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A simple model for predicting the global distribution of the N_2 fixing host genus *Alnus Mill.*: impact of climate change on the global distribution in 2100

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A global distribution model of the N_2 fixing host genus Alnus

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Abstract

The importance of N_2-fixing plants has increased in last decades. *Alnus* (alder) is an important plant group because of its nitrogen fixation ability. Alders are generally distributed in humid locations of boreal, temperate and tropical climate zones, where the nitrogen fixation is an important nitrogen source for other plants. To model the nitrogen fixation by alder, data about the global distribution of alder is absolutely required. In this study a new method and model to predict the distribution of N_2-fixing genus on global scale is presented. Three linear functions were defined for the determination of climate area of alder locations. The distribution model was improved with the aid of the soil units from FAO-Unesco Soil Database, and vegetation types from Schmithüsen's biogeographical atlas. The model (Alnus-Distribution-Model, ADM) was also developed to predict the impact of climate change on alder distribution by using climate data of five relevant climate models (PCM, ECHam4, HadCM3, CSIRO2 and CGCM2), and four IPCC climate scenarios (i.e. A1FI, A2, B1 and B2) in 2100. The model covered basic approaches to understand the climate change effect on plant migration in the future.

1 Introduction

In recent years, the importance of the nitrogen cycle for the sequestration of atmospheric carbon dioxide in the terrestrial biosphere has become obvious (Vitousek et al., 2002; Galloway et al., 2004; Reich et al., 2006; Wang et al., 2007; Esser et al., 2011). While the fixation of CO_2 by photosynthesis produces carbohydrates, nitrogen is required to bind carbon in the phytomass. If the carbon content of the biospheric carbon pools increases, an adequate increase of the biospheric nitrogen pools is required. Atmospheric N_2 may be incorporated in the biosphere, but only a limited number of organisms are able to fix it, because of the high activation energy for the decomposition. These organisms are the free-living or symbiotic cyanobacteria, actinomycetes, and bacteria in the roots of host plants (Galloway, 2002). Not only the N_2-fixing bacteria but also the host plants which supply the required energy for the fixation to the bacteria have enormous importance for the ecosystems. Most of the host plants belong to the families *Fabaceae, Mimosaceae, Caesalpiniaceae* (legumes) as well as to the *Betulaceae* (alder spp.), and they are called N_2-fixing plants (Saikia and Jain, 2007; Lepper and Fleschner, 1977). Because of their participation in the N_2 fixation the modelling of distribution of the N_2-fixing plant species play a key role in the ecosystem. Several ecosystem, and biogeochemical models try to predict the nitrogen fixation by using empirical functions (Vitousek et al., 2002; Wang et al., 2007; Galloway, 2002; Esser, 2007). Yet, such models do not include the N_2 fixation by alders. To predict the amount of nitrogen fixation under global climate change conditions it is indispensable to have a mechanistic description of the N_2 fixation. It includes the description of the distribution of the symbiont's host plants, their density distribution in the vegetation types in which they occur, the type and the number of root nodules, and the activity of the nitrogen fixing enzyme systems in the nodules. Since, density of alders in their native locations amounts ca. 8 % of total plant biomass (Schwintzer, personal communication, 2010), a modelling of the distribution enables us to calculate alders biomass density according total plant biomass in a location by using models like Nitrogen-Carbon-Interaction-Model (NCIM) (Esser et al., 2011).

Alder roots are generally infected with the symbiotic endophytic genus *Frankia*. As a symbiont *Frankia* is able to convert atmospheric N_2 into reactive nitrogen usable by using the supplied carbohydrates from alders as energy source (Myrold and Huss-Dannel, 1994; Schwintzer and Tjepkema, 1990; Binkley, 1994). Thus, the N_2 fixation by alders can range from 20 $kg\,ha^{-1}\,yr^{-1}$ (Binkley, 1994) to 320 $kg\,ha^{-1}\,yr^{-1}$ (Van Miegroet et al., 1989). Therefore, alders play an important role in the respective ecosystems due to its ability to enrich poor soils with reactive nitrogen compounds. About 30 species belong to the genus alder, and to the family *Betulaceae*. The species are mainly distributed in the northern boreal and temperate zones e.g. *Alnus glutinosa (L.)* Gaerten, *A. incana (L.)* Moench, *A. viridis* (Chaix) D. C., *A. rubra* Bong., *A. oblongifolia* Torr, and *A. serrulata* (Ait.) Willd (Tutin et al., 2001). Some species extend into the subpolar

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zones, including *A. hirsuta (Fischer) C. K. Schneider*, *A. viridis* (Chaix) D. C. (Wiedmer and Senn–Irlet, 2006). In the Mediterranean zone occurs for example *A. cordata* (Loisel.) Duby. (Quezel et al., 1999). Numerous species are native to the mountains of the subtropical and tropical zones. *A. nitida* (Spach) Endl. occurs in the temperate Himalayas in altitudes from 1000 to 2900 m (Nasir, 1975). *A. nepalensis* D. Don is widely distributed in southeast Asia from subtropical China, Indochina, the Burmese (Shin) Hills, to the Himalayas in altitudes between 300 and 3000 m (Dai et al., 2004). Some alder species also distribute in the southern temperate zone, e.g. *A. acuminata* HBK, and the evergreen *A. jorullensis* Kunth are found in the Chilean Andes at high altitude (Reese, 2003).

Within the distribution area of the alders the mean annual temperature is reported to range from −14 °C to more than 20 °C (NACS, 1980). The annual precipitation probably ranges from less than 150 mm (WRCC, 2009; Hagenstein and Rickets, 2001) to more than 5600 mm (Harrington, 1991). Alder species prefer poor soils of various particle sizes from gravel and sand to silt, loam, and even clay as well as organic soils. Most species occur on fenlands, in swamp areas, along brooks, rivers, and streams in bogs, but regularly not in riparian areas with highly varying water levels.

Several studies show that the main factors which influence the distribution of plant species in their natural ecosystem are climatic factors like temperature and precipitation (Woodward, 1996; Dukes and Mooney, 1999; Walther et al., 2002). Not only the climate change is a critical factor for the plant distribution, but also the soil units via their different physical or/and chemical conditions can influence the plant distribution (Brown, 1984; Min and Kim, 1999; Wu et al., 2011). Therefore, the soil units should be considered in the modelling studies about the prediction of plant distribution. Also, the occurrence of a plant species in its natural area is depending on the plant–plant interactions. Plant species often favor to grow with specific other species (Pyke and Archer, 1991; Brooker, 2006). Several models like NCIM (Esser et al., 2011), LPJ-GUESS (Smith et al., 2001), and EMEP (Simpson et al., 2012) consider the plant–

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plant interactions due to use potential natural vegetation groups or biome units in the model simulations.

In this paper I reported my aims to model the global distribution of the N_2 fixing host genus alder, and then the effect of climate change effect on the globally alders distribution. To predict the global distribution of alders, an available gridded data sets on climate, soil units and potential natural vegetation groups will be used. I tested the individual contribution of each data type on the correctness of the predicted distribution. This work should be seen as a first step to predict the N_2-fixation by alders in NCIM model.

2 Materials and methods

In this paper a new model based on four progress steps was developed for the predicting of distribution of alder spp. on global scale. This new model is called "Alnus-Distribution-Model (ADM)". In the first step I used the values of annual average temperature and precipitation from Leemans and Cramer 0.5° degree grid element global climate database (Cramer and Leemans, 1991). In the second step I extended the climate based ADM with soil units after FAO soil classification (1974) in "Soil Types of the World" (FAO-Unesco, 1974). In the third step I extended the climate parameters based ADM with potential natural vegetation groups after Esser et al. (2011). The vegetation data set is our own digitized data base from the "Atlas for Bio-geography" after Schmithüsen (1976). The vegetation map after Schmithüsen comprises 176 vegetation units globally. These 176 vegetation units were aggregated in 31 potential natural vegetation groups in the research group at the institute, and it published in the study Esser et al. (2011). In the fourth step I merged all three methods to model the potential alders distribution by ADM. The used climate, soil, and vegetation data sets are on identical global grids of half degrees longitude and latitude as commonly used by global vegetation models. 62 483 grid elements are characterized for the land areas

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excluding Antarctica. Each grid element is characterized by its lower left (south-east) corner coordinate in decimal degrees.

