# A climate-induced tree species bottleneck for forest management in Europe

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# Abstract

Large pulses of tree mortality have ushered in a major reorganization of Europe's forest ecosystems. For initiating a robust next generation of trees, the species that are planted today need to be climatically suitable throughout the entire 21st century. Here, we developed species distribution models for 69 European tree species based on occurrence data from 238,080 plot locations to investigate the options space for current forest management in Europe. We show that the average pool of tree species continuously suitable throughout the century is smaller than that under current and end-of-century climate conditions, creating a tree species bottleneck for current management. If the need for continuous climate suitability throughout the lifespan of a tree planted today is considered, climate change shrinks the tree species pool available to management by between 33% and 49% of its current values (40% and 54% of potential end-of-century values), under moderate (RCP 2.6) and severe (RCP 8.5) climate change, respectively. This bottleneck could have strong negative impacts on timber production, carbon storage and biodiversity conservation, as only 3.18, 3.53 and 2.56 species of high potential for providing these functions remain suitable throughout the century on average per square kilometre in Europe. Our results indicate that the options space for silviculture is narrowing substantially because of climate change, and that an important adaptation strategy in forestry – creating mixed forests – might be curtailed by widespread losses of climatically suitable tree species.

**Keywords:** climate change – ecosystem services – forestry – habitat suitability – persistence – trees

# Main text

Human well-being essentially depends on nature's contribution to people. Forest ecosystems provide a diverse suite of services to society, including the production of timber and fuel, sequestration of carbon, buffering of microclimate, protection of drinking water, and provision of recreational space for humans as well as habitat for forest-dependent species[1,2]. Global forests are thus critical for mitigating the ongoing climate and biodiversity crises[3,4]. Yet, forests themselves are increasingly under pressure from climate change[5-7], challenging the contribution of forests to people. In Europe, for instance, tree mortality has increased strongly in the past three decades, and recent pulses of tree mortality were likely unprecedented in the past 170 years[8].

The ongoing changes in forest ecosystems around the globe pose important challenges to policy and management. Large areas of disturbed forests need to be regenerated with tree species that are able to tolerate future climate conditions[9,10]. However, given the long life-span of trees, selecting tree species for regeneration requires that they are adapted to a warmer (and possibly drier) future, but at the same time are able to tolerate current climatic conditions (e.g., with regard to the occurrence of frost events[11]). Furthermore, in initiating the forests of the future, mixing different tree species is recommended to increase the robustness to perturbations and hedge risks[12-14]. Yet, whether the pool of tree species that are suitable under current *and* future climate conditions contains a large enough set of ecologically compatible species to generate the positive effects associated with mixed forests remains unclear. This is a particular concern in Europe, which – as a result of Pleistocene climate fluctuations – is relatively poor in naturally occurring tree species compared to other regions of the world[15,16].

Moreover, tree species differ in the functions and services they provide for humans. Physical properties of wood (e.g., fibre length, wood strength and density), for instance, vary widely between tree species[17], making some species more suitable for timber usage than others. Furthermore, dense canopies of high leaf area are most efficient in utilizing light, water, and nutrients to fix carbon via photosynthesis[18], yet only a subset of tree species are able to form such canopies. Also, the composition and diversity of arthropods, fungi and other organisms associated with trees varies strongly across tree phylogeny, making tree species identity an important indicator for the conservation of these groups[19,20]. In summary, the choice of tree species is arguably one of the most important management decisions in forestry; a decision that – once taken – will influence forest development and functioning for decades to centuries. Nonetheless, the tree species pool which managers can utilize today (e.g., for reforesting large areas affected by high-severity disturbance) to create the forests of the future remains widely uncertain because of climate change.

The climate suitability of tree species has frequently been assessed by means of species distribution modelling. This approach statistically describes the realized climatic niche of a species based on its current distribution, and allows the assessment of a species' climate suitability under future climate scenarios, assuming that a species' niche requirements remain constant. For many European tree species, these models indicate pronounced geographical displacement of suitable ranges under the climate expected for the late 21$^{th}$ century, with those of broadleaved species expanding and those of coniferous species contracting[9,10]. What is rarely considered, however, is that climate change could create a considerable tree species bottleneck for current forest management: Species that are climatically suitable in a particular region today could be no longer suitable under future climate (inset Figure 1B). And while new species might become suitable as climate change progresses, current conditions will still be outside of their climatic niche today (inset Figure 1C), hindering their establishment and survival if they are planted now. Put differently, for species to be considered in current forest management they need not only to be climatically viable today or in the future, but today *and* in the future, i.e., throughout the *entire* 21$^{st}$ century (given that rotation periods in Europe range from 60 to 100 years, inset Figure 1A). As important climate variables such as mean annual temperature are expected to change by several degrees until the end of the century, the range of tree species currently available for afforestation narrows to those having a climatic niche broad enough to encompass both current and future conditions, in order to tolerate the expected shift in climate *in situ*. This possible tree species bottleneck for current forest management, induced not only by the absolute magnitude, but also by the rapid rate of climate change, has not yet been quantified to date, but could have substantial negative effects on ecosystem functions and services. Reference[9], for instance, assessed the economic implications of potential changes in tree species pools in Europe, and reported large losses in land expectation value as a result of a shift towards more warm-adapted species. Reference[21] estimated how climate-induced changes in tree species pools might affect the potential for primary productivity and carbon uptake, suggesting that diverse forests could strengthen the forest carbon sink. Yet, both studies compare species pools under future climate to current conditions (i.e., a time slice approach), and thus disregard the bottleneck that potentially results from the need for a continuous and uninterrupted long-term climate suitability of tree species in forest management.

# Results

We parameterized species distribution models for 69 European tree species (i.e., 91% of the tree species listed in the European atlas of forest tree species[22]) based on data from 238,080 sample plots (Ref.[23] and Ref.[24]), including both natural and planted species occurrences (see Methods). We modelled tree species suitability throughout the 21st century at 1 km horizontal resolution and decadal time steps for three different IPCC AR5 climate scenarios (representative concentration pathways RCP 2.6, RCP 4.5 and RCP 8.5). To quantify the tree species pool available for current forest management, we determined those species that find climatically suitable conditions in a given grid cell throughout the entire century. The tree species bottleneck for management was quantified by contrasting this set of continuously suitable species with the set of those suitable today (i.e., under the climatic conditions of 2020 to 2029) and in the future (i.e., under the climatic conditions of 2090 to 2099). We further evaluated each tree species with regard to its potential to provide timber, store carbon, and provide habitat (see Methods for details) based on a comprehensive literature synthesis across all 69 tree species. Subsequently, we quantified the potential implications of a climate-induced tree species bottleneck for these important forest functions.

On average across Europe, 9.4 tree species per square kilometre can be continuously sustained throughout the 21st century under intermediate climate change (RCP 4.5, Fig. 1A, 9.8 under RCP 2.6). This value decreases to 8.4 species under more extreme climate change (RCP 8.5, see Supplementary Table 1). The pool of species continuously supported throughout the century is highest in central-eastern Europe (15.9, RCP 4.5), and lowest in northern Europe (4.0, RCP 4.5, Supplementary Table 2). It also decreases from east to west, particularly in central and southern Europe (Figure 1A, see Extended Data Figures 1 and 2 for all climate change scenarios).

Compared to species pools suitable under current climatic conditions, these numbers represent a decrease by 38.1% (5.8 species) per square kilometre on average across Europe under intermediate climate warming, and 33.1% and 49.2% under moderate (RCP 2.6) and severe (RCP 8.5) climate change, respectively (see Supplementary Table 3). Species loss relative to the number of species suitable under current climate was strongest in northern Europe (-52.0%, RCP 4.5) while central-eastern Europe was least affected (-30.8%, RCP 4.5, see Supplementary Table 3 for results of all regions and climate change scenarios). Major European mountain ranges (i.e., the Alps, Scandes, Cairngorms, Rhodopes, Balkan Mountains, and Pyrenees) and high northern latitudes were relatively buffered from a reduction in the tree species pool (Figure 1B) (decreasing 33.5% in mountain ranges compared to 40.3% lowland areas under RCP 4.5), indicating that a larger share of the tree species that are currently climatically suited in these areas will remain so throughout the century. The likely reason is that many tree species are at their cold range limits in these regions, and will remain suitable under climate warming. In contrast, the reduction of the current species pool is largest in south-western Europe and in the hemiboreal zone, due to the strong climatic changes expected for these regions and the location of the hemiboreal zone at the ecotone between two major biomes.

These reductions are contrasted by new species for which conditions are not yet suitable today, but will become suitable later in the 21st century. On average, species pools per grid cell are increased by +85.5% at the end of the century (RCP 4.5, +66.9% and +118.5% for RCP 2.6 and RCP 8.5, respectively; Supplementary Table 4) relative to the pools that can be sustained throughout the 21st century. Increases are greatest in northern Europe (+259.9%, RCP 4.5) and lowest in south-eastern Europe (+40.7%, RCP 4.5, Figure 1C, see

Supplementary Table 4 for all regions and climate change results). We hence find clear evidence for a considerable tree species bottleneck for European forest management under climate change, i.e., the species pools calculated under both current and end-of-century climate conditions are considerably larger compared to the species pool obtained when continuous suitability throughout the century is considered. In fact, the average number of climatically suitable species per square kilometre is even larger in the 2090s than it is currently, but the number of species which are continuously suitable throughout the century is substantially lower than both in the 2090s and today, and decreases with time span under consideration. When calculated at decadal time steps between the 2030s and 2090s the mean number of species continuously suitable per square kilometre decreases by 6.5% (compared to the current species pool) per decade, accumulating to a net reduction of 38.1% in the 2090s under RCP 4.5 (Figure 2, see Extended Data Figure 3 and 4 for all other climate change scenarios). Basing decisions on which tree species to plant today on analyses of climate suitability for either current or future climate (i.e., static time slice approaches) is thus likely to overestimate the potential species pool available for management. The issue, here termed tree species bottleneck, is increasing with two factors, the rate of environmental change and the length of the period considered. While the former cannot be influenced directly by forest managers the latter can, suggesting that new silvicultural systems should aim for shorter planning periods and the possibility to adapt tree species compositions with higher frequency (e.g., via opening the canopy early in order to introduce newly suitable species already during the course of stand development).

The climate-induced tree species bottleneck in Europe's forests could have considerable consequences for the achievement of major goals of forest policy and management. Only a fraction of the tree species that can be sustained throughout the 21st century has high potential for contributing to important forest functions. Of the 9.4 tree species available for management on average across Europe (RCP 4.5), only 3.18, 3.53 and 2.56 are high-potential species for timber production, carbon storage and biodiversity conservation, respectively (Figure 3 and Supplementary Table 5, Extended Data Figure 5 and 6 for all climate change scenarios). These values are 43.6%, 33.6% and 39.6% lower than corresponding values under current climatic conditions (Figure 3 and Supplementary Table 5), with an even stronger reduction under more extreme climate change (RCP 8.5, Supplementary Table 6). For 6.2% of the study area, the species pool that can be sustained throughout the 21st century under RCP 4.5 did not include a single tree species with high timber production potential (5.9% and 9.8% for carbon storage and biodiversity conservation, respectively). Losses of high value species relative to current conditions were particularly pronounced in low-elevation forests of the temperate and hemiboreal zone for all three forest functions (see interactive online mapping tool, https://bdc.univie.ac.at/forest-bottleneck). Across the three functions, the tree species bottleneck affected the capacity to produce timber more strongly than the potential to store carbon and harbour biodiversity. To assess impacts on forest multifunctionality (i.e., the ability to provide multiple functions simultaneously) we determined the area where at least two species with high potential for all three functions were present in the tree species pool (results for one and three species are shown in Supplementary Table 7). Based on this analysis the species pool climatically suitable throughout the 21st century holds high potential for multifunctionality on 56.3% of the study area (RCP 4.5, see Extended Data Figure 7 for maps of all climate change scenarios). This is a reduction by 43.6% relative to the species pool available for forest management under current climate.

# Discussion

Forest ecosystems and the services they provide to society are increasingly under pressure from climate change[5]. As a result of large-scale disturbances, the forests of Europe are currently undergoing a profound reorganization[25]. This reorganization holds the opportunity to initiate a new cohort of climate-adapted forests that are robustly able to provide ecosystem services also under climate change. In order to seize this opportunity, however, suitable tree species need to be identified. Here, we present tree species pools that can be sustained throughout the 21st century, representing the option space for current European forest management. We show that climate-adapted tree species pools are shrinking relative to the species that are currently suitable, i.e., the option space for forest management is narrowing substantially because of climate change. While progressing climate change also renders new species climatically suitable in the future, current conditions are still outside of their climatic niche, inhibiting their immediate introduction and creating a bottleneck for forest management. Technically speaking the emergence of such a bottleneck is a necessary consequence of comparing species pools suitable over long timespans with those suitable over short periods within these timespans if climate is not stationary. From an applied perspective, the existence of this bottleneck has significant implications for forestry policy and management, yet has rarely been discussed in the literature and never been quantified across large scales to date.

We here quantify tree species pools suitable throughout the 21st century to illustrate the implications of climate change for current forest management decision making. We base our analysis on the relationship between current tree distribution and climatic averages rather than extreme events which often are the root cause of tree mortality. However, as extremes are deviations from the average, what is considered an extreme today may become the new normal under shifting average climate. Likewise, conditions beyond the ones occurring today will become the new extremes in the future. A change in the average hence includes information on changes in intensity and frequency of extremes, and is preferable for modelling because of better data availability and quality compared to extremes. Moreover, long-term averages are good indicators for determining the growth and carbon balance of trees, and hence for their fitness and long-term persistence. We also note, that we here focus purely on potential species pools for management, disregarding technological and socio-economic dimensions that might be relevant in realizing this potential for sustainable forest management, such as the capacity to grow plants of desired species in nurseries and to plant them on site. Furthermore, natural processes of adaptation such as species migration[26,27] and intra-specific variation in climate responses[28] as well as species interactions[27,29] were not considered explicitly here. We moreover emphasize that our results are contingent on a number of general shortcomings of species distribution models. Of particular relevance here is that using current distributions to fit such models may underestimate the climatic tolerances of species, in particular those with restricted natural ranges and low importance in forestry to date[30,31]. Our results might thus be pessimistic with regard to the climatic tolerances of tree species. However, part of the occurrences in our data represent species occurrences that were already growing outside their climatic niches at the time of sampling[32], resulting in overestimating their climatic tolerances. Moreover, we maintain that under the precautionary principle it is advisable to base forest management decisions on the subset of species most likely to be robust against climate change rather than to speculate about potentially wider but yet unknown climatic tolerances of species that are currently rare. In this context, SDMs can provide important insights for forest management under climate change despite their inherent shortcomings[33,34].

The native tree species diversity in Europe is relatively low, and the tree species pool currently available for forest management is further constricted by climate change. Non-native tree species were excluded from our analysis, but might offer opportunities to buffer locally shrinking tree species pools[35]. However, a careful consideration of the advantages and disadvantages of introducing non-native species is required, including the consideration of their potential to invade adjacent areas, threaten native biodiversity[36] and reduce ecosystem service provision[37].

The demonstrated tree species bottleneck for current forest management does not only affect total species pool sizes but also the number of species with high potential for providing important ecosystem functions. With an average of only 3.18, 3.53 and 2.56 such species (for timber production, carbon storage and biodiversity conservation, respectively) per km², and only 56% of Europe remaining suitable for mixtures of at least two species with high multifunctionality potential, insurance of service provisioning against uncertainty by mixing tree species appears significantly reduced. We note that assessing the potential to contribute to forest functions at the level of individual tree species (as done here) is inherently incomplete, as it disregards elements such as environmental context[38] and β diversity[39]. Furthermore, our indicator of biodiversity – while focusing on an important and species-rich group of organisms – might not be representative for the full diversity associated with individual tree species. We here addressed three forest functions that are of wide relevance across the entire European continent (timber, carbon, biodiversity). Yet, also other functions matter locally, such as the ability of forests to protect against natural hazards or provide space for recreation[40,41]. Future work should thus broaden the scope and assess the effect of changes in the tree species pool also on other ecosystem services.

