

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 ≤ 1 km 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 (≤ 1 km), 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 Europe 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 in 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 a 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

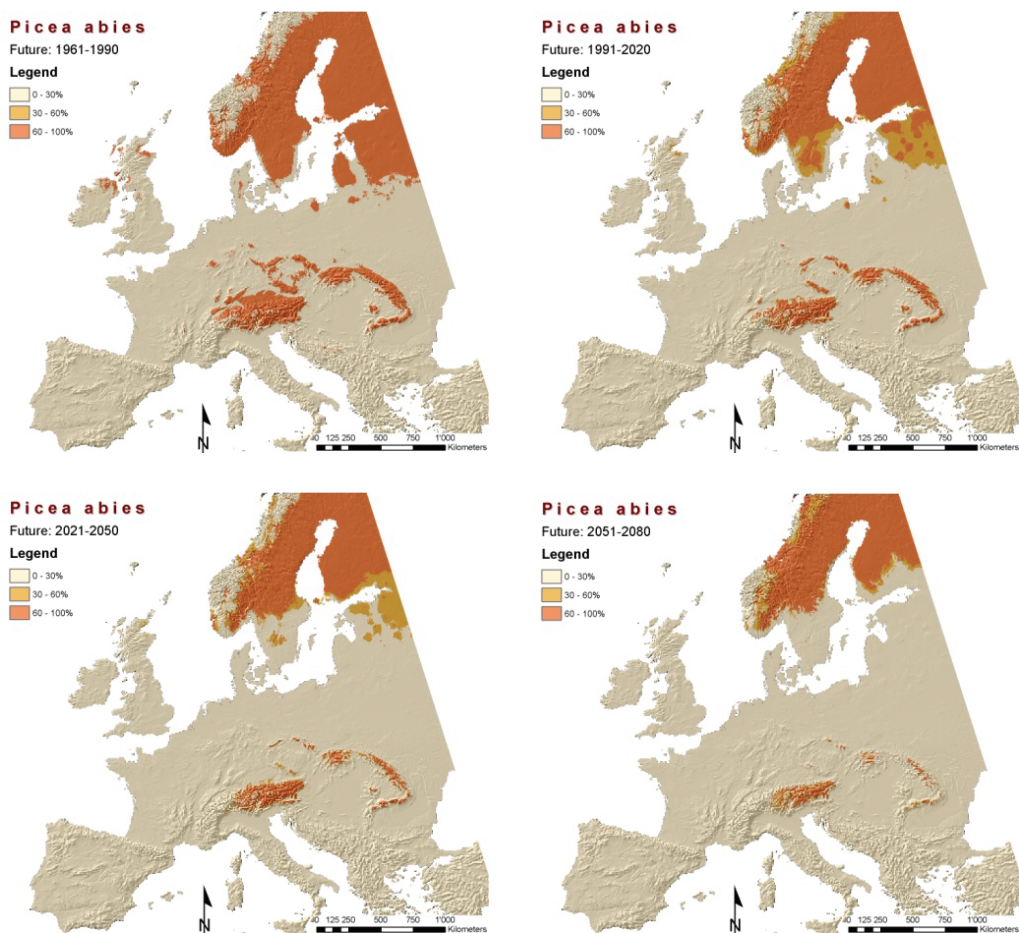


Figure 1. Ensemble projected change in habitat suitability for Norway spruce (*Picea abies*) in Europe following climate change in response to 6 RCM climate models using the A1B scenario and calibrated from 6 statistical models. The legend gives the agreement for simulating suitable habitat among all 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 website¹. It becomes obvious that mostly the more drought-tolerant species such as Sessile