2.1 Construction's data

For the construction of ADM I extracted data on the global distribution of species of the genus *Alnus Mill.* from seven data bases (Tropicos.org, 2009; eFloras, 2008; WWF, 2009; Tutin et al., 2001; US Forest Service, 2008; USDA–NRCS, 2009; Li and Skvortsov, 1999). The number of data for alders occurrence is very unevenly distributed worldwide. To get data points which were more or less evenly distributed in the area of distribution of this genus I preferred data of regions with scarce distribution. The name of the alders species, the altitude, and the coordinates of the origin place were collected. A total of 308 data sets including the data were extracted.

2.2 "Clim"

I determined the grid elements in which alders occur according to the 308 sites which I extracted from the seven data bases. All further analyses were made by using the gridded data sets. First I extracted mean annual temperature (T_{ann}) and annual total amounts of precipitation (P_{ann}) from the gridded climate data set for the sites of alders. The altitudes of the alder locations within a grid element may deviate from the mean altitude of the grid element, making corrections of the gridded climate data necessary. For this purpose I used the altitude of the site given in the original data bases. If altitudes were lacking, I determined the altitude of the sites from the GTOPO30 global elevation dataset (GTOPO30, 2010). If the altitude could not be determined the data were eliminated, except whose situated in flat terrain. Nearby climate stations were selected from Walter and Lieth (1961–1967), Müller (1982) and Mitchell and Jones (2005). I compared the climate data found for the alder sites with the data from these stations by means of the dry or its altitudinal gradients of temperature, and corrected the data if necessary. I plotted the arrays of T_{ann} and P_{ann} for the 308 alder sites. Three linear

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functions were then determined which envelop the field of climate data of the alder sites. The T_{ann} and P_{ann} values of the 308 locations were presented in the Fig. 3. I fitted three linear functions F_1–F_3 to the six cardinal points P_1–P_6: $F_1(P_1,P_2)$; $F_2(P_3,P_4)$; $F_3(P_5,P_6)$. These linear functions which form the borderlines of alder distribution in the temperature-precipitation matrix are:

$$F_1(x) = 172.58 - 2.04 \cdot x \quad (1)$$

$$F_2(x) = 16\,141.87 - 561.58 \cdot x \quad (2)$$

$$F_3(x) = 1\,658.64 + 110.67 \cdot x \quad (3)$$

The x equals to T_{ann} and $F_{(1,2,3)}(x)$ to P_{ann}. In Fig. 3 a plot of these functions can also be found.

To determine the potential distribution areas for alders by using climate based method the following equation is used:

$$D_{\mathrm{Clim},i} = \begin{cases} \text{true, if } \mathrm{Clim}_{T_{ann},P_{ann},i} \text{ inside of the climate matrix field,} \\ \text{false, else} \end{cases} \quad (4)$$

where i is grid number of actual half degree grid element, T_{ann} is mean annual temperature, and P_{ann} is annual total amounts of precipitation of the grid element, respectively. The distribution of alder species based on climate parameter ($D_{\mathrm{clim},i}$) is true in a grid element if the certain criteria of the grid element are fulfilled (see Eq. 4).

2.3 "Soil"

I used the FAO soil units of the "Soil Types of the World" (FAO-Unesco, 1974) to enhance the climate based ADM for prediction of potential alders distribution. I verified the soil units which occur in the 308 grid elements with alder sites. Soil units were used as additional determinants for alder occurrence. If soil units were present in only one grid element with alder data record they were not considered. Grid elements were marked as potential alder habitats if they lie within the climate field limited by the three linear functions of the temperature-precipitation field, and have suitable soil unit which occurs in more than one grid elements with alder distribution. For this step the following equation was used:

$$D_{\mathrm{Soil},i} = \begin{cases} \text{true, if} \begin{cases} \mathrm{Soil}_i = \mathrm{Soil}_\mathrm{a} \\ D_{\mathrm{Clim},i} = \text{true} \end{cases} \\ \text{false, else} \end{cases} \quad (5)$$

where i is grid number of actual half degree grid element, Soil_i is the soil unit of the grid element, and Soil_a is the soil unit of the grid elements with data record about alder distribution in 308 study sites, respectively.

2.4 "Veg"

In the next steps, the potential natural vegetation groups were used to investigate the correlation between the alder distribution and climate–vegetation aspect in this study. I verified the potential natural vegetation groups which occur in the grid elements with alder sites. These potential natural vegetation groups were used as additional determinants for alder distribution. If a potential natural vegetation groups were present in only one grid element with alder data record, they were not considered in the prediction. Grid elements were marked as potential alder habitats if they lie within the climate field limited by the three linear functions of the temperature-precipitation field, and have suitable potential natural vegetation group which occurs in more than one grid elements with alder distribution. For this step the following equation was used:

$$D_{\mathrm{Veg},i} = \begin{cases} \text{true, if} \begin{cases} \mathrm{Veg}_i = \mathrm{Veg}_\mathrm{a} \\ D_{\mathrm{Clim},i} = \text{true} \end{cases} \\ \text{false, else} \end{cases} \quad (6)$$

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where i is grid number of actual half degree grid element, Veg_i is the vegetation type of the grid element, and Veg_a is the vegetation type of the grid elements with data record about alder distribution in 308 study sites, respectively.

2.5 "All"

Finally I combined all three method for modelling of potential alder distribution. The verified the soil units, and the potential natural vegetation groups which occur in the grid elements with alder sites were used together as additional determinants for alder occurrence. The equation of this step is as follows:

$$D_{\mathrm{All},i} = \begin{cases} \text{true, if} \begin{cases} D_{\mathrm{Clim},i} = \text{true} \\ D_{\mathrm{Soil},i} = \text{true} \\ D_{\mathrm{Veg},i} = \text{true} \end{cases} \\ \text{false, else} \end{cases} \tag{7}$$

where i is grid number of actual half degree grid element.

2.6 Observations and statistical analyses

For the evaluation of the model results I used the Global Biodiversity Occurrence Data Base (GBIF) (GBIF, 2010), which has not been used for the model construction. The database includes 237 178 data records about the alder occurrence worldwide. The majority of these observations crowds together in a few regions of the world, while data in other regions are very scarce, so that the global coverage is very uneven. The database includes global maps as well as the opportunity to download informations amongst others the coordinate, name of the occurred alder species, and basis of records (unknown, herbarium, observed or specimen) in the locations. In the Table 3 is presented the 49 countries which extracted from the database with data records about the alder distribution. The countries with just one data record for alder distribution or data records without the coordinate of the location or with the "unknown" basis of records were not considered in this study. Therefore, 215 444 of 237 178 were selected as useful data records in the 49 countries (see Table 3). The first 13 countries in the Table 3 include 93 % of the useful data records and the most data density for alder distribution. Therefore I used these 13 countries for the validation of model prediction about alder distribution.

I compared the prediction of the ADM model with the data records from the GBIF database as well as analyzed the correlations between the observed and predicted data in the 13 countries by calculation regression coefficient, index of agreement d (Willmott, 1982) (see Eq. 9), mean absolute error (MAE) (see Eq. 8) to determine the best method for the prediction of the alder distribution.

$$\mathrm{MAE} = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i| \tag{8}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}((|P_i - \overline{O}|) + (|O_i - \overline{O}|))^2} \tag{9}$$

where P is the simulation and O is the observation data, i a particular sample, n the number of samples, overbar represents mean values, and d is the index of agreement, respectively.

3 Distribution simulations with climate change scenarios

The second aim of this paper was to show the prediction of climate change effect on alder spatial and temporal distribution by using the climate parameter of five relevant climate models according to four IPCC SRES scenarios (i.e. A1FI, A2, B1, B2) in 2100. For this aim I used the climate parameters "T_{ann}" and "P_{ann}" of TYN SC 2.0 high resolution gridded datasets from the climate models CGCM2, CSIRO2, HadCM3, ECHam4 and PCM (Mitchell and Jones, 2005) to show the effects of climate change by using

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different climate scenarios of different climate models on alder distribution in 2100. The using of different models and scenarios given the opportunity to compare the effects of the models and scenarios on the migration of alders on global scale in 2100. In the Figs. 1 and 2 the values of the mean annual temperature and the annual total amount of precipitation from the climate models and scenarios in a sample location to show the differences between the models, and also its SRES scenarios from 2001 to 2100.

4 Results

4.1 Evaluation of distribution methods

In Fig. 3 the distribution of the 308 data points in the field of T_{ann} and P_{ann} is shown. It is to see that there is a lower limit of annual precipitation which excludes the occurrence of alders. This lower limit depends on the T_{ann}. At the alder distribution sides when the low T_{anns} of $-10\,^{\circ}$C and less is the P_{ann} limit at ca. 190 mm. When the T_{ann} amounts to 28 °C at the alder distribution areas the alder require ca. 115 mm annual precipitation for their presence. Since alders occur at low precipitation values mainly along rivers and brooks, I believe that the occurrence of alders in areas with low value of P_{ann} due to the probability of the occurrence of suitable water content of the soil throughout the year. The presence of nearby mountains may also be in favor of the formation of permanent surface waters.