Here, we present an approach for using species distribution models to quantify management-relevant parameters, such as the set of tree species that is climatically suitable throughout the 21$^{st}$ century (and thus forms the species pool on which management can draw upon for current decision making). Our application of species distribution models differs distinctly from previous efforts e.g., ref.[9,10]. Notably, reference[42] also focus on the process of successive species loss from local pools associated with a continuously changing climate. However, these authors do not touch on the aspect of the pace of climate change, which – as demonstrated here – might render a site unsuitable for a species within the life-time of a single generation. This temporal dynamics create what we term a bottleneck, i.e., that the number of tree species that can be sustained throughout the century is considerably lower than what is projected in a classical time-slice application of species distribution models, comparing current species pools to end-of-century estimates see e.g., ref.[9,10]. We hypothesize that the bottleneck identified here for Europe's forests also occurs in many other parts of the world, and also applies to other time frames than the one assessed here, as it is an inherent effect of the relationship between the magnitude and pace of climate change and the width of the climatic niches of tree species as well as their longevity.

Mixed species stands and diverse portfolios of tree species are suggested as a solution to buffer negative effects of climatic and social uncertainty[12,14]. Yet, our analysis indicates that the possibility to utilize the positive effects of tree species mixing could be severely constrained by climate change. In many parts of Europe, even a relatively small set of four or five climatically suitable tree species that can be combined in mixed-species stands might not be available under climate change. A reduction in species pools thus not only narrows the option space for silviculture under climate change, but also curtails an important adaptation strategy for dealing with increasing uncertainty in forestry by limiting the possibility for creating mixed forests. We conclude that climate change could erode the potential of forests to provide ecosystem services in Europe more than previously acknowledged via constricting local tree species pools. This underlines the need for effective climate change mitigation in order to maintain the integrity and ecosystem service potential of forest ecosystems.

# Methods

## Study region, species and climate data

We focused our analyses on Europe west of E 59.506°, and excluded regions of European countries that are not part of a geographically defined Europe (e.g., Macaronesian Islands).

Presence absence data of tree species was compiled from two data sources. First, we used plot data from the ICP Forest dataset[24] containing 38,578 occurrence records of 132 species in 18,367 plots surveyed between 1987 and 2017 across 38 European countries. Only data from live trees in the last year a plot was censused were considered. Second, we used plot data from ref.[23] who harmonised an unpublished, large database containing forest plot surveys from National Forest Inventories, resulting in data for 249,410 plots across Europe (30 countries) containing 242 species. Both datasets were homogenized to a common raster of 1x1 km, where multiple presences in one cell were combined (resulting in 18,179, 225,082 and 239,173 data points for the two original datasets and their combination, respectively). A species was defined to have a true absence if it was absent in all plots contained in a cell. As our data came from systematic sampling, no pseudo absences were generated. Finally, all presence-absence data were constrained to our study region, resulting in 238,080 plots. From the resulting dataset we compiled a list of all native European tree species with a minimum of 50 occurrences. This list encompassed 69 tree species, including both common species and small-range endemics as well as species with only marginal use in current forestry (Supplementary Table 8). We did not differentiate between natural and planted occurrences, neither within and beyond the native range of the respective species. The inclusion of planted tree occurrences corresponds well with the scope of our study, as we aimed to model the climatically suitable tree species pool for forestry.

For characterizing climatic conditions we used four variables: mean annual temperature, mean annual temperature seasonality (derived as the mean annual standard deviation of monthly temperatures), mean annual precipitation seasonality (derived as the mean annual standard deviation of monthly precipitation sums) and the ombrothermic index (derived as the minimum over all years of annually summed precipitation of months with an average temperature above 0° C divided by the sum of average temperature of those months[43]). We chose these four variables as they i) are not strongly correlated (Pearson correlation < 0.7) and ii) are important descriptors for all 69 modelled species as they include information about drought stress and temperature stress. Our selection of variables is similar to those of other large-scale SDM applications[44,45] with the exception of the ombrothermic index, which we here used to better capture the drought sensitivity of trees. For past climatic conditions we used monthly temperature and precipitation data from CHELSA[46] from 1980 to 1999 to calculate these variables. The original resolution of 30 arcsec was resampled using the nearest neighbour method to 1km resolution. Possible future climates in Europe were represented by three different emission scenarios of the IPCC CMIP5 scenario family, the moderate RCP 2.6, the intermediate RCP 4.5, and the severe RCP 8.5 scenario. All scenarios were generated by Météo-France/Centre National de Recherches Météorologiques using the CNRM-ALADIN53 model, fed by output from the global circulation model CNRM-CM5[47]. Monthly temperature and precipitation data from 2020 to 2100 was derived from the CORDEX portal (https://euro-cordex.net/) and downscaled to a resolution of 30 arcsec using the delta method. Specifically, we downloaded hindcasted data (1980 to 1999) from the same platform, in order to derive changes of temperature and precipitation (as delta and ratio, respectively) within the climate models. These changes were subsequently resampled to a 1km resolution and combined with the climate data from CHELSA to obtain future monthly temperature and precipitation trajectories. All four climatic variables were subsequently averaged to decadal time steps (i.e., 2020-2029, 2030-2039, …2090-2099).

## Modelling

Climate suitability of tree species was modelled using ensembles of species distribution models (SDMs) from the biomod2 package[48] in R[49]. Models were parameterized by relating species presence absence data to climate data for the reference period 1980-1999. Ensemble models were built from four different individual modelling algorithms, namely Generalised Linear Models (GLM), Generalised Additive Models (GAM), Random Forests (RF) and Boosted Regression Trees (BRT). All models were run under the default settings of the biomod2 package. Model performance was evaluated using a repeated split-sampling approach (three replicates), in which 70% of the presence absence data were used for parametrisation and the remaining 30% for evaluation using the TSS score[50]. Of all 69 species, only *Salix caprea* had to be dismissed due to poor model quality (TSS value of all single models below 0.4). For all other species, the resulting twelve models per species were combined as weighted (by their evaluation score) means. Subsequently, the thus derived ensemble model for each species was used to predict occurrence probabilities for the reference period as well as for each decade until the end of the 21st century (i.e., 2020 to 2090). Finally, the resultant probabilistic information was converted to binary suitability maps using the probability threshold that maximised the TSS value[51] (range sizes, evaluation scores, and number of occurrences are shown in Supplementary Table 8).

From the binary results for each decadal time step between 2030 and 2090 we calculated the mean number of species per square kilometre continuously suitable from 2020 until the respective decade, as well as the number of species suitable in the respective decade but not over the entire period until then. From the three resulting layers number of species continuously suitable, number of species suitable under current (2020 to 2029) and end of the century (2090 to 2099) climatic conditions we derived two measures: First, the percentage of species from the current species pool (2020-2029) that cannot be sustained throughout the entire century, derived as (number of species current – number of species throughout) / number of species current. Second, the percentage of species that are gained at the end of the century (2090-2099) relative to the species that are climatically suitable throughout the century, was derived as: (number of species end – number of species throughout) / number of species throughout.

This publication is supplemented by an interactive online mapping tool (https://bdc.univie.ac.at/forest-bottleneck) that provides all results for all modelled tree species across all grid cells. For reasons of computational performance, results are aggregated to a 10x10km resolution in the online tool, where a species occurs in one cell if it occurs in at least one underlying 1km² cell.

All analyses and graphics were done in R 3.6.0[49].

## Potential of tree species to contribute to forest management objectives

We combined information from multiple sources to assess the potential contribution of tree species to three important objectives of forest management: timber production, carbon storage, and habitat provisioning for biodiversity. Specifically, we compiled trait data from respective databases (e.g., TRY trait database[52], HOSTS biodiversity database[53], European atlas of forest tree species[22]), and amended it with life history data[54], as well as information on societal dimensions such as wood use[55]. For characterizing the different potential of tree species to contribute to the three forest functions analysed, we selected variables that are both relevant for the respective ecosystem function as well as broadly available across the selected species from published sources.

We compiled individual profiles for all 69 tree species assessed (see online mapping tool and Supplementary Table 10). Each profile contains a verbal description of the species in the context of the three forest functions considered here. Furthermore, six species characteristics with importance for the three functions were analysed by comparing each species to the distribution of the full set of 69 species. The characteristics analysed include maximum obtainable tree dimensions (maximum tree height (m), maximum tree age (years)) and physiological variables (shade tolerance, photosynthesis rate (μ mol $m^{-2}$ $s^{-1}$) as well as important wood properties (wood density (g $cm^{-3}$)). Given that insects are the most diverse species group in forest ecosystems[56], and that herbivorous caterpillars are the principal defoliators in forests of the northern hemisphere[57], the contribution of tree species to habitat quality was assessed with a special focus on Lepidopteran species. Based on these indicators (described in more detail below) the potential of a species to contribute to specific forest functions was assessed in three broad categories (low, medium, high potential). Initial assessments based on the six quantitative indicators (maximum tree height, maximum tree age, shade tolerance, photosynthesis rate, wood density and number of Lepidopteran species associated with a tree species) and their distributions were cross-checked by the authors and adjustments were made for information that was only available verbally (e.g., on different timber uses and markets).

The potential of a species for timber production was assessed based on its ability to form sizeable tree trunks (i.e., positively correlated with the ability to grow tall and old). Furthermore, the documented historical and current wood uses for different species and the existing timber markets were factored into the assessment[22,55], with more documented uses and the existence of a market being positively related to the timber production potential of a species. The potential of a species to sequester and store carbon was assessed based on its ability to take up carbon from the atmosphere (as indicated by a high photosynthetic rate and the ability to utilize radiation efficiently, approximated by tree shade tolerance), and the ability to store this carbon efficiently for extended periods of time (as indicated by tree longevity and maximum size as well as wood density). As an indicator of insect biodiversity associated with tree species we focused on Lepidoptera (i.e., moths), whose larval stages feed on tree tissue. Lepidopteran larvae comprise the full range of organisms with regard to host specificity (and thus dependence on trees), from highly polyphagous generalists to leaf miners that are monophagous at the level of individual tree species. They are also an important food source for other organisms such as birds and bats, and thus are a good indicator of the biodiversity value of tree species. Data compilation started from a recent synthesis[58], and was further augmented by host plant lists such as the HOSTS database[53] and the Database of insects and their food plants (http://dbif.brc.ac.uk/, last accessed 2022 09 12). To estimate the number of Lepidoptera species associated with each tree species, we combined species occurrence data from the HOSTS database with an exhaustive literature search for 20 out of the 69 tree species. The exhaustive search revealed on average 1.98 times the number of associated species compared to the database ($r^2=0.74$), and we used this simple linear relationship to extrapolate the number of associated Lepidoptera species for the remaining 49 tree species. Based on this estimate we classified a tree species' habitat value in three broad categories (low, medium, high potential). The full profiles of each tree species and their respective characteristics can be found in the online mapping tool and Supplementary Table 10.

Of the 69 species analysed, only three were rated to have high potential to contribute to all three forest functions simultaneously (i.e., *Fagus sylvatica, Quercus robur, Quercus petraea*). A total of 36%, 27%, and 21% of species were of high value for the objectives timber production, carbon uptake and storage, and habitat value, respectively (Supplementary Table 9).

Based on this assessment of tree species potential we quantified how many high potential species for the three functions are available for forest management per square kilometre, considering the constraint of continuous climatic suitability throughout the $21^{st}$ century. Furthermore, we assessed the potential for multifunctional forests by quantifying the forest area where a high potential contribution to all of the three management objectives from at least two species (results for one and three species in Supplementary Table7) is possible (either because individual species have high potential for multiple objectives, or because the species pool contains complementary species that each are able to make a strong contribution to individual objectives).

## Data availability

The data that supports the findings of this study are available online in the Phaidra database: https://phaidra.univie.ac.at/o:2046439

## Code availability

All code used for simulations, analysis and producing the figures is available online in the Phaidra database: https://phaidra.univie.ac.at/o:2046439

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## Author contributions

SD, RS, WR and FE conceived the idea, JW led data compilation and analyses, with contributions by all authors. AG, DM and JW derived the climate data. OI produced the dashboard and BH produced single species webpages. KF compiled all lepidoptera data. Tree species profiles were derived by RS, WR and KF. All authors contributed to interpretation of the results, RS and JW led the writing of the manuscript, with contributions from all authors.

## Competing Interests

The authors declare no competing interests

## Figure legends

Figure 1: Tree species suitability in Europe throughout the 21st century. (A) Map of the number of tree species that are climatically suitable continuously throughout the 21st century at 1 km² grid cells, and thus form the species pool that can be utilized by current forest management. (B) Percent of species from the current species pool (2020-2029) that cannot be sustained throughout the century. (C) Percent of species that are gained at the end of the century (2090-2099) relative to the species that are climatically suitable throughout the century. Tick mark in legend shows the average value across Europe. Values are shown for the climate change scenario RCP 4.5. Stylized figures illustrate exemplary climate niches (green ellipses) for (inset A) species that are climatically suitable throughout the 21st century, (inset B) species suitable under current climate but not under the climate at the end of the century, and (inset C) species suitable only under future, but not current climate. Black lines exemplarily indicate climatic development in temperature-precipitation-space throughout the 21st century.

Figure 2: Average number of tree species per square kilometre climatically suitable across Europe (6168545 cells) under intermediate climate change (RCP 4.5). Bars in dark green show the number of species continuously suitable from 2020 until the respective decade. For example, tree species in dark green in the 2090s are the species that can be planted today and will be within their climatic niche throughout the entire 21st century. Bars in light green show the number of species that become additionally suitable in this decade because of climate change, but are not yet within their climatic niche under current conditions (and thus have a high planting risk today). Bars in brown show the number of species lost until this decade, relative to current conditions, i.e., species that cannot be sustained within their climatic niche. Error bars show the coefficient of variation across Europe.

Figure 3: The number of tree species with high ecosystem function potential continuously suitable per grid cell (1 km²) under intermediate climate change (RCP 4.5). Number of species that have high potential for addressing three important ecosystem functions (timber production, carbon storage, biodiversity conservation) are shown in different colours (brown, black, green). Colour intensity indicates the number of cells for a certain number of species, and reaches from 0 (white) to the maximum number of cells per ecosystem function and region

(dark hues). For each ecosystem function the first column shows the number of species with high potential for the current species pool (2020-2029). High potential species that are continuously suitable throughout the 21st century (and thus potential options for current management) are shown in the second column. Red lines indicate the average number of species.

