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LITHUANIAN FORESTS AND CLIMATE CHANGE: POSSIBLE EFFECTS ON TREE SPECIES COMPOSITION

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Abstract:	Outputs from the HadCM3 Global Climate Circulation model according scenarios A2 and B1 were used for climate change predictions in Lithuania. According to scenario A2, the annual temperature will increase by approximately 4.0°C from 2061-2090, while scenario B1 predicts an increase of 2.0°C. In contrast to scenario B1, scenario A2 predicts an annual increase in precipitation of 15-20 % at the end of the century. Based on the predicted climatic data for the two scenarios and climate maps by EFSA (European Food Safety Authority) for the EU, we created climatic envelopes for Lithuania for 2031-2060 and 2061-2090. These areas (climatic envelopes) were overlain by the digital map of native tree species distributions in Europe, which was created from the EUFORGEN (European forest genetic resources programme) database. If climate changes occur according to scenario B1, in 2031-2060, Lithuania's climate will become suitable for approximately 5-6 alien species, such as Acer campestre, A. pseudoplatanus, Fagus sylvatica, Populus nigra, and Prunus avium. In 2061-2090, these species will be joined by Sorbus domestica and Tilia platyphyllos. If climate changes occur according to scenario A2, at the end of the 21st century, Castanea sativa, Quercus pubescens, Sorbus torminalis could expand this list. With respect to species dispersal rates, there is a low probability that the species Acer campestre, Acer pseudoplatanus, Populus nigra and Prunus avium will become immigrants to Lithuanian forests at the end of the 21st century. Approximately 20 new species native to Europe will be suitable for cultivation (scenario A2). Climate change will affect the distributions of native species too. An increase in the proportion of deciduous tree species (except Alnus incana) and some reduction in the

	proportion of conifers, Norway spruce (Picea abies) and Scots pine (Pinus sylvestris) are expected in Lithuanian forests.
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LITHUANIAN FORESTS AND CLIMATE CHANGE: POSSIBLE EFFECTS ON TREE SPECIES COMPOSITION

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Outputs from the HadCM3 Global Climate Circulation model according scenarios A2 and B1 were used for climate change predictions in Lithuania. According to scenario A2, the annual temperature will increase by approximately 4.0°C from 2061-2090, while scenario B1 predicts an increase of 2.0°C. In contrast to scenario B1, scenario A2 predicts an annual increase in precipitation of 15-20 % at the end of the century.

Based on the predicted climatic data for the two scenarios and climate maps by EFSA (European Food Safety Authority) for the EU, we created climatic envelopes for Lithuania for 2031-2060 and 2061-2090. These areas (climatic envelopes) were overlain by the digital map of native tree species distributions in Europe, which was created from the EUFORGEN (European forest genetic resources programme) database.

If climate changes occur according to scenario B1, in 2031-2060, Lithuania's climate will become suitable for approximately 5-6 alien species, such as *Acer campestre*, *A. pseudoplatanus*, *Fagus sylvatica*, *Populus nigra*, and *Prunus avium*. In 2061-2090, these species will be joined by *Sorbus domestica* and *Tilia platyphyllos*. If climate changes occur according to scenario A2, at the end of the 21st century, *Castanea sativa, Quercus pubescens*, *Sorbus torminalis* could expand this list.

With respect to species dispersal rates, there is a low probability that the species *Acer campestre*, *Acer pseudoplatanus*, *Populus nigra* and *Prunus avium* will become immigrants to Lithuanian forests at the end of the 21st century. Approximately 20 new species native to Europe will be suitable for cultivation (scenario A2).

Climate change will affect the distributions of native species too. An increase in the proportion of deciduous tree species (except *Alnus incana*) and some reduction in the proportion of conifers, Norway spruce (*Picea abies)* and Scots pine (*Pinus sylvestris*) are expected in Lithuanian forests.

Keywords: climatic envelopes, native species, potential immigrants

There are at least three widely discussed aspects of global environmental change to which plants are generally thought to respond: increasing temperature, rising concentration of carbon dioxide, and increasing deposition of nitrogen (Schwartz 1991; Subedi 2009). Climate change is mostly related to the increases in temperature and carbon dioxide concentration (Schwartz 1991). According to the Intergovernmental Panel on Climate Change (2007), increases in CO_2 concentrations and average global temperatures are likely during the 21st century. These changes can have various effects on fauna and flora. The potential effects of climate change on forest ecosystems are widely recognised and discussed.

It is expected that rapid environmental changes may alter forest functioning, and tree species will become "unsuitable" for local conditions. For example, by the middle of the century (assuming a high emission scenario), 7% of stands in England will be classed as unsuitable, and, by 2080, 67% of stands would be classed as unsuitable or marginal (Broadmeadow 2011). According to the modelling, at the end of the 21st century, the habitat suitable for the spruce–fir and aspen–birch forests in the eastern United States will decrease dramatically (–97% and –92%) and will be replaced by oak–hickory and oak–pine habitat: the area of habitat suitable for oak–hickory will expand by an average of 34%, primarily to the north and east, and the area of oak–pine habitat will expand by roughly 290% to the southeast (Hansen et al., 2001). The analysis indicates that the effects of "habitat changes" will have large regional variation. For example, in England, forest productivity is increasing in the north and west and declining in the south and east (Broadmeadow 2011). Species of boreal and temperate deciduous forests are predicted to face a higher risk from the loss of climatically suitable areas than species from warmer and drier parts of Europe by 2095 (Ohlemüller et al. 2006).