I selected six cardinal points $P1 \ldots P6$ to define the borderline of the alder distribution in a matrix (see Fig. 3). The point $P1$, $P2$ and $P6$ refers to *Alnus viridis* (Chaix) Lam. and DC., which occurs in the northern boreal regions of Asia, Europe, and North America. In temperate regions it may occur at high elevations (Kamruzzahan, 2003). The P_{ann} range for *Alnus viridis* (Chaix) Lam. and DC. is between 150 mm yr^{-1} and 3000 mm yr^{-1} in its native distribution areas (Racine et al., 2001). The points $P3$ and $P4$ belong to the two species *A. acuminata* HBK, the Andean alder, and *A. jorullensis* Kunth, the Mexican alder, which are native to the mountains of Central and South America.

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Their distribution defines the upper temperature limit of the alder distribution, which seems to be below 30 °C average annual temperature. The P_{ann} may range from 500 to 4000 mm yr^{-1}. The point *P*5 refers to *Alnus rhombifolia Nutt.*, which occurs in the lower areas of the northern Pacific coast of North America in humid to per-humid climates (USDA–NRCS, 2009). The P_{ann} within the distribution areas of *A. rhombifolia Nutt.* is reported to vary from 508 to 3175 mm, and the lowest temperature is −4.4 °C in the distribution areas (USDA–NRCS, 2009).

4.2 Further stages of the model

The climate based ADM were refined by means of the soil units. The soil units which recorded in the 308 grid elements are shown in Table 1. The considered alder distribution areas involve 53 of 130 FAO soil units. Lithosols and Cambisols are the dominated soil units in the 308 distribution areas. About half the grid elements include the two soil units. Although most alder species prefer to distribute in It soils and in soils with high water availability, I found the Gleysols only in 21 of 308 grid elements. I did not consider soil units which were present in only one grid element.

In Table 2 the potential natural vegetation groups of the 308 grid elements after Esser et al. (2011) and their vegetation units which occur in digitized version of the atlas for bio-geography after Schmithüsen (1976) were shown. 50 of 176 vegetation units according to Schmithüsen (1976) were recorded in the 308 grid elements. The most common vegetation units in the distribution areas belong to the potential natural vegetation group “Temperate deciduous forests” (68 of 308 grid elements). 97 locations have the tropical and subtropical potential natural vegetation groups. In 32 grid elements were recorded dry vegetation units (“Open conif. dry woodland”, “Conif. dry forest”, “Puna dry steppe”, “Drought-deciduous and part evergreen thorn bush formation”, “Artemisia dry steppe”, and “Trop. lowland dry forest”). In these grid elements the alders may be distribute in moist areas along rivers and streams. The “drought-deciduous and part evergreen thorn bush formation” (7 sites) for example occurs on the east slopes of the Argentinian and southern Bolivian Andes, where lots of brooks

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and rivers are present. There are also 33 grid elements with sclerophyllous formations of Mediterranean type climates. These sites may also be supported by water currents occurring in these formations. From the 308 grid elements of Table 2, I selected the potential natural vegetation groups which are represented by more than one occurrence. I assumed that alders occur within the selected formations only.

4.3 Observed alder distribution

In Table 3 I presented the data about the 49 countries with data records for alder distribution in GBIF database. The 49 countries includes 215 444 data records with coordinates of the locations, name of the occurred alder species, and the basis of the records for alder occurrences. The countries were ordered after having most data records (i.e. countries with most data records first). The 13 countries on the left side of the Table 3 (11 of them in Europe, one in Central America, and one in Asia) included the most data records for alder distribution in the GBIF database (see Table 3 column "Rec."). The total number of records in these countries is 206 672 of 215 444 in 1754 of 4098 half degree grid elements (see Table 3 columns "Rec.", and "GBIF 05"). The other 36 countries on the right side of the Table 3 included the rest of data records (8768) for the alder distribution in GBIF database. Two countries after the middle line the table (US and Canada) have indeed high data records but less data density (records number per grid elements). Therefore I did not consider these countries within the 13 countries. Countries with only one data record in GBIF data base were also not considered and not presented in this paper.

4.4 Observed vs. predicted alder distribution

Since the 13 countries had the most density for data records about the alder distribution in GBIF database, I did statistical analysis between the observed and predicted alder distribution in these countries to find out, which method of the four methods ("Clim", "Soil", "Veg", and "All") is more suitable for the modelling of alder distribution. In the

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Fig. 4 the results of the correlation and statistical analyses between the observed and predicted number of half degree grid elements with data records about alder distribution were presented. The correlation functions ($f(x)$), 1 : 1 lines, correlation coefficients (r^2), index of agreement (d), and mean absolute error (MAE) were also presented in the scatter plots. The actual data of the scatter plots may be found in the Table 4 columns "Grid", "Soil" "Veg", and "All", respectively. The r^2 values of the correlation analyses ranged between 27 % and 76 %. The lowest correlation were found between the observed and "Clim" method based ADM results with $r^2 = 27\,\%$. The d and MAE values of the of this correlation analysis were 0.56 and 73, respectively (see Fig. 4a). The "Clim" method shown also a large intercept with 81 grid elements. The "Soil" and "Veg" methods shown better correlation with the observed data than the "Clim" method (see Fig. 4b and c). The correlation coefficients r^2 between these two methods and observed data were 68 % and 71 %, respectively. The d of these two methods shown quite good values with 0.86 ("Soil" method) and 0.90 ("Veg" method), where the MAE value was 46 for "Soil" method and 35 for "Veg" method. The best correlation coefficient ($r^2 = 76\,\%$) were found between the observed and "All" method based ADM results (see Fig. 4d). And also the highest d value with 0.90, and the lowest MAE value with 34 were found between the "All" method based ADM and observed data. The intercept of this method was around 30 grid elements. Thus, the correlation analyses shown the best performance between the "All" method based ADM results and the observed data in the high relevant 13 countries. Because of the best r^2, d, intercept, and MAE values I used the "All" method based ADM to predict the potential alder distribution areas globally.

4.5 Global potential alder distribution

The predicted alder distribution by using "All" method based ADM was shown in Fig. 6. It is to see that alder has a large potential distribution areas in Asia and North America. In comparison to the global alder distribution on GBIF map (see Fig. 5) the ADM also predicted the potential distribution in several grid elements of South America, Africa, and Australia (see Fig. 6). The ADM predicted the alder distribution in 1870 grid elements in the 13 countries where the GBIF database has the data records in 1754 grid elements (see Table 4 columns "Grid" and "All"). The most of the eliminated grid elements have the suitable soil unit but not the vegetation type for the potential alder distribution in this countries. For example, the eliminated grid elements in Norway have the soil unit "Lithosols" and the vegetation type "Mountain vegetation above the tree line". The "Lithosols" are the second largest occurred soil units in the 308 grid elements (75 of 308) of the evaluation's grid elements (see Table 1). These grid elements have the suitable climate conditions and soil units but not the vegetation types. The most eliminated grid elements in the 13 countries after using "Soil" and "Veg" methods in ADM were located in Mexico. The dominant soil units in Mexico are "Leptosols", "Regrosols", and "Calcisols" (FAO-Unesco, 1974). Only the "Regrosols" were presented in 308 evaluation's grid elements (see Table 1). Also, the dominated vegetation types are the "Shrub desert", "Thorn savanna", and also the "Open deciduous small leafed" in Mexico. Only the vegetation units "Thorn savanna" were recorded in one of 308 grid elements. In Russia and China the ADM shown the potential alder distribution in 67, and 460 times more grid elements than the GBIF database records. In Russia the grid elements with potential alder distribution have the suitable climate conditions, soil units ("Lithosols" and "Cambisols") as well as the potential natural vegetation groups ("Boreal coniferous forest" and "Boreal woodlands"). These two soil units were recorded in 45 of the 308 evaluation's grid elements (see Table 1) and the vegetation types in 75 of the 308 grid elements (see Table 2). In China the same vegetation types are also the dominant in potential distribution areas. However, the mostly coming soil units in that areas are the "Cambisols", "Gleysols" and "Acrisols". These three soil units were found in 121 of 308 grid elements. In comparison to the 13 countries the US and Canada have also large data records but appreciably low data density per grid elements. The ADM predicted the alder distribution in 499 grid elements more in US and in 1613 in Canada than the GBIF database. In these areas the soil units "Lithosols", "Podzols", "Luvisols", and "Phaozems" are mostly documented (FAO-Unesco, 1974). The

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potential natural vegetation groups are mainly the "Temperate deciduous forests", and "Mediterranean sclerophyll formations" in the US, the "Boreal evergreen conif. forests" in Canada. These soil and vegetation types were found in most of the 308 grid elements.