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**Supplementary Material:**

Supplementary Table 1: Average number of suitable tree species per square kilometre across Europe for three climate change scenarios. Values are shown for the current climate (2020-2029), continuous climate (from 2020 to 2099) and the climate of the end of the century.

| Climate change scenario | 2020-2029 | 2020-2099 | 2090-2099 |
|---|---|---|---|
| RCP 2.6 | 14.68 | 9.82 | 16.38 |
| RCP 4.5 | 15.22 | 9.42 | 17.47 |
| RCP 8.5 | 16.57 | 8.42 | 18.39 |

Supplementary Table 2: Average number of tree species continuously suitable from 2020 to 2099 per square kilometre for three climate change scenarios, evaluated separately for each region.

| Region | RCP 2.6 | RCP 4.5 | RCP 8.5 |
|---|---|---|---|
| Europe | 9.82 | 9.42 | 8.42 |
| Central-eastern Europe | 16.31 | 15.90 | 15.99 |
| Central-western Europe | 7.67 | 7.49 | 5.13 |
| Northern Europe | 3.97 | 3.98 | 3.27 |
| Russian Federation | 6.18 | 6.07 | 5.70 |
| South-eastern Europe | 15.74 | 14.62 | 15.83 |
| South-western Europe | 8.21 | 7.42 | 6.00 |

Supplementary Table 3: Average tree species loss (%) per square kilometre calculated from comparing the number of species with continuous suitability to the number of species suitable under current climate (with the latter indicated in parentheses); evaluated separately for each region and three climate change scenarios.

| Region | RCP 2.6 | RCP 4.5 | RCP 8.5 |
|---|---|---|---|
| Europe | -33.1 (14.68) | -38.1 (15.22) | -49.2 (16.57) |
| Central-eastern Europe | -29.7 (23.20) | -30.8 (22.96) | -38.5 (26.02) |

| | | | |
|---|---|---|---|
| Central-western Europe | -34.6 (11.73) | -40.4 (12.58) | -62.2 (13.56) |
| Northern Europe | -45.7 (7.32) | -52.0 (8.45) | -66.4 (9.74) |
| Russian Federation | -34.1 (9.39) | -39.3 (10.00) | -51.5 (11.76) |
| South-eastern Europe | -27.0 (21.55) | -32.6 (21.68) | -38.5 (22.48) |
| South-western Europe | -38.2 (13.29) | -47.1 (14.03) | -56.5 (13.78) |

Supplementary Table 4: Percentage of species per km² for which climatic conditions are suitable at the end of the century (i.e., 2090-2099), but not currently (‘new species’), compared to the number of species continuously suitable (2020-2099) under three climate change scenarios (number of species continuously suitable in parenthesis).

| Region | RCP 2.6 | RCP 4.5 | RCP 8.5 |
|---|---|---|---|
| Europe | +66.9 (9.82) | +85.5 (9.42) | +118.5 (8.42) |
| Central-eastern Europe | +63.6 (16.35) | +60.1 (15.90) | +62.0 (15.99) |
| Central-western Europe | +62.7 (7.67) | +73.3 (7.49) | +159.8 (5.13) |
| Northern Europe | +133.0 (3.98) | +259.9 (3.98) | +416.6 (3.27) |
| Russian Federation | +124.3 (6.18) | +253.8 (6.07) | +318.8 (5.70) |
| South-eastern Europe | +35.1 (15.74) | +40.7 (14.62) | +46.4 (13.83) |
| South-western Europe | +72.7 (8.21) | +73.1 (7.42) | +126.5 (6.00) |

Supplementary Table 5: Tree species that have high potential for addressing three important objectives of forest management in Europe: Timber production, carbon storage, biodiversity conservation. Shown are, for each region, the average numbers of species per km² which are suitable throughout the 21st century (values for current climate in parenthesis). Absolute values are numbers of species, relative values are percentages of the total species pool.

| | Timber | Carbon | Biodiversity |
|---|---|---|---|
| Europe | 3.18 (5.64)<br>33.8% (37.0%) | 3.53 (5.32)<br>37.5% (34.9%) | 2.56 (4.24)<br>27.2% (27.9%) |
| Northern Europe | 1.91 (4.34)<br>48.1% (51.3%) | 1.63 (2.95)<br>40.9% (34.9%) | 1.94 (4.22)<br>48.8% (50.0%) |
| Russian Federation | 2.47 (4.75)<br>40.8% (47.5%) | 1.97 (3.20)<br>32.5% (32.0%) | 3.18 (5.02)<br>52.4% (50.2%) |
| Central-western Europe | 3.41 (5.23)<br>45.5% (41.6%) | 3.55 (5.18)<br>47.4% (41.2%) | 1.91 (6.33)<br>25.5% (26.4%) |

| | | | |
|---|---|---|---|
| Central-eastern Europe | 4.57 (8.10)<br>28.7% (35.3%) | 5.41 (7.93)<br>34.0% (34.5%) | 4.33 (6.33)<br>27.3% (27.5%) |
| South-western Europe | 1.98 (3.65)<br>26.8% (26.0%) | 2.93 (4.36)<br>39.5% (31.1%) | 1.08 (1.92)<br>14.5% (13.7%) |
| South-eastern Europe | 4.23 (6.97)<br>28.9% (32.1%) | 4.88 (7.09)<br>33.4% (32.7%) | 3.14 (4.63)<br>21.5% (21.3%) |

Supplementary Table 6: Tree species that have high potential for addressing three important objectives of forest management in Europe: Timber production, carbon storage, biodiversity conservation. Shown are, for each region, the average numbers of species per km² which are suitable throughout the 21st century for RCP 2.6/ RCP 8.5.

| | Timber | Carbon | Biodiversity |
|---|---|---|---|
| Europe | 3.57/ 2.78 | 3.79/ 3.08 | 2.75/ 2.35 |
| Northern Europe | 1.98/ 1.53 | 1.64/ 1.33 | 1.97/ 1.64 |
| Russian Federation | 2.91/ 2.04 | 2.10/ 1.74 | 3.15/ 3.08 |
| Central-western Europe | 3.64/ 2.36 | 3.70/ 2.68 | 1.97/ 1.44 |
| Central-eastern Europe | 5.45/ 4.89 | 6.05/ 5.01 | 4.94/ 4.33 |
| South-western Europe | 2.16/ 1.49 | 3.00/ 2.57 | 1.34/ 1.01 |
| South-eastern Europe | 4.77/ 3.80 | 5.32/ 4.58 | 3.34/ 2.99 |

Supplementary Table 7: Percentage of the study region holding high potential for multifunctionality under future climatic conditions, as well as the decrease of the area of high multifunctionality (current compared to future climatic conditions). Values are shown for three climate change scenarios. Multifunctionality is defined as areas with at least one, two or three species with high potential for each management objectives.

| | RCP 2.6 | | RCP 4.5 | | RCP 8.5 | |
|---|---|---|---|---|---|---|
| Number of species | Continuous potential for multifunctionality | Decrease | Continuous potential for multifunctionality | Decrease | Continuous potential for multifunctionality | Decrease |
| 1 | 88,9 % | 10,8 % | 88,6 % | 11,2 % | 84,2 % | 15,6 % |
| 2 | 57,8 % | 42,1 % | 56,3 % | 43,6 % | 49,9 % | 50,0 % |
| 3 | 38,1 % | 61,8 % | 37,3 % | 62,6 % | 31,9 % | 68,1 % |

Supplementary Table 8: Individual range sizes at the beginning of the century (2020-2029), at the end of the century (2090-2099) as well as over the entire century (2020-2099) under intermediate climate change (RCP 4.5). Range sizes are given in km². Furthermore, TSS values of the ensemble models, the threshold used for translating occurrence probabilities into suitable/not suitable as well as the number of occurrences in the dataset (N) are shown.

| **Species** | **Scenario** | **2020-2029** | **2020-2100** | **2090-2099** | **TSS** | **Threshold** | **N** |
|---|---|---|---|---|---|---|---|
| Abies alba | rcp45 | 669725 | 249523 | 667048 | 0.755 | 0.514 | 9532 |
| Acer campestre | rcp45 | 2599852 | 1988314 | 3352647 | 0.711 | 0.567 | 5792 |
| Acer monspessulanum | rcp45 | 193478 | 25735 | 150487 | 0.798 | 0.665 | 719 |
| Acer opalus | rcp45 | 139189 | 15329 | 155145 | 0.81 | 0.618 | 1013 |
| Acer platanoides | rcp45 | 1379578 | 523795 | 1239418 | 0.756 | 0.653 | 2163 |
| Acer pseudoplatanus | rcp45 | 897982 | 238455 | 613899 | 0.707 | 0.586 | 12429 |
| Acer tataricum | rcp45 | 726603 | 514124 | 1574748 | 0.983 | 0.502 | 173 |
| Aesculus hippocastanum | rcp45 | 2026746 | 854240 | 1469412 | 0.682 | 0.365 | 310 |
| Alnus cordata | rcp45 | 147092 | 15894 | 116236 | 0.818 | 0.701 | 152 |
| Alnus glutinosa | rcp45 | 1488910 | 728048 | 2426411 | 0.735 | 0.544 | 9915 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Alnus incana | rcp45 | 1090066 | 357326 | 604509 | 0.701 | 0.606 | 6622 |
| Betula pendula | rcp45 | 1532567 | 298309 | 1107794 | 0.654 | 0.591 | 21822 |
| Betula pubescens | rcp45 | 1083016 | 598609 | 651445 | 0.793 | 0.307 | 28108 |
| Carpinus betulus | rcp45 | 2882069 | 2104990 | 3191820 | 0.764 | 0.538 | 13408 |
| Carpinus orientalis | rcp45 | 1444811 | 691092 | 1882905 | 0.9 | 0.562 | 175 |
| Castanea sativa | rcp45 | 963170 | 700318 | 1508203 | 0.753 | 0.597 | 8929 |
| Celtis australis | rcp45 | 1672645 | 1401384 | 2740300 | 0.865 | 0.319 | 155 |
| Cupressus sempervirens | rcp45 | 1149544 | 692279 | 1621219 | 0.729 | 0.394 | 199 |
| Fagus orientalis | rcp45 | 299886 | 52552 | 251959 | 0.954 | 0.471 | 57 |
| Fagus sylvatica | rcp45 | 1400414 | 448508 | 1058790 | 0.68 | 0.590 | 35610 |
| Fraxinus angustifolia | rcp45 | 1346725 | 1091065 | 2062007 | 0.748 | 0.636 | 1029 |
| Fraxinus excelsior | rcp45 | 1767154 | 753690 | 2259417 | 0.664 | 0.601 | 17724 |
| Fraxinus ornus | rcp45 | 1649972 | 743285 | 1707184 | 0.843 | 0.564 | 2130 |
| Juglans regia | rcp45 | 2440022 | 1960352 | 3013701 | 0.851 | 0.353 | 177 |
| Juniperus thurifera | rcp45 | 6997 | 809 | 4283 | 0.94 | 0.620 | 1681 |
| Larix decidua | rcp45 | 503387 | 77287 | 356479 | 0.756 | 0.610 | 8380 |
| Laurus nobilis | rcp45 | 663661 | 317403 | 970350 | 0.926 | 0.407 | 113 |
| Malus sylvestris | rcp45 | 3056886 | 1973139 | 2952766 | 0.548 | 0.522 | 552 |
| Ostrya carpinifolia | rcp45 | 405741 | 119121 | 382461 | 0.896 | 0.604 | 1539 |
| Picea abies | rcp45 | 2243534 | 1197626 | 1314931 | 0.731 | 0.443 | 71616 |
| Picea omorika | rcp45 | 283635 | 4308 | 81635 | 0.818 | 0.548 | 129 |
| Pinus brutia | rcp45 | 837144 | 686630 | 1524657 | 0.964 | 0.462 | 137 |
| Pinus cembra | rcp45 | 238680 | 41176 | 200616 | 0.968 | 0.449 | 354 |
| Pinus halepensis | rcp45 | 113131 | 40094 | 199433 | 0.901 | 0.666 | 11452 |
| Pinus nigra | rcp45 | 441926 | 44043 | 127998 | 0.725 | 0.550 | 9992 |
| Pinus pinaster | rcp45 | 132603 | 43006 | 114109 | 0.828 | 0.659 | 14815 |
| Pinus pinea | rcp45 | 301952 | 167679 | 355333 | 0.898 | 0.713 | 3879 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pinus sylvestris | rcp45 | 1508830 | 455866 | 685033 | 0.634 | 0.570 | 74814 |
| Populus alba | rcp45 | 3297879 | 2884554 | 4402608 | 0.739 | 0.415 | 594 |
| Populus canescens | rcp45 | 1934279 | 1128613 | 2574482 | 0.862 | 0.440 | 555 |
| Populus nigra | rcp45 | 2655240 | 2213031 | 3535492 | 0.746 | 0.411 | 2119 |
| Populus tremula | rcp45 | 2565145 | 1292342 | 1875434 | 0.462 | 0.499 | 10722 |
| Prunus avium | rcp45 | 2148773 | 1266707 | 2583671 | 0.669 | 0.600 | 5733 |
| Prunus padus | rcp45 | 649556 | 18266 | 418909 | 0.699 | 0.600 | 1210 |
| Pyrus pyraster | rcp45 | 2049490 | 1683051 | 2666476 | 0.803 | 0.415 | 579 |
| Quercus cerris | rcp45 | 1992203 | 1363938 | 2555883 | 0.863 | 0.565 | 3828 |
| Quercus coccifera | rcp45 | 449156 | 192695 | 541747 | 0.815 | 0.460 | 64 |
| Quercus faginea | rcp45 | 48407 | 2551 | 43003 | 0.813 | 0.677 | 4779 |
| Quercus frainetto | rcp45 | 2102530 | 1794276 | 2964072 | 0.912 | 0.312 | 466 |
| Quercus ilex | rcp45 | 369723 | 106683 | 273383 | 0.815 | 0.697 | 20867 |
| Quercus petraea | rcp45 | 1766702 | 801446 | 1859120 | 0.734 | 0.653 | 17329 |
| Quercus pubescens | rcp45 | 1124862 | 553535 | 1300933 | 0.794 | 0.564 | 8448 |
| Quercus pyrenaica | rcp45 | 80585 | 21657 | 60472 | 0.832 | 0.583 | 5410 |
| Quercus robur | rcp45 | 2916677 | 2341617 | 3809380 | 0.67 | 0.516 | 30769 |
| Quercus suber | rcp45 | 343424 | 126540 | 210336 | 0.898 | 0.540 | 5453 |
| Salix alba | rcp45 | 2704477 | 2175841 | 3651156 | 0.769 | 0.520 | 718 |
| Salix caprea | rcp45 | ------ | ------ | ------ | ------ | ------ | 6796 |
| Salix fragilis | rcp45 | 3099393 | 2527488 | 3779070 | 0.692 | 0.438 | 127 |
| Sorbus aria | rcp45 | 160874 | 26115 | 312927 | 0.754 | 0.643 | 2114 |
| Sorbus aucuparia | rcp45 | 974168 | 391414 | 689861 | 0.645 | 0.589 | 10881 |
| Sorbus domestica | rcp45 | 2789471 | 2294433 | 3990725 | 0.693 | 0.241 | 281 |
| Sorbus torminalis | rcp45 | 1531631 | 728533 | 2490936 | 0.776 | 0.650 | 1629 |
| Taxus baccata | rcp45 | 809969 | 556516 | 1037706 | 0.743 | 0.355 | 425 |
| Tilia cordata | rcp45 | 2206331 | 1444774 | 2215235 | 0.763 | 0.508 | 2810 |
| Tilia platyphyllos | rcp45 | 2797341 | 2172526 | 3464879 | 0.733 | 0.422 | 1105 |

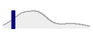
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tilia tomentosa | rcp45 | 916714 | 584850 | 1558329 | 0.972 | 0.308 | 186 |
| Ulmus glabra | rcp45 | 2691819 | 1550330 | 2571985 | 0.576 | 0.426 | 924 |
| Ulmus laevis | rcp45 | 1886922 | 811837 | 1520469 | 0.863 | 0.401 | 175 |
| Ulmus minor | rcp45 | 3106467 | 2831318 | 4116684 | 0.75 | 0.443 | 1854 |

Supplementary Table 9: Number of tree species with different potential to contribute to three important objectives of forest management.

| Potential | Contribution to… | | |
|---|---|---|---|
| | timber production | carbon uptake and storage | habitat value |
| High | 25 | 19 | 15 |
| Medium | 36 | 44 | 47 |
| Low | 9 | 7 | 8 |

Supplementary Table 10: Individual tree species profiles.