Many authors find or predict that climate change will influence tree line shifts; that is, species will move to higher altitudes (Malanson and Butler 1994; Kittel et al. 2000; Meshinev et al. 2000; Theurillat and Guisan 2001; Dullinger et al. 2004; Bertin 2008) and migrate to the north (Davis and Shaw 2001; Hansen et al. 2001; Dullinger et al. 2004; Bertin 2008). The treeline shifts in response to climate change showed a wide gradient, from rapid dynamics to complete inertia (Kullman 1993, 2002; Lavoie and Payette 1994; Meshinev et al. 2000; Dullinger et al. 2004). If species are not able to reach new suitable habitat and fail to adapt to changing conditions, range losses and species extinctions are likely (Schwartz 1991; Davis and Shaw 2001; Milad et al. 2011). The habitat for several species may shift to the north by as much as 530 km at the end of this century (Hansen et al. 2001). However, latitudinal changes in plant distributions have been demonstrated in only a few instances in some areas (Bertin 2008) because of (1) physiological plasticity to endure climate change without migrating (Schwartz 1991; Lekevičius et al. 2011); (2) habitat fragmentation (Schwartz 1991); and (3) dispersal and interactions between species (Davis et al. 1998; Dullinger et al. 2004).

The evidence for the migration or return of tree species to their previous habitats can be taken from the Holocene. M.W. Schwartz (1991) made three generalisations based on a literature review: (1) post-Pleistocene tree migrations proceeded at an average rate of 10-40 km per century, with a maximum migration rate of 200 km per century for *Picea glauca*; (2) the colonisation of suitable habitat, in particular by tree species with relatively slow migration rates, can lag considerably behind predicted high rates of climate change; (3) the individual responses of species to climate change are species specific. Therefore, climate change can alter species distributions and community composition. Using long-term data on temperature and polynological analysis, curves of tree species distributions in Lithuania during the boreal and Atlantic periods have been drawn. It was found that a temperature increase of 2°C over the course of approximately 2000 years has doubled the abundance of *Quercus*, *Alnus* and *Tilia* trees, while the number of *Betula* trees decreased by more than half (Kairiukstis et al. 1990). It is predicted that new suitable areas outside a species' current range are expected to have greater increases in suitability for Mediterranean species than for boreal and temperate species (Ohlemüller et al. 2006). Over the long-term, increased temperatures and droughts would lead to a shift in the natural species composition toward more drought tolerant species (Lasch et al. 2002; Mueller et al. 2005; IPCC 2007). Analysing the geographical range of forest species composition across a gradient from north to south, it is evident that the proportion of Norway spruce decreases drastically with increased average air temperature and decreased precipitation, approximately 30-40% in boreal forests and less than 2% in steppes (Atmosferos taršai 1999). Field trials suggest that the best performing provenances are those from regions with a climate similar to that of the trial site (Broadmeadow et al. 2005). The tree genotypes best suited to future climate currently reside at large distances from their future optima (Rehfeldt et al. 2002).

Many factors may play a critical role in determining the response of species distributions to climate change: temperature, precipitation, climatic anomalies, photoperiod, highly fragmented and intensively used landscapes, as well as the absence of so-called “chance-events”, geomorphic restrictions, and extreme weather events (Bugmann 1999; Parmesan 2006; Schwartz 1991; Kappelle et al. 1999; Davis and Shaw 2001; Honnay et al. 2002; Archaux and Wolters 2006). However, temperature and precipitation are recognised as the most important or limiting factors for tree species distribution by many authors. Treeline elevations seem to be correlated more strongly with temperature than with any other variable. In search of a functional explanation for climatic tree line positions globally, a recent model suggests that a 6.7±0.8°C mean growing season temperature threshold (Körner and Paulsen 2004) or a winter minimum temperature of 40°C should be recognised as the exotherm of the woody plant distribution limit (Sakai and Weiser 1973, George et al. 1974). It has been suggested that precipitation changes may have limited range shifts in response to warming in some areas (Bertin 2008). Annual precipitation is correlated with the distribution limits of many species (Schwartz 1991). Usually, the climatic variables of temperature and precipitation are used to predict potential future distribution of tree species due to climate change (Davis and Zabinski 1991; Shao et al. 2003).

Lithuania occupies the western edge of the East European plain, which is located in the mixed forest belt of the temperate climate forest zone. The average land surface altitude is 99 m (0-292 m). The area of forests is approximately 20 000 km^2 or 32% of the total territory. Native tree species are the prevailing species. The share of coniferous tree species in the overall species composition is 58.2% with Scots pine (*Pinus sylvestris*) dominating (36.2%) and Norway spruce (*Picea abies*) second (21.8%). Coniferous forests are located in the southern part of their distribution range. Deciduous trees (41.8%) are mainly represented by birch (20.6%), black alder (6.6%), grey alder (6.3), and aspen (3.2%). The majority of deciduous species are located in almost the centre of their distribution range ((http://www.euforgen.org/distribution_maps.html).