It is generally to see that the "Soil" method eliminated more grid elements than the "Veg" method in 10 of the 13 countries as well as in Russia, in China, and in the US. In France, Germany, Poland, and Canada more grid elements were eliminated by using the "Veg" method than the "Soil" method.

4.6 Potential distribution of alder in 2100

The migration of alder species in 2100 was shown in the Fig. 7. For this step of the study I assume that the soil unit and the potential natural vegetation groups of a grid element will not be changed in 2100. The results show that the alder can extend its distribution northwards. Especially the alder species may be frequently occur furthermore in northern Russia and Alaska at all scenarios of the climate models (see the blue areas in Fig. 7). Few grid elements in Norway, Finland, the US and Canada may also additionally to be suited for the alder distribution in all scenarios in 2100. On the other hand a range of grid elements close to coast in Europe, southern US and southern China may not have proper conditions anymore for alder distribution (see the green areas in Fig. 7). It is further to see that most of the grid elements in Africa, Indonesia and middle and south America may be eliminated for the alder distribution by all scenarios of the climate models in 2100. The scenarios A1FI and A2 as well as B1 and B2 in all five climate models show globally quite the same effect on the alder distribution. In comparison to the other four climate models more grid elements were eliminated in southeast USA and southern China by using the climate parameters of the HadCM3 climate model (see Fig. 7-HadCM3).

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5 Discussion

The begin of the record for the distribution of the world's vegetation types was by foundations of plant geography in von Humboldt ca. 200 yr ago (Humboldt, 1807). Also at the beginning of 18th century the scientist started to investigate about the potential effect of climate on plant distribution (Schouw, 1823; Meyen, 1846). Nowadays numerous models use the climate conditions for the prediction of the plant species distribution, and for the modelling of phenological processes of the plants (Prentice et al., 1992; Brovkin et al., 1997; Smith et al., 2001; Skjøth et al., 2008; Sakalli and Simpson, 2012). Lantz et al. (2010) investigated the regional temperature effect on the *Alnus viridis subsp. fruticosa* (green alder) patch dynamics and plant community (Lantz et al., 2010). They found out that the regional temperature influence the cover, growth, reproduction and age distributions of the green alder. Martínez-Meyer and Peterson (2006) worked on niche models to determine the distribution of eight taxa including *A. incana* and *A. viridis* in North America by using pollen distribution data on present day, and climate data from the Palaeoclimate Modelling Intercomparison Project in Last Glacial Maximum (LGM) (Martínez-Meyer and Peterson, 2006). They found a similar temperature-precipitation demand for the distribution of *A. incana* (see Fig. 3 in the paper). However, the using of only climate parameter in ADM predicted the distribution of all alder species almost in whole Australia, and Middle and South Africa where there is no or very poor record about the distribution of alder (see Fig. S1 in Supplement). Also, the statistical analysis of the "Clim" methods has the poorest correlation in the 13 countries with high density records about the alder distribution. Sykes et al. (1996) developed a bioclimatic model based on climatic geography of the European plants to predict the distribution of northern Europe's dominant trees including the alder species *A. incana* (Sykes et al., 1996). They used the bioclimatic factors as winter cold tolerance, summer heat and winter cold requirements, and drought tolerance (soil moisture) of the species. Although the bioclimatic model supplied quite good result for the *A. incana* distribution, it also showed that the distribution of the plants is not only depending

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on the climate factors but also the soil conditions can play a crucial role in the prediction. Like most of the models the bioclimatic model can be used for prediction of the distribution of specific alder species on regional scales and needs predefined parameter for each species. The ADM has the advantage to predict the distribution of all alder species on global and regional scale.

Since the selected climate factors were alone inadequately to predict the distributions of alder species, and it is well known that the components of each plant community are influenced by soil units, and the alders prefer some specific soil conditions for the occurring in a natural ecosystems (Bean, 1989; Wheeler and Miller, 1990; Claessens et al., 2010), the soil units were used as additionally determinant to the selected climate factors for the modelling of potential alder distribution areas. The addition of the soil units to the “Clim” method showed its effect mostly in East Europe, Australia, Central and South Africa as well as in North America. But in comparison to the distribution Map from GBIF and the literature data, quite a lot areas were still selected as potential distribution locations for the alder species in that areas (see Fig. 5 and Fig. S2 in Supplement). Also the statistical analysis between the observed and predicted data in the 13 countries resulted a rare correlation (see Fig. 4b).

In the natural ecosystems the plants are living in a species compositions which are called plant communities (Schmithüsen, 1968). Each plant species belongs to a community and is related to other species of the community (Breckle, 2002). Therefore the relations of the species in the plant communities, and the using of the relations in modelling of distribution of plant species are vitally important. Woodward and Williams (1987) investigated the effect of climate on the plant distribution on global and local scales (Woodward and Williams, 1987). Their predictions of the distribution of the vegetations were based on temperature, precipitation and annual water balance of the distribution areas. They enhanced also that the climate conditions are not sufficiently for the modelling of the distribution of vegetations or species, and in such modelling studies the population dynamics (plant–plant interactions) should be also considered. Due to this informations the potential natural vegetation groups after Schmithüsen (1976)

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were used as additional determinant to the "Clim" method for the prediction of the potential distribution areas for alder species. The statistical of the results in the 13 countries showed quite good correlation with the observed data from the GBIF database (see Fig. 4c). But on the global scale it is to see that the comparing of the results (see Fig. S3 in Supplement) with the distribution map from GBIF database (see Fig. 5) presented noticeable differences in East Europe, in Canada, southeast Australia and America.

The additions of soil units and potential natural vegetation groups to the "Clim" method pointed out that both determinants can influence the prediction of the potential distribution areas of alder species in different regions. Therefore I decided to merge all determinants in one method (see Sect. 2.5) for the modelling of the potential distribution areas of alder species. The "All" method of the ADM shows a new kind of modelling issue for plant distribution. The statistical analysis of the "All" method results showed quite good correlation and the best value of index of agreement as well as the lowest MAE (see Fig. 4d). The predicted potential distribution areas for alder species using the "All" method is presented in the Fig. 6. In comparison to the potential distribution maps of the "Clim", "Soil" and "Veg" methods there is a further improvement of the predicted distribution especially in Central and Eastern Asia, and in America. But there is still differences between the observed and predicted distribution areas in Asia, Africa, southeast Australia and America. It is well known that alder grows well on acid soils and its growth can reduced under the alkaline or neutral conditions. "Lithosols" are typical soil unit in temperate climate zone under coniferous forests, and the "Camsbisols" are particularly well represented in boreal and temperate regions. Both of the soil units are well distribute in Russia and known as acid soils. Suitable climate conditions and vegetation groups make possible to distribute the alders in large areas in Russia. Murai (1968) published the potential distribution areas of alder species (*A. viridis* and *A. crispa*) in Russia in a vegetation map (see Fig. 9) (Murai, 1968). It is to see that the distribution of *A. viridis* and *A. crispa* stretches in most vegetation zones of Russia. Also, Kajba and Gracan (2003) illustrated a map (see Fig. 8) for the distribution of *A.*

