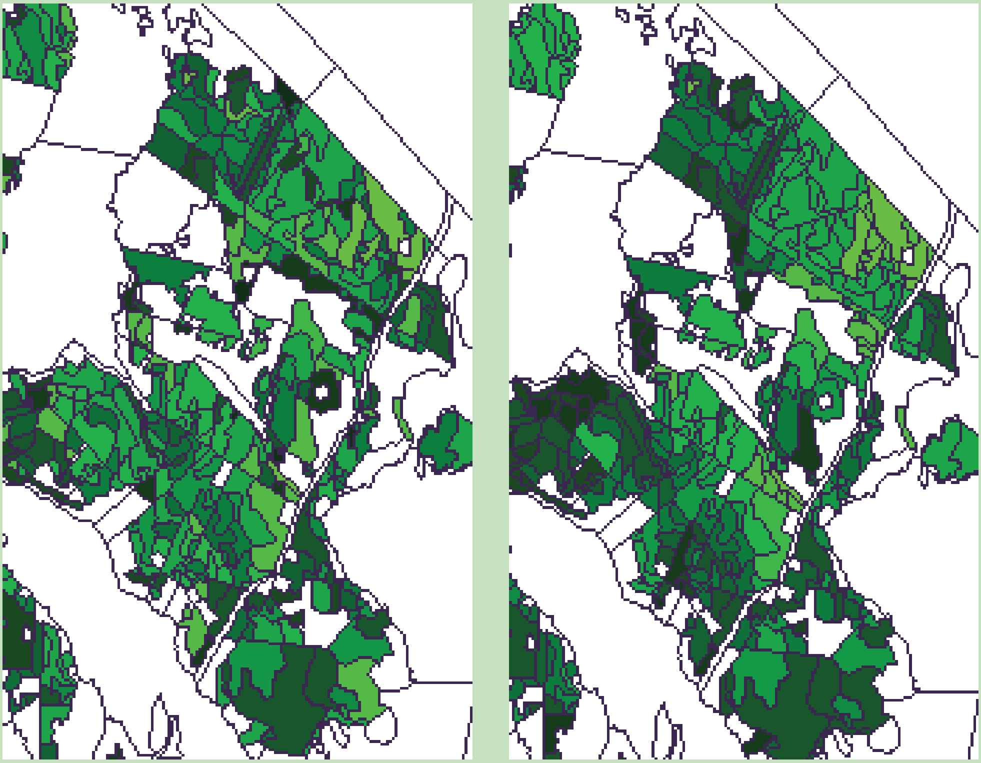
Photo: Heli Peltola.

Under the warming climate, the decrease in duration of frozen soil period will increase the risk of wind and snow damages in forests regardless of any change in windiness.

Photo: Heli Viiri.

Risks from wind are highest in Norway spruce with shallow anchorage but Scots pine and birch (in leaf) are also vulnerable.

Wind risks to forests can be decreased in forest planning by decreasing the mean height difference at the boundary of adjacent stands by applying proper temporal and spatial patterns of interventions such as final harvesting (clear cut). In this way it is possible to decrease the risks to forests by wind even without decreasing the Net Present Value significantly.



Stand height in managed forests after 60 years from now for two alternative forest plans. Plan 1: Max NPV (3%) with total harvest of 30,000 m^3 / 10 years, no consideration of wind risks to forests. Plan 2: Max NPV (3%) with total harvest of 30,000 m^3 / 10 years and consideration of wind risks to forests by minimizing the height difference at the boundary of adjacent stands. Gradual climate change was assumed in all plans for a 60-year period.

Conclusion

With gradual and proper adaptation of forest management, we can successfully minimize the expected negative impacts of climate change, while gaining on the positive ones. Proper and timely management of young stands will be particularly important for the resistance of stands against abiotic and biotic damages.

Sweden – Kronoberg case study

Case study forest area: 662,000 ha

Ownership: 79% private

Forest goods and services:
Timber, pulpwood and biomass, recreation, foraging for mushrooms and berries, hunting, heritage, game production, biodiversity, water and soil conservation.

Special local conditions:
The Right of Public Access is part of the Swedish constitution and allows the general public to roam the land and to pick wild berries, mushrooms and flowers, regardless of land ownership.

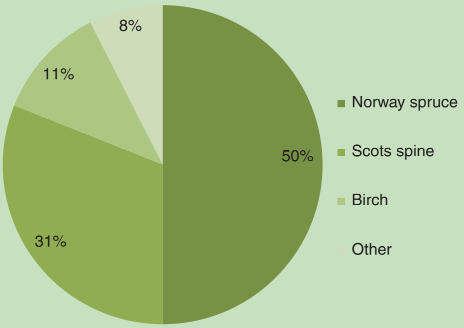
Stakeholders

Land owners, general public, nature conservation agencies, Kronoberg County Board, Swedish Forest Agency, wood and pulp based industry.

Management and governance issues

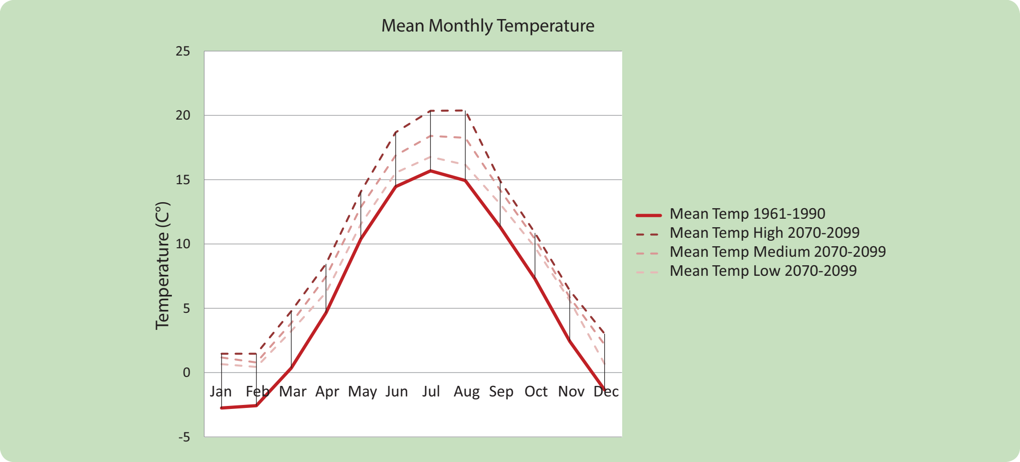
In 1993 the Swedish Forestry Act was revised. With that revision, the objective of maintaining biodiversity took equal priority with production objectives. Other public interests are also taken into account in forest management. Owners are able to influence the management of their forests to a greater extent than pre 1993. The clear-felling silviculture system is applied on almost all productive forest land. However, according to current regulations planting or measures for natural regeneration must have been completed by the end of the third year after felling or when agricultural land falls into disuse. Forest certification systems have been developed to promote responsible use of forests. Owners wishing to follow the rules may certify their forestry on a voluntary basis. In Sweden a vast majority of the productive forest land is certified.

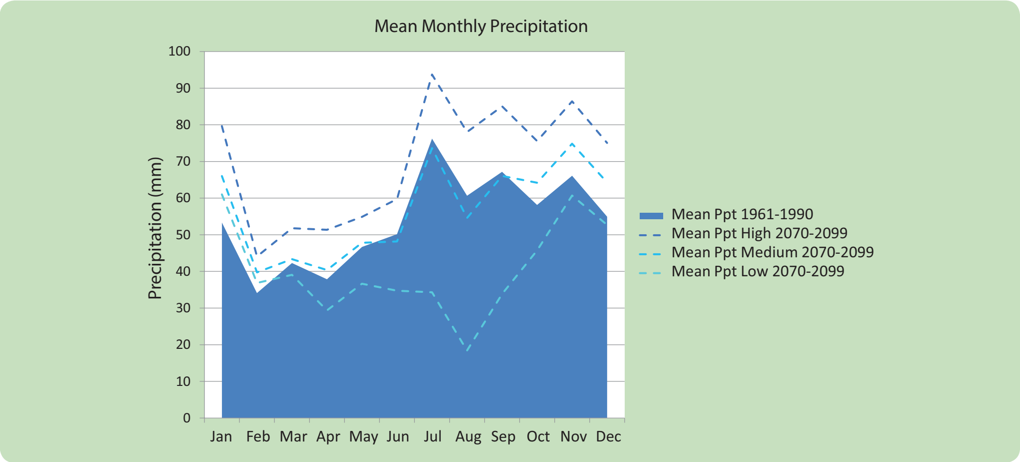
Proportion of species of Kronoberg



Climate change challenge

With respect to addressing climate change issues, an individuals' strength of belief in local effects of climate change and measures for adaptation are crucial for explaining whether and what adaptive measures are taken. Among Swedish private individual forest owners belief in local effects of climate change appears to be less strong than among Swedish citizens in general.





MOTIVE

Under changing climate, the growth of forests in Sweden is expected to in general increase significantly towards the end of this century unless biotic and abiotic damage increases. The growth of Norway spruce is expected to suffer from water stress especially in south-eastern Sweden on sites with low water-holding capacity.

Photo: Mikael Andersson.

Photo: Kristina Blennow.

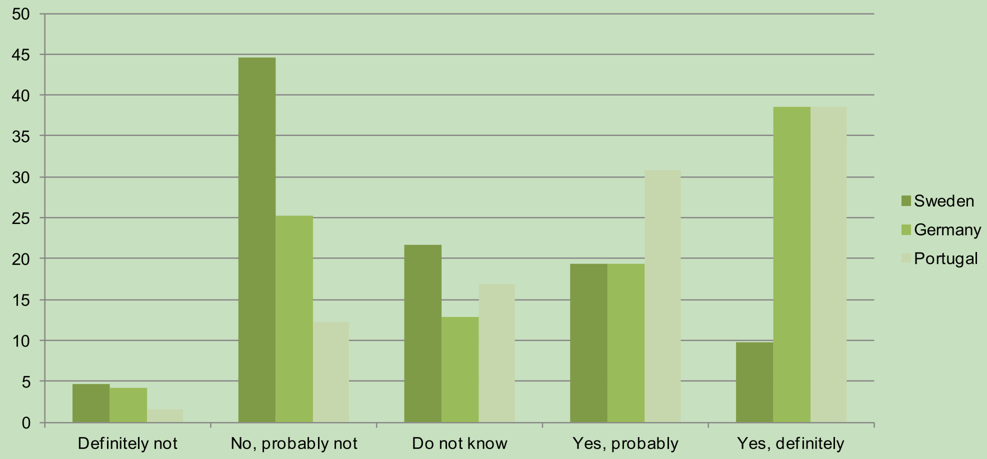
The susceptibility of the forest to wind is expected to increase under a warmer climate and maintained management regime. The future wind climate is uncertain, but it cannot be ruled out that the windiness will increase in which case the probability of wind damage will increase further.