The climate in Lithuania is relatively mild and ranges between maritime and continental. The climatological average temperature (1961-1990) in Vilnius (continental part of Lithuania) is -6.1 °C in January and 16.9 °C in July. The average temperature in Klaipėda (coastal part of Lithuania) is -2.8 °C in January and 16.6 °C in July. The average annual precipitation is 700-850 millimetres on the coast and in the Samogitia highlands, and it is 550-700 millimetres in the central and eastern part of the country. The analysis of climate change data in Lithuania corresponds to findings at the global level. A rise in average temperature of 0.7-0.9^{o}C during the last century, particularly significant in the last decades (over the last 15-30 years), was observed: winter became milder (the highest rate of temperature increase was recorded in winter) with a shorter period of snow cover and an increased amount of precipitation; summer developed severe droughts, especially in July-August; and the duration of thermal spring and autumn lengthened **(**Bukantis and Rimkus 2005; Galvonaitė et al. 2007; Rimkus and Bukantis 2008).

The Intergovernmental Panel on Climate Change (IPCC) has presented various scenarios of climate change: A1FI, A1B, A1T, A2, B1, and B2 (IPCC, 2007). Climate scenarios A2 and B1 have been recognised as pessimistic and optimistic, respectively. Scenario A2 is characterised by a world of independently operating, self-reliant nations and regionally oriented economic development. According to scenario A2, the concentration of greenhouse gasses will increase drastically. The B1 scenario is optimistic: rapid economic growth but with rapid changes towards a service and information economy; reductions in material intensity and the introduction of clean and resource efficient technologies; and an emphasis on global solutions to economic, social and environmental stability. The modelling of global climate change using scenarios A2 and B1 predicts an increase in global temperature and an increase in precipitation by 8-9% during the 21st century (IPCC, 2007).

The aim of the study was to forecast possible changes of tree species composition in Lithuanian forests due to climate warming according to the A2 and B1 greenhouse gas emission scenarios.

MATERIALS AND METHODS

Forecasts of air temperature, precipitation and active temperature sum (t > 10°C) were generated based on the A2 and B1 greenhouse gas emission scenarios of the HadCM3 Global Climate Circulation Model. The prognostic values were derived from the CERA database. A linear and multiple regression downscaling procedure was performed to obtain a local prediction scale. The results show that air temperatures will increase in the 21st century, especially during the winter season (4-8°C), without substantial precipitation changes. The configuration of climate change scenarios used in our simulation is presented in Table 1.

Table 1. Configuration of Lithuanian climate change scenarios used in the simulation

According to scenario A2, the annual temperature will increase by approximately 4.0°C in 2061-2090, whereas the annual temperature will increase by 2.0°C according to scenario B1. In contrast to scenario B1, scenario A2 predicts that the annual precipitation will increase by 15-20% at the end of the century. As was stated above, an increase in winter temperature is predicted. The coldest months in Lithuania are January and February, so the average temperature of February was selected for modelling. Based on the predicted climatic data for the two scenarios and climate maps by EFSA (European Food Safety Authority) for the EU (http://eusoils.jrc.ec.europa.eu/library/Data/EFSA/), we created climatic envelopes for Lithuania in 2031-2060 and 2061-2090 using the method described by Skov et al., (2009) and implemented them in ArcGIS 9.3, ESRI, Redlands, CA, USA (http://www.esri.com). The climate envelope (climate matching) approach is used in many studies to predict a species' response to climate change. The approach relies on the climate-mapped current distribution of a species: if the position of that climate space changes, the distribution of the species is predicted to shift to the suitable range or habitat (Davis et al. 1998; Skov and Svenning, 2004; Broadmeadow et al. 2005; Skov et al. 2009).

Climatic envelopes were as areas with climates most similar to that is predicted for Lithuania. These areas (climatic envelopes) were overlain by the digital map of native tree species distributions in Europe that was created in the EUFORGEN (European Forest Genetic Resources programme) database (http://www.euforgen.org/distribution_maps.html).

RESULTS AND DISCUSSIONS

Areas of the climatic equivalents of Lithuania's climate and areas of possible immigrants

The climate (mean annual temperature, February temperature, and annual amount of precipitation) that is characteristic for Lithuania can be found in neighbouring territories or in other parts of Europe. Currently, Latvia, Estonia, the southern part of Sweden, the Kaliningrad region of Russia, northern Poland, central and southern Germany, Czech Republic and Slovakia, and the Alps and Carpathian Mountains have climates similar to Lithuania (Fig. 1).

Fig. 1. Territories of Europe with climate that is similar to the present climate of Lithuania.

Nonetheless, the species composition of forests in these regions is different. For example, in Finland, there are two abundant tree species (stands of species occupy 80% of the forest area); in Lithuania, there are 3-4 dominant species; and in Germany (state Baden-Württemberg), there are approximately six dominant species (Forests and forestry 2006). It is evident that in the southern areas of Europe (for example, in Germany), the number of tree species is larger. This trend confirms the generalisation that tree migration and the colonisation of suitable habitat lag considerably behind the predicted rates of climate change (Schwartz 1991; Svenning and Skov, 2004). On the other hand, natural barriers such as mountains and large water basins (in our case, the Baltic sea) play a substantial role in species distribution (Schwartz 1991; Skov et al. 2009). Species that are geomorphically restricted from shifting their ranges to higher altitudes, such as mountain species, are expected to be replaced by more competitive species (Bugmann 1999; Parmesan 2006).

In 2031-2060, according to scenario B1 (for which the modelling predicts that the annual temperature will increase by 1°C without a change in precipitation), the climate of Lithuania will become similar to the present climate in the north-western and south-western regions of Germany. According to scenario A2 (in which the annual temperature will increase by 2°C with a similar amount of precipitation) the climate will be similar to the present climate in northwestern and southwestern Germany, the Netherlands and the north-eastern region of France.