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glutinosa in Europe (Kajba and Gracan, 2003). It shows that *A. glutinosa* also distribute in several locations in Russia. These maps confirm that the results of ADM prediction could be accepted as true in Russia. Furthermore, the GBIF database does not indicate the absence of alders. As a consequence, grid elements with no data records may indicate either the absence of alders or the absence of observations. Because of the suitable climate, soil, and vegetation conditions it is highly probable that alders can distribute in these areas (Czerepanov, 1995). For this country ADM may provide better results for the distribution of this genus. The discussion of this results also shows the importance to improve the GBIF database for validation of the model results. In China the alder distribution was recorded in only three grid elements (see Table 3). But "All" method based ADM predicted the distribution in 1376 grid elements more than the GBIF database. Yet, it is well known that *A. nepalensis* D. Don distributes moist, cool, subtropical monsoon climates with a dry season of 4–8 months in Guangxi, Guizhou, SW Sichuan, Xizang, Yunnan of China (Furlow, 1979; Sharma and Ambasht, 1991; Chen, 1994; Jackson, 1994; Dorthe, 2000; Chen and Li, 2004). It also shows that the prediction of ADM for alder distribution is more reliable than GBIF database in China. Some sites in Central Africa and southeast Australia also still remain. These sites in Central Africa are known to be suitable for alder cultivation, although no natural occurrence of alders is recorded in the areas. Such plantations of alder species are also recorded in African highlands (Wajja-Musukl et al., 2008; Muthuri et al., 2009; Siriri et al, 2013). Niang et al. (1996) published data about the adapted alder species (*A. acuminata* HBK) to the highlands of Rwanda in Central Africa (Niang, 1996). The average annual rainfall is 1500 mm and the annual mean temperature is 14.6 °C in the study site. The values of the climate parameters are in the climate field (see Fig. 3). The dominant soil unit is a "Podzols" and the vegetation group is a "tropical forests of higher elevation". Both the soil unit and the vegetation group are presented in the 308 evaluation's data (see Tables 1 and 2). This result shows that the alder species can well distribute in some areas of Central Africa, and the prediction of ADM can be right in Central Africa. In southeast Australia 8 records in totally 3 grid elements were

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recorded in GBIF data base (see Table 3). But the model results shown that alders potentially can distribute in 157 grid elements in this area. The T_{ann} and P_{ann} values in the regions range 8–15 °C and 500–1100 mm, respectively. The dominant vegetation unit is "Laurel mountain forests" as well as "Laurel forest w. conf. trees", and the "Luvisols" are the most recorded soil types in southeast Australia. The values of the climate parameter in the 157 grid elements are found in the climate matrix field in the Fig. 3 as well as the vegetation units and the soil types are appropriate units and types for a potential alder distribution. Therefore, it is quite possible that the alders can have larger distribution than as recorded in GBIF database for southeast Australia. Hnatiuk (1990) also recorded a alder species (*A. glutinosa*) in Australia, and indicated that four related species have also naturalized in Australia Hnatiuk (1990). But, there is no information about the distribution locations of the alders in his study.

A visible and an important difference between the predicted and observed alder distribution is to see in South American lowland and *Araucaria* forests in Brazil and Paraguay (see Fig. 6). The ADM show the potential alder distribution in 168 of 1653 grid elements in Brazil and in 40 of 143 in Paraguay where the GBIF database does not include data records about the alder distribution. But, Ledru et al. (2007) and Behring (1997) published data about the pollen distribution of some alder species in *Araucaria* forests in South Brazil (Ledru et al., 2007; Behling, 1997). Also, Marchant et al. (2002) presented data about pollen distribution of alder in several Middle and South American countries (Marchant et al., 2002). They found alder pollen in gallery forests and forests with *Quercus*-*Pinus* species. These pollen data shows that alder species have distributed in the regions of South America with suitable climate conditions, soil units and vegetation groups. But, data records about current occurrence of alders with coordinate data are still needed in the regions for a reliable comparison of the model results.

The pollen records of the alder species in some areas where the alders currently do not represent show that the alders have potential for migration. Van Minnen et al. (2000) reported that the alders need between 50 and 200 yr to change its distribution areas

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due to the climate change (Van Minnen et al., 2000). The migration of nitrogen fixers will absolutely influenced the natural nitrogen fixation in the ecosystems. Esser et al. (2011) showed the effect of nitrogen fixation on carbon biogeochemical cycle by switching off and on the nitrogen fixation fluxes in the nitrogen carbon interaction model (NCIM) (see model scenarios in Esser et al., 2011). Therefore the investigation of the spatial and temporal alder migration is extreme important. The using climate parameters from different climate models and scenarios gives important indications of climate change effects on alnus distribution in the future. As it presented in Figs. 1 and 2 five climate models provide variously T_{ann} and P_{ann} by using four IPCC SRES scenarios. Although there is quite difference between the values of the T_{ann} as well as P_{ann} of the models. Further, the difference between the four scenarios of the models are quite large (ca. 16 °C at T_{ann} and ca. 250 mm at P_{ann} in 2100). Though, the effects of the climate parameter of the models, and scenarios on the alder distribution on global scale are quite similar (see Fig. 7). There is unfortunately no similar study to compare the results of the ADM by using values of the climate parameter from the five climate models and four IPCC SRES scenarios for each climate model.

6 Conclusions

Climate is the main predictor for the identification of regions which are potential habitats for the alders. But climate alone may not predict the range of alders correctly. By using soil units and potential natural vegetation groups as additional predictors, the identification of potential alder sites is much closer to the presented distribution map of GBIF database. For the prediction of migration of the alder species in the future, which may result from the climate changes, not only data from climate models are required, but also from dynamic vegetation models, which are driven by climate date in the future, and modelling of dynamic soil units are necessarily. The distribution of soil units on half degree grid elements can be assumed to change so slowly so that their changes do not need to be considered. The results of the ADM show that quite a lot areas in

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Northern Hemisphere will get the suitable conditions for the migration of alder species. But also, a lot of grid elements in Southern Hemisphere will be not more eligible for alder occurrence.

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Table 1. Soil units after FAO-UNESCO (1974 ff.) which dominate in the 0.5° grid elements where alder species occur according to the GBIF database.

Number of grid elements	FAO unit	Soil name
78	**B**	**Cambisols**
21	BK	Calcic Cambisol
19	BD	Dystric Cambisol
19	BE	Eutric Cambisol
15	BH	Humic Cambisol
2	BG	Gleyic Cambisol
2	BX	Gelic Cambisol
75	**I**	**Lithosols**
35	**A**	**Acrisols**
26	AO	Orthic Acrisol
4	AF	Ferric Acrisol
4	AH	Humic Acrisol
1	AG	Gleyic Acrisol
1	AP	Plinthic Acrisol
22	**P**	**Podzols**
17	PO	Orthic Podzol
5	PL	Leptic Podzol
20	**G**	**Gleysols**
15	GD	Dystric Gleysol
4	GE	Eutric Gleysol
1	GM	Mollic Gleysol
18	**L**	**Luvisols**
7	LC	Chromic Luvisol
6	LO	Orthic Luvisol
5	LA	Albic Luvisol
14	**T**	**Andosols**
7	TV	Vitric Andosol
5	TH	Humic Andosol
2	TM	Mollic Andosol
13	**H**	**Phaeozems**

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Table 1. Continued.

Number of grid elements	FAO unit	Soil name
6	HG	Gleyic Phaeozem
5	HL	Luvic Phaeozem
2	HH	Haplic Phaeozem
7	**R**	**Regosols**
4	RX	Gelic Regesol
2	RC	Calcaric Regesol
1	RD	Dystric Regesol
5	**Y**	**Yermosols**
3	YL	Luvic Yermosol
2	YK	Calcic Yermosol
4	**N**	**Nitosols**
4	NE	Eutric Nitosol
4	**O**	**Histosols**
4	OX	Gelic Histosol
3	**J**	**Fluvisols**
3	JE	Eutric Fluvisol
3	**U**	**Rankers**
3	X	Xerosols
2	XH	Haplic Xerosol
1	XL	Luvic Xerosol
1	**F**	**Ferrasols**
1	FX	Xanthic Ferrasol
1	**K**	**Kastanozems**
1	KL	Luvic Kastanozem
1	**W**	**Planosols**
1	WE	Eutric Planosol
1	**ICE**	**Ice**

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Table 2. The potential natural vegetation groups after Esser et al. (2011) (name with bold character) and the vegetation units according to Schmithüsen (1976) which occur in the 0.5° grid elements which include the data records about alder occurrence. The left column gives the respective number of grid elements.

Rec.	Vegetation group
68	**Temperate deciduous forests**
22	Cold-deciduous broadleafed forest w. evergreen conif. trees
20	Cold-deciduous mesophytic broadleafed forest
10	Submediterranean cold-deciduous broadleafed forest
6	Mountain cold-deciduous mesophytic broadleafed forest
4	Cold-deciduous mesophytic broadleafed forest w. Quercus
3	Cold-deciduous broadleafed forest w. evergreen broadleafed trees
3	Mountain cold-deciduous broadleafed forest w. conif. trees
50	**Tropical mountain forests**
24	Tropical evergreen cloud forest
12	Tropical deciduous moist mountain forest
9	Tropical mountain rain forest
5	Tropical evergreen oak-pine forest
43	**Boreal evergreen conif. forest**
21	Boreal evergreen mountain conif. forest
15	Boreal evergreen conif. forest w. cold-deciduos broad-leafed trees
7	Boreal evergreen conif. forest
33	**Mediterranean sclerophyll formations**
16	Sclerophyllous forest w. Quercus ilex
15	Sclerophyllous forest w. Olea
2	Sclerophyllous forest w. Quercus suber
32	**Boreal woodlands**
32	Boreal, subpolar open conif. woodland
22	**Temperate woodlands**
16	Open conif. dry woodland
4	Cold-deciduous tree steppe
2	Conif. dry forest
10	**Subtropical evergreen forests**
6	Laurel mountain forest
2	Laurel forest w. conif. trees
1	Subtropical semi-deciduous rain forest
1	Laurel forest
10	**Temperate evergreen forests**
7	Temperate conif. rain forest

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Table 2. Continued.