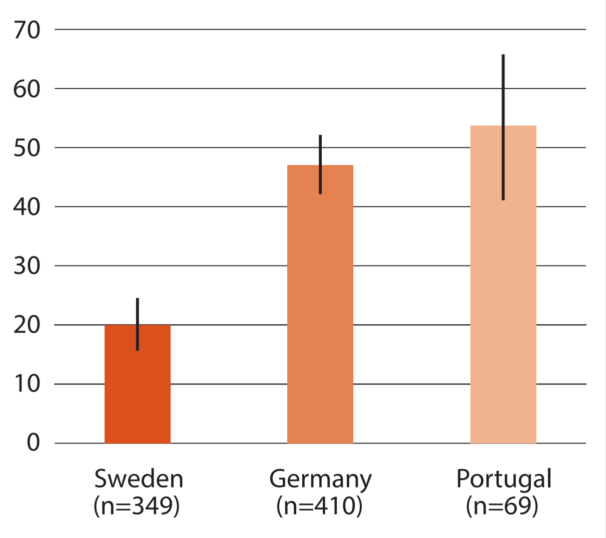
Photo: Martin Ahlström.

Climate change may result in shorter winters which would also make forests more susceptible to wind.

When forest owners believe in and see the effects of climate change, they are more likely to have taken adaptive measures. These two personal factors almost completely explain and predict forest owners´ adaptation to climate change.

Percentage of those surveyed who alleged strength of belief in having experienced climate change, per country. Source: Blennow et al. 2012. PLOS ONE 7/11 e50182





A lower proportion of forest owners in Sweden (Kronoberg County) stated that they had adapted their management practices in response to climate change compared to those surveyed in Germany (Black Forest) and Portugal (Chamusca). Bars denote 95% confidence intervals.

Source: Blennow et al. 2012. PLOS ONE 7/11 e50182

Conclusion

The probability of wind damage to forests can be decreased by spatial and temporal forest planning, the choice of tree species, adapted thinning regime, and reduced length of the rotation period. Communicating evidence of climate change and its effects is crucial to facilitate adaptation.

UK – North Wales case study

Case study forest area: Clocaenog 5,662 ha, Gwydyr 5,839 ha

Forest goods and services:
Sustainable production of timber, paper pulp, biomass for energy
Recreation
Habitat protection and connectivity
Water

Ownership: 100% public

Special local conditions:
Gwydyr and Clocaenog represent contrasting forest types in north Wales, Gwydyr being relatively low lying and sheltered while Clocaenog is more typical of an exposed upland site. Both forests were largely created in their current form, through planting over a relatively short period of time.

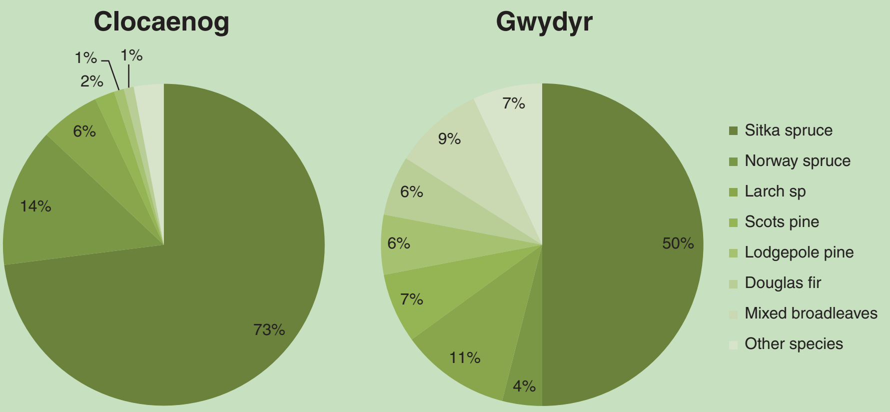
Stakeholders

Natural Resources Wales (formerly Forestry Commission Wales)

Management and governance issues

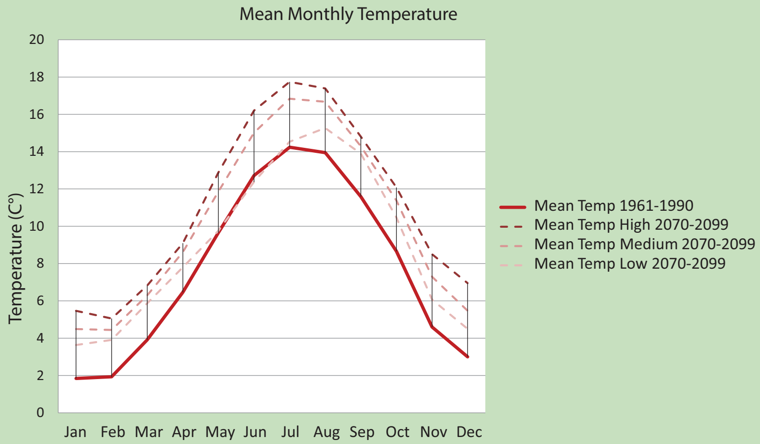
The forest is managed by Natural Resources Wales who practice sustainable forest management – balancing the needs of people and the environment, as well as generating income and providing jobs. It is following a policy of species diversification set out in a strategy document called 'Woodland for Wales'

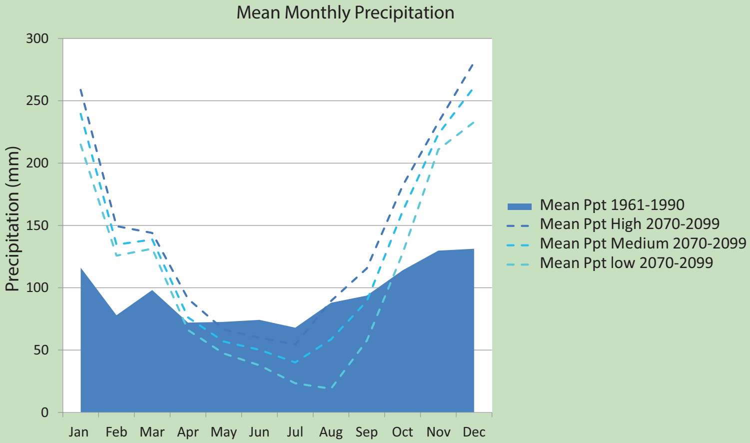
Proportion of species of Wales



Climate change challenge

Climate change is expected to affect the growth and survival of forest trees through increased mean annual temperature and rainfall, while increasing the risks from storms, summer drought, pests and diseases. Towards the end of century some variants of the A1B scenario indicate much drier conditions in the region. This would be expected to cause previously high yielding sites to be constrained by drought, so yield would drop.





Gwydyr forest

Clocaenog forest

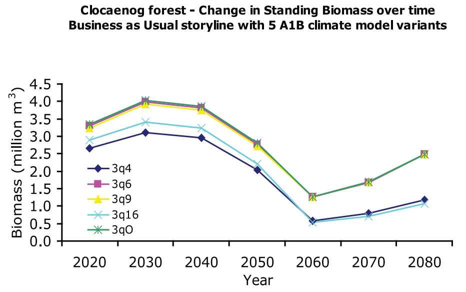
Photo: Crown Copyright
Forestry Commission.

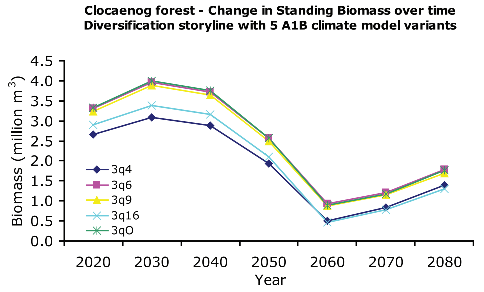
Differences between the two forests

Clocaenog forest has a relatively high elevation and is dominated by Sitka spruce plantations. These are mostly managed as clearfell – replant stands, but where possible they are being converted to continuous cover to provide some structural diversity. Gwydyr is largely more sheltered, has a much greater diversity of tree species in the baseline and has much greater potential for continuous cover.

Case study

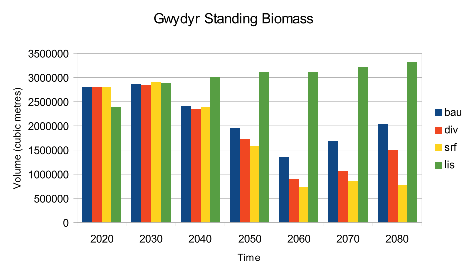
A suite of decision support tools and models were used to examine case study outcomes to 2080 based on differing management strategies: Business as Usual, Species Diversification, Short-rotation forestry and Low-impact silvicultural systems (LISS) that is essentially conversion to continuous cover. These were run with five variants of the HadRM3 A1B climate model.

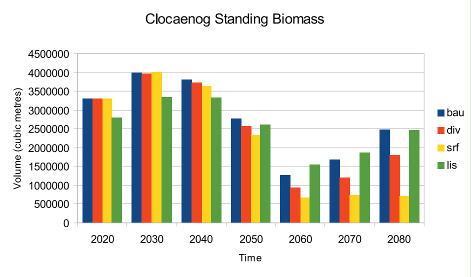




The Diversification storyline resulted in much closer trajectories between climate model variants than Business as Usual (see line chart). In this modelling exercise the age structure is evident through large peaks and troughs associated with the felling and restocking cycles in forests that have low structural diversity.

Gwydyr forest can largely be converted to LISS which would allow standing biomass to be maintained through the century. Clocaenog, in contrast, is less suitable for LISS due to its exposure, and the peaks and troughs will have to be managed in practice by adjusting rotation lengths.





Conclusion

Diversification as an adaptation strategy led to less uncertainty, with projected standing biomass for all variants being between the highest and lowest projections for Business as Usual. Therefore although BAU has a possibility of higher returns, it also has a possibility of much lower returns, and the safer strategy in Wales would be to select a Diversification strategy. Where there are opportunities for improving structural diversity through converting forests to continuous cover (LISS), there are benefits of maintaining a more even standing biomass over time.

Netherlands – Veluwe case study

Case study forest area: 8,246 ha

Ownership: 75% NGOs, 5% state, 20% private

Forest goods and services:
Main functions of the area nowadays are recreation, nature and landscape protection. Wood production is mostly a secondary goal, but the actual mix of goals depends on the owner.

Special local conditions:
Cultural history: 22% heath land and some open driftsands. Old broadleaved remnants. High grazing pressure, affecting tree regeneration. High recreational pressure.