¹ <http://www.wsl.ch/lud/motive>

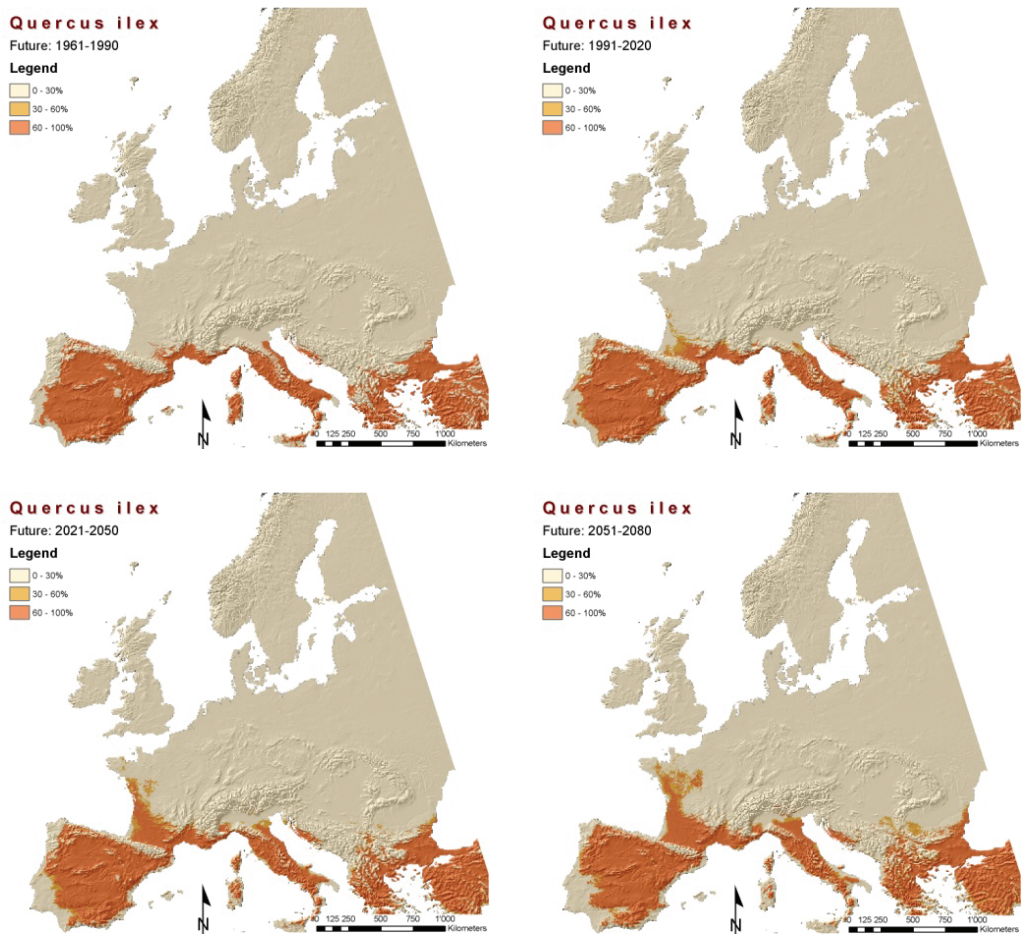


Figure 2. Ensemble projected change in habitat suitability for *Quercus ilex* in Europe following climate change in response to 6 RCM climate models using the A1B scenario and calibrated from 6 statistical models. The legend gives the agreement for simulating suitable habitat among all climate model 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

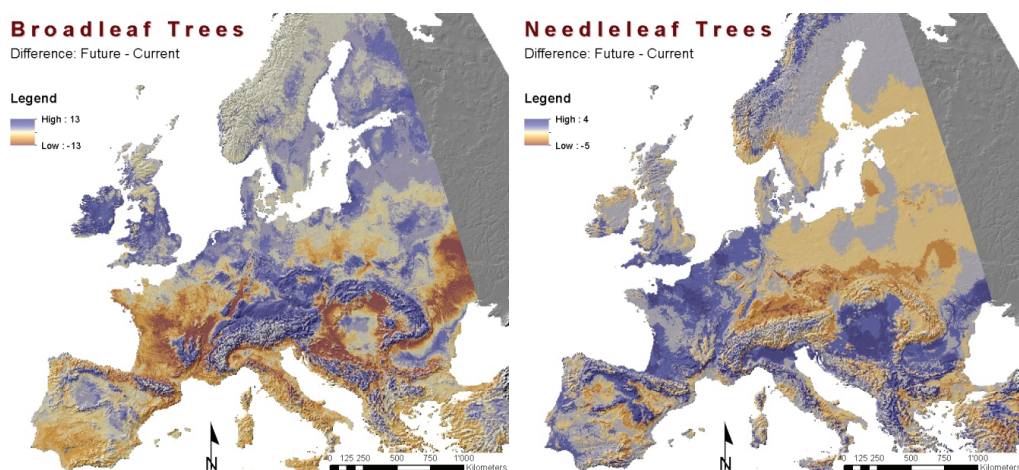


Figure 3. Changes in plant functional type composition from single species habitat suitability changes following climate change. The two panels indicate to what degree broadleaf (left panel) and needleleaf (right panel) tree species are expected to increase (blue) or decrease (red) in numbers. The results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

References

- Hanewinkel, M., Cullmann, D.A., Schelhaas, M.-J., Nabuurs, G.-J. and Zimmermann, N. E. 2013. Climate change may cause severe losses in economic value of European forestland. *NATURE Climate Change* 3: 203–207.
- Lorenz, M. 1995. International co-operative programme on assessment and monitoring of air pollution effects on forests – ICP Forests. *Water, Air and Soil Pollution* 85: 1221–1226.
- Meier, E.S., Lischke, H., Schmatz, D.R. and Zimmermann, N.E. 2012. Climate, competition and connectivity affect future migration and ranges of European trees. *Global Ecology and Biogeography* 21:164–178.
- Thuiller, W., Lafourcade, B., Engler, R. and Araujo, M.B. 2009. BIOMOD – a platform for ensemble forecasting of species distributions. *Ecography* 32:369–373.
- Zimmermann N.E. et al. 2009. Climatic extremes improve predictions of spatial patterns of tree species. *Proceedings of the National Academy of Sciences of the United States of America* 106:19723–19728