Rec.	Vegetation group
2	Extra-boreal mountain conif. forest
1	Extra-boreal mountain conif. forest w. Pinus
9	**Tropical Paramo woodlands**
7	Paramo heath
2	Paramo laurel woodland
8	**Puna steppes**
6	Moist Puna steppe
2	Puna dry steppe
7	**Mediterranean woodlands, shrub formations**
5	Drought-deciduous, part evergreen thorn bush formation
1	Open sclerophyllous woodland
1	Sclerophyllous garrigue
7	**Xerophyte formations**
7	Tropical-subtropical deciduous scrub
5	**Temperate shrub formations**
2	Artemisia dry steppe
2	Hard, thorn pillow mountain formation
1	Peat-moss raised bog w. conif. trees
5	**Tropical lowlands dry forests**
5	Tropical deciduous dry forest
4	**Tropical lowlands rain forests**
2	Tropical evergreen lowland rain forest
1	Tropical semi-deciduous lowland rain forest
1	Tropical deciduous moist forest
2	**Subtropical savannas**
1	Sclerophyllous shrub formation
1	Thorn savanna
2	**Temperate steppes, grasslands**
2	Transitional steppe
1	**Subtropical deciduous forests**
1	Subtropical cold-deciduous conif. swamp-forest
1	**Subtropical halophyte formations**
1	Saltings or coastal dune vegetation
1	**Tropical savannas**
1	Open evergreen savanna woodland
1	**Tropical Paramo grasslands**
1	Paramo grassland
1	**Ice**

Table 3. Analysis of the data distribution in the GBIF database GBIF (2010) which was used for the validation of the ADM model results for 49 countries with data records for alder distribution. Meaning of the columns: (Country) name of the countries; (Rec.) Number of data records for alder distribution in each country (countries with just one data record are not shown); (Grid 0.5) Number of half degree grid elements of the country; (GBIF 0.5) Number of half degree grid elements with data records about the alder distribution.

Country	Rec.	Grid 0.5	GBIF 0.5
UK	44 911	146	146
NL	35 785	17	17
BE	23 668	17	9
SE	22 889	321	292
FI	19 292	253	246
FR	15 868	261	160
NO	15 761	271	237
DE	11 905	191	191
IE	7521	43	43
ES	3819	212	134
JP	1993	163	101
PL	1898	168	46
MX	1362	715	132
US	5166	4469	1413
CA	1439	7004	555
TW	480	14	13
AT	393	36	28
PT	169	48	33
RU	143	14 283	73
KR	132	40	9
AR	117	1138	23
BO	112	365	10
EC	106	83	19

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Table 3. Continued.

Country	Rec.	Grid 0.5	GBIF 0.5
CN	80	3834	3
PE	50	427	30
CO	46	377	16
PA	39	30	2
DK	38	30	6
IT	34	145	14
CH	30	19	10
GT	27	37	10
GR	23	61	8
CZ	23	63	15
PK	19	326	4
NZ	17	135	10
ZA	14	479	2
NP	10	53	4
TR	8	332	4
IN	8	633	5
HN	8	42	3
AU	8	2826	3
RO	7	111	4
VN	5	105	2
CL	5	351	3
VE	3	304	2
BG	3	49	2
IL	2	6	2
HU	2	45	2
GL	2	2770	2

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Table 4. Analysis of the data distribution in the GBIF database (GBIF, 2010) which was used for the validation of the ADM model results for 49 countries with data records for alder distribution, and comparison with model results using different constraints besides climate. Meaning of the columns: (Country) name of the countries; (Grid) Number of half degree grid elements with data records about the alder distribution; (Clim) Number of simulated half degree grid elements with potential alder distribution by using "Clim" method based ADM; (Soil) by using "Soil" method based ADM; (Veg) by using "Veg" method based ADM; (All) by using "All" method based ADM.

Country	Grid	Clim	Soil	Veg	All
UK	146	146	138	118	110
NL	17	17	17	16	16
BE	9	17	17	17	17
SE	292	319	319	302	302
FI	246	247	247	247	247
FR	160	261	238	256	233
NO	237	267	267	172	172
DE	191	191	165	184	162
IE	43	43	43	38	38
ES	134	212	206	181	177
JP	101	163	163	163	163
PL	46	168	134	168	134
MX	132	652	329	122	99
US	1413	3925	2920	2130	1912
CA	555	4625	3139	3403	2168
TW	14	14	14	13	13
AT	28	36	23	34	23
PT	33	48	48	47	47
RU	73	10 695	7952	7018	4881
KR	9	40	40	40	40
AR	23	950	746	34	32

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Table 4. Continued.

Country	Grid	Clim	Soil	Veg	All
BO	18	259	238	24	24
EC	19	60	59	18	18
CN	3	3070	2980	1411	1379
PE	30	240	233	53	53
CO	16	110	105	51	51
PA	2	5	5	4	4
DK	6	30	30	30	30
IT	14	143	134	137	129
CH	10	19	16	14	11
GT	10	27	18	14	11
GR	8	61	61	58	58
CZ	15	63	59	63	59
PK	4	279	237	25	24
NZ	10	135	135	7	7
ZA	6	461	308	5	5
NP	4	43	43	3	3
TR	4	332	325	211	204
IN	5	1204	957	187	171
HN	3	30	26	18	16
AU	3	2739	1773	169	157
RO	4	111	94	104	93
VN	2	75	75	29	29
CL	3	217	206	95	95
VE	2	192	183	58	58
BG	1	49	34	48	34
IL	1	6	6	0	0
HU	2	45	29	45	29
GL	3	388	131	0	0

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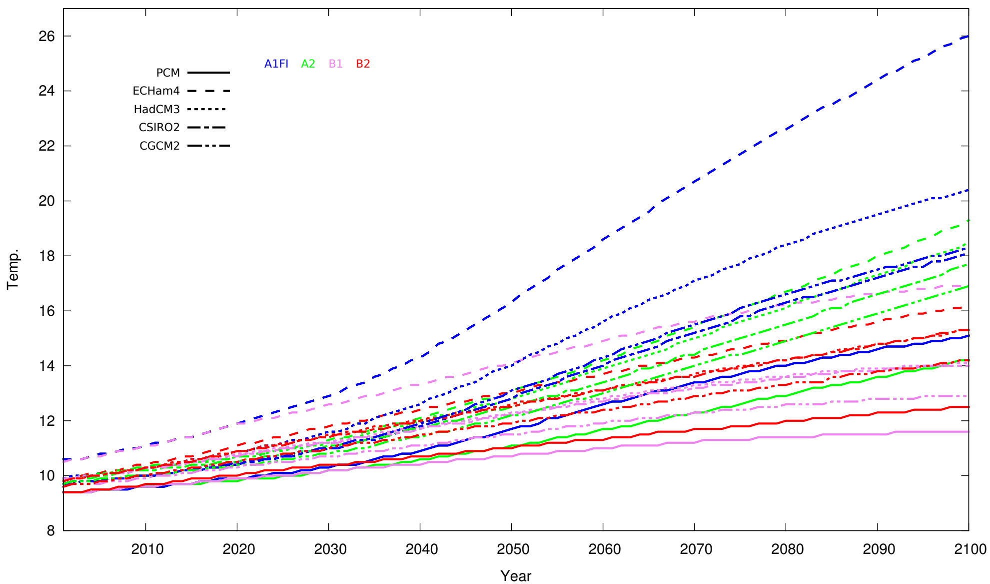

Fig. 1. The change in temperature (2001–2100) in a location in Gießen Germany of the five models and its IPCC SRES scenarios from TYN SC 2.0 climate database.