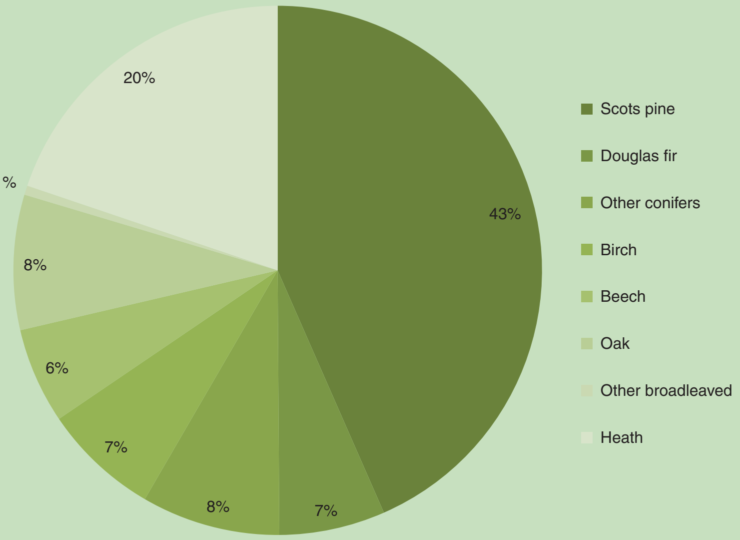
Stakeholders

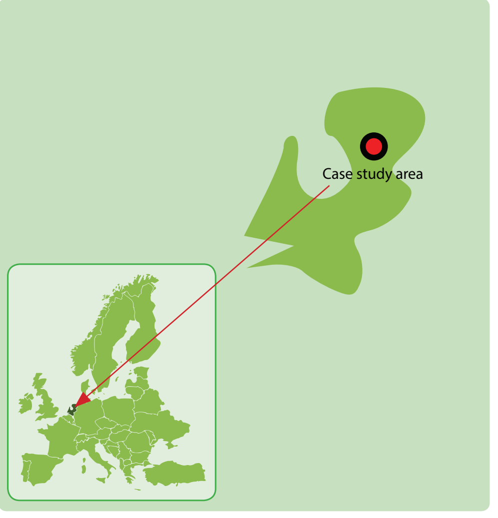
Forest owners/managers
Fire brigade
Recreational sector

Management and governance issues

Heath land, drift sand and old broadleaved forests are classified as Natura2000 core habitat areas and need to be maintained.

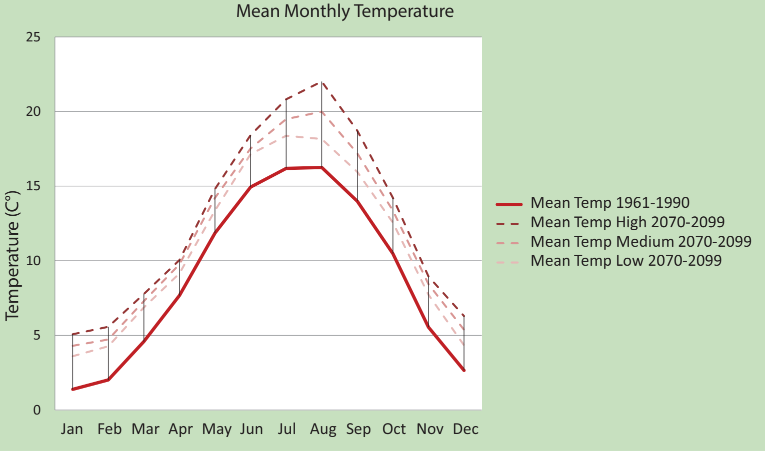
Proportion of species of Veluwe

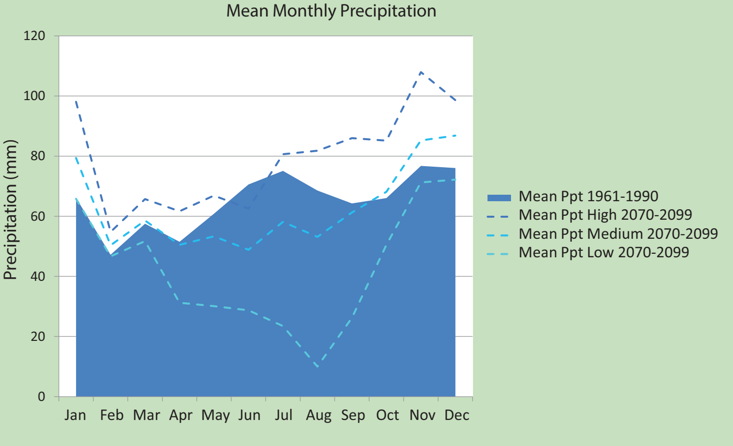




Climate change challenge

Moderate changes in climate are not expected to lead to major problems or changes in the area. Drier and hotter summers are expected to lead to a decline in oak and beech forests and increased dominance of coniferous species like Scots pine and Douglas fir.





Increased future fire risk due to more extreme fire weather and more conifers under climate change conditions?

Photo: Mathijs Schuijn.

Regeneration is affected by the high grazing pressure. Photo: Mart-Jan Schelhaas.

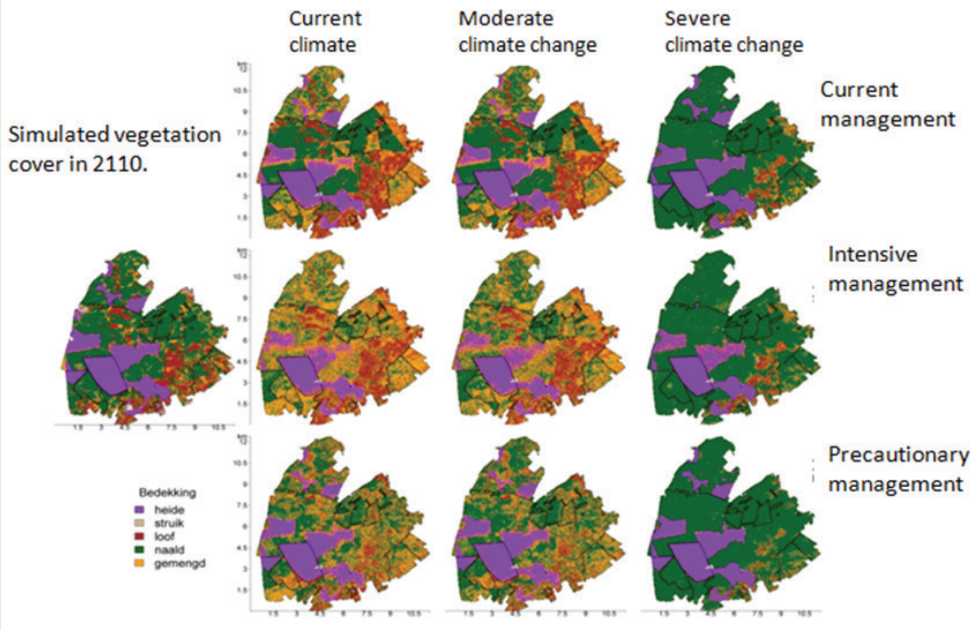
Photo: Mart-Jan Schelhaas.

Will these young beech trees survive under drier and warmer climate?

Current management and moderate climate change will lead to a more intimate mixture of tree species

Photo: Mart-Jan Schelhaas.

Current management is already well adapted to the sites and climatic conditions, and already takes into account natural developments. A mild climate change scenario can be easily dealt with in the current management schedules. More severe climate change leads to a loss of biodiversity due to replacement of oak and beech by more drought-tolerant species like Scots pine and Douglas fir. These developments will probably become visible in the medium term only. Adaptive management will not be sufficient to curb these developments.


Simulated vegetation cover in 2110.

Conclusion

Continuation of current management is the best option to maintain the current levels of service provisioning. However, the development of forest and climate should be monitored closely to be able to adapt the management if necessary. However, individual owners may decide differently for their own properties, based on different preferences.

Germany – Black Forest case study

Case study forest area: 1,400 ha

Forest goods and services:
Timber production, tourism, recreation, biodiversity.

Ownership: Community 60%, State 24%, Private 16%

Special local conditions: The promotion of Norway spruce at the expense of European beech and other deciduous tree species in the past resulted in large areas stocked with Norway spruce outside its potential natural distribution.

Stakeholders

Local state forest administration (County of Rastatt), Community forest administration (town of Baden Baden), State Forest – Baden-Wuerttemberg (ForstBW), Nature park agency, Nature protection organisations, Tourism, Private forest owners, Timber processing industry, Conservation NGOs.

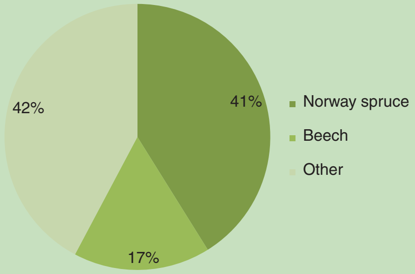
Management and governance issues

The city of Baden-Baden with a community forest area of 8,578 ha and a 61% share of the total forest area is the largest communal forest owner in Germany. The urban district of Baden-Baden therefore has a forest administration of its own.

The State Forest is run by ForstBW, the official State Forest Company of Baden-Wuerttemberg that manages around 350,000 ha of forest.

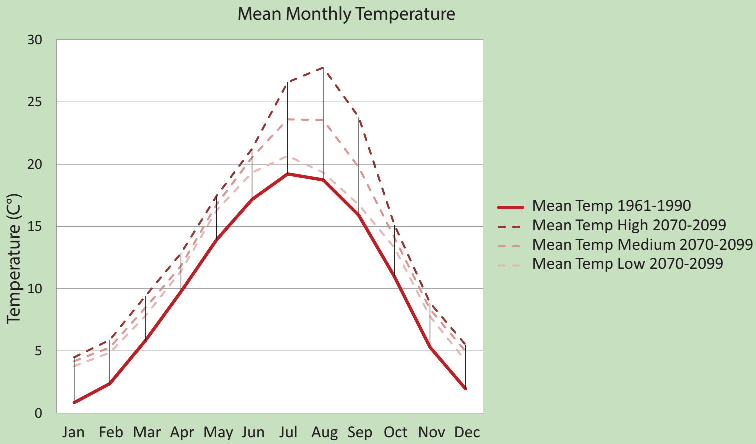
Private forests in the county of Rastatt cover an area of 6700 ha, from which 5450 ha are managed as a cooperative forest called “Murgschifferschaft”. This old German cooperative accrued from a forest owner cooperative dating back to the 15th century. The goal of the cooperative is to achieve the maximum sustainable yield of valuable timber and benefit. The financial surplus of the cooperative is distributed among the shareholders on a yearly basis.

Proportion of species of Baden Baden



Climate change challenge

Norway spruce stands are susceptible to increasing occurrence of drought and disturbances such as bark beetle attacks.



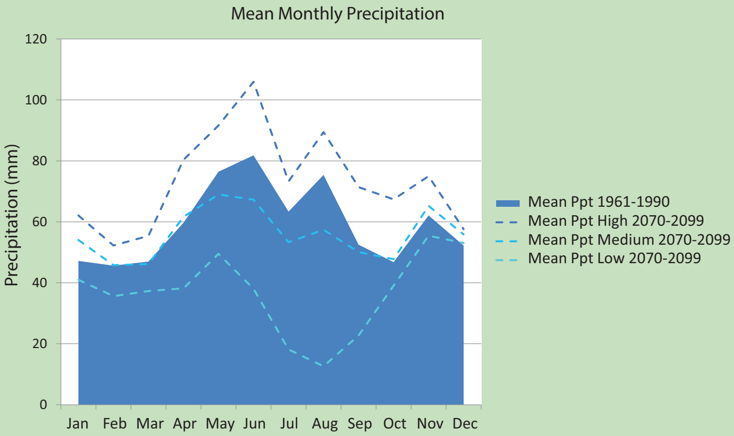


Photo: Thomas Nissen.

In the region climate change induced droughts threaten the forests directly and indirectly via insect calamities, especially Norway spruce plantations outside their natural distribution.

