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How can effect the synergy of climate change, soil units and vegetation groups the potential global distribution of plants up to 2300: a modelling study for prediction of potential global distribution and migration of the N_2 fixing species *Alnus* spp.

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Abstract

Plant migration is a well known adaptation strategy of plant groups or species with evidence from historical to present observation and monitoring studies. 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 are presented to predict the distribution of N_2-fixing genus on global scale and its migration in the future by using climate change scenarios. Three linear functions were defined for the determination of climate niche of alders. The distribution and migration model (Alnus-Distribution-Model (ADM)) was improved with the aid of the soil units from FAO-Unesco Soil Database, and vegetation types from Schmithüsen's biogeographical atlas. The model was also developed to predict the impact of climate change on alder distribution by using climate data from experiments performed by the Community Climate System Model version 4 (CCSM4) including the representative concentration pathways (RCPs) mitigation scenarios, and extensions of the scenarios beyond 2100 to 2300. The model covered basic approaches to understand the combine effect of climate, soil and vegetation on plant distribution and migration in the current time and future.

1 Introduction

It is well known that the plants can change their distributing area over the landscape with time when the environmental conditions (i.e. soil, climate, CO_2) and biological factors (i.e. plant–plant interaction) for their existence are changed for a long period (Sauer, 1988; Dawis and Zabinski, 1992; Iverson and Prasad, 2002). Overpeck et al. and Bartlein et al. reported 100–1000 m yr^{-1} an expand rate of trees due to the change in environmental conditions (Overpeck et al., 1991; Bartlein et al., 1997). Climate change in the 21st and 23th of century driven by emission change and its impacts on different spatial and temporal scales and sectors have been addressed by numerous studies and projects.

It is also documented that rapid climate change may put some species at risk of extinction, possibly reducing the functionality of ecosystem due to the rapid change, which possibly enhance the potential for positive feedbacks and have consequences for ecosystem processes such as global carbon storage and biodiversity (Thomas et al., 2003). For future time periods, the change of the land cover due to migration of plant species can also effect the enhancement or reduction of the projected climate change as well as greenhouse gas concentration in the atmosphere, since the migration of the nitrogen fixing plants influences the carbon uptake and nitrogen availability in soil (Kurz and Apps, 1999).

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). Nut 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. A spatial change in distribution areas of the nitrogen fixers affects directly available nitrogen in soil, carbon uptake and allocations in the biosphere Galloway et al. (2004). Numerous ecosystem and biogeochemical models aim to predict the nitrogen fixation by using empirical functions (Vitousek et al., 2002; Wang et al., 2007; Galloway, 2002; Esser, 2007). Still, the modelling of nitrogen fixation by alders is missing in most of the models. 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, for instance the density of alders in their native locations in Europe amounts between 0 and 40 % of total plant biomass (Skjøth et al., 2008), 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 $\mathrm{kg\,ha^{-1}\,yr^{-1}}$ (Binkley, 1994) to 320 $\mathrm{kg\,ha^{-1}\,yr^{-1}}$ (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 zones, including *A. hirsuta* (FISCHER) C.K. SCHNEIDER, *A. viridis* (CHAIX) DC (Wiedmer and Senn-Irlet, 2006). In the Mediterranean zone occurs for example *A. cor-*

data (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. However, some species such as *A. firma* SIEB. AND ZUCC. and *A. crispa* (DRYAND. IN AIT.) PURSH are distribute steep slopes.

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

In this paper the aims were reported for modelling 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. The individual contribution of each data type were tested for the correctness of the predicted distribution. This work should be seen as a first step to predict the potential occurrence and distribution of alders depending on their climate requirements, soil conditions, and plant–plant interactions. This study should also give the basic informations for implementation of the N_2-fixation by alders in biogeochemical and ecosystem models since the N_2 fixation is directly depending on the occurrence of N_2-fixing plants in the terrestrial ecosystem.

2 Materials and methods

In this paper a new model based on four progress steps was developed for the predicting of potential distribution of alder spp. on global scale. This new model is called “Alnus-Distribution-Model (ADM)”. In the first step the values of annual average temperature and precipitation were used from Leemans and Cramer 0.5° degree grid element global climate database (Cramer and Leemans, 1991) to define a bioclimatic niche of *Alnus* spp.. The climate database includes 30 years (1961–1990) average of the climate parameters for 0.5° resolution on global scale. In the second step the climate based ADM was extended with soil units after FAO soil classification (1974) in “Soil Types of the World” (FAO-Unesco, 1974). In the third step the climate parameters based ADM was extended 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 all three methods were merged to predict 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 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 the global distribution data for the species of the genus *Alnus Mill.* 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). 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 locations including the data were extracted. All species of genus *Alnus Mill.* from the Table 1 are represented in the 308 locations.