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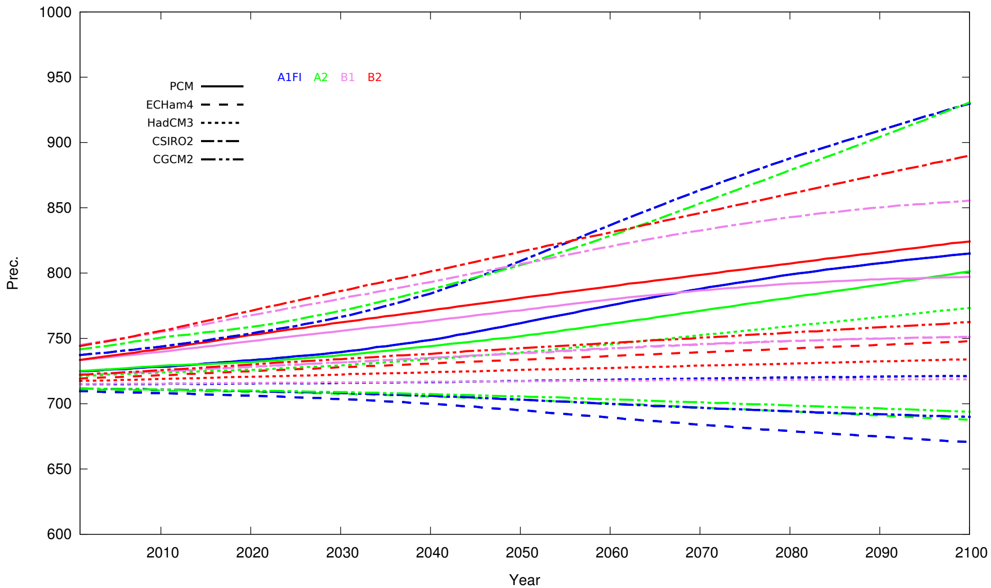

Fig. 2. The change in mean annual precipitation (2001–2100) in a location in Gießen Germany from five models and its IPCC SRES scenarios from TYN SC 2.0 climate database.

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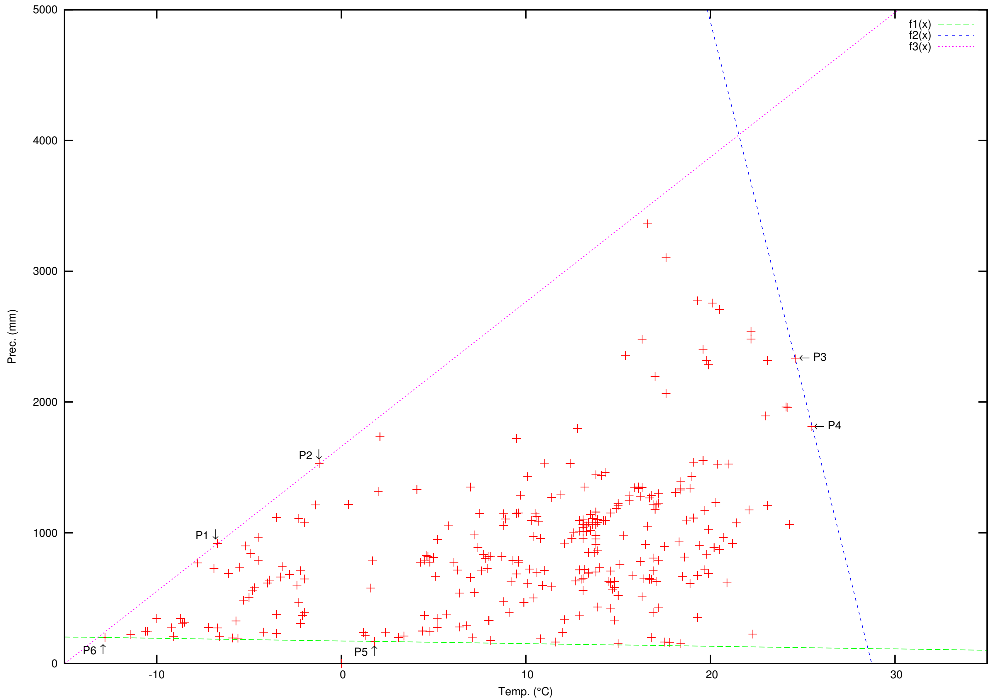

Fig. 3. The temperature-precipitation field of the 308 data points which were extracted from seven data bases (Tropicos.org, 2009; eFloras, 2008; WWF, 2009; Tutin et al., 2001; US Forest Service, 2008; USDA–NRCS, 2009; Li and Skvortsov, 1999) as sites of alder occurrence. The cardinal points $P_1, \ldots, P_6$ define the borderline of the distribution of alder in this field. They define the three linear Eqs. (1) through (3) which were used to select appropriate grid elements from a global 0.5° grid of climate data (Cramer and Leemans, 1991).

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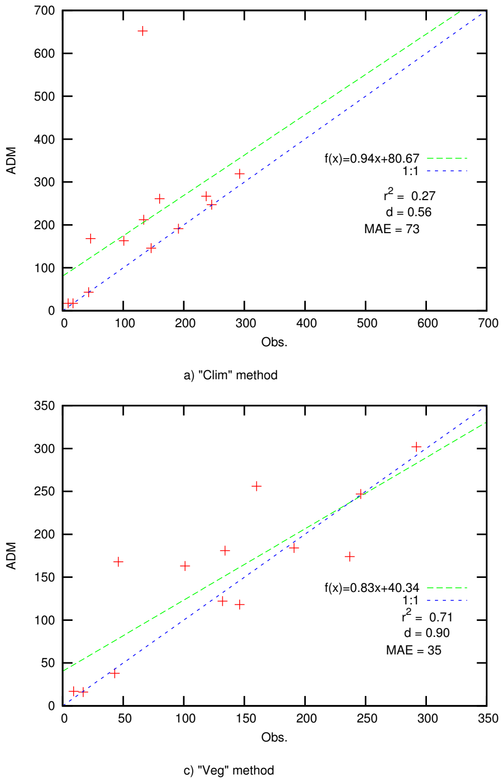

Fig. 4. The correlation between the observed and predicted alder distribution in half degree grid elements in nine European countries. The regression and 1 : 1 lines are shown along with correlation coefficient (*r*), index of agreement (*d*), mean absolute error (MAE).

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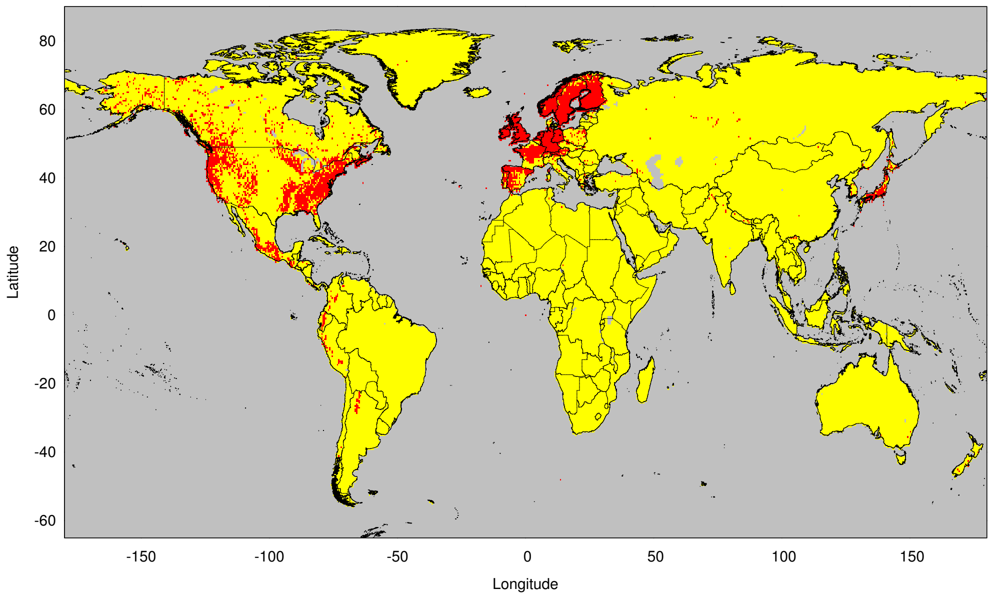

Fig. 5. Distribution of alders (red) according to the GBIF database (GBIF, 2010). For the locations with yellow colour there is no data record in the database.