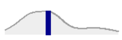
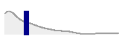
## Abies alba

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 600 |  | *$Height_{max}$* | 65 |  | *Density* | 0.5 |  |
| *STOL* | 4.6 |  | *PSR* | 5.32 |  | *$N_{lepidoptera}$* | 48 |  |

Abies alba is a large conifer that is common in Central Europe and some parts of Eastern and Southern Europe. It is a very tall tree that forms large trunks with little taper. A. alba is very shade tolerant and can form dense stands or grow in the understory of other tree species. The wood is lightly colors, has no resin ducts and is of medium density. It is currently used mainly for construction lumber, plywood and other purposes.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Acer campestre

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 200 |  | *$Height_{max}$* | 22 |  | *Density* | 0.58 |  |
| *STOL* | 3.18 |  | *PSR* | 9.5 |  | *$N_{lepidoptera}$* | 54 |  |

Acer campestre is a medium sized broadleaved tree that is common throughout many parts of Europe with the exception of Fennoscandinavia. It forms medium-sized trees which can reach considerable diameters, but often only occurs as shrub or understory species. A. campestre has moderate shade tolerance and only reaches moderate age. The wood is white, hard and strong, and is used for furniture or instruments when sizable lumber is available. However, due to the small dimensions A. campestres most common used is currently fuel wood.
*References:* [1,2,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Acer monspessulanum

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA |  | *$Height_{max}$* | 12 |  | *Density* | 0.83 |  |
| *STOL* | 2.66 |  | *PSR* | 9.39 |  | *$N_{lepidoptera}$* | 8 |  |

Acer monspessulanum is a small broadleaved tree occuring in southern Europe at the border between the Mediterranean biom and the warm-temperate biome. It is of small stature (frequently occuring as shrub or small tree) and of relatively low shade tolerance. The wood is redish in color and has the highest hardness and density of all Acer species. Because of its low stature the A. monspessulanum is not traded or used as lumber, but is of importance for revegetating degraded sites in southern Europe, and also has high energy content when used as fuel wood.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Acer opalus

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 20 | | *Density* | 0.71 | |
| *STOL* | 3.48 | | *PSR* | 7.43 | | *$N_{lepidoptera}$* | 2 | |

Acer opalus is a small- to medium-sized broadleaved tree occuring in Southern and South-Eastern Europe. It can form sizeable trunks of >100cm in diameter, but usually remains a small tree that occurs in mixed stands. The wood is of redish yellow color and the wood density is high. The wood is used in furniture and for decorative purposes, but it also can be glue-laminated or used for charcoal and fuel wood.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **low** |

## Acer platanoides

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 600 | | *$Height_{max}$* | 35 | | *Density* | 0.56 | |
| *STOL* | 4.2 | | *PSR* | 6.75 | | *$N_{lepidoptera}$* | 52 | |

Acer platanoides is a large broadleaved tree common in Central Europe and extending east all the way to the Ural mountains. It forms sizeable stems and large crowns and is fairly shade-tolerant. It usually occurs in mixed stands with other hardwoods. The wood is lightly colored and is moderately dense, tough, and elastic. It can be used for turned objects and instruments, but also as veneer.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Acer pseudoplatanus

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 600 | | *$Height_{max}$* | 35 | | *Density* | 0.52 | |
| *STOL* | 3.73 | | *PSR* | 7.1 | | *$N_{lepidoptera}$* | 55 | |

Acer pseudoplatanus is a large broadleaved tree common to Central, Southern, and Eastern Europe. It forms sizeable stems, has a medium to long lifespan and is fairly shade tolerant. The wood is light and moderately dense, and can be used for veneer, furniture, and other wooden objects. Curly and quilted grain patterns are highly priced for decorative uses.
*References:* [1,2,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

# Acer tataricum

| | | | | | |
|---|---|---|---|---|---|
| *$Age_{max}$* | NA | *$Height_{max}$* | 8 | *Density* | NA |
| *STOL* | 3.48 | *PSR* | NA | *$N_{lepidoptera}$* | 10 |

Acer tataricum is a small broadleaved tree of dry-continental areas in South-Eastern Europe. It often grows as shrub or forms irregular and multiple stems. Shade-tolerance is moderate and A. tataricum forms narrow crowns when grown in shade. The wood density is intermediate, and the wood is mostly used for fuel wood.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **medium** |

# Aesculus hippocastanum

| | | | | | |
|---|---|---|---|---|---|
| *$Age_{max}$* | NA | *$Height_{max}$* | 30 | *Density* | 0.49 |
| *STOL* | 3.43 | *PSR* | 11.49 | *$N_{lepidoptera}$* | 8 |

Aesculus hippocastanum is a sizeable tree native to the mountains of the Balkan penninsular, but widely distributed throughout as ornamental tree in parks and gardens. It forms large-diameter stems and can grow to moderate age. The wood is creamy white or yellowish brown and of moderate density. It can be used as veneer, furniture and plywood, but its durability is low.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

# Alnus cordata

| | | | | | |
|---|---|---|---|---|---|
| *$Age_{max}$* | NA | *$Height_{max}$* | 30 | *Density* | 0.39 |
| *STOL* | NA | *PSR* | NA | *$N_{lepidoptera}$* | 0 |

Alnus cordata is a medium-sized broadleaved tree native to Italy and Corsica. It is a fast-growing pionier species that is able to fix nitrogen, and can reach diameters of up to 80 cm. The wood is bright orange in color and of low density and durability (unless when used under water). It was traditionally used for fire wood in coppice systems, but can also be used for carpentry and furniture.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

# Alnus glutinosa

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 150 | | *$Height_{max}$* | 30 | | *Density* | 0.45 | |
| *STOL* | 2.71 | | *PSR* | 6 | | *$N_{lepidoptera}$* | 138 | |

Alnus glutinosa is a medium-sized tree that can be found all across Europe with the exception of the very far North. It is fast-growing but short-lived, and is often found along lake shores and river banks. It is a nitrogen fixing species that has soft wood of light tan or redish color. Density and durability are low, except when used under water. The wood has been used for funiture and veneers. A. glutinosa has been managed in coppice systems for fuel wood and also yields high quality charcoal.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

# Alnus incana

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 50 | | *$Height_{max}$* | 30 | | *Density* | 0.48 | |
| *STOL* | 2.3 | | *PSR* | 7.2 | | *$N_{lepidoptera}$* | 163 | |

Alnus incarna is a medium-sized broadleaved tree of Central and Northern Europe. As a. glutinosa it is fast-growing but short-lived, and is often found along lake shores and river banks. It is more frost-tolerant than A. glutinosa, but tends to occur as smaller and often multi-stemmed tree or shrub. It is a nitrogen fixing species that has soft wood of light tan or redish color. Density and durability are low, except when used under water. The wood has little commercial value but can be used for fuel wood and charcoal production.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

# Betula pendula

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 120 | | *$Height_{max}$* | 30 | | *Density* | 0.61 | |
| *STOL* | 2.03 | | *PSR* | 10.66 | | *$N_{lepidoptera}$* | 253 | |

Betula penudla is a medium-sized tree that is distributed widely in Central and Northern Europe, but is mostly confined to mountain ranges in Southern Europe. It is a short-lived, fast-growing pioneer species that is light-demanding and able to colonize extreme sites, yet is not particularly drought tolerant. B. pendula forms light canopies that are often invaded by more shade-tolerant species, which eventually outcompete it. It is an important hardwood species particularly in Northern Europe. Its light-colored wood is widely used for plywood and veneer. It is also frequently grown in cities and can be used for reclaimation of contaminated sites.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

# Betula pubescens

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 120 | | $Height_{max}$ | 30 | | *Density* | 0.58 | |
| *STOL* | 1.85 | | *PSR* | 11.75 | | $N_{lepidoptera}$ | 155 | |

Betula pubsecens is a medium-sized tree of Central and Northern Europe. Compared to B. pendula B.pubescens is even less drought tolerant, limiting its southern distribution, yet it is more frost tolerant, allowing it to colonize higher latitudes than B. pendula. It is a short-lived, fast-growing pioneer species that is light-demanding. B. pubsecens often is one of the first species colonizing a site, yet is eventually outcompeted by more shade-tolerant species. Its wood is light reddish-brown and of lower value compared to B. pendula. It is currently mostly used as fuelwood or for pulp production.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

## Carpinus betulus

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 250 | | $Height_{max}$ | 25 | | *Density* | 0.66 | |
| *STOL* | 3.97 | | *PSR* | 6.82 | | $N_{lepidoptera}$ | 107 | |

Carpinus betulus is a medium-sized tree that occurs in temperate Europe from the Pyrenees to southern Sweden. It is often associated with oak-forests, where it forms a fairly shade-tolerant understory. C. betulus is a strong resprouter, which makes it an important component in coppice and coppice with standards forests. Its wood is white, hard, dense and strong. Yet, stems tend to have irregular forms and it shrinks strongly when drying, limiting its uses as sawn wood.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

## Carpinus orientalis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 5 | | *Density* | NA | |
| *STOL* | NA | | *PSR* | NA | | $N_{lepidoptera}$ | 0 | |

Carpinus orientalis is a large shrub or small tree occuring on steep slopes of South-Eastern Europe. It is a light-demanding pinoeer species that resprouts well after disturbance. Hence it is often managed in coppice systems. The wood of C. orientalis is hard and strong, yet rarely reaches dimensions that allow material uses. Consequently, C. orientalis is mainly used for fuel wood and charcoal production.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Castanea sativa

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 30 | | *Density* | 0.56 | |
| *STOL* | 3.15 | | *PSR* | 6.96 | | $N_{lepidoptera}$ | 26 | |

Castanea sativa is a tall tree occuring naturally around the Mediterranean sea that has been planted widely as ornamental also in Central and Western Europe. It is a long-lived species that can reach substantial diameters of several meters. The wood is a light to medium brown with a very high tannin content, making it very durable. C. sativa is a species of multiple uses: It is a valuable timber species (furniture, veneers) that can be grown in high forests, but also resprouts well when managed for fuelwood in coppice systems. Furthermore, fruit production is another important usage of C. sativa.

*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Cedrus atlantica

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 50 | | *Density* | 0.47 | |
| *STOL* | NA | | *PSR* | NA | | *$N_{lepidoptera}$* | 4 | |

Cedrus atlantica is a tall conifer that naturally occurs in mountainous regions of northern Africa, yet was frequently cultivated as ornamental in Southern Europe. It is of intermediate shade tolerance and is long-lived and can reach diameters of >100cm. The wood is dark-brown and can be used for furniture, veneers and in construction.

*References:* [1,4]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **low** |

## Celtis australis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 25 | | *Density* | 0.53 | |
| *STOL* | NA | | *PSR* | 3.48 | | *$N_{lepidoptera}$* | 12 | |

Celtis australis is a medium-sized tree of Southern Europe, occuring aournd the Mediterranean Basin. It is a thermophile species occuring in mixed deciduous forests and can reach sizeable stem diameters >100 cm. The wood is greyish-white, heavy and elastic. It is fairly resistant to rot and has been used for furniture, instruments, and other wooden objects. It also resprouts vitaly and is used for fuelwood and charcoal production.

*References:* [1,2]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **low** |

## Cupressus sempervirens

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 30 | | *Density* | 0.53 | |
| *STOL* | 1.35 | | *PSR* | NA | | *$N_{lepidoptera}$* | 0 | |

Cupressus sempervirens is a medium-sized conifer native to the Eastern Mediterranean. Is is a fast-growing, light-demanding pinoeer that is long-lived and can reach diameters of >100 cm. Its wood is yellowish-brown and has been used widely from utility lumber to furniture, musical instruments and turned objects. The species has a long history of human use and exploitation and is also widely used as an ornamental in gardens and parks.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **low** |

## Fagus orientalis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 40 | | *Density* | NA | |
| *STOL* | 4.2 | | *PSR* | NA | | *$N_{lepidoptera}$* | 0 | |

Fagus orientalis is a medium to large deciduous tree that is native mainly around the Black Sea. It is very shade tolerant and can reach diameters of >100 cm. It's wood is reddish brown, fairly dense and heavy. Fagus orientalis' main use is currently fuelwood, but it can also be used for particleboards, furniture, veneer as well as paper.
*References:* [1,2,7]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Fagus sylvatica

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 900 | | *$Height_{max}$* | 45 | | *Density* | 0.68 | |
| *STOL* | 4.56 | | *PSR* | 6.9 | | *$N_{lepidoptera}$* | 111 | |

Fagus sylvatica is a large deciduous tree that occurs throughout Europe, with the exception of northern Fennoscandinavia and southwestern Europe. It is very shade-tolerant and able to form dense and dark canopies, reaching diameters of >100 cm. With its dense, homogeneous, cream-reddish wood Fagus sylvatica is one of the most diversely used tree species in Europe, with over 250 documented uses. It is used for flooring, furniture, musical instruments, plywood, panels, veneering and cooking utensils, amongst others. It is also used for paper and can be coppiced for fuelwood and charcoal production.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **high** |

## Fraxinus angustifolia

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 25 | | *Density* | 0.52 | |
| *STOL* | NA | | *PSR* | 19.28 | | *$N_{lepidoptera}$* | 0 | |

Fraxinus angustifolia is a medium-sized tree distributed throughout Southern Europe. It is a fast-growing pioneer species that can reach diameters of >100 cm. The wood likens that of Fraxinus excelsior but is of lower strength and elasticity. Due to its fast growth Fraxinus angustifolia is used in plantations, producing wood for the pulp and paper industry. It can, however, also be used for plywood production and glue-laminated timber.
*References:* [1,2]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Fraxinus excelsior

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 300 | | $Height_{max}$ | 40 | | *Density* | 0.65 | |
| *STOL* | 2.66 | | *PSR* | 9.57 | | $N_{lepidoptera}$ | 68 | |

Fraxinus excelsior is a medium-sized tree that grows throughout the temperate forests of Europe. It has intermediate shade tolerance and a wide fundamental niche, growing on dry calcareous sites as well as on wet lowland soils. The wood is light to medium brown, elastic, hard, and resistant to shock and splintering. It has a wide range of uses, from flooring and furniture to millwork and turned objects (e.g., tool handles).
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Fraxinus ornus

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 20 | | *Density* | NA | |
| *STOL* | 3.02 | | *PSR* | 4.71 | | $N_{lepidoptera}$ | 0 | |

Fraxinus ornus is a small to medium-sized tree native to South-Eastern Europe. It is a pioneer species that rarely grows beyond 100 years of age. While the timber quality is generally comparable to that of the other European ash species, it is rarely used as a timber species due to low dimensions and irregularily growing stems. It's main current use is to produce firewood in coppice systems.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **low** |

## Juglans regia

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 50 | | *Density* | 0.55 | |
| *STOL* | 2.27 | | *PSR* | 14.35 | | $N_{lepidoptera}$ | 26 | |

Juglans regia is a large deciduous tree that was introduced from Asia already more than two Millenia ago and is widespread in Southern and Central Europe. It is fairly light-demanding and can reach diameters of >100 cm. Widely cultivated because of its nuts Juglans regia also has one of the most valuable woods in Europe. It is chocolate brown, strong and easy to work with. It is used for furniture, veneer, and turned objects, among others.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Juniperus thurifera

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 15 | | *Density* | 0.53 | |
| *STOL* | NA | | *PSR* | NA | | $N_{lepidoptera}$ | 4 | |

Juniperus thurifera is a small conifer native to the Western Mediterranean basin. It is light-demanding and forms sparse canopies. Juniperus thurifera is mainly used as fuelwood, but also construction and furniture uses are reported.
*References:* [1,2]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **low** | *Biodiversity* | **low** |

## Larix decidua

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 600 | | $Height_{max}$ | 50 | | *Density* | 0.51 | |
| *STOL* | 1.46 | | *PSR* | 7.32 | | $N_{lepidoptera}$ | 54 | |

Larix decidua is a tall, deciduous conifer that is native to the mountains of Central Europe. It is a long-lived pioneer species that is very light-demanding, grows fast and can reach diameters of >100 cm. The heartwood is medium brown and has high tannin content, making it very durable. It is frequently used in construction, but is also a valuable pulpwood species.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Laurus nobilis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 12 | | *Density* | 0.67 | |
| *STOL* | NA | | *PSR* | NA | | $N_{lepidoptera}$ | 4 | |

Laurus nobilis is a small tree or large shrub that is evergreen and native to the Mediterranean basin. It is a very light-demanding species that has also been widely cultivated as ornamental. The wood is rarely used, and the species is mainly valued for its leaves and fruits.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **low** |

## Malus sylvestris

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | NA | $Height_{max}$ | 10 | *Density* | 0.6 |
| *STOL* | 2.32 | *PSR* | 10.79 | $N_{lepidoptera}$ | 67 |

Malus sylvestris is a small tree potentially distributed throughout temperate Europe yet exceedingly rare in Europe's forests and woodlands. It is light-demanding and thus often occuring in open forests or along permanent edges. The light reddish brown wood is dense yet shrinks strongly. It can be used for turned objects or fuelwood.
*References:* [1,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Ostrya carpinifolia

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | NA | $Height_{max}$ | 20 | *Density* | NA |
| *STOL* | 3.94 | *PSR* | NA | $N_{lepidoptera}$ | 4 |

Ostry carpinifolia is a small to medium-sized broadleaved tree native to South-Eastern Europe. At ist northern range limit it is highly light-demanding while growing in intermediate shade in the south. The wood is light-colored, hard and dense. It can be used for turned objects, yet tends to crack when dried. Its most common use is for fuelwood, often managed in coppice systems.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Picea abies

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | 300 | $Height_{max}$ | 60 | *Density* | 0.46 |
| *STOL* | 4.45 | *PSR* | 8.83 | $N_{lepidoptera}$ | 68 |

Picea abies is a tall conifer that is native to Central European mountains as well as Fennoscandinavia. It is moderately shade tolerant, and forms dense canopies in which individuals can reach diameters >100 cm. It is currently one of the most important timber species in Europe. The wood is creamy white, and the boles are usually straight and regular. It can be used for timber construction, pulpwood, furniture and instruments, amongst other uses.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Picea omorika

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | NA | $Height_{max}$ | 40 | *Density* | NA |
| *STOL* | 4.65 | *PSR* | NA | $N_{lepidoptera}$ | 4 |

Picea omorika is a tall conifer species that today only occurs in a small area at the border between Serbia and Bosnia Herzegowina, yet was widely distributed throughout Europe prior to the last glacial period. It is shade tolerant and has columnar, slender and dense crowns, reaching diameters of >100 cm. The wood is very similar to that of Picea abies, and can be used for construction as well as for pulp production. It is also often used as an ornamental in cities, because of its high tolerance to air pollution.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus brutia