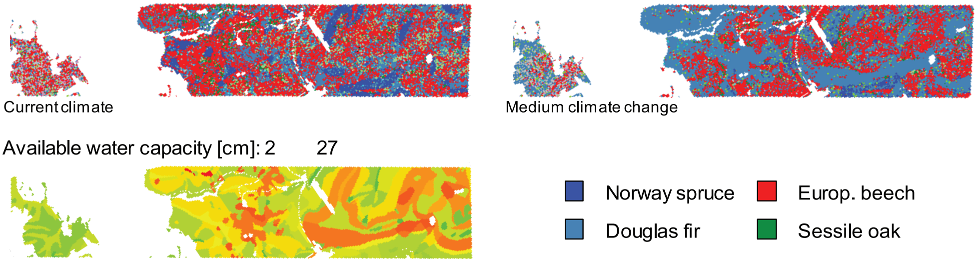
Photo: Thomas Nissen.

Photo: Thomas Nissen.

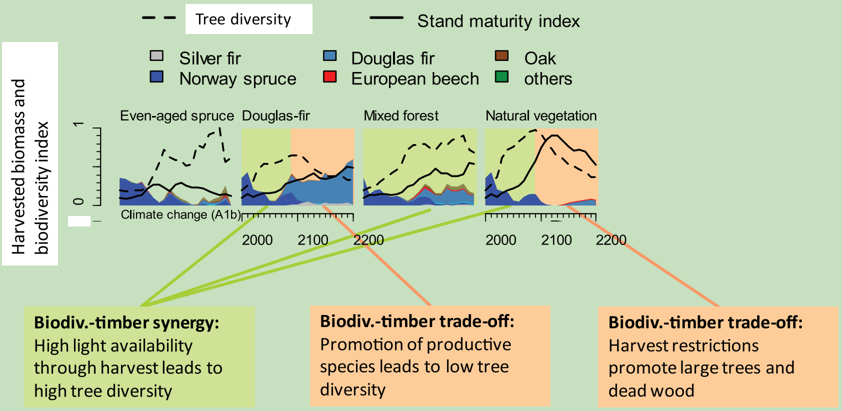
In addition to droughts and insect calamities, large-scale storm events like the hurricane "Lothar" in 1999 or local thunderstorms are the major disturbance regime in the region.

Simulation results confirm the long-term landscape trends of increasing Norway spruce mortality and dominance of more drought-adapted species (e.g. Douglas fir and beech). This underpins the need to convert low-elevation spruce forests to more drought-resilient forest types.

Species dominance after conversion to *Natural vegetation* (year 2100):



Under climate change, timber production in even-aged spruce forests cannot be maintained. Adaptive management needs to consider trade-offs. However, in the long term a joint promotion of forest diversity and timber production can be achieved by mixed forest management.



Biodiv.-timber synergy: High light availability through harvest leads to high tree diversity

Biodiv.-timber trade-off: Promotion of productive species leads to low tree diversity

Biodiv.-timber trade-off: Harvest restrictions promote large trees and dead wood

Modeled harvested biomass and biodiversity indices (tree diversity and stand maturity index) under business-as-usual (Even-aged spruce) and three uneven-aged adaptive management scenarios (Douglas fir, Mixed forest and Natural vegetation) and under climate change (A1B, HCCPR) for the mid-elevation sub-area of the Black Forest study landscape (500–1000 m a.s.l.).

Conclusion

Adaptive management is inevitable in order to maintain the provision of ecosystem goods and services under climate change. The species mixture has to be adapted to dry environmental conditions. Adaptive management does not necessarily impose a trade-off between resource use and conservation objectives. In contrast, 'win-win' situations accrue along some of the conversion pathways.

Austria – Montafon Valley case study

Case study forest area: 6470 ha

Forest goods and services:
Timber and fuel wood for local citizens, wood processing and biomass heating plants. Protection against avalanches, rock fall, landslides and erosion. Grazing, hunting, tourism.

Ownership: 100% public

Special local conditions: There is a long tradition of public land-use in the Montafon region. The inhabitants of the Montafon valleys have had the chartered right to use the non-private forests in their valleys as a source for timber and fuel wood since 1601.

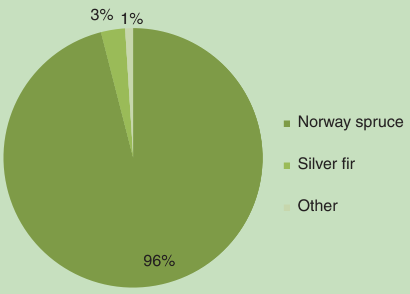
Stakeholders

Stand Montafon Forstfonds (owner), local citizens, hunters, local farmers, tourism, federal service for torrent and avalanche control, wood processing industry, hydropower companies.

Management and governance issues

Stand Montafon Forstfonds (SMF) is the largest forest owner in the Province of Vorarlberg. The management objective of the SMF is for the well-planned, sustainable and economic use of forest resources for all possible demands of society. Most notably this involves the protection of the (cultural) habitat Montafon (biological as well as social), the fulfilment of services and the sustainable production of timber.

Proportion of Species of Montafon

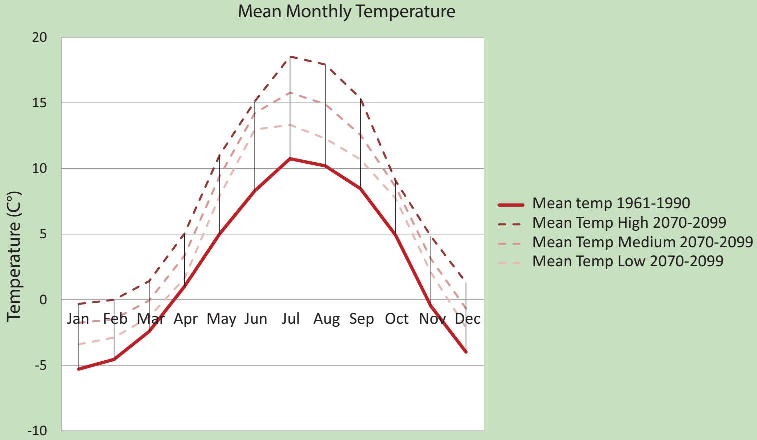



A limestone rock retained by beech trees.

Photo: Rupert Seidl.

Climate change challenge

Due to the high share of Norway spruce in the Montafon forests, timber production, as well as protection against gravitational hazards are likely to be negatively affected by an increase in disturbances, particularly from bark beetles.



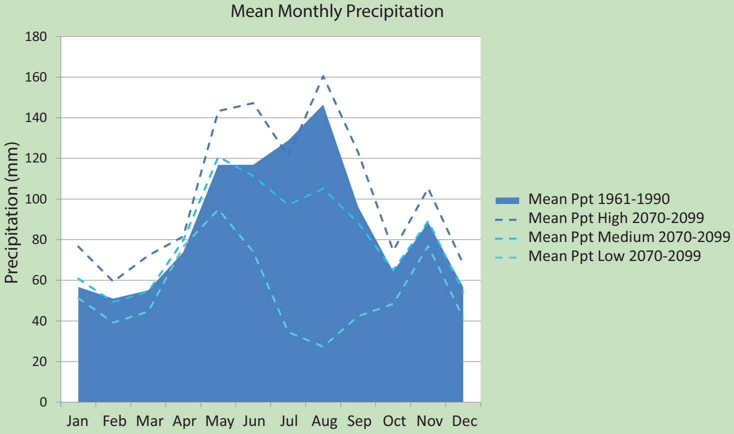


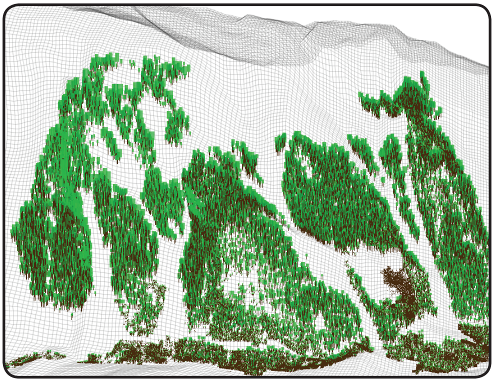
Photo:
Stand Montafon Forstfonds.

For Norway spruce the risk of bark beetle (*Ips typographus*) infestations will increase substantially due to better development conditions for poikilothermic insects. Especially during the second half of the 21st century a strong increase in bark beetle induced mortality can be expected for Norway spruce.

All tree species in the region will physiologically benefit from a warmer climate because water supply on most sites is not a limiting factor (current precipitation levels exceed 1100 mm/year and only minor changes are expected for the future). Tree growth and reproduction will be facilitated because of more favorable growing conditions and longer growing seasons.

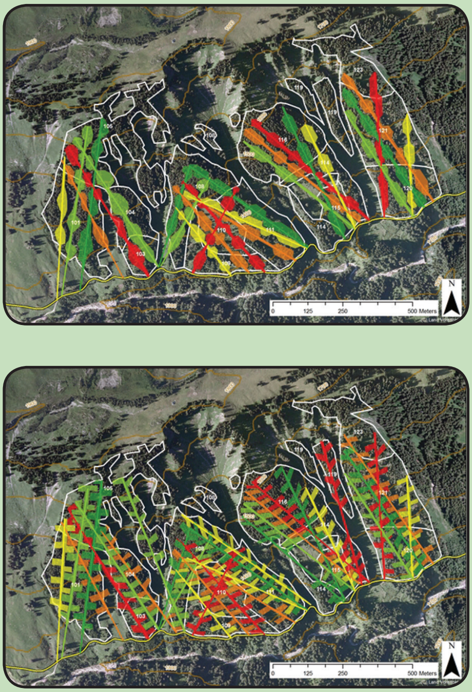
Due to the large proportion of Norway spruce in the Montafon region, timber production as well as protection against gravitational hazards are likely to be negatively affected by bark beetles. The need for salvage operations will increase in a warmer climate which will negatively affect the harvesting costs. However, due to a higher share of standing deadwood caused by bark beetles the habitat and biodiversity functions for different vertebrate (e.g. woodpeckers) and invertebrate (e.g. longicorn beetles) species are expected to improve.

Photo: Manfred J. Lexer



Visualization of 70 ha forest on a slope in the Rellstal Valley.

Continuation of current management results in increasing timber stocks, which increases susceptibility to bark beetle infestations and may also increase damage levels. Clumped tree mortality will negatively affect protective functionalities. As an adaptive measure it is recommended to increase the annual cuttings by increasing the number of skyline tracks and modifying the cutting pattern. To keep gaps in slope direction small, a horizontal slit cut approach is recommended. Furthermore other species than Norway spruce should be facilitated and game management intensified to reduce browsing.



On the left: Slit cuts as performed under current management for a forest compartment of ca. 70 ha (stands in white, forest road in yellow). The colors of the slit cuts indicate 20 year periods from green to red (2010 to 2110). This approach results in a virtual rotation period of 250 years. On the right: Fishbone shaped slit cuts as proposed as an adaptation measure for the same period and area. This approach results in a faster turnover of tree generations by 20%, reducing susceptibilities to bark beetle damages and improving protective functionalities.

Conclusion

In order to sustain the long-term provision of demanded ecosystem services under a changing climate it is recommended to combine adaptation measures (species composition, spatial structure of silvicultural measures, management intensity and game management).

Chapter VII: How fast can European forests adapt to a changing climate?