In 2061-2090, according to scenario B1 (for which the annual temperature will increase by 2°C and the amount of precipitation will be the same) the climate in Lithuania will be similar to the present climate in Denmark, western Germany, the Netherlands and Northern France. According to scenario A2 (for which the annual temperature will increase by 4°C and precipitation will increase by 15-20%), the climate will be similar to the climate that is currently characteristic of the western parts of Belgium and in the northern and southern territories of France.

European territories that correspond to the future climate of Lithuania are presented in Fig. 2.

Fig. 2. European territories that are similar to the future climate of Lithuania, according to various climate change scenarios.

It is evident that these areas (climatic envelops) differ under various climate change scenarios, and their changes in time-scale have a southwest direction. This finding corresponds to modelling results for the climate of Denmark (Skov et al. 2009).

Tree species – potential immigrants to Lithuania in the 21st century

First of all, we must separate two definitions: potential species and potential immigrants. Potential species can be defined as species that will be suitable to grow in the corresponding climatic conditions. Potential immigrants are species that can naturally spread (in our case, due to climate change) and reach territory that is suitable for their growth. The list of potential immigrants will not include species that are distributed in small areas, endemic species (for example, *Acer monspessulanum* and *A. opalus*), species that have slow dispersal speeds or that remain in a natural mountain range for a long time because of their biological particularities (for example, *Abies alba*, *Larix decidua*, and *Pinus mugo*), and species that have natural barriers (seas, mountains) that limit their expansion, i.e., species that grow under the northern line of the *Abies alba* distribution area (for example, *Pinus cembra*).

It is evident that these areas (Fig. 2) differ under various climate change scenarios, and their changes over time occur in a southwestern direction. This corresponds to the modelling results in Denmark (Skov et al. 2009).

Many authors agree that natural barriers can be a significant obstacle for species migration and distribution (Skov and Svenning 2004; Bugmann 1999; Parmesan 2006); therefore, species do not cover the entire suitable area for their growth. For example, during the Holocene, only five species from the list of 55 occupied 90% of the territories suitable for their growth, and the rest of the 50 species occupied only 40% of their potential area (Skov and Svening, 2004).

When analysing our data, the natural barriers for species migration that were defined for the modelled area of Lithuania could be the Baltic and North Seas in the north and northwest and large mountain areas in the south (Alps, Carpathian mountains) and southwest (Pyrenees). Similar restrictions were applied in a study in which the impact of climate change on the flora of Denmark was analysed (Skov et al. 2009).

In our study, the southern borderline of the species migration corridor was defined using the map of the *Abies alba* distribution in Europe (Fig. 3) ((http://www.euforgen.org/distribution_maps.html). *Abies alba* is very well known as Europe's mountain species. Therefore, tree species that naturally grow beneath the northern line of the *Abies alba* distribution area (for example, *Pinus cembra*) were not treated as possible migrants to Lithuania.

Fig. 3. Potential area (migration corridor) of possible immigrants to Lithuania. The natural distribution area of *Abies alba* is dark (map from *www.euforgen.org*).

The analysis of matching species distribution and climate maps show that, even now, Lithuania's climate is suitable for the growth of some foreign species, i.e., the mapped territories with climate similar to present-day Lithuania fall into the distribution area of some species (Fig. 4).

The modelling shows that areas with climates similar to that of present-day Lithuania, as predicted according to climate change scenarios A2 and B1, fall into the distribution range of some species. In some cases, these areas will occupy the western part of a species distribution range (Fig. 5).

Fig. 4. Territories of Europe that correspond to the present climate of Lithuania (black area) and the distribution of some European tree species (grey area).

Fig. 5. Species distribution and territories with climate predicted according to the climate change scenarios in 2061-2090 (blue– predicted climate according to scenario B1; red- predicted climate according to scenario A2; green –current species distribution area).

After the above analysis, we produced a list of possible immigrant species. The list is presented in Table 2. It is evident that the climate suitability of Lithuania for the growth of the chosen species depends on the climate change scenario. In general, scenario A2 is more favourable for immigrant species.

Table 2. Possible immigrant species to Lithuania under the A2 and B1 scenarios of climate change: + Lithuania's climate suitable for species; +? possibly suitable; - not suitable

If the climate changes according to scenario B1, it is probable that, in 2031-2060, the climate of Lithuania will become suitable for approximately 5-6 alien species that will become potential immigrants - *Acer campestre, A. pseudoplatanus, Fagus sylvatica, Populus nigra,* and

Prunus avium. In 2061-2090, these species will be joined by *Sorbus domestica* and *Tilia platyphyllos.* If climate changes according to scenario A2, at the end of the 21^{st} century, *Castanea sativa, Quercus pubescens,* and *Sorbus torminalis* could expand the list of possible immigrants.

The selection of potential immigrants to the forest of Lithuania at the end of the 21^{st} century must be based on the distance between their natural range and Lithuania. Post-Pleistocene tree migrations proceeded at an average rate of 10-40 km per century, with a maximum migration rate of 200 km per century for *Picea glauca* (Schwartz, 1991). The predictions of northward shifts of the range of climate suitable for individual species during the 21^{st} century vary from 100 km to 500 km (Melillo et al., 1990; Davis and Zabinski 1991; Hansen et al., 2001). Therefore, trees that have a distribution border line at a distance greater than 500 km do not have a high chance of reaching Lithuania. In this respect, there is some, but presumably relatively low, probability that *Acer campestre, Acer pseudoplatanus, Fagus sylvatica*, *Populus nigra* and *Prunus avium* will become immigrants to Lithuanian forests. We can add *Quercus petraea* to this list because there is a small island outside of its natural range in the southern part of Lithuania (Navasaitis et al. 2003), and we can also add *Larix decidua*, which has spread in some parts of Poland.