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 35 | | *Density* | NA | |
| *STOL* | NA | | *PSR* | NA | | *$N_{lepidoptera}$* | 0 | |

Pinus brutia is a tall conifer that is native to the Eastern Mediterranean. It is a light-demanding early seral species that regenerates vigorously after fire. It is fast-growing and forms open canopies that favor dense undergrowth. The wood of Pinus brutia is of medium quality, but is used for construction puroposes, as pulp wood as well as for fuelwood.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus cembra

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 500 | | *$Height_{max}$* | 25 | | *Density* | 0.47 | |
| *STOL* | 2.87 | | *PSR* | 5.44 | | *$N_{lepidoptera}$* | 16 | |

Pinus cembra is an medium-sized conifer native to the subalpine zone of the European Alps with isolated occurences also in the Carpathian mountains. It is slow-growing and long-lived and can reach diameters >100cm. The heartwood is reddish and has a strong aromatic odor. Where Pinus cembra forms regular trunks the wood is of high quality and is used for furniture making and construction.
*References:* [1,2,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus halepensis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 25 | | *Density* | 0.61 | |
| *STOL* | 1.35 | | *PSR* | 6.38 | | *$N_{lepidoptera}$* | 16 | |

Pinus halepensis is a medium-sized conifer that is native around the Mediterranean basin. It is fast-growing, light-demanding and regenerates vigorously after fire via serotinous cones. The heartwood is reddish-brown. The species is of limited timber value due to its size, shape and relatively poor wood quality. It is, however, used as pulpwood and firewood.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus nigra

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 50 | | *Density* | 0.61 | |
| *STOL* | 2.1 | | *PSR* | 16.79 | | $N_{lepidoptera}$ | 26 | |

Pinus nigra is a tall conifer that has a wide but fragmented natural distribution across Southern and Central Europe. It is light-demanding and able to colonize extreme sites, where it forms light canopies with oftentimes dense undergrowth. The heartwood is light reddish brown and rich in resin. Pinus nigra can be used for furniture, as construction lumber as well as pulpwood.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus pinaster

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 35 | | *Density* | 0.51 | |
| *STOL* | NA | | *PSR* | 9.54 | | $N_{lepidoptera}$ | 14 | |

Pinus pinaster is a tall conifer native to the Western Mediterranean. It is light-demanding, fast-growing and relatively short lived. The heartwood is light reddish brown and rich in resin. The wood is of medium quality and can be used for construction wood, furniture, poles and posts as well as for pulpwood.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus pinea

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 25 | | *Density* | 0.59 | |
| *STOL* | NA | | *PSR* | 8.21 | | $N_{lepidoptera}$ | 24 | |

Pinus pinea is a medium-sized tree occuring natively in scattered populations around the Mediterranean Sea. It is light-demanding and not very long-lived. The wood is rich in resin and yellow-brown. It can be used for construction timber and poles. The main economic use of the species is for the production of pine nuts.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Pinus sylvestris

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 711 | | $Height_{max}$ | 45 | | *Density* | 0.54 | |
| *STOL* | 1.67 | | *PSR* | 9.75 | | $N_{lepidoptera}$ | 70 | |

Pinus sylvestris is a tall conifer that is widely distributed throughout Europe, occuring from the Iberian penninsular all the way across Eurasia. It is long-lived, light-demanding and forms a light canopies. The wood is light reddish-brown and has a good strength-to-weight ratio. It is currently one of the commercially most important tree species in Europe, used for construction wood, furniture, and as pulp wood.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

# Populus alba

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 35 | | *Density* | 0.45 | |
| *STOL* | 2.3 | | *PSR* | 18.45 | | *$N_{lepidoptera}$* | 56 | |

Populus alba is a tall broadleaved tree that occurs along rivers and coasts of Central and Southern Europe. It is a fast-growing and light-demanding, reaches diameters of >100 cm and reproduces primarily from root suckers. The wood is not very valuable as it is light, soft, not durable and of low flammability. It can, however, be used as pulpwood and for packaging material (crates), amongst other uses
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

# Populus canescens

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | NA | | *Density* | 0.4 | |
| *STOL* | NA | | *PSR* | NA | | *$N_{lepidoptera}$* | 12 | |

Populus canescens is a natural hybrid of Populus tremula and Populus alba that occurs in floodplain forests and along rivers in Central and Southern Europe. It is a fast-growing pioneer species that is highly light-demanding. The wood is comparable to that of Populus alba, yet is more durable than the wood of many other Populus species.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

# Populus nigra

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 35 | | *Density* | 0.42 | |
| *STOL* | 2.46 | | *PSR* | 16.04 | | *$N_{lepidoptera}$* | 105 | |

Populus nigra is a tall broadleaved tree widely distributed throughout Europe (with the exception of Fennoscandinavia) and mainly occuring along rivers and in floodplain forests. It is a light-demanding species that is fast-growing and can reach diameters of > 100 cm. The wood is light brown, of low density and strength, yet of high shock resistance. It is used for furniture, packaging and as pulpwood.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **high** |

## Populus tremula

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 150 | | $Height_{max}$ | 35 | | *Density* | 0.5 | |
| *STOL* | 2.22 | | *PSR* | 16.14 | | $N_{lepidoptera}$ | 158 | |

Populus tremula is a tall broadleaved tree native to temperate and boreal Europe. It is a light-demanding, fast-growing and relatively short-lived pioneer species. Its wood is light brown and has low strength. It is used mainly as pulpwood but can also be used for construction as well as to produce veneers and charcoal.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

## Prunus avium

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 150 | | $Height_{max}$ | 30 | | *Density* | 0.59 | |
| *STOL* | 3.33 | | *PSR* | NA | | $N_{lepidoptera}$ | 42 | |

Prunus avium is a medium-sized broadleaved tree distributed widely throughout Central Europe. It is fast-growing and short-lived and can reach diameters of > 100 cm. The wood is reddish and of moderate to high density. It is highly valuable and used for panelling and cabinet making, veneers and musical instruments.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Prunus padus

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 18 | | *Density* | 0.47 | |
| *STOL* | 3.26 | | *PSR* | NA | | $N_{lepidoptera}$ | 105 | |

Prunus padus is a small broadleaved tree or shrub and is widely distributed throughout Central and Northern Europe. It is short-lived and able to regenerate vigoroulsy from sprouts. Due to its low dimensions and often shrubby growth form the wood of Prunus padus is of little commercial value.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **high** |

## Pyrus pyraster

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 20 | | *Density* | NA | |
| *STOL* | 2.26 | | *PSR* | NA | | $N_{lepidoptera}$ | 89 | |

Pyrus pyraster is a medium-sized broadleaved tree occuring in the warm-temperate forest types of Europe. It is relatively slow-growing, of moderate light demand and reaches intermediate age. The wood of Pyrus pyraster is dark reddish-brown and dense. It is highly priced for uses in instruments, as veneer, and for decorative purposes as well as turned objects.
*References:* [1,5,9]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

## Quercus cerris

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 35 | | *Density* | 0.77 | |
| *STOL* | 2.55 | | *PSR* | 12.1 | | $N_{lepidoptera}$ | 69 | |

Quercus cerris is a tall deciduous tree native to South-Eastern Europe. It is light-demanding and can reach large diameters, yet is relatively short-lived. Compared to other major Quercus species of Europe the wood is inferior in quality, as it has a tendency to crack. It is mainly used for shuttering and fuel wood (often in coppice systems).
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus coccifera

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 12 | | *Density* | 0.16 | |
| *STOL* | NA | | *PSR* | 9.17 | | $N_{lepidoptera}$ | 24 | |

Quercus coccifera is a shrub or small tree occuring around the Mediterranean basin, where it forms a typical component of Macchia shrublands. It is slow-growing and light-demanding. The wood is dense, yet of no commercial value because of the mainly shrubby growth form of Quercus coccifera.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **medium** |

## Quercus faginea

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 20 | | *Density* | 0.79 | |
| *STOL* | NA | | *PSR* | 14.11 | | $N_{lepidoptera}$ | 0 | |

Quercus faginea is a medium-sized broadleaved tree occuring on the Iberian Penninsula. It has intermediate light demand and grows usually in association with other Quercus species. It has slow growth and has generally low timber yield. The wood is dark-brown, dense, and durable. It is mostly used as fuel wood in coppice systems, or cultivated in agro-forestry systems to as a fruit tree to support livestock.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus frainetto

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 40 | | *Density* | NA | |
| *STOL* | NA | | *PSR* | NA | | $N_{lepidoptera}$ | 0 | |

Quercus frainetto is a large broadleaved tree native to South-Eastern Europe. It is light-demanding, relatively short-lived and can reach dimensions of up to 60 cm in diameter. The wood is very durable yet hard to work with. It is lighter in color than that of most other European oak species and is mostly used as fuel wood (coppice systems).
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus ilex

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 25 | | *Density* | 0.87 | |
| *STOL* | 3.02 | | *PSR* | 11.1 | | $N_{lepidoptera}$ | 60 | |

Quercus ilex is an evergreen shrub or medium-sized tree that is native to the Central and Western Mediterrenean basin. It is a dominant component of Macchia shrublands, but can reach sizeable dimensions (up to 200 cm in diameter) and is very long-lived. It is fairly shade-tolerant and regenerates well under canopy. The wood is light-brown, very dense, hard, and difficult to dry and carve and is mainly used for speciality items like tool handles. Other uses include firewood (coppice systems) and as fruit tree in agroforestry systems.
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus petraea

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 800 | | $Height_{max}$ | 40 | | *Density* | 0.71 | |
| *STOL* | 2.73 | | *PSR* | 11.04 | | $N_{lepidoptera}$ | 117 | |

Quercus petraea is a tall broadleaved tree common to the temperate forests of Europe. It is a tree of intermediate light demand that forms light canopies and favors the regeneration of associated species such as Carpinus betulus. Quercus petraea is able to reach high age and sizeable dimensions (diameters of > 100 cm). The wood is yellowish-brown, dense, and highly valuable. It is hard, durable, and used for a variety of purposes from furniture and floorboards to veneer and barrels. It can be managed as high forest or as coppice with standards.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **high** |

## Quercus pubescens

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 25 | | *Density* | 0.64 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *STOL* | 2.31 | | *PSR* | 7.96 | | $N_{lepidoptera}$ | 32 | |

Quercus pubescens is a mid-sized broadleaved tree that has a wide distribution across Southern and Central Europe. It is relatively light-demanding and is often associated with other Quercus species of Southern and Central Europe. Its wood is dense and durable. However, the timber value of Quercus pubescense is low because of its irregular stem forms. It is mainly used as fuel wood in coppice systems, and is also appreciated for its fruit crop.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus pyrenaica

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 20 | | *Density* | 0.77 | |
| *STOL* | NA | | *PSR* | 17.23 | | $N_{lepidoptera}$ | 2 | |

Quercus pyrenaica is a mid-sized broadleaved tree of the western Atlantic-Mediterranean region. It is a light-demanding tree of intermediate longevity that forms closed canopies. The wood is very dense and hard, but the species is generally not used as timber species because of its stature and irregular growth form. Because of its high resprouting capacity it is frequently used as fuelwood in coppice systems.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Quercus robur

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 500 | | $Height_{max}$ | 45 | | *Density* | 0.6 | |
| *STOL* | 2.45 | | *PSR* | 9.66 | | $N_{lepidoptera}$ | 280 | |

Quercus robur is a tall broadleaved tree common to the temperate forests of Europe. It is a tree of intermediate light demand that forms light canopies and is thus often associated with a number of admixed species. Quercus petraea is able to reach high age and sizeable dimensions (diameters of > 100 cm). The wood is yellowish-brown, dense, and highly valuable. It is hard, durable, and used for a variety of purposes from furniture and floorboards to veneer and barrels. It can be managed as high forest or as coppice with standards.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **high** |

## Quercus suber

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA | | $Height_{max}$ | 20 | | *Density* | 0.83 | |
| *STOL* | NA | | *PSR* | 14.34 | | $N_{lepidoptera}$ | 22 | |

Quercus suber is a medium-sized broadleaved tree native to the Western Mediterranean Basin. The species is light-demanding, of intermediate longevity and resistant to fire due to its thick bark. Harvesting the corky bark is an important use of the species that exceeds its relevance as timber species. The wood is brown, dense and durable. It is mostly used as fuelwood and is also valued in silviopastoral systems.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Salix alba

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 35 | | *Density* | 0.35 | |
| *STOL* | 1.99 | | *PSR* | NA | | *$N_{lepidoptera}$* | 73 | |

Salix alba is a tall broadleaved tree distributed throughout Europe with the exception of Fennoscandia and occurs mostly along rivers and in floodplain forests. It is fast-growing, light-demanding yet not very long-lived and can reach diameters of >100 cm. The heartwood is tan to pinkish brown and has very low density yet high shock resistance. It can be used for baskets (because of its pliable branches), for furniture and construction, and also as fuel wood (often in coppice systems).
*References:* [1,2,3,6]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Salix caprea

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 13 | | *Density* | 0.47 | |
| *STOL* | 2.16 | | *PSR* | 7.43 | | *$N_{lepidoptera}$* | 224 | |

Salix caprea is a small broadleaved tree distributed throughout Europe. It is a light-demanding, fast-growing and short-lived pioneer species that rarely reaches diameters > 40 cm. The wood is pinkish and of low density, strength, and durability. It is mainly used as fuelwood and for charcoal production.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **high** |

## Salix fragilis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 25 | | *Density* | 0.42 | |
| *STOL* | 1.42 | | *PSR* | 9.5 | | *$N_{lepidoptera}$* | 95 | |

Salix fragilis is a medium-sized broadleaved tree distributed widely throughout Europe and mainly growing along water bodies. It is fast-growing, light-demanding and short-lived. It's uses are similar to that of Salix alba (baskets, furniture, fuelwood), yet the usually smaller dimensions restrict its commercial exploitation.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **high** |

## Sorbus aria

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | NA | $Height_{max}$ | 25 | *Density* | 0.72 |
| *STOL* | 3 | *PSR* | NA | $N_{lepidoptera}$ | 28 |

Sorbus aria is a medium-sized broadleaved tree occuring in the mountains of Central, Southern and Western Europe. It has intermediate light demand and is a component of xero-thermophile deciduous forests, yet rarely reaches diameters >40 cm. The wood is reddish-brown, hard, tough and elastic. Because of its slow growth and limited dimensions there is very limited commercial use of the species.
*References:* [1,2,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Sorbus aucuparia

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | 60 | $Height_{max}$ | 18 | *Density* | 0.6 |
| *STOL* | 2.73 | *PSR* | 9.48 | $N_{lepidoptera}$ | 142 |

Sorbus aucuparia is a small tree occuring throughout Europe with the exception of the very south of the continent. It is of intermediate shade-tolerance and often occurs as pioneer after disturbance. The wood is reddish-brown, strong, hard and tough. It has been used for tool handles, turned objects and craftwork, yet its overall use as timber species is very limited.
*References:* [1,2,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **low** | *Carbon uptake and storage* | **low** | *Biodiversity* | **high** |

## Sorbus domestica

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | NA | $Height_{max}$ | 20 | *Density* | NA |
| *STOL* | 3.53 | *PSR* | NA | $N_{lepidoptera}$ | 0 |

Sorbus domestica is a medium-sized tree occuring in Central and Southern Europe. It is of intermediate shade-tolerance yet is a poor competitor in the warm-temperate broadleaved forest types it occurs in. The wood is reddish-brown, strong, hard and tough. It can command high prices if available in sizeable dimensions, and is used for carpentry and small objects that have to tolerate considerable amounts of friction (e.g., screws). Other uses include fruit production and ornamental use.
*References:* [1,2,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Sorbus torminalis

| | | | | | |
|---|---|---|---|---|---|
| $Age_{max}$ | 200 | $Height_{max}$ | 22 | *Density* | 0.66 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *STOL* | 3.38 | | *PSR* | NA | | $N_{lepidoptera}$ | 22 | |

Sorbus torminalis is a medium-sized broadleaved tree of Central and Southern Europe. It is fast growing, has intermediate light demand and can reach diameters of >100 cm. The wood is dark-red to brown, fine-grained, dense and has high bending strength. It is one of the most valuable hardwoods of Europe and is mostly used as veneer and in furniture making.
*References:* [1,2,3,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Taxus baccata

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 500 | | $Height_{max}$ | 20 | | *Density* | 0.62 | |
| *STOL* | 4.43 | | *PSR* | 4.47 | | $N_{lepidoptera}$ | 4 | |