2.2 "Clim"

I determined the grid elements in which alders occur according to the 308 sites. All further analyses were made by using the gridded data sets. First the mean annual temperature (T_{ann}) and annual total amounts of precipitation (P_{ann}) were extracted 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 the altitude of the site which was given in the original data bases was used. If altitudes were lacking, I determined the altitude of the sites from the GTOPO30 global elevation dataset

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(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 also 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 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. 2. three linear functions F_1–F_3 were fitted 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. 2 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:

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

where i is grid number of 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 ($D_{\text{Clim},\, i}$) is true in a grid element if the certain criteria of the grid element are fulfilled (see Eq. 4).

2.3 “Soil”

For this aim the FAO soil units of the “Soil Types of the World” (FAO-Unesco, 1974) were used 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:

$$D_{\text{Soil},\,i} = \begin{cases} \text{true}, & \text{if} \begin{cases} \text{Soil}_i = \text{Soil}_\text{a} \\ D_{\text{Clim},\,i} = \text{true} \end{cases} \\ \text{false}, & \text{else} \end{cases} \tag{5}$$

where i is grid number of 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 also 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:

$$D_{\text{Veg},\,i} = \begin{cases} \text{true}, & \text{if} \begin{cases} \text{Veg}_i = \text{Veg}_\text{a} \\ D_{\text{Clim},\,i} = \text{true} \end{cases} \\ \text{false}, & \text{else} \end{cases} \tag{6}$$

where i is grid number of 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:

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

where i is grid number of half degree grid element.

2.6 Migration of alder species in 2100 and 2300

To predict the migration of alder species climate data of T_ann and P_ann were needed for the requested future time period. For this step the mean annual value of temperature and precipitation for four IPCC SRES scenarios (i.e. RCP 2.6, RCP 4.5, RCP 6.0

and RCP 8.5) were selected from the CCSM4 data model outputs for the time period between 2000 and 2300. The selecting the climate parameter from the four different SRES scenarios allows the scientists to check the potential effect of variability in temperature and precipitation on the plant distribution (i.e. *Alnus* spp.) due to change in anthropogenic emission of green house gases, technology and population density according to the IPCC SRES scenarios. Since the used climate data for the prediction of alder distribution in the "Clim" stage (see Sect. 2.2) were the 30 years annual average data from Leemans and Cramer data base, I also used 30 years annual average value of T_{ann} and P_{ann} from 2071 to 2100, and from 2271 to 2300 for prediction of alder distribution in 2100 and 2300, respectively. This 30 years time period give the plants the possibility for adaptation to the climate change in a location. To avoid the jump of alder species over long distance (i.e. more than one grid cell), I also assume that the alder can not migrate to a grid cell if at least one of the neighbor grid cell was not a potential distributed grid cell.

2.7 Observations and statistical analyses

The Global Biodiversity Occurrence Data Base (GBIF) (GBIF, 2010) which has not been used for the model construction was used for the evaluation of the model results. 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 4 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 4).

The prediction of the ADM model was validated with the data records from the GBIF database for each step as well as analyzed the correlations between the observed and predicted data in the 20 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.

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

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

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 Results

3.1 Evaluation of distribution methods

In Fig. 2 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_{ann} of −10 °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 assumed 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. 2). 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 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. 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 $P5$ 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).

3.2 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 2. 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 wet soils and in soils with high water availability, the Gleysols were found only in 21 of 308 grid elements. The soil units which were present in only one grid element were not considered in this work.

In Table 3 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 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 3, the potential natural vegetation groups which are represented by more than one occurrence were selected. I assumed that alders occur within the selected formations only.

3.3 Observed alder distribution

In Table 4 the data about the 49 countries with data records for alder distribution in GBIF database were presented. 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 first 20 countries in the Table 4 included the most data records for alder distribution in the GBIF database (see Table 4 column “Rec.”). The total number of records in these countries is 208 181 of 215 444 in 1 866 of 4 098 half degree grid elements (see Table 4 columns “Rec.”, and GBIF 05”). Also, the first 20 countries (14 in Europe, 3 in South America, 2 in Asia, and 1 in Central America,) in the Table 4 include 97 % of the useful data records and the most data density for alder distribution. Each country has over 100 data records, and also 5 data records per half degree GBIF grid cell. Thus, these 20 countries were used for the validation of model prediction about alder distribution. The other 29 countries in the Table 4 included the rest of data records 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 20 countries. Countries with only one data record in GBIF data base were also not considered and not presented in this paper.