Among species for which the climatic conditions of Lithuania can be suitable for growth (potential species), some European species other than *Quercus petarea* and *Larix decidua* should be added to the list presented in Table 2: *Aser monspessulanum*, *A. opalus*, *Abies alba*, *Alnus cordata*, *Larix decidua*, *Pinus cembra*, *P. halepensis, P. nigra*, and *Quercus pubescens.* Therefore, approximately 20 new species native to Europe will be suitable for cultivation in the forests of Lithuania at the end of the current century (scenario A2).

Climate change and native species

The modelled data predict that climate warming will also affect the distributions of native species. It is expected that there will be an increase in the proportion of deciduous tree species and that there will be some reduction in conifers such as Norway spruce (*Picea abies)* and Scots pine (*Pinus sylvestris).* The analysis revealed that, according to climate change scenarios A2 and B1, climatic conditions will become less suitable for conifers and more suitable for almost all deciduous species, except *Alnus incana* (Table 3).

Table 3. Climatic conditions predicted for some Lithuanian native forest tree species according to the A2 and B1 scenarios: + suitable for growth; +? possibly suitable; - not suitable

Particularly negative climate changes are forecasted for *Picea abies.* The climatic conditions according to both scenarios will become unsuitable (less suitable) at the middle of the current century (Fig. 6).

Fig. 6. Distribution range of *Picea abies* (green) and area of climate predicted for Lithuania in 2061-2090 (black).

Currently, the southern borderline of the *Picea abies* distribution range is a distance of 200 km (albeit, some islands of *Picea abies* exist in the Alps and Carpathian Mountains). Some authors predict that this line will occur 250 km to the northeast of Lithuania at the end of the 21st century (Sykes and Prentice 1995, 1996).

A similar situation exists for *Pinus sylvestris*. If the climate changes according to scenario A2, the climate in Lithuania will be not suitable for *Pinus sylvestris* at the end of the century (Fig. 7). Only if the climate changes according to scenario B1 will there be some areas (eastern part of Lithuania) suitable for *Pinus sylvestris*. Currently, natural pine stands grow in a large area that ranges from the Alps through Europe to the northeast. Some authors predict that the southern line of the *Pinus sylvestris* distribution range will shift 300 km to the northeast from Lithuania due to climate change, and only some small islands will remain in the Alps and Carpathian Mountains (Sykes and Prentice 1996).

Fig. 7. Distribution range of *Pinus sylvestris* (green) and area of climate predicted for Lithuania in 2061-2090 (black).

The results of the modelling predict that climatic conditions at the end of the century will become more suitable for almost all deciduous species, including the most common: *Betula pendula*, *Populus tremula* and others. The area of predicted future climate (using both scenarios A2 and B1) will remain in the distribution range of this species (Fig. 8). The climatic conditions will only be unsuitable for *Alnus incana* if the climate changes according to scenario A2. Our conclusions support the predictions of other authors (Sykes, Prentice 1995; 1996).

Fig. 8. Distribution range of *Betula pendula* (green) and the area of climate predicted for Lithuania in 2061-2090 (black).

CONCLUSIONS

1. The climatic envelopes that have been modelled according to the climate change scenarios B1 and A2 have a southwestern direction over time.

2. The migration corridor from which we predict tree species migration to Lithuania in the 21st century covers the northern part of Poland, Germany and France. The area of the migration corridor is limited by the Baltic and North Seas in the north, by the northern line of the *Abies alba* distribution range in the south, and by the Pyrenees Mountains in the southwest.

3. According to climate change scenarios B1 and A2, the climate of Lithuania will become suitable for immigrant tree species. If climate changes according to scenario B1, in 2031-2060, the climate of Lithuania will become suitable for approximately 5-6 alien species, such as *Acer campestre, A. pseudoplatanus, Fagus sylvatica*, *Populus nigra,* and *Prunus avium*. In 2061-2090, these species will be joined by *Sorbus domestica* and *Tilia platyphyllos.* If climate changes according to scenario A2, at the end of the 21st century, *Castanea sativa*, *Quercus pubescens,* and *Sorbus torminalis* could expand this list.

4. With respect to species dispersal rate, there is the highest probability that species *Acer campestre*, *Acer pseudoplatanus*, *Fagus sylvatica*, *Populus nigra* and *Prunus avium* will become potential immigrants to Lithuanian forests at the end of the 21st century. Approximately 20 new species, native in Europe, will be suitable for cultivation (scenario A2).