Taxus baccata is a small- to mid-sized conifer that is naturally occuring throughout temperate and mediterranean ecosystems of Europe. It is extremely shade-tolerant, long-lived, slow-growing and has a high capacity to resprout. It often forms multiple stems yet can reach large diameters >100 cm due to its long lifespan. The wood is orange-brown, heavy yet elastic. While it was heavily used historically it is of little commercial relevance today, and mostly used for art pieces and turned objects.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **low** |

## Tilia cordata

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 400 | | $Height_{max}$ | 30 | | *Density* | 0.45 | |
| *STOL* | 4.18 | | *PSR* | 10.49 | | $N_{lepidoptera}$ | 83 | |

Tilia cordata is a tall broadleaved tree that occurs throughout Europe with the exception of the very North and the very South of the continent. It can tolerate a fair amount of shade, is able to resprout vigorously, is very long-lived and can reach sizable dimensions of diameters >100 cm. The wood is light reddish in color, soft, and resistant to splitting. It is favored for carving and used for musical instruments. It would also be suitable as pulpwood and for particle boards, but currently has little commercial importance.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Tilia platyphyllos

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | 350 | | $Height_{max}$ | 40 | | *Density* | 0.43 | |
| *STOL* | 4 | | *PSR* | 7.12 | | $N_{lepidoptera}$ | 28 | |

Tilia platyphyllos is a tall broadleaved tree that occurs mainly in Central and Eastern Europe. It can tolerate a fair amount of shade, is able to resprout vigorously, is very long-lived and can reach sizable dimensions of diameters >100 cm. The wood properties and usage is similar to Tilia cordata: The wood is light reddish in color, soft, and resistant to splitting. It is favored for carving and used for musical instruments. It would also be suitable as pulpwood and for particle boards, but currently has little commercial importance.
*References:* [1,2,3,6,8]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Tilia tomentosa

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | NA | | *$Height_{max}$* | 30 | | *Density* | NA | |
| *STOL* | 3.34 | | *PSR* | NA | | *$N_{lepidoptera}$* | 0 | |

Tilia tormentosa is a tall broadleaved tree occuring in Eastern and South-Eastern Europe. It tolerates a fair amount of shade when young but becomes more light-demanding with age. It is of smaller stature than the other European Tillia species and comparably short-lived. The wood is yellowish-white and very light. It can be used for carving as well as for furniture.
*References:* [1,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **medium** | *Biodiversity* | **medium** |

## Ulmus glabra

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 400 | | *$Height_{max}$* | 40 | | *Density* | 0.6 | |
| *STOL* | 3.53 | | *PSR* | 9.58 | | *$N_{lepidoptera}$* | 58 | |

Ulmus glabra is a tall broadleaved tree occuring throughout the temperate and hemiboreal forests of Europe. It is of intermediate shade-tolerance, able to resprout and is a common component in temperate mixed broadleaved forests. Its wood is light to medium brown and of good quality for furnitur, flooring and as firewood.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Ulmus laevis

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *$Age_{max}$* | 400 | | *$Height_{max}$* | 35 | | *Density* | 0.6 | |
| *STOL* | 3.67 | | *PSR* | NA | | *$N_{lepidoptera}$* | 10 | |

Ulmus laevis is a tall broadleaved tree occuring throughout the temperate forests of Europe, from Central France to the Ural mountains. It is of intermediate shade-tolerance, able to resprout and is a common component in temperate broadleaved forests. Its heartwood is light to medium brown, and the light sapwood takes up ~2/3 of the stem. Its wood is of lower quality as that of Ulmus glabra and Ulmus minor. Its uses are nonetheless fairly similar.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **medium** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

## Ulmus minor

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $Age_{max}$ | NA |  | $Height_{max}$ | 40 |  | *Density* | 0.59 |  |
| *STOL* | 3.36 |  | *PSR* | NA |  | $N_{lepidoptera}$ | 0 |  |

Ulmus minor is a medium-sized to tall broadleaved tree occuring in Southern and Central Europe all the way to the Baltic Sea. It is of intermediate shade-tolerance, able to resprout and is a common component in temperate mixed broadleaved forests. Its wood is light to medium brown and of good quality for furnitur, flooring and as firewood.
*References:* [1,2,3]

| | | | | | |
|---|---|---|---|---|---|
| *Wood value* | **high** | *Carbon uptake and storage* | **high** | *Biodiversity* | **medium** |