3.4 Validation of the methods

Since the 20 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 Fig. 3 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 5 columns "Grid", "Soil" "Veg", and "All" respectively. The r^2 values of the correlation analyses ranged between 6 and 84 %. The lowest correlation were found between the observed and "Clim" method based ADM results with $r^2 = 6\,\%$. The d and MAE values of the of this correlation analysis were 0.36 and 117, respectively (see Fig. 3a). The "Clim" method shown also a large intercept with 117 grid elements. The "Soil" method shown similar correlation with the observed data as the "Clim" method (see Fig. 3b). The correlation coefficients r^2 between this method and observed data were 11 %. The value of d for this method was 0.50, where the MAE value was 86. The method "Veg" provided a better correlation with the observed data (see Fig. 3c). The values of index of agreement and mean absolute error shown quite good results with $d = 0.93$, and MAE = 28, respectively. But the best correlation coefficient (r^2=84 %) were found between the observed and "All" method based ADM results (see Fig. 3d). And also the highest d value with 0.96, and the lowest MAE value with 27 were found between the “All” method based ADM and observed data. The intercept of this method was around 27 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 20 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.

The figures in the Supplement give an overview about the statistical analyses between the results of ADM by using the each single parameter and observation in the 20 countries, and also about the results of “CLIM”, “Soil” and “Veg” methods on global scale.

3.5 Global potential alder distribution

The predicted alder distribution by using “All” method based ADM was shown in Fig. 5. 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. 4) the ADM also predicted the potential distribution in several grid elements of South America, Africa, and Australia (see Fig. 5). The ADM predicted the alder distribution in 1 898 grid elements in the 20 countries where the GBIF database has the data records in 2 066 grid elements (see Table 5 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 2). These grid elements have the suitable climate conditions and soil units but not the vegetation types. The most eliminated grid elements in the 20 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 2). 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 2) and the vegetation types in 75 of the 308 grid elements (see Table 3). 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 20 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 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 “Veg” method eliminated more grid elements than the “Soil” method in 12 of the 20 countries as well as in Russia, in China, and in the US. In France, Germany, Poland, Austria, and Canada more grid elements were eliminated by using the “Soil” method than the “Veg” method.

The results shown that the existence of alders in natural ecosystems is not only depending on climate conditions but also on soil types, and vegetation units. The the potential distribution of alders are mainly in Northern Hemisphere, but they also have found to exist quite a few locations in south hemisphere with adequate climate conditions, soil types and vegetation units (see Fig. 5). Since the alders can fix atmospheric nitrogen, the considering of the nitrogen fixation by alders in their distributional areas in ecosystem and biogeochemical models give the scientist the opportunity to investigate and predict the nitrogen fixation impacts on CO_2 uptake, and also carbon storage in the biosphere (for more information and discussion see Sect. 4).

3.6 Potential distribution and migration of alder in 2100 and 2300

The absence of alders in the natural ecosystems can also cause an extremely decrease of nitrogen input by N_2 fixation of this plants group, and as a result can have gravely consequences for the nitrogen availability in soil of the areas. Therefore it is important to model the migration of the N_2 fixing plants on global scale. To investigate this, the climate data of CCSM4 by driven four IPCC RCP scenarios up to 2300 were used. The rising of atmospheric CO_2 has enormous impact on climate change in the future. The using of climate data by driven different RCP scenarios enables to understand the effects of changed climate parameter (i.e. the T_{ann} and P_{ann}) by rising CO_2 on plant migration (in this study for alders).

For this step of the study I assumed that the soil unit and the potential natural vegetation groups of a grid element will not be changed in 2100 and 2300. The migration of alder species for those two prediction periods by using the ADM was shown in the Figs. 6 and 7. 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 red 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 prediction of potential migration of *Alnus* spp. by using the climate parameter of four RCP scenarios shown differences on global scale for the two projection periods (2100 and 2300).

The results indicated that only a change in two climate parameter (i.e. T_{ann} and P_{ann}) can effect the existence and distribution of plants in terrestrial ecosystems in the end of the 21th century. The validation of the methods also pointed out that the changes of soil types and vegetation compositions have enormous influences on the distribution of alders, and this have to consider in modelling studies about the plant distribution.