Geerten Hengeveld, Mart-Jan Schelhaas, Christopher Reyer, Niklaus E. Zimmermann, Dominik A Cullmann and Gert-Jan Nabuurs

The large diversity in abiotic and biotic circumstances in European forests makes it extremely difficult to predict what the impacts of climate change will be on the various tree species, and ecosystems at the various localities. This makes it even more difficult to analyse how forest management should adapt in order to take the changing circumstances into account at the right time and at the right pace. The case studies in MOTIVE provide a basis for upscaling to the European scale. For the first time we combine here species changes as predicted by a climate envelope model, with an incorporation of forest management responses in an empirical European forest resource model (EFISCEN).

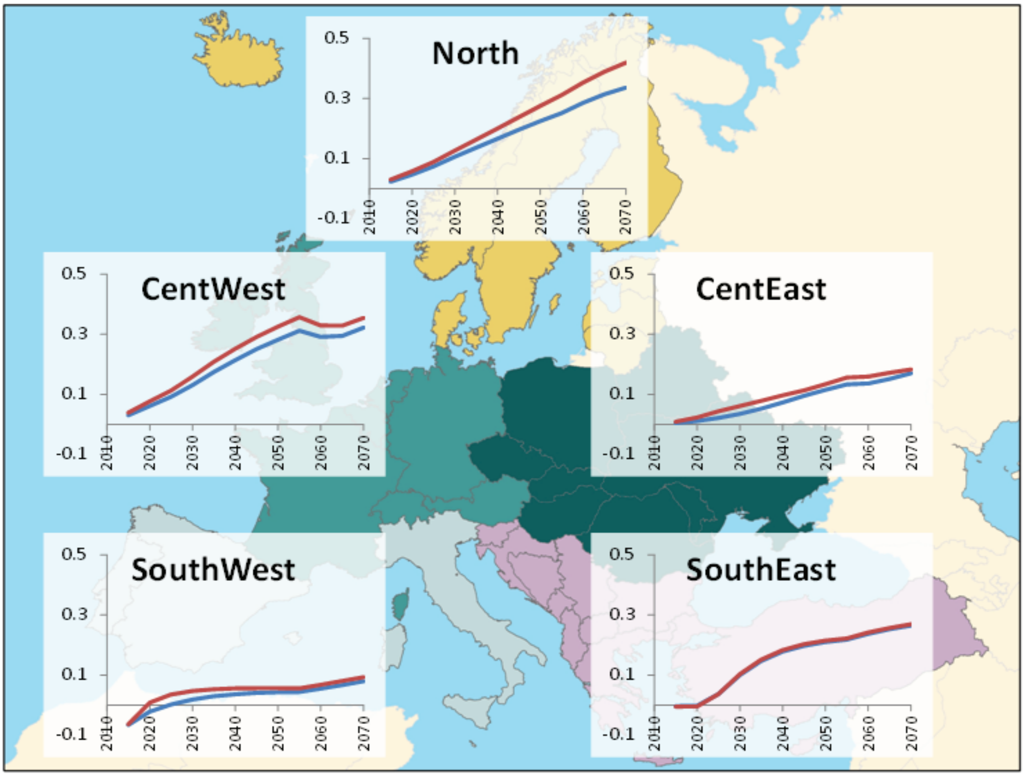


Figure 1. Realised area change for species with decreasing suitability as compared to Hanewinkel et al. 2013 maps (ie 0.5 means that 50% of the proposed area change by Hanewinkel has been realised.) blue is BAU management, red is adaptive management.

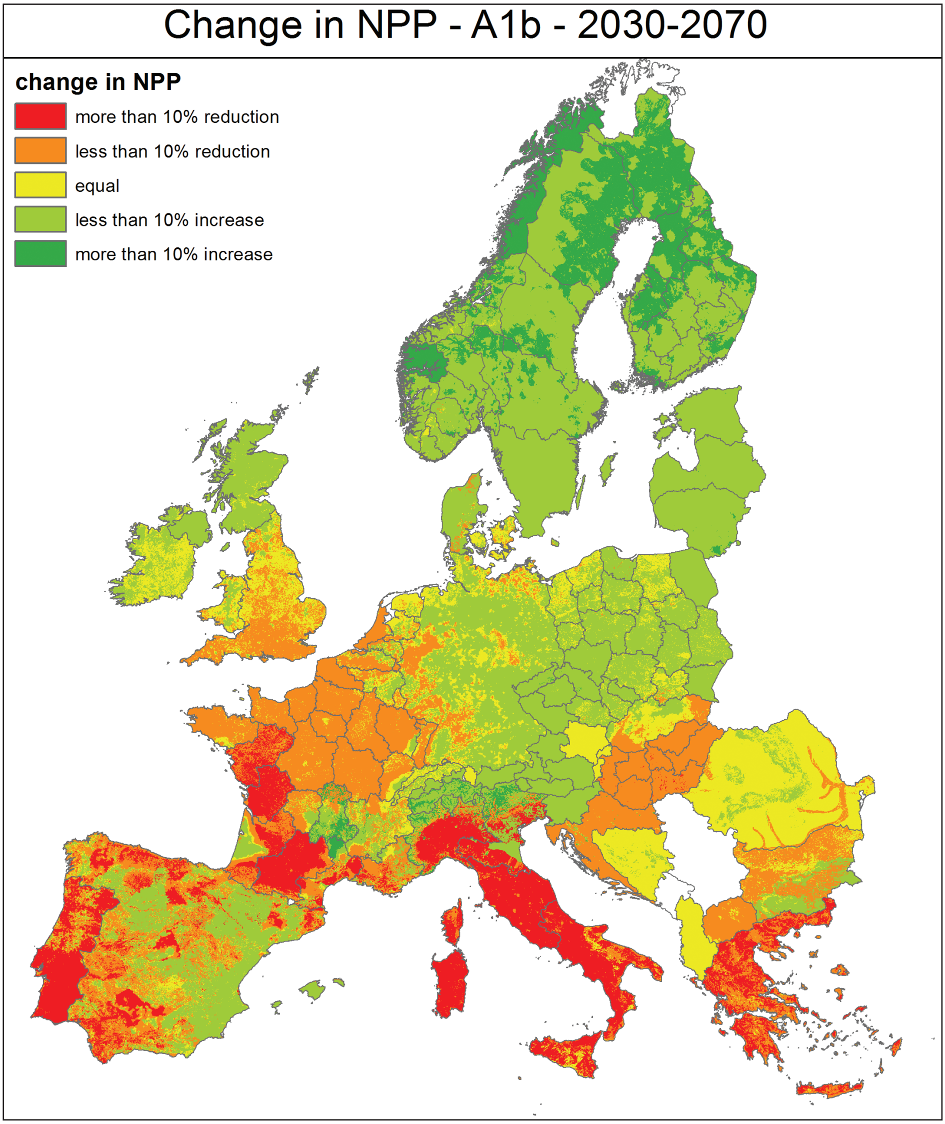


Figure 2. Expected average change in NPP in the period 2030–2070 per km2, derived from Reyer et al. (2012).

This combination allows at the European scale to estimate how fast forest resources will change, under the assumption that existing trees on a site are plastic enough to survive the climate changes until the end of their normal rotation. It is assumed that only then a forest owner will decide to change tree species at that site towards one that is more preferred according to the climate envelope model. The owner will do this through shortening the rotation by approximately 10 years for susceptible species in order to speed up conversion towards more preferred species. This gives insight into fulfilment of raw material supply, forest resources, tree species, and increment under this adaptive management.

The results indicate that tree species composition will change only slowly at the European scale. By 2070, 10% of the total forest area will have changed species if species change at rotation end follows the climate envelope models. This can be increased to 12% by adaptive management, anticipating expected species shifts. This is respectively 20% and 23% of the area change that is indicated by the envelope models. Large differences occur in Europe, with Northern Europe and Central Western Europe showing a higher rate of adaptation and especially South Western Europe a slower rate.

Overall, growth increment increases under climate change as compared to current climate giving rise to positive production effects especially in Northern Europe. However, climate change effects are negative in South Western Europe. Adaptive management slightly reduces increment as compared to current management under climate change due to a higher share of temporarily slower growing forest (forest under regeneration). Raw material supply is not affected by climate change or adaptive management in this modelling study.

Chapter VIII: Climate change and practical forest management - when to worry and when not?

Jette Bredahl Jacobsen, Rasoul Yousefpour and Bo Jellesmark Thorsen

Across Europe climate change is expected to have quite different impacts on forest ecosystems varying with e.g. latitude, altitude, local ecological conditions and forest management practises. However, just how large and how severe the changes will be is subject to considerable uncertainty. Therefore a crucial question is when to adjust to such long-term expected changes. Should adjustment be made now in anticipation of change but with great uncertainty about changes and impacts, or made only when changes and their impacts are observed and understood better, or should they be made gradually as we see the impact on forests? To what extent is it relevant and possible to go for strategies that try to optimize expected outcomes and make the most of forthcoming changes? When might it be equally relevant to pursue strategies that focus on reducing, as far as possible, the potential losses, and hence maximize the outcome in the worst case?

This chapter discusses these issues using two stylised approaches to handling the uncertainty forest managers face. These approaches we call the reactive approach and the proactive approach. We discuss when the benefits and importance of encouraging a proactive decision making approach among forest owners is particularly large, and when a more reactive management approach might be favourable or at least justified.

The reactive management approach

The reactive manager can be described as a decision maker who awaits and observes the actual outcomes and impacts of climate change as it develops, and adjusts management gradually to observed effects only. This decision making approach does not include forecasting or forming expectations about the likelihood of different climate change developments, nor their potential future impacts on forest ecosystems. A decision maker using this approach does not adjust current decisions to the possible implications indicated by such forecasts or expectations.

The results of forest owner surveys undertaken in MOTIVE indicate that while many forest owners do consider climate change a factor in their decision making, others are less explicit about this. Decision making approaches like this may be quite widespread among forest managers. If uncertainty about direction and/or impact of climate change is very large, the decision maker has little basis for firm expectations, and it may be a relevant approach if not the most favourable one. It may also be a relevant approach to follow if the expected changes are small, or if they are of gradual form. This could be where changes mainly affect growth or other ecosystem aspects in a way where management schemes like thinning or regeneration decisions can be adjusted smoothly and gradually fitted to the changed forest state.

Among the MOTIVE case studies, we do find specific cases, where such an approach is at least close to optimal. The Boreal case in North Karelia, eastern Finland, is an example of that. They analysed management schemes for mixed stands of Norway spruce, Scots pine and birch, and found that with respect to handling the uncertain growth development under climate change, reactive (anticipatory) approaches are not truly different from a proactive (adaptive) management approach. The reason is that in this specific case, climate change is not likely to drastically impact the health or stability of the ecosystem, but rather it gradually changes the absolute and relative performances of the species. Forest management, however, can capture and react adequately to most of this in a reactive manner. They also find, as is a standard result, that the proactive approach is much more important when it comes to handling price uncertainty.

There may be situations, also in the Boreal areas, where forest managers and society may benefit significantly more from talking a proactive approach. An example of this could be where the choice of tree species to favour regeneration would be better based on expectations than past observations. Or there may be cases, where climate change induced increases in hazard risks may call for early action to avoid losses.