List of references


```
## [1] "TRY"
## [2] "JRC 2016"
## [3] "Schütt et al. 2006"
## [4] "Seho (2019)"
## [5] "Grosser https://www.lwf.bayern.de/forsttechnik-holz/holzverwendung/069700/index.ph
p"
## [6] "Meier 2021"
## [7] "Kandemir and Kaya (2009)"
## [8] "Grabner 2017"
## [9] "Häne https://www.waldwissen.net/de/lebensraum-wald/baeume-und-waldpflanzen/laubbae
ume/die-wildbirne-pyrus-pyraster"
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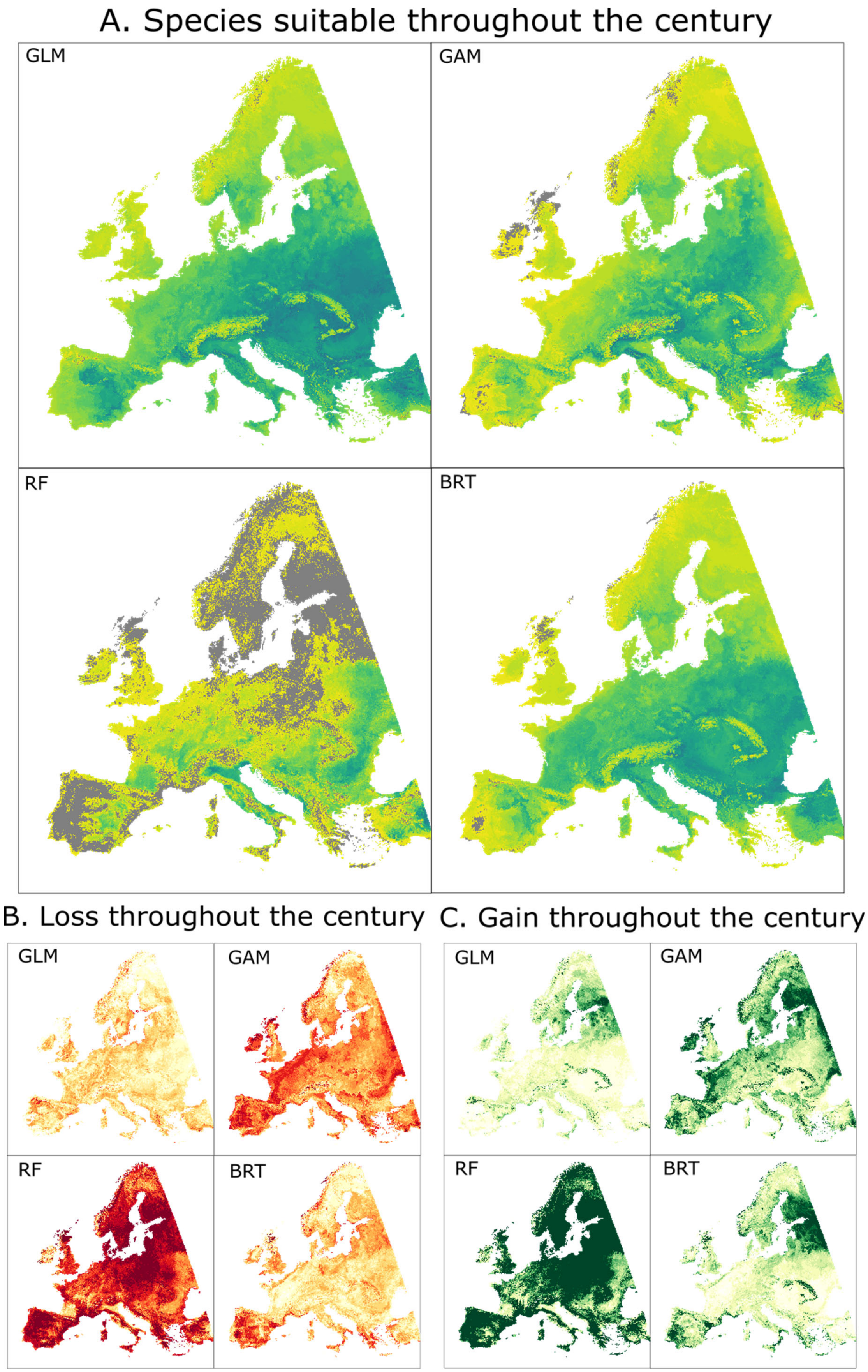
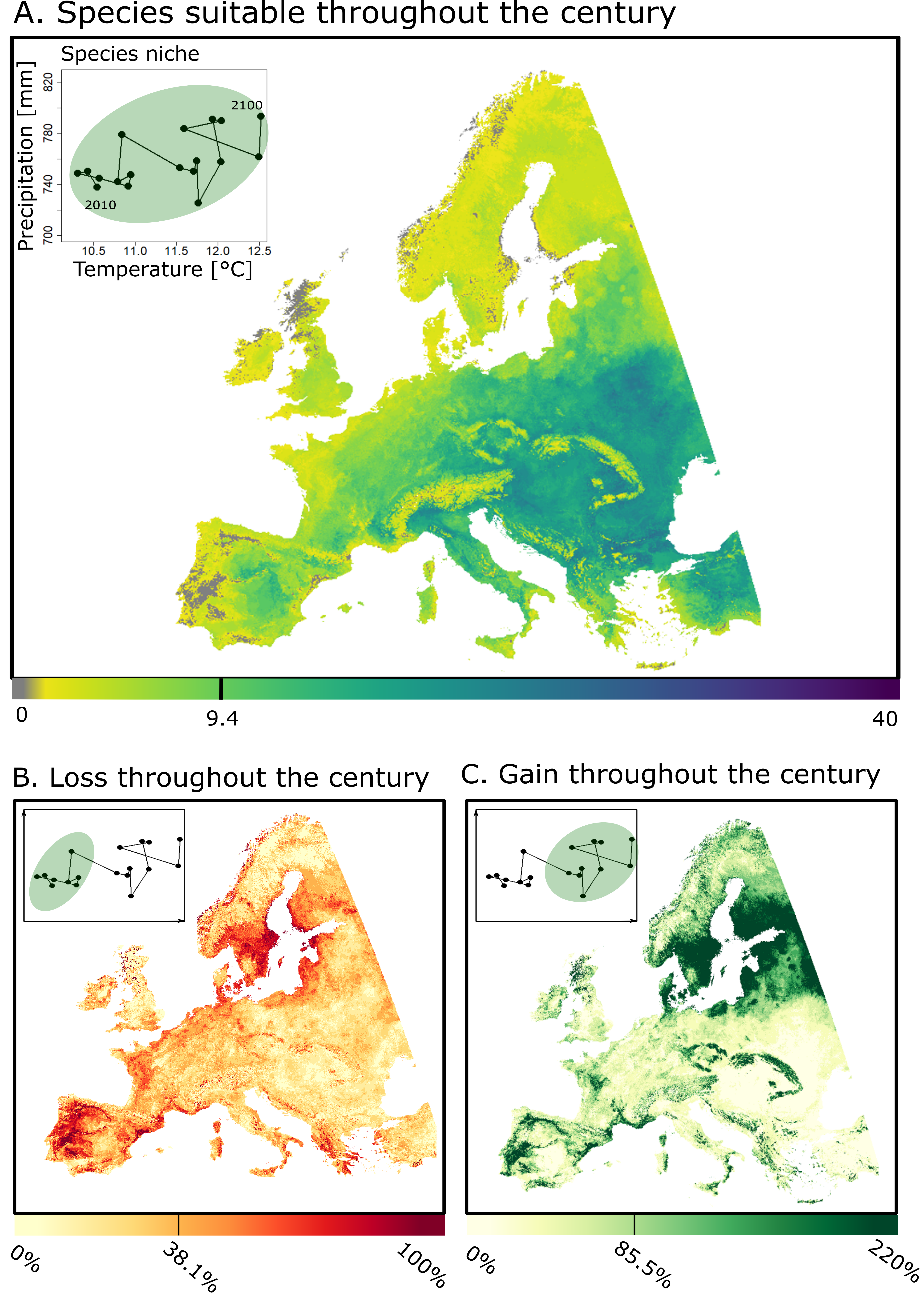
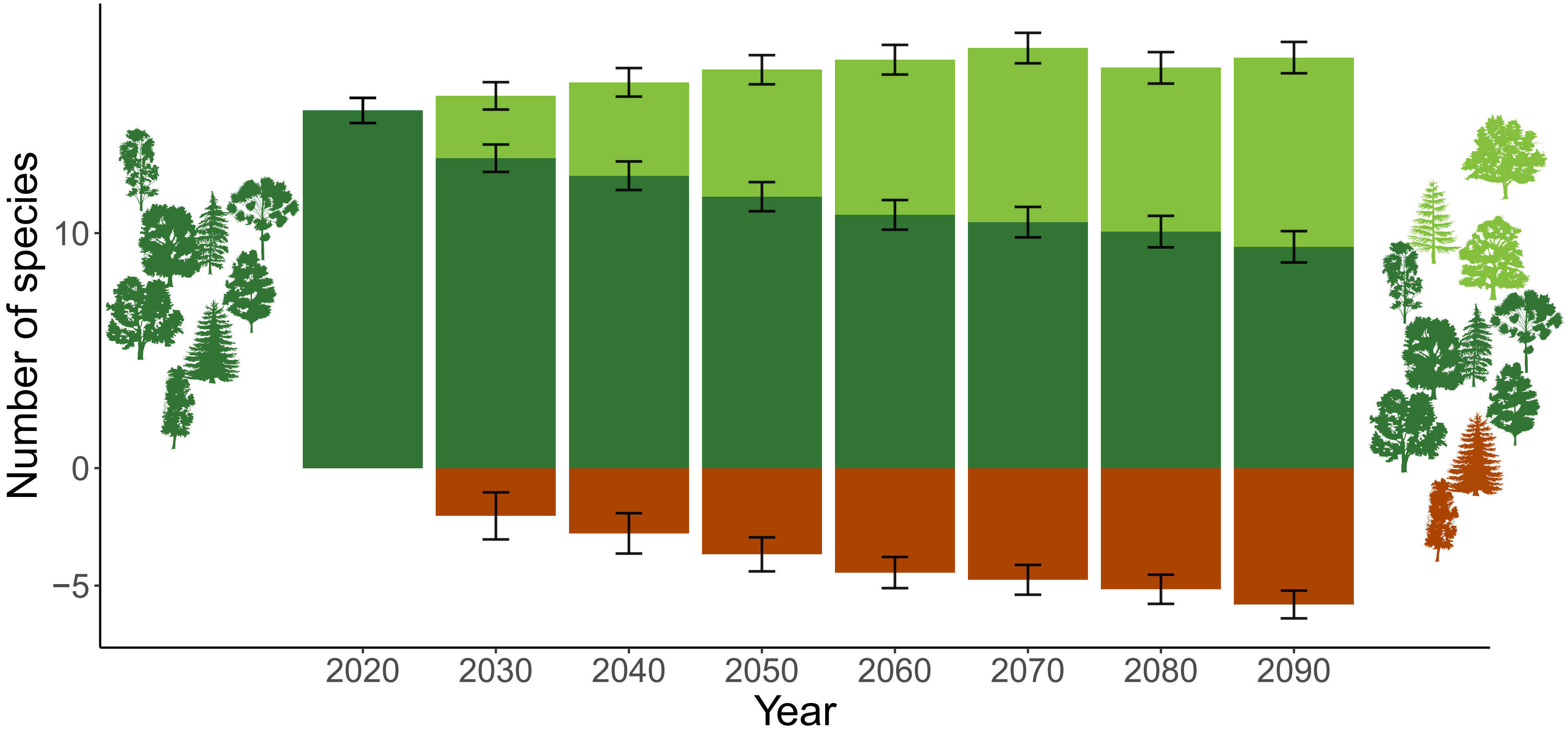
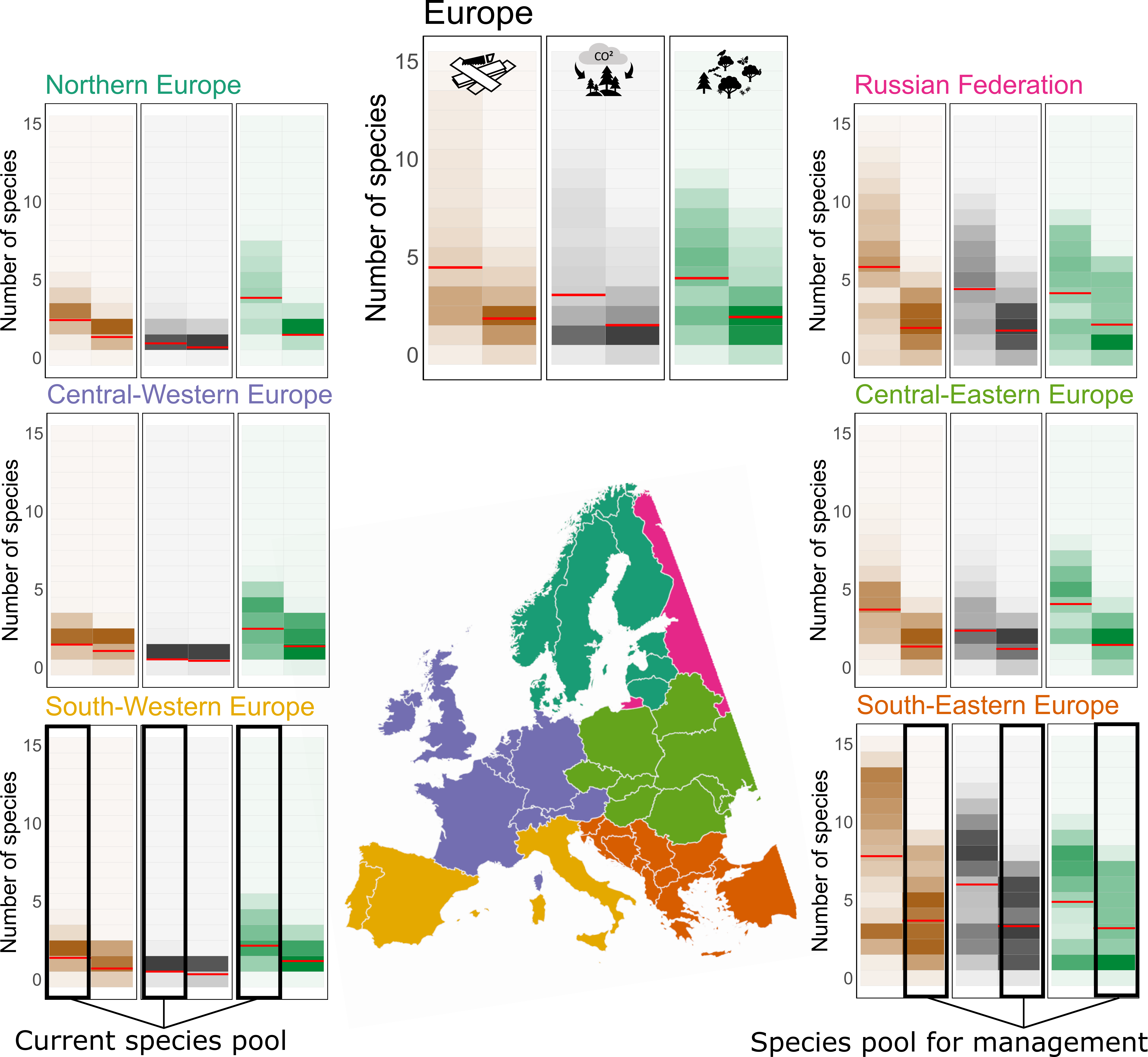
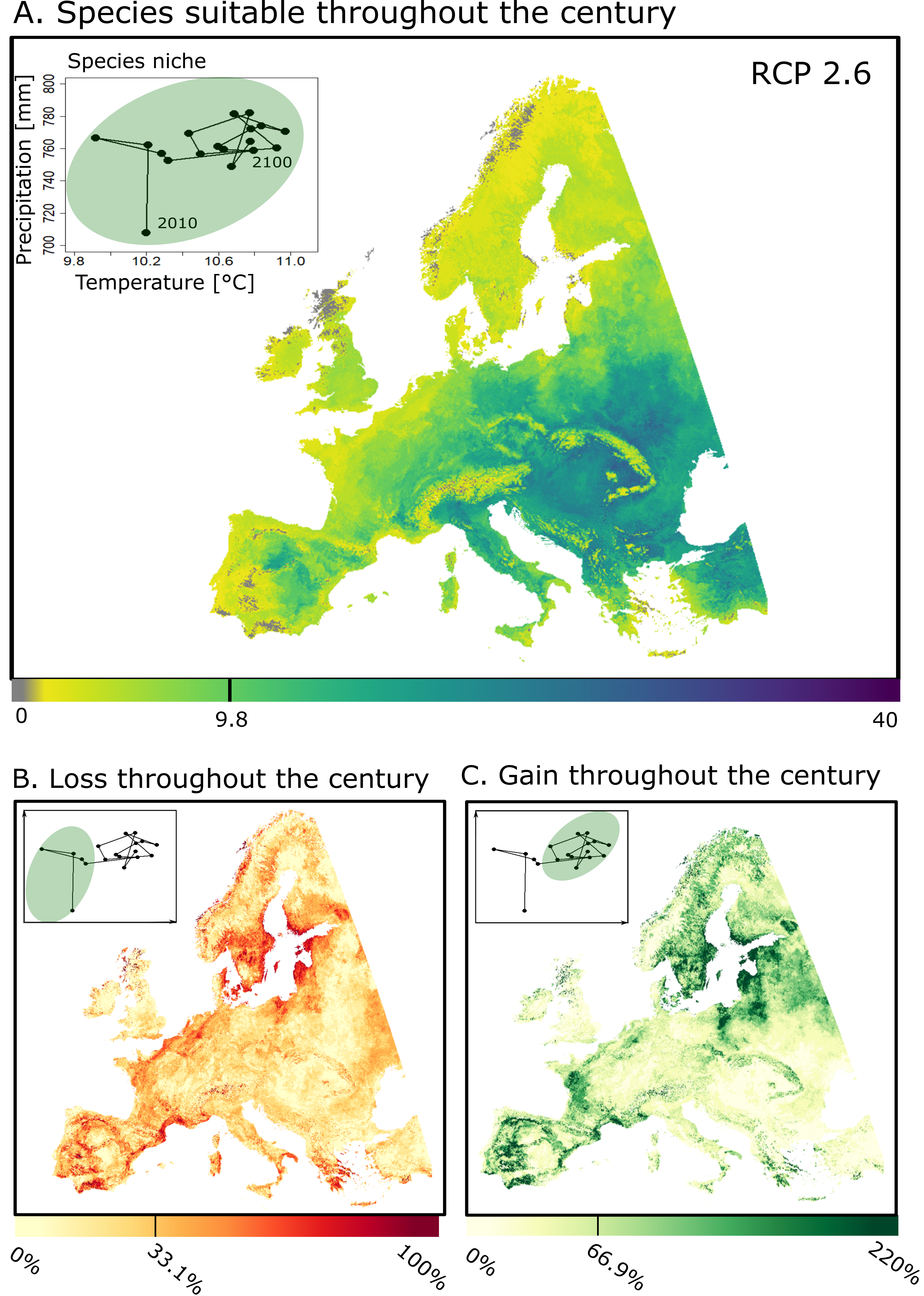

A. Species suitable throughout the century
GLM
GAM
RF
BRT
B. Loss throughout the century
GLM
GAM
RF
BRT
C. Gain throughout the century
GLM
GAM
RF
BRT

Supplementary Figure 1: Tree species suitability in Europe throughout the 21$^{st}$ century for the four modelling algorithms used. (A) Map of the number of tree species that are climatically suitable continuously throughout the 21$^{st}$ century at 1 km² grid cells, and thus form the species pool for current forest management (mean value across Europe 12.6, 8.5, 3.7 and 10.0 for GLM, GAM, RF and BRT, respectively). (B) Percent of species from the current species pool (2020-2029) that cannot be sustained throughout the century management (mean value across Europe 24.5%, 52.8%, 76.6% and 33.9% for GLM, GAM, RF and BRT, respectively). (C) Percent of species that are gained in grid cells (1 km²) at the end of the century (2090-2099) relative to the species that are climatically suitable throughout the century management (mean value across Europe 69.8%, 161.0%, 632.2% and 104.6% for GLM, GAM, RF and BRT, respectively). Values are shown for the climate change scenario RCP 4.5.