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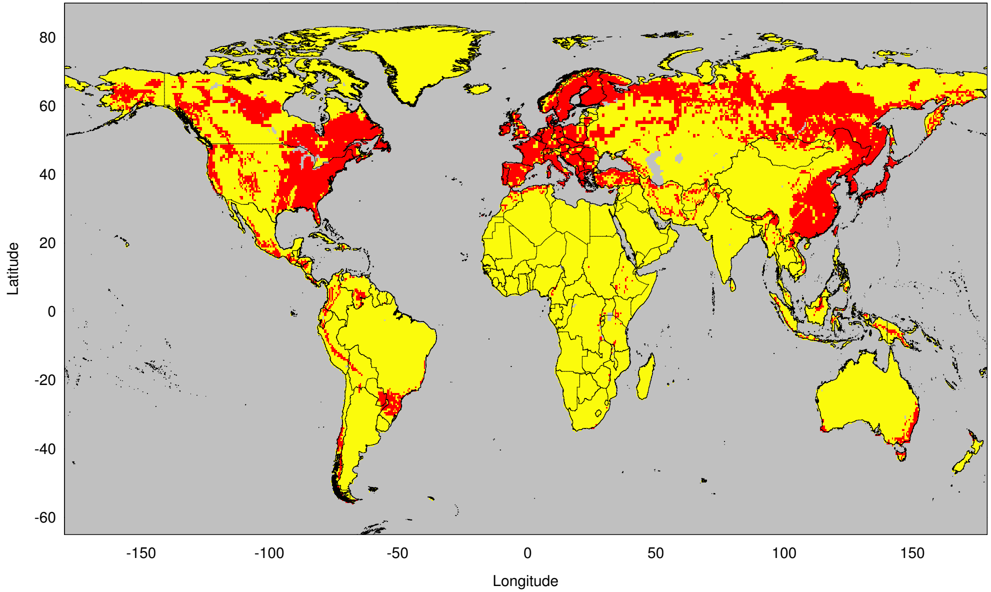

Fig. 6. Distribution of grid elements (red) which were identified as potential sites with alder based on the climate functions Eqs. (1)–(3) (see also Fig. 3). In this version of the model, restriction by vegetation types (see Table 2) and by soil units as found in Table 1 was applied. Yellow: grid elements were not identified as potential distribution area for alder.

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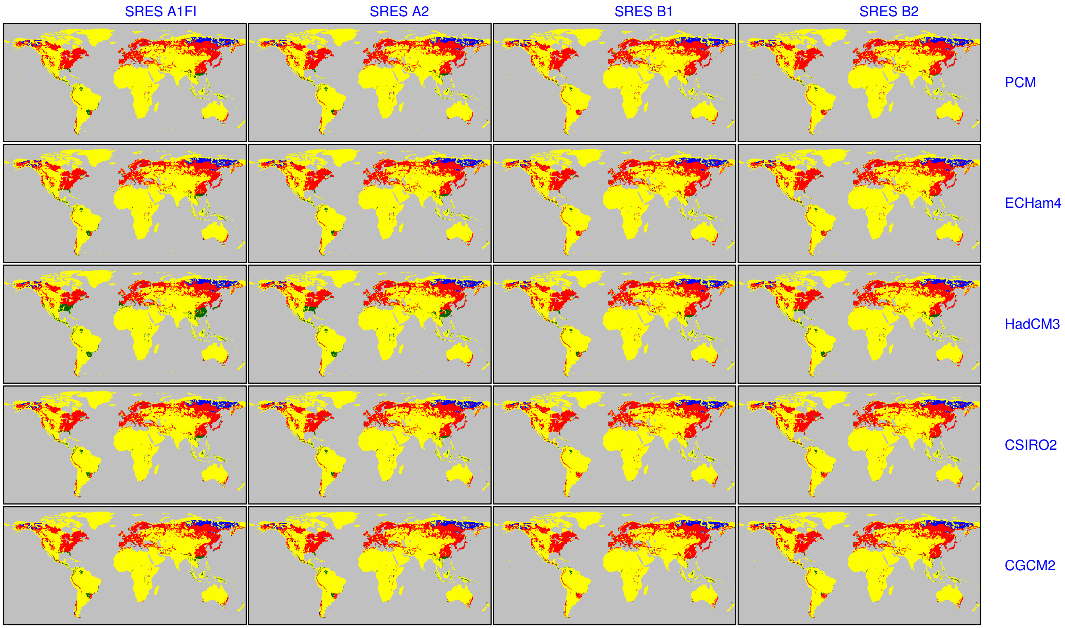

Fig. 7. Distribution of grid elements which were identified as potential sites for alder distribution based on the "All" method in ADM by using the climate data from CGCM2, CSRIO2, HadCM3, ECHam4 and PCM climate model and four IPCC climate change scenarios. The colour "red" represents the potential distribution areas both actual and in 2100, where the colour "green" shows the grid elements with actual potential distribution but not in 2100, and also the colour "blue" the grid elements with potential distribution in 2100 but not actual.

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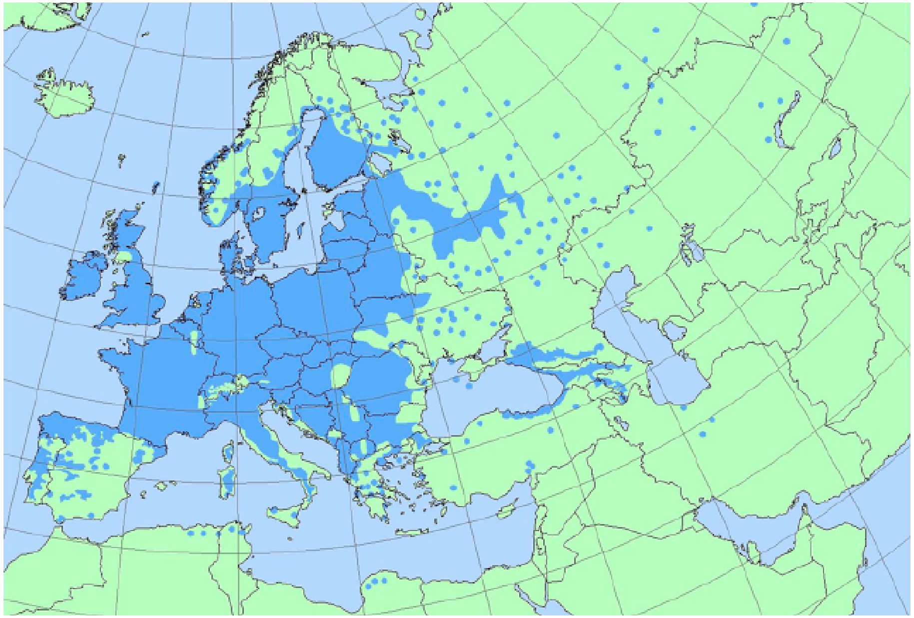

Fig. 8. Distribution of *A. glutinosa* (blue) according to Kajba and Gracan (2003) (Kajba and Gracan, 2003).

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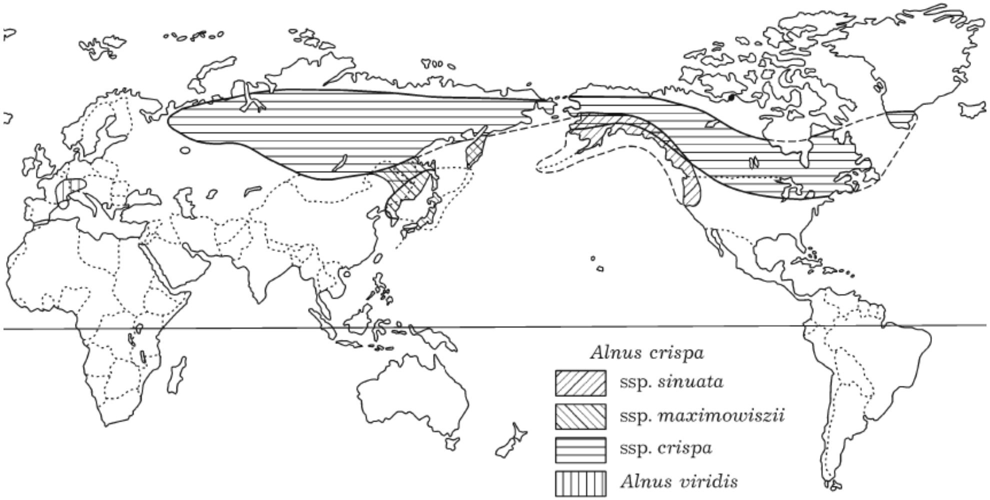

Fig. 9. Distribution of *A. viridis* and *A. crispa* in Northern Hemisphere according to Murai (1968) (Murai, 1968).

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