The proactive management approach

The proactive management approach is in the literature also referred to as the fully adaptive management approach. As opposed to the former, the decision maker applying this approach does not only observe the development of the current climate and the state of the forest ecosystems; (s)he also assess likely developments and impacts of climate change using numerous sources of information and observations. The decision maker bases current decisions as much on observed status of the forest as on expectations of future climate change impacts and implications for forest management. If the proactive manager makes good forecasts and forms well-founded expectations, (s)he should perform at least as well as the reactive manager. However, searching for and assessing information is costly and expectations and forecasts may be imprecise, ill-founded or biased, and it is in some situations not obvious that much is gained from such an approach. In other cases, it is more obviously a clear advantage.

In MOTIVE a decision model for even-aged beech stand in Switzerland was developed, assessing the optimal management scheme for a number of site conditions for given future climate developments (Trasobares et al., 2013). However, there is uncertainty with respect to which scenario is the more realistic, so management was optimised (thinning and timing of clear-felling) for 4 different climate change scenarios at various locations. The financial results, in terms of Land Expectation Values (LEV), from a site with good current

Table 1. Land expectation values for beech in Switzerland on good soil conditions, depending on which climate scenario is realized and which climate scenario management is optimized for. For details of the model, see Trasobares et al. (2013).

LEV2 (CHF/ha) WP (m^3/ha*y)	MANAGEMENT OPTIMIZED FOR:				
REALIZED CLIMATE	CURRENT	A1B_MPI	A1B_HADLEY	A1B_RCA-ECHAM5	RISK %
CURRENT	**LEV2 = 3023.4**	LEV2 = 2880.8	LEV2 = 2927.8	LEV2 = 2880.9	4.7 (142.2)
A1B_MPI	LEV2 = 4255.5	**LEV2 = 4330.2**	LEV2 = 4139.8	LEV2 = 4312.3	4.4 (190.4)
A1B_HADLEY	LEV2 = 1864.8	LEV2 = 1811.8	**LEV2 = 1969.2**	LEV2 = 1803.1	8.4 (166.1)
A1B_RCA_ECHAM	LEV2 = 3945.9	LEV2 = 3998.2	LEV2 = 3824.5	**LEV2 = 4001.4**	4.4 (176.9)
Average	3272.4	3255.1	3215.3	3249.4	ryerey

growth conditions are shown in Table 1. The diagonal shows the return from the optimal management for the four different climate scenarios. As is seen, two scenarios (A1B_MP1 and A1B_RCA_ECHAM5) will result in an improved return whereas the opposite is true for the more extreme scenario predicted by the AqB_Hadley climate change model. Proactive managers may consider these different scenario optimal strategies and base their decision on their beliefs or expectations about the probability of different scenarios becoming true.

It may be relevant to consider what the consequences are on forest revenue in case we optimize for one climate development, but another is realised. These returns are given by the off diagonal results. As can be seen the losses are up to 8% in case we believe the A1B_MPI climate change scenario to be the one realized and optimize management for that, but it turns out that A1B_Hadley is realised instead. A minimax strategy would therefore suggest that we choose the management optimized for A1B_Hadley , as it has the largest minimum outcome. Optimising the expected return across climate change scenarios requires some beliefs or probabilities of each scenario. If we assume that they are equally likely, i.e. we believe 25% in each, then picking the management strategy optimised for the current climate gives the highest average result (bottom row), though it is only slightly higher than the best alternative. Other locations in Switzerland show other results; in general the poorer the soil, the more severe the consequences of choosing the wrong management strategy.

The results show that the proactive decision approach takes more information into account and the decision maker may gain from this. The specific analyses of Trasobares et al (2013) also demonstrate that while climate change may both bring gains and losses, and while both may be of significant sizes at least in relative terms, the potential losses are not necessarily catastrophic for the current tree generations, even if long term consequences may perhaps be more significant (Hanewinkel et al 2012).

Only a few cases in MOTIVE have considered the issue of tree species choice, which is one of the most far-reaching decisions in forestry where proactive assessment of the potential long term impacts may play the largest role. In one such MOTIVE application (Schou et

Table 2. Simulated land expectation values (LEV) [€/ha] for given climate change outcomes for a new forest stand. The expected LEV are estimated under equal subjective probabilities (beliefs) about which scenario is true. The "before ("after") values are maximized values before (after) uncertainty about climate development is resolved.

	Climate change outcome			Expected LEV	
Species	Worst	No-change	Best	Before	After
Norway spruce	-17882	807	7540	-3178	2993
Oak	632	632	632	632	

al., 2012), we analysed the case of a forest manager in Denmark who needs to decide when to harvest an existing, maturing Norway spruce stand and whether to reforest using Norway spruce or oak. Oak is projected to be fairly insensitive to climate change in this region and a likely future main species, whereas this is not so for Norway spruce (Hanewinkel, 2012). At current growth conditions Norway spruce economically outperforms oak on most sites, even with mediocre performance. With climate change, increased risks of windthrows, drought-related bark beetle pests and the like may reduce the profitability of Norway spruce, but economic sensitivity analyses reveal that quite a bit of negative impact is needed to reduce the expected economic performance below that of oak.

We investigated the effects on the forest owner's decision when (s)he faces possible climate change, simplified into three scenarios among which oak is only truly superior to Norway spruce in one, and when (s)he may be uncertain as to which of these scenarios come true for still either 10, 20 or 30 years. Under a proactive decision approach, forthcoming information implies a value of waiting, as can be seen in Table 2 where the expected LEV of making the best decision *after* the climate change development is evident (€ 2,993) is higher than the expected value of making the best decision *before*. If we can wait establishing the new stand until we are fairly certain, we may rule out the worst alternative, thereby increasing the expected value. However, if the worst of the modeled climate scenarios does not come true, then it will still be favourable on this location to establish Norway spruce also in the next rotation.

However, waiting has a cost in terms of delaying the harvest of the existing stand. The decision maker needs to trade off this cost against the positive impact of waiting for information evident on the expected value of the new stand. The further into the future the decision maker thinks information will be available, the more costly is waiting, and the more likely (s)he will base her decision on her/his *ex ante* expectations. Table 3 illustrates the decisions made for different ages of the Norway spruce stand and time periods until the climate change uncertainty is resolved, when (s)he currently find all scenarios equally likely and is risk neutral. As can be seen, with more than 20 years of continued uncertainty, the decision maker will for all ages above 50 harvest now and reforest with oak. When uncertainty is resolved in 10 years the decision maker can postpone harvesting of the 60 year old stands, and wait for certainty.

Table 3. The optimal harvest decisions for the proactive decision maker, when (s)he finds all three scenarios equally likely ex ante, across the Norway spruce current stand age and for the three different periods before climate development is known.

	50 years	60 years	70 years	80 years
Certainty in 10 years	Delay harvest	Delay harvest	Harvest now	Harvest now
Certainty in 20 years	Delay harvest	Harvest now	Harvest now	Harvest now
Certainty in 30 years	Delay harvest	Harvest now	Harvest now	Harvest now

Again this case illustrates that proactive decision making and optimal delaying of decisions may outperform other decision approaches. However, the case also shows that if uncertainty is expected to prevail for longer periods, the decision maker may in any case resolve to making decisions based on *ex ante* lack of information.

The forest owner's decision and society's

In many of the cases analysed in MOTIVE, the forest owners may consider the economic consequences of climate change on the current forests health and production likely to be not too severe for the nearest decades. For that reason (s)he may be less likely to engage in dramatic adaptation measures in forest management, and is more likely to resort to reactive decision approaches. However, from a welfare economic perspective, that is society's point of view; the potential consequences of climate change may be more severe, the reason being that the long-term provision of many ecosystem services like biodiversity conservation, recreational uses, and erosion protection may be more sensitive to climate change. An obvious case is the increased risks of forest fires in Southern Europe, which calls for adaptive management measures that may not be preferable for the individual owners. This potential discrepancy between what adaptive forest management may be optimal for society and what may be optimal for the forest owner should be addressed, It may be wise for society to coordinate the collection of better information on likely impacts and to disseminate and advise forest owners on adaptive measures, or to design policy instruments and regulation measures that create incentives for forest managers to align decisions and management with society's objectives.

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Chapter IX: A decision support system for forest management planning under climate change

José G.Borges, Jordi Garcia-Gonzalo, Juan Guerra-Hernandez, Susete Marques and João Palma

Introduction

Climate change may substantially impact the forest sector around Europe, therefore, forest managers need new tools that aid the efficiency and effectiveness of forest management under changing environmental conditions. Namely, they need decision support systems (DSS) incorporating growth and yield models that are sensitive to environmental changes. A decision support system is a computer-based information system which supports decision making activities. In forest management, a DSS can allow a forest practitioner to evaluate the future consequences of various management decisions. In this chapter, we look at an example of a DSS applied to a eucalypt forest in Portugal.

In the Mediterranean area, several studies point to the warming of winters and to the increase of both the length of the dry season and the frequency of extreme events like forest fires. This will impact growth and survival of plants as well as their geographical distribution and the composition of plant communities. Eucalypt is the most important forest species in Portugal, extending over 812 000 ha corresponding to 26% of the forest territory (according the last national forest inventory). It is the main source of raw material used by the pulp and paper industry, a leading Portuguese export driven industry

In Chamusca, (Central, Portugal), the eucalypt test forest extends over 6138 ha. Chamusca is a rural county 120 km away from Lisbon. The forest landscape was classified into 1722 stands with areas ranging from 4.8 to 18 ha. The current distribution of stand area by age class is very even, with ages ranging from 0 to 16.5 years, and an average age of 8 years. In this case study, a typical eucalyptus rotation may include up to 2 or 3 coppice cuts, each coppice cut being followed by a stool thinning that may leave an average number of shoots per stool ranging from 1 to 2. Harvest ages ranged from 9 to 14 with a 1-year interval. Initial density was 1400 trees per ha.

The Decision Support System

In order to analyse how the forest management should be adapted under changing climatic conditions we developed a DSS (SADfLOR v ecc 1.0). This DSS integrates four independent and compatible modules, encapsulated in one single graphical interface. The four modules are: i) a management information system to store all relevant information about the target forest (e.g. inventory), ii) a prescription generator module including growth and yield functions (GLOB3PG process-based model) iii). a decision module to assemble these alternative prescriptions into a consistent mathematical model which is solved, iv) a reporting module which allows viewing and reporting the results generated by the decision module.

The DSS helps develop an easy formulation of the problem (Figure 1). It provides information to the user in order to develop and adapt forest management plans. The main steps to use in order to evaluate forest management plans under changing climatic conditions are:

1. Selection of study area and inventory data.
2. Selection of the climate change scenarios.
3. Generation of management alternatives.