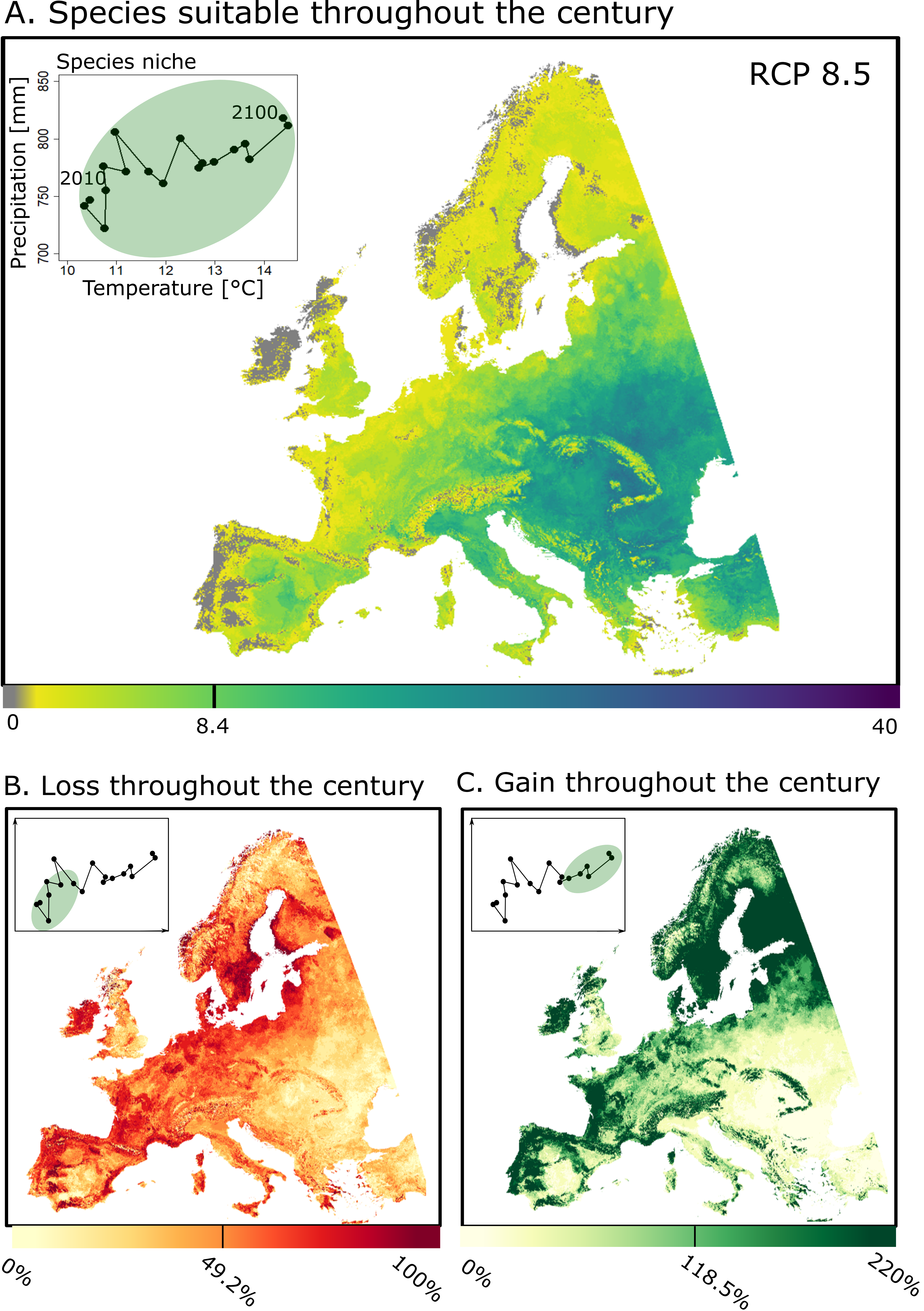

A. Species suitable throughout the century
Species niche
Precipitation [mm]
820
780
740
700
2100
2010
10.5
11.0
11.5
12.0
12.5
Temperature [°C]
0
9.4
40
B. Loss throughout the century
0%
38.1%
100%
C. Gain throughout the century
0%
85.5%
220%

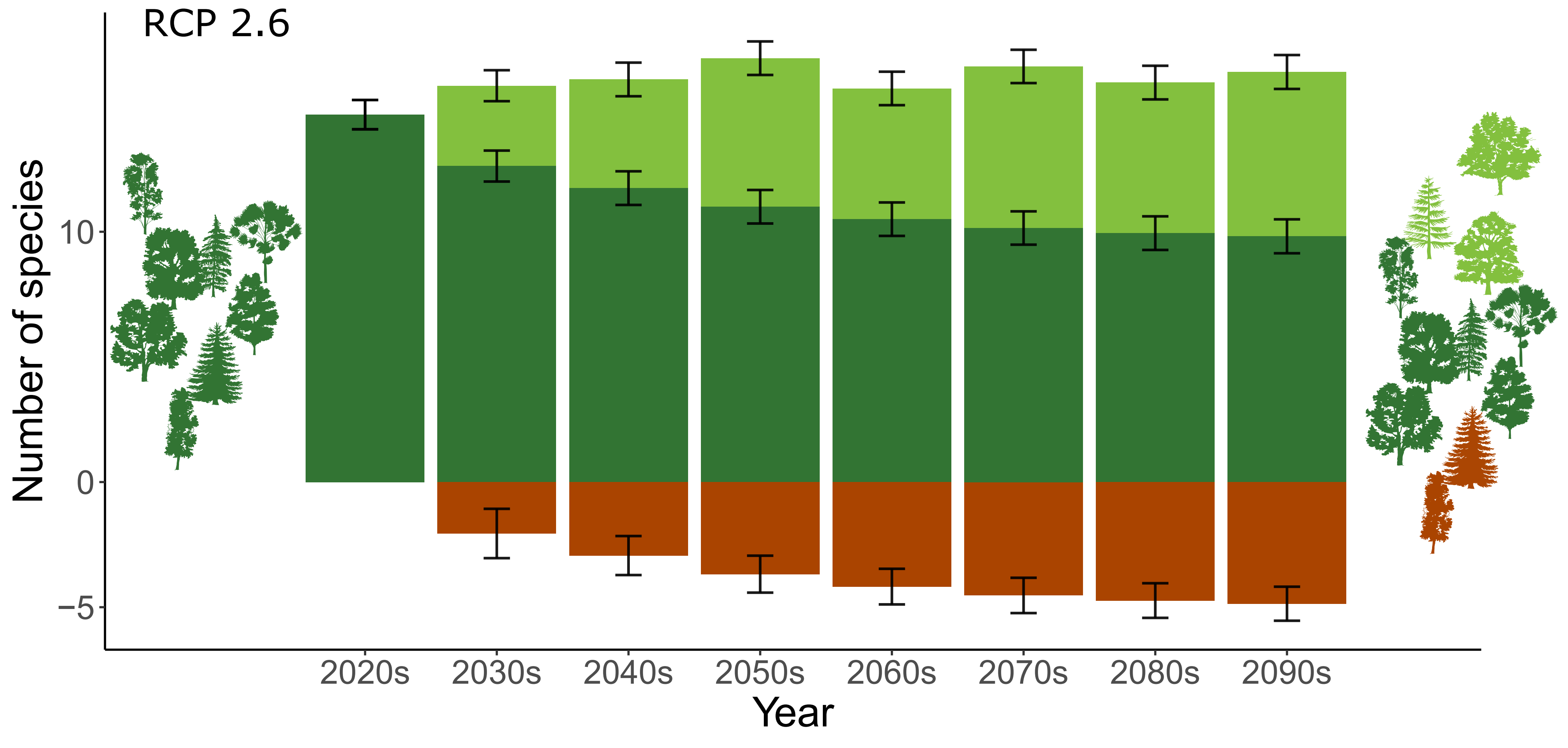

Number of species
10
0
−5
2020
2030
2040
2050
2060
2070
2080
2090
Year


Europe
Northern Europe
Russian Federation
Central-Western Europe
Central-Eastern Europe
South-Western Europe
South-Eastern Europe
Number of species
CO²
Current species pool
Species pool for management

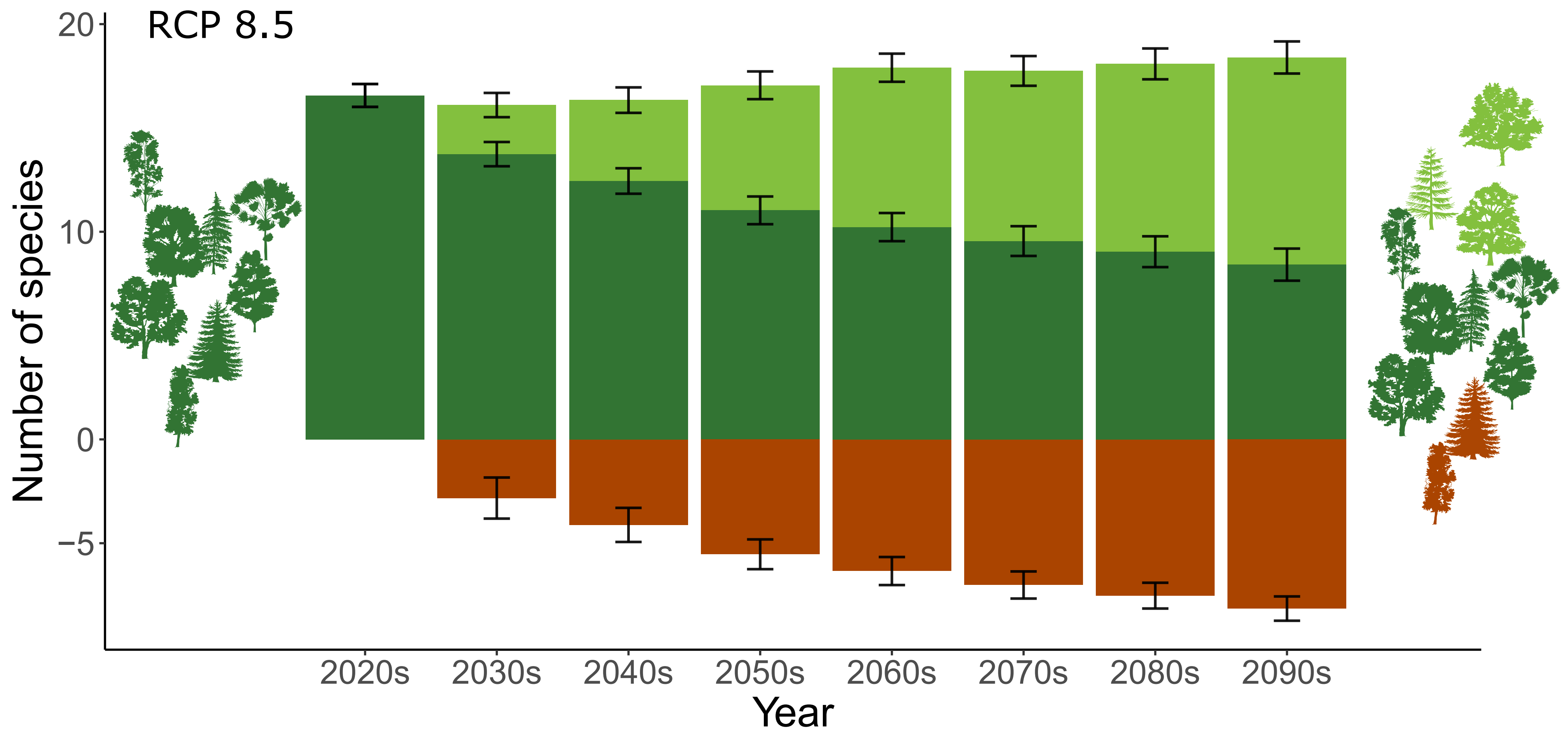


A. Species suitable throughout the century
RCP 2.6
Species niche
Precipitation [mm]
700
720
740
760
780
800
9.8
10.2
10.6
11.0
Temperature [°C]
2010
2100
0
9.8
40
B. Loss throughout the century
0%
33.1%
100%
C. Gain throughout the century
0%
66.9%
220%

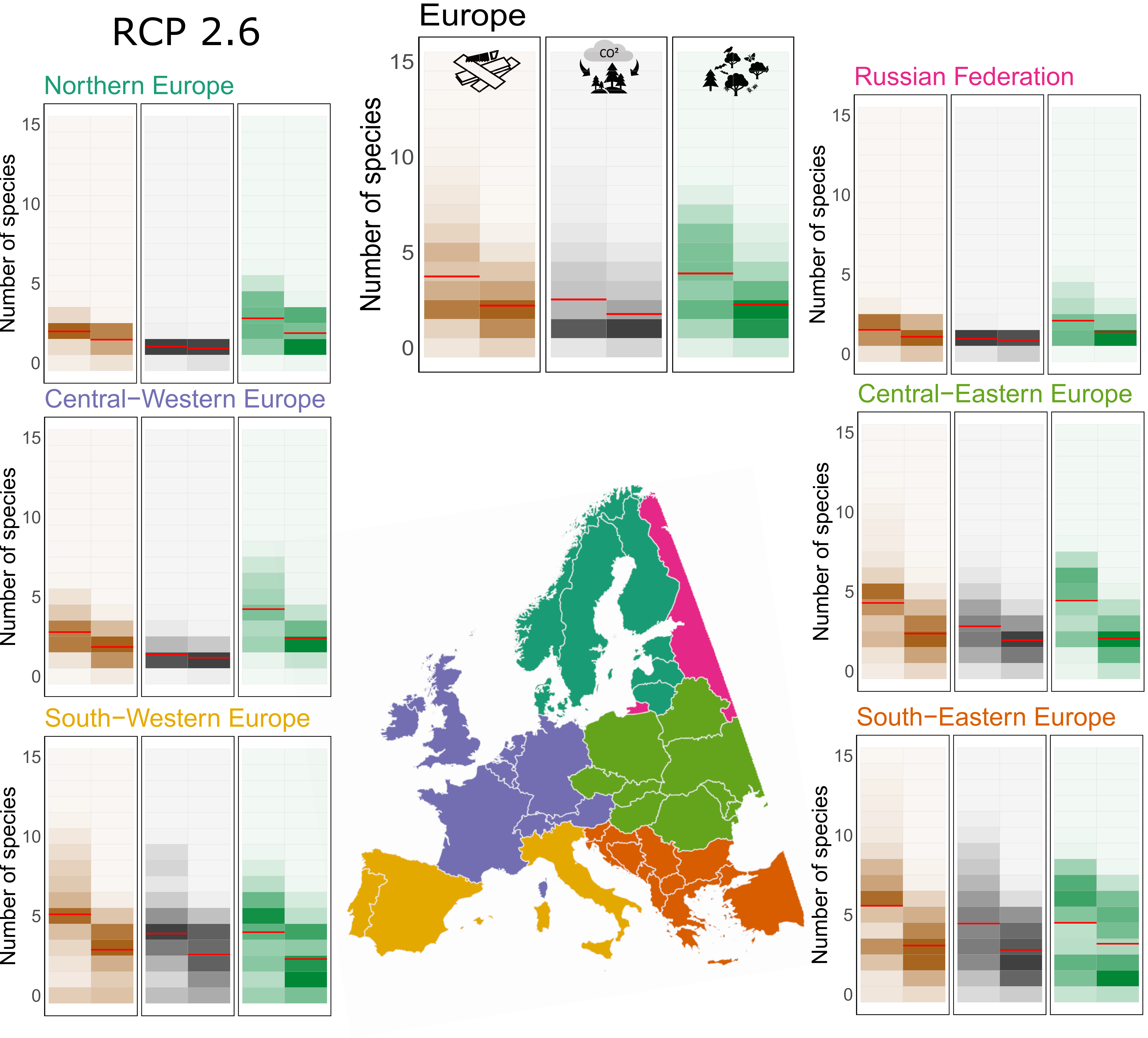

A. Species suitable throughout the century
Species niche
Precipitation [mm]
850
800
750
700
10
11
12
13
14
Temperature [°C]
2010
2100
RCP 8.5
0
8.4
40
B. Loss throughout the century
0%
49.2%
100%
C. Gain throughout the century
0%
118.5%
220%



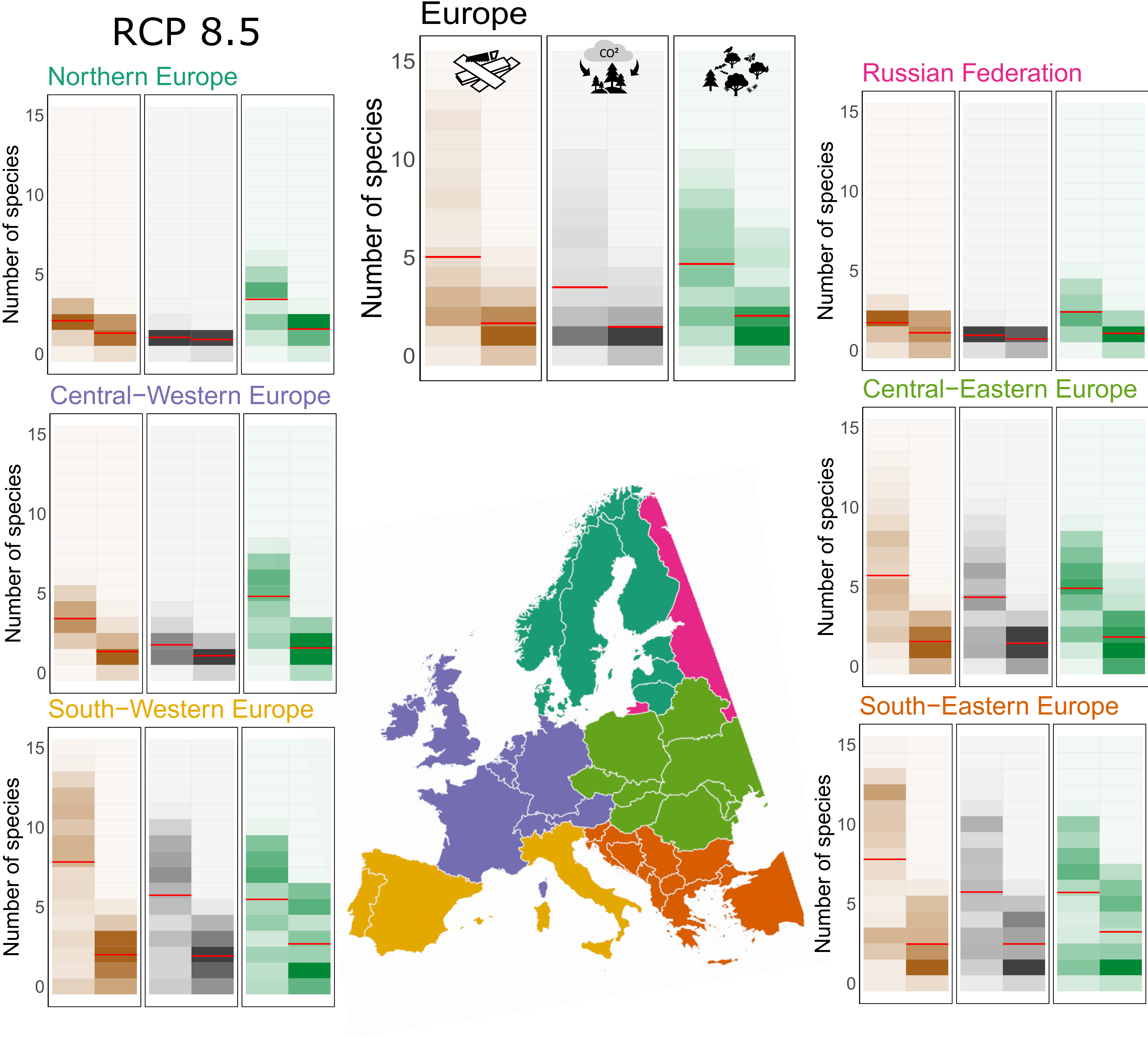
RCP 2.6
Number of species
10
0
−5
2020s
2030s
2040s
2050s
2060s
2070s
2080s
2090s
Year

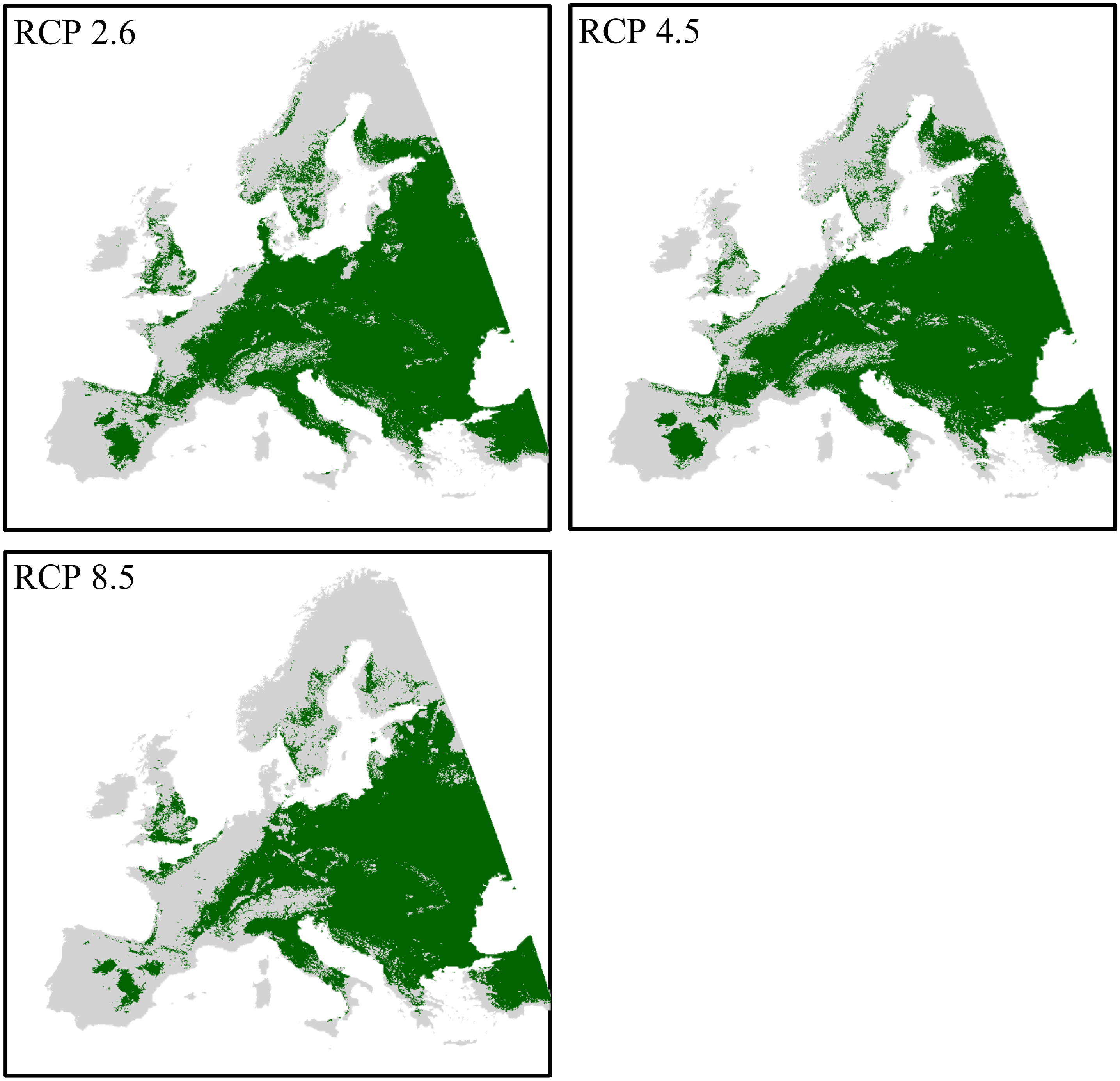


RCP 8.5
Number of species
20
10
0
−5
Year
2020s
2030s
2040s
2050s
2060s
2070s
2080s
2090s



RCP 2.6
Europe
Northern Europe
Russian Federation
Central−Western Europe
Central−Eastern Europe
South−Western Europe
South−Eastern Europe
Number of species
CO²
0
5
10
15


RCP 8.5
Europe
Northern Europe
Central−Western Europe
South−Western Europe
Russian Federation
Central−Eastern Europe
South−Eastern Europe
Number of species
CO²
0
5
10
15


RCP 2.6
RCP 4.5
RCP 8.5