5. The increase in the proportion of deciduous tree species (except *Alnus incana*) and the significant reduction in the proportion of conifers, Norway spruce (*Picea abies)* and Scots pine (*Pinus sylvestris*), are expected. An especially negative effect of climate changes is forecasted for *Picea abies.* The climate conditions will become unsuitable for *Picea abies* at the middle of the current century. If climate changes occur according to scenario A2, at the end of the century, the climate in Lithuania will be not suitable for *Pinus sylvestris.*

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Figure

Fig.1

Figure

Fig.2

Scenario A2, year 2031-2060

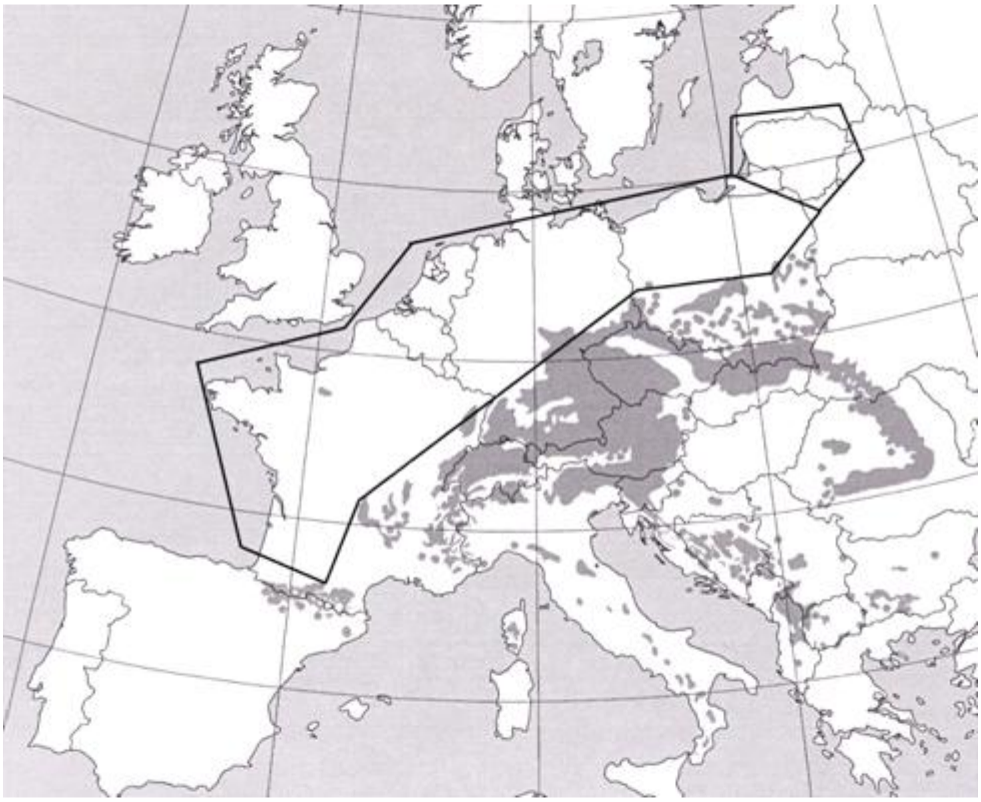
Scenario A2, year 2061-2090

Scenario B1, year 2031-2060

Scenario B1, year 2061-2090

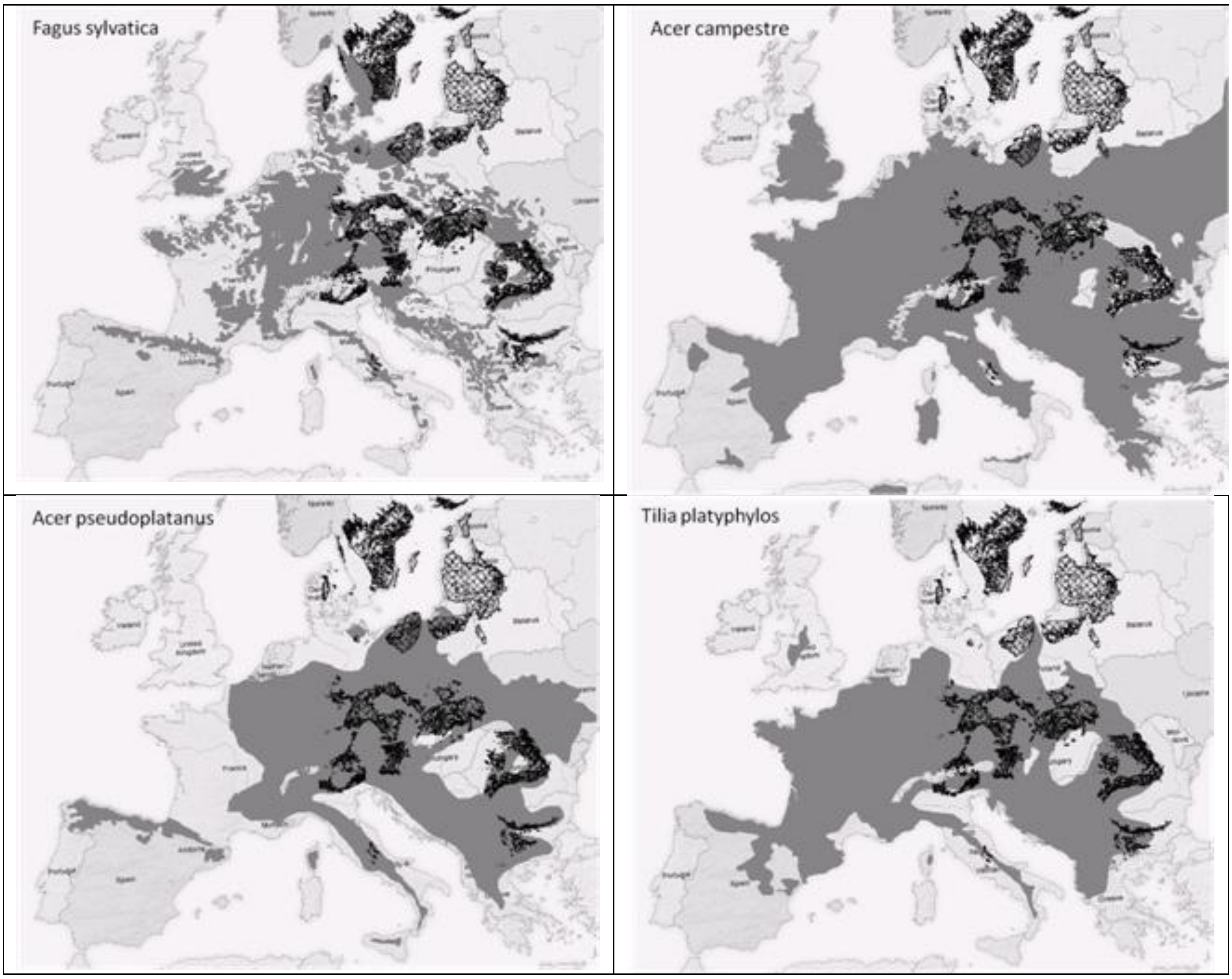
Figure

Fig.3



Figure

Fig. 4



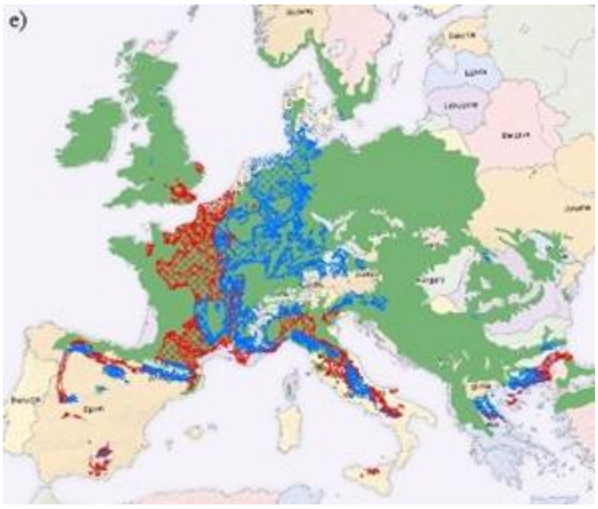
Fagus sylvatica
Acer campestre
Acer pseudoplatanus
Tilia platyphylos