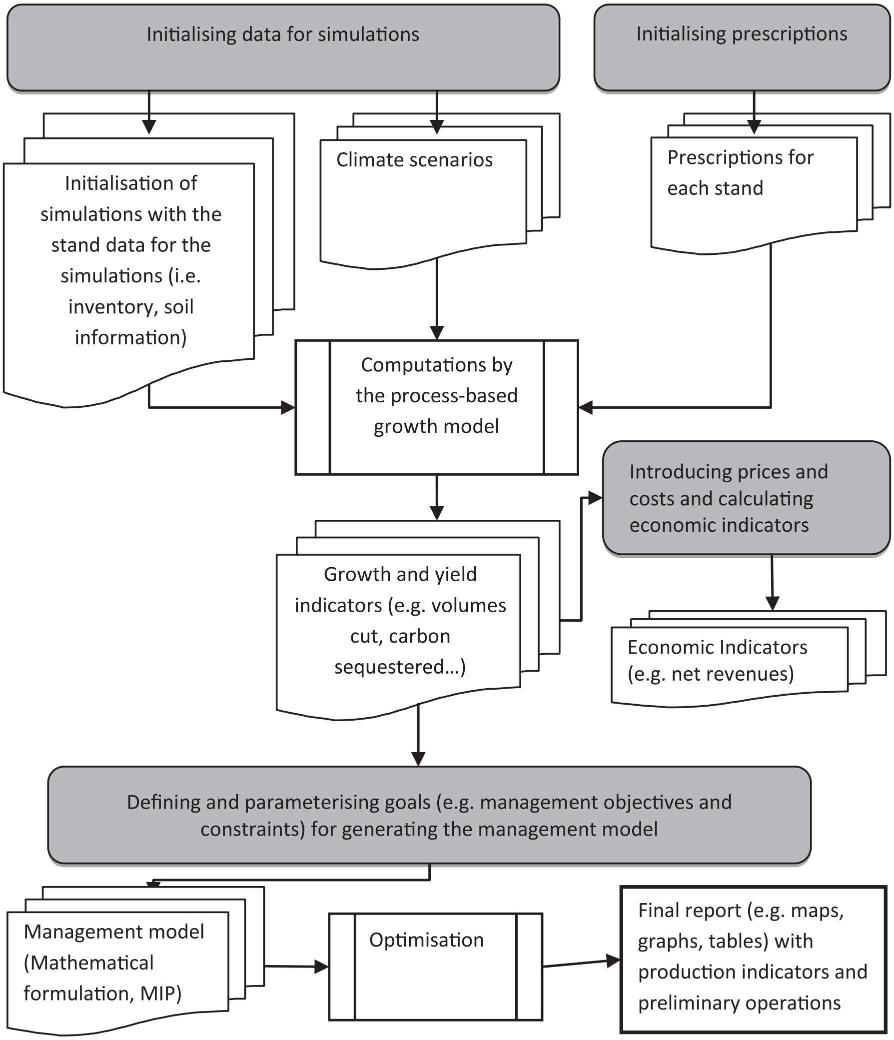

Figure 1. Scheme of the simulation-optimization process.

4. Simulating all management alternatives in all the stands of the forest over the planning horizon (i.e. 30 years).
5. Introducing prices and costs of operations and calculating revenues.
6. Optimizing forest management.
7. Finally, the report with the strategic management plans is produced. The report includes information in tables, maps, word documents.

Some results

The proposed approach was first used to assess the climate change effect on the potential eucalypt pulpwood yield and carbon stock in the whole study area over a 30 year time horizon. Results under "current climate" showed that the maximum eucalypt pulpwood yield would be around 2.35 million m^3 with a corresponding value of 81.13 million € and total carbon stock was 228.3 Mg C. Under the "climate change" scenario the timber production was reduced to 2.19 million m^3, the corresponding forest value was reduced to 74.7 M € and carbon stocks decreased to 212.7 Mg C.

The DSS was further used to check what would happen if the optimal management plans developed for current climate were implemented under climate change conditions. If the forest management plans designed for current climate conditions are not adapted to climate change, the pulpwood yield would be slightly reduced but the harvests in consecutive years would be very uneven.

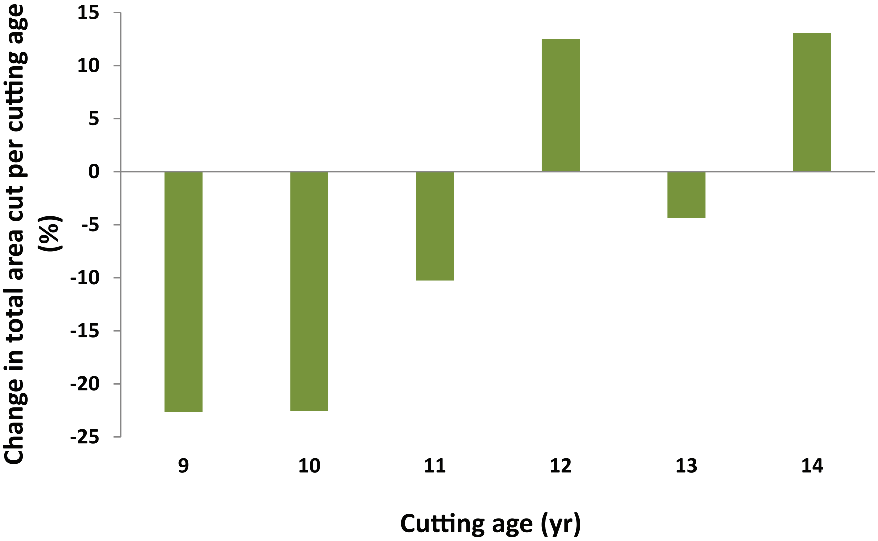

Figure 2. Percentage of change in the total harvested area (%) per age class associated with the constrained solutions i.e. maximization of forest value (Max FV) under 15% even flow constraints for the optimal solution under the climate change scenario assumed here (CC) compared to the solution found for current climate conditions.

If the total area cut at different ages is accounted for, results show that under climate change conditions a delay in the optimal year of cuttings is observed. For example, when switching from current climate scenario to the climate change scenario, the area cut when the stands are 9 to 11 years old is reduced by up to 20%, while the area cut when the stands are 12 and 14 years old increases by 12 and 13% (Figure 2). This clearly shows a delay in the harvest ages at landscape level.

Conclusions

Climate changes may substantially impact the forest adding uncertainty to future forest productivity. For this reason forest managers need new tools that may increase the efficiency and the effectiveness of forest management under changing environmental conditions.

The DSS presented here allows the analysis of the impacts of climate change on managed forests. According to the results, the changing environmental conditions will impact forest growth and forest production decisions. In this context, the DSS developed may help forest owners to prepare management plans under uncertain future conditions.

Chapter X: A web-based ToolBox approach to support adaptive forest management under climate change

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Introduction

The identification and design, selection and implementation of adaptive measures in forest management requires a sound knowledge base as well as tools to support the forest manager. Decision support systems (DSS) are considered as particularly useful for unstructured, ill- and semi-structured decision making problems. Thanks to the recent huge advances in information technology, DSS are nowadays usually computer-based tools that help decision makers through direct interaction with data and analysis models. They are, however, usually built for a specific context and specific decision making procedures, making a broader adoption of DSS into practice difficult.

A typical setting in forest resource management combines one responsible decision maker and a heterogeneous group of stakeholders having a diversity of partly contrasting interests and expectations towards forest management and who are usually not involved formally in decision making processes about forest management. Forest resource planning and decision making deals with highly complex socio-ecological systems with multiple interacting spatial and temporal dimensions. Finding ways and means to communicate findings about forest ecosystems and their management via information technology is a challenge in itself. This is amplified if decision problems include land use and climate change issues as inherent uncertainty in planning outcomes increases.

Therefore it is likely that a highly pre-determined decision making process (i.e. the decision model) will not be accepted in this area. Moreover, beyond the different procedural approaches to decision making, it is obvious that a single decision support tool will not be sufficient to cover all needs of any kind of decision makers and stakeholders. However, considering that context specificity and flexibility is a key requirement for acceptance of decision support tools by end users calls for a tool box approach where a diverse set of tools is made available to potential users. A tool box approach was also found to be more suitable for addressing different user and problem types simultaneously.

In the context of the MOTIVE project we set out to design and implement a decision support tool box for adaptive forest management which is based on a thorough analysis of contemporary DSS development activities. The objectives of this contribution are to introduce the conceptual frame of the MOTIVE ToolBox decision support system, and to outline the technical implementation of the ToolBox.

Conceptual frame for DSS development

The concept of the AFM ToolBox

Based on prior experiences with the development of DSS a number of principles were derived for the design of the MOTIVE AFM ToolBox.

(i) **Modularity**. The metaphor of a "tool box" hints already at modularity: it should be easy to add new tools (also from third parties) or to exchange existing tools. Similarly, tools should be able to share common elements (e.g., administrative functionalities such as user management, data import and export, saving DSS sessions, printing).

(ii) **Internet**. Recent technological advances allow the development of web-based decision support tools. Improved internet browsers can run complex web applications which can be accessed with increasing ease due to the widespread availability of broadband internet connections. Specific advantages of a web-based approach are the reduced access barrier (no downloads and installations required) and the adequacy for decision support in a group setting.

(iii) **Different types of knowledge and information**. The ToolBox should support both interactive, data driven tools and "softer" types of information such as demonstration examples and FAQs. The data for the interactive tools are produced externally using various types of models (e.g., forest ecosystem models, optimization tools).

(iv) **Different data sources**. The AFM ToolBox offers easy try-out of tools with ready-to-use data from the MOTIVE case study regions. Ultimately, the usefulness of available tools can be efficiently evaluated with data that represent the intended application domain. Users who find a tool useful for their problem domain can then invest in preparing own customized data for use with AFM ToolBox tools.

(v) **Problem types.** The AFM ToolBox in its current version is designed for (a) the comparative analysis of management alternatives at stand or landscape level with regard to portfolios of ecosystem services which may comprise timber production, carbon sequestration, and nature conservation and biodiversity under current climate and climate change scenarios, (b) the generation of optimized management plans at landscape level. Assessment entities are either stands or a collection of stands (i.e. landscape). The time frame extends up to 100 years. The temporal resolution of the ecosystem service indicators depends on the forest model used.

ToolBox components

ToolBox overview and data flow

The implementation of the AFM ToolBox consists of a "ToolBox Framework" acting as the "shell" for the data driven tools and the ToolBox website with the knowledge base (see Figure 1). The input data for the tools are stored in the ToolBox database.

External forest models are required to simulate forest development in response to management and climate scenarios and to provide performance indicators of different alternatives either directly as model output, via linker functions establishing a relationship between model output and a suitable ecosystem service indicator, or to feed other specialized models of ecosystem services with forest structure and composition. Such raw data are transferred to the database by a special tool, the AFM ToolBox client (see Figure 1). The client is highly customizable and has the ability to handle the outputs of a diverse set of forest models (e.g., LandClim or PICUS).

ToolBox database

The data format of the AFM ToolBox database contains two types of data: on the one hand, it stores the indicators describing the development of the simulated forest stands. The time resolution is annual or lower (e.g., 10 year periods), and the data is on stand and/ or species level (see Table 1). On the other hand, it includes metadata providing context information to the numerical simulation data (see Table 1). As an example, the "site type" is defined using seven attributes (soil type, soil texture, water influence, stoniness, water holding

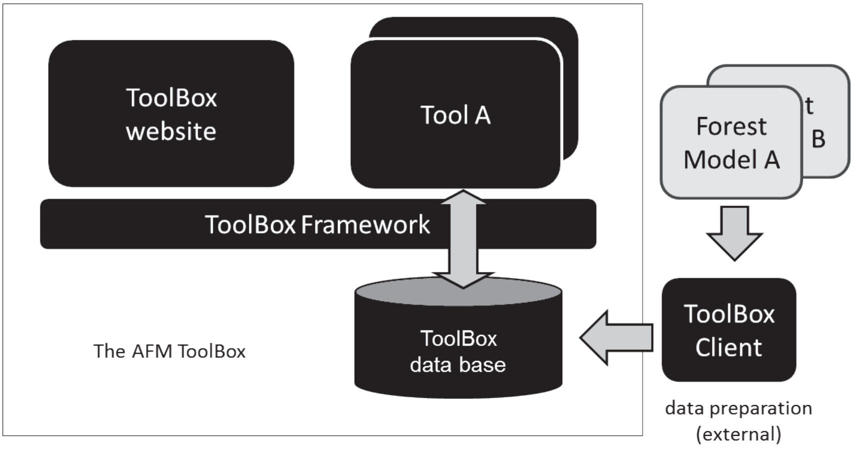

Figure 1. Conceptual scheme of the AFM ToolBox. Arrows indicate the flow of data.

Table 1. Several data and metadata types for the AFM ToolBox database. The forest state, flows and activities are related to actual simulation results, while the other types are related to context metadata.

Data type	Description
Forest state	Time series of indicators related to the forest state. Examples are the standing timber, biomass, carbon storage in the soil, but also indicators such as species diversity.
Forest flow	Time series of indicators related to the flows from and to the forest stand (e.g. annual increment, timber harvests, tree mortality, carbon sequestration).
Activities	Time series of management activities.
Site type	Description of site properties such as soil type, nutrient and water supply
Stand type	Describes initial forest stand condition (species composition, silvicultural system, age, …).
Climate	Characterization of the used climate scenario including basic climatic averages.
Management	Description of the applied management concept including the regeneration phase.

capacity, water supply rating, nutrient supply rating). Attributes are either numerical (e.g., water holding capacity) or use a pre-defined classification scheme (e.g., soil texture is either "sandy", "loamy", or "clay"). Subsequently, simulation output data is linked to these metadata types. This approach provides flexibility from the perspective of the data provider and it enables automatic processing of the data by the tools in the ToolBox.

Knowledge base

The AFM ToolBox website is the central start page providing access to the AFM knowledge base and the means to start the tools of the ToolBox (Figure 2). The main elements of the knowledge base are a conceptual description of the forest management planning process (Rauscher 1999), a collection of FAQs from the adaptive forest management domain and a set of case study examples from the MOTIVE project. The different types of information are intensively interlinked. In addition, information is tagged based on two archetypic user types (manager/analyst).

The FAQs aim at the most relevant aspects of climate change (How will the future climate look like?), impacts on forests (How may tree species distribution look like under an altered climate?), potential adaptive measures in forest management and silviculture, planning approaches, and how to deal with uncertainty in climate projections. Whenever possible, the knowledge base integrates data from recent research and networking activities (e.g. COST ECHOES on silviculture and forest management for adaptation and mitigation).

The case study examples comprise of several detailed, science-based regional examples from all over Europe which were collected in the MOTIVE project. The examples have been prepared so as to share a common structure and are thus easily comparable. The contents cover the regional background and its specific challenges, provide options and recommendations for forest management under climate change, and they give an overview over methodologies and tools that were used in analyzing the case study problem situation.

Figure 2. Main page of the AFM ToolBox and access to "*Adaptive Management*" and "*Examples*".

Vulnerability assessment tool

For the AFM ToolBox we have used the vulnerability approach as introduced by Seidl et al. (2011). Sensitivity to impacts and adaptive capacity of forests are placed on a two dimensional surface and are characterized by a set of indicators. The sensitivity indicators represent a set of ecosystem services and are stored in the database for each available management alternative. The indicators for adaptive capacity are qualitative and need to be provided by the user of the tool. For sensitivity indicators the difference between indicator value under baseline climate and the respective value under a climate change scenario is employed in the vulnerability assessment.

The application of the vulnerability assessment tool is split into three general steps: First, the cases for analysis are selected. Secondly, the value-based preferences of the user or user group are defined, and the third step is the interactive analysis of the results.

The cases for analysis can be selected based on the available metadata in the database. For instance, a user may be interested in forest stands that are dominated by beech at sites with a poor water supply. The selection can be further explored using an integrated map or via diagrams. In the second step, the task of the user is to select relevant ecosystem services and assign weights reflecting the relative subjective importance of the indicator/ ecosystem service.

Finally, the results can be visually analyzed using interactive diagrams that provide insight into the perceived impacts of management and climate scenarios and their relation to the adaptive capacity of the forests. Additional analysis diagrams for a detailed analysis of single cases are available.

A special feature of the vulnerability assessment tool is the “group mode”. Here, a facilitator works together with a group of stakeholders on an assessment problem.

Optimal Management Plan

The Optimal Management Plan tool (OMP) tool assigns one of the available management options to each stand entity to optimize the objective function at landscape level while meeting constraints (e.g. even flow constraints). This tool is designed to formulate forest management problems in mixed integer programming (MIP) (see Falcão and Borges (2005), Garcia-Gonzalo et al. (2013)). Further it presents a graphical user interface allowing an easy definition of the objective function as well as the constraints.

In contrast to other tools of the ToolBox, the OMP is considered as an expert tool only, because the application of optimization technique per se requires some profound knowledge of the methods. Notwithstanding, the graphical user interface of the tool is designed for easy and visually pleasing use.

The work process is split into four phases: First, the data set for analysis is selected from a list of available data sets in the database. Typically, a data set is a region comprising of forest stands. Second, a specific part of the region (but also the full region) can be specified from a map or a list. Third, the parameters for the optimization process are provided. They consist of an objective function (the variable to maximize or to minimize) as well as flow and target constraints. Additionally, the user can specifies economic parameters such as interest rate or harvesting costs and revenues.

And fourth, the results of an optimization can be viewed and analyzed as a summary, or as more detailed table view. The tool also contains an option to visualize results on top of a Google Maps rendered map.

”*Make your own*” – Customizing the AFMToolBox

Getting started with the data driven tools of the AFM ToolBox is simple, since it is web based and comes with ample demonstration data from the MOTIVE project. The AFM ToolBox, however, supports also the use of customized data (i.e., data that is generated by the user or for the user). Full control over all aspects of the AFM ToolBox can be exercised

Table 2. Synthesis of AFM ToolBox tools and major functionalities.

Tool/ functionality	Type	Data source	Manager/Analyst	Participatory
General information, FAQs	Info	Scientific literature, experts	M/A	No
Case study examples	Info	MOTIVE case study reports	M/A	No
Vulnerability Assessment tool (single user)	interactive	MOTIVE data; user data	M/A	No
Vulnerability Assessment tool (group mode)	Interactive	MOTIVE data; user data	M/A	Yes
MIP optimizer tool	Interactive	MOTIVE data; user data	A	No
Data client / data generation	Data	NA	A	No
Data viewer	Data	NA	A	No

with a local installation of the complete AFM ToolBox either directly to the user's PC or on a local server. This process is facilitated by a download package of the ToolBox containing all necessary underlying software components and the code for the AFM ToolBox.

Technically, the AFM ToolBox builds upon on a number of open source technologies which are frequently used for web development. Since the ToolBox components are open source itself, it can easily be extended or modified by interested parties. Currently, the AFM ToolBox is can be locally installed on Microsoft Windows or Linux platforms.

Discussion and Outlook

Table 2 lists all tools and major functionalities of the MOTIVE AFM ToolBox. It is a balanced set of information, exploration and analysis components. For the AFM ToolBox we have decided to focus on relatively simple graphical representation where the user can shift between several graphical variants to explore effects of climate and management on ecosystem service performance. To promote the idea of an adaptive management approach and to improve the quality of decision making, ample emphasis is on the interlinkage of the tools and the knowledge base.

What are the limitations and the benefits of the current version? Free accessibility via the internet can definitely be seen as a huge advantage in transferring state of the art knowledge and tools to endusers.

However, this flexibility easily masks the fact, that the users have not per se access to analyze their own data. The provisioning of own data is technically challenging (operating simulation models and other tools) and very likely beyond the scope of the typical forest manager. In this case, consultancy is indicated to overcome the technical complexity. If, on the other hand, the procedural complexity of a decision support process is high (e.g. group mode of the Vulnerability Assessment tool) a facilitator may be required to fully utilize the potential of the tool.

These two perspectives link back to the initial challenge of implementing decision support systems. We strongly believe that several user profiles need to be considered when developing advanced DSS. For the AFM ToolBox we distinguish the forest manager and the analyst as target users.

Finally, the openess (use of open source and easy extensibility) allows for an extended life time of the ToolBox. Any DSS developer can take up the AFM ToolBox and continue, extend or improve. Future planned developments include new tools (spatially explicit analysis).

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Glossary

AFM Toolbox: Adaptive Forest Management toolbox which contains a suite of decision support tools and information.

Bioclimatic zone/Bioclimate range/Bioclimate envelope: An area of relatively uniform macroclimate characterized by vegetation, soils and animal life which reflect that climate.

Biogeochemistry: The study of the cycles of chemical elements, such as carbon and nitrogen, and their interactions with and incorporation into living things.

COST ECHOES: COST is an intergovernmental framework for European Cooperation in Science and Technology, allowing the coordination of nationally-funded research on a European level. COST funds pan-European, bottom-up networks of scientists and researchers across all science and technology fields. These networks, called ‚COST Actions‘, promote international coordination of nationally-funded research. Expected Climate Change and Options for European Silviculture (ECHOES) is one such COST Action.

Climate Envelope Models (CEM): See species distribution models.

Decision Support Tool (DSS): An information system (often computer based) which supports decision making activities.

Demographics: quantifiable statistics of a population.

ENSEMBLES project: A project supported by the European Commission‘s 6th Framework Programme as a 5 year Integrated Project from 2004–2009 under the Thematic Sub-Priority "Global Change and Ecosystems" which developed an ensemble prediction system for climate change.

Empirical Model: A model based entirely on observed relationships and not on predetermined theory. When an empirical model is formulated mathematically, the equations used are not based on any inherent understanding of the underlying mechanisms.

General Circulation Model (also known as Global Climate Model)(GCM) is a mathematical model of the general circulation of the global atmosphere.

Hybrid model: A combination of empirical and process-based modeling approaches.

Phenology: The study of periodic plant and animal life cycle events such as breeding, flowering and migration and how these are influenced by seasonal and inter-annual variations in climate, as well as habitat factors such as elevation.

Population dynamics: A branch of science which studies short-term and long-term changes in the size and age composition of populations, and the biological and environmental processes influencing those changes. One well-known mathematical model for population dynamics is the exponential growth model.

Process-based model: Also referred to as a mechanistic model, it contains understanding or explanation of the system being modeled rather than simple cause-effect relationships. Process-based models in forestry are mathematical representations of biological systems that incorporate understanding of physiological and ecological mechanisms.

Regional Climate Model (RCM): These models contain the same physical mechanisms as GCMs, are fed by GCM output, and simulate the climate development within the study region by using GCMs data as boundary input to the study region.

Species Distribution Model (SDM): A model which can integrate population dynamics, disturbance and dispersal. Based on resources limiting climate, and other species distribution, predictions of species distribution can create a bioclimate range, or bioclimate envelope.

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