Figure

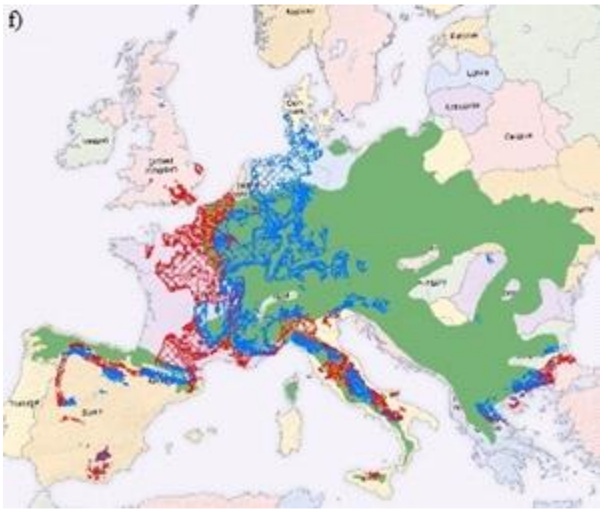
Fig. 5

Fagus sylvatica

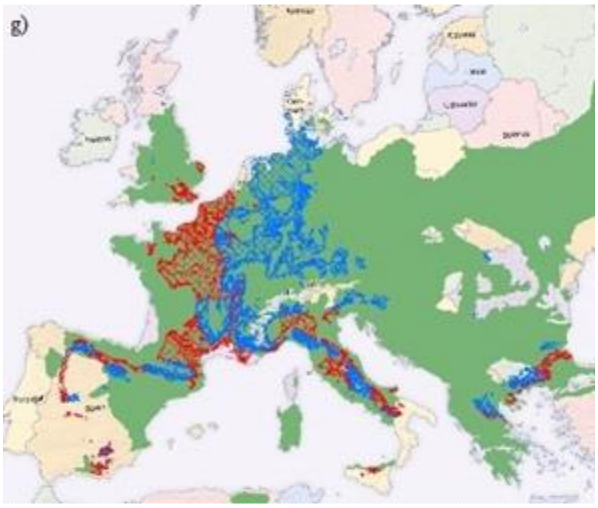
Tilia platyphyllos



Quercus petarea



Acer pseudoplatanus

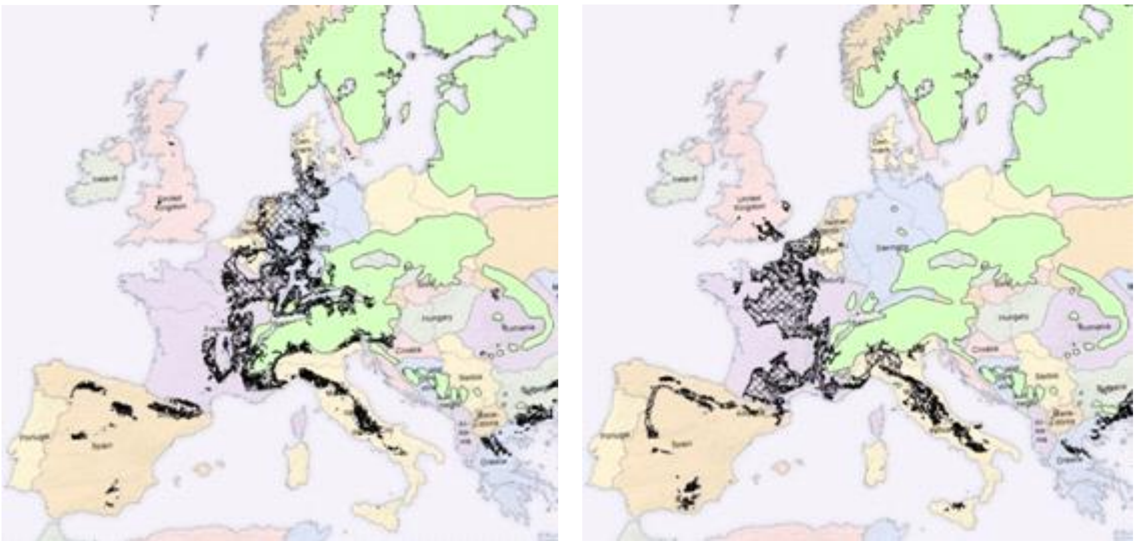


Acer campestre

Castanea sativa

Figure

Fig. 6



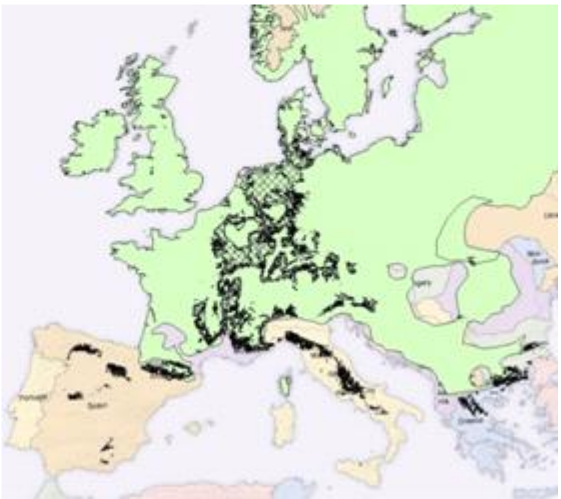
Scenario B1 *Scenario A2*

Fig. 7

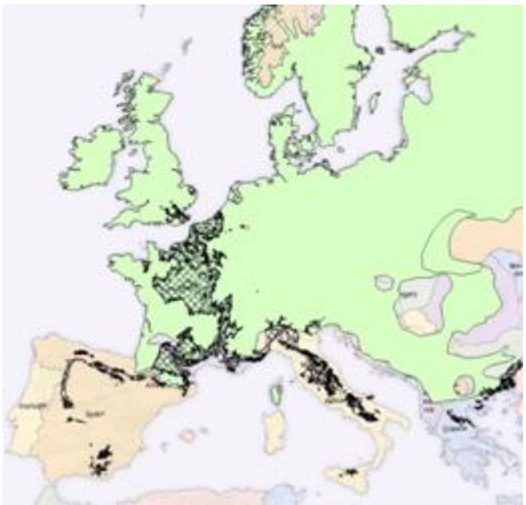
Scenario B1

Scenario A2

Fig. 8



Scenario B1



Scenario A2

Table

Table 1.

Scenarios	**Year**	**Changes in annual temperature, °C**	**Changes in winter (February) temperature, °C**	**Changes in precipitation, %**
A2 (1)	2031-2060	+2.0	+4.0	no change
A2 (2)	2061-2090	+4.0	+7.0	+15-20
B1 (1)	2031-2060	+1.0	+2.0	no change
B1 (2)	2061-2090	+2.0	+3.0	no change

Table 2

Species	Scenario A2		Scenario B1	
	2031-2060	2061-2090	2031-2060	2061-2090
Acer campestre	+	+	+	+
Acer pseudoplatanus	+	+	+	+
Castanea sativa	-	+	-	-
Fagus sylvatica	+	+	+	+
Populus nigra	+	+	+	+
Prunus avium	+	+	+	+
*Quercus petraea**	+	+	+	+
Quercus pubescens	+?	+	-	+?
Sorbus domestica	+	+	-	+
Sorbus torminalis	+?	+	+?	+?
Tilia platyphyllos	+	+	+?	+

* There is a small island of *Quercus petraea* in the southern part of Lithuania.

Table

Table 3

Species*	Scenario A2		Scenario B1	
	2031-2060	2061-2090	2031-2060	2061-2090
Acer platanoides	+	+	+	+
Alnus glutinosa	+	+	+	+
Alnus incana	+?	-	+?	+?
Betula pendula	+	+	+	+
Betula pubescens	+	+	+	+
Fraxinus excelsior	+	+	+	+
Malus sylvestris	+	+	+	+
Picea abies	-	-	-	-
Pinus sylvestris	+	-	+	+?
Pyrus pyraster	+?	+	-	+?
Populus tremula	+	+	+	+
Quercus robur	+	+	+	+
Tilia cordata	+	+	+	+
Ulmus laevis	+	+	+	+

* Species *Abies alba, Larix decidua, Pinus mugo* that have a stable distribution range in a mountain area have not been assessed;
** There is a small island of *Quercus petarea* in the southern part of Lithuania.