4 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 years 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) . 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 the Supplement). Also, the statistical analysis of the “Clim” methods has the poorest correlation in the 20 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*. 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 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 (not for all species of genus Alnus) on regional scales and needs predefined parameter for each species. Compared to the bioclimatic model, 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. 4 and Fig. S2 in the Supplement). Also the statistical analysis between the observed and predicted data in the 20 countries resulted a rare correlation (see Fig. 3b).

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. 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) 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 20 countries showed quite good correlation with the observed data from the GBIF database (see Fig. 3c). But on the global scale it is to see that the comparing of the results (see Fig. S3 in the Supplement) with the distribution map from GBIF database (see Fig. 4) presented noticeable differences in East Europe, in Canada, Southeast Australia and America.

In some local studies the scientist tried to find out the interspecific relationships between the plant species in plant communities and also the relationships between the dispersal of the species and the environmental, biological, and geological factors Jones et al. (2008); Flinn et al. (2010); Aiba et al. (2012); Lin et al. (2013). They pointed out that the plant dispersal is not depending on environmental factors. They found a poor correlation between the environmental factors and plant dispersal. On the other hand, they also did not use the combination of yearly average temperature and sum of the precipitation as determinant in their studies. The used parameters (Wind, NO_3, soil humus content etc.) were also dynamic parameters which can have strong seasonality. The ADM considers the average of 30 years of the climate data (1961–1990) from Leemans and Cramer. That eliminated the uncertainties regarding to the dynamic seasonality of climate parameters. However, only 6 % of the alder distribution can be explained by using the climate data in this study (see Fig. 3). The results of this study have shown, that the dispersal of plant species is not only depending on the climate factors but also on the soil types, and the vegetation units should be considered together.

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. 3d). The predicted potential distribution areas for alder species using the “All” method is presented in the Fig. 5. 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 (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 for the distribution of *A. 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 4). But "All" method based ADM predicted the distribution in 1 376 grid elements more than the GBIF database. Yet, it is well known that *A. nepalensiss* 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-Musukwe 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. The average annual rainfall is 1 500 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. 2). 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 2 and 3). 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 recorded in GBIF data base (see Table 4). 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. 2 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. 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. 5). The ADM show the potential alder distribution in 168 of 1 653 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. Also, Marchant et al. (2002) presented data about pollen distribution of alder in several Middle and South American countries. 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 years to change its distribution areas due to the climate change. 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). They presented a three times carbon storage with a nitrogen availability than without in the biosphere. Since a migration of N_2-fixing plants changes the amount of available nitrogen in soil for soil microorganisms and plants, as important

N_2-fixing group, the investigation of the spatial and temporal alder migration is quite important.

The using climate parameters from different climate models and scenarios gives important indications of climate change effects on alnus distribution and migration in the future. As it presented in Fig. 1 CCSM4 provides variously T_{ann} and P_{ann} by using four IPCC RCP 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 four IPCC RCP scenarios of a GCM model.

5 Conclusions

Since the nitrogen plays a key factor for carbon uptake processes by photosynthetic organisms, and the main resource of the available nitrogen for biogeochemical processes in ecosystems is the N_2 fixation by the symbiotic pathways between the host plants and N_2-fixing bacteria, the determination of distribution of the host plants has been gaining very important meaning and role in modelling of biogeochemical cycles. Numerous biogeochemical, biome models use empirical or statistical methods to predict the nitrogen fixation by N_2 fixing plants. However, none of them considers the N_2 fixation by alders since there is limited information about the distribution of alder species on global scale. It makes difficult to implement the N_2 fixation process in biogeochemical, biome models to investigate the interactions between the carbon and nitrogen biogeochemical cycles.

In this paper, a new methodology for predicting of potential distribution of alder species on global scale is presented. The new methodology of ADM gives the scientist the possibility to understand the climatological and ecological requirements of alder species to distribute in natural areas and the opportunity to implement a simple method to predict the potential distribution locations of the alder species on each resolution.

The ADM is a simple empirical model, based upon simple equations. The using simplified approaches as in "All" method of the model allows the scientist to understand the functionality of the plant distribution by considering the environmental and geological factors. The model shows that 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.

By using the new methodology of ADM, the spatial and temporal change of alder distribution can be investigated with required generated climate variables. In this paper, the temporal and spatial change of alder distribution was modeled by using the climate variables from the CCSM4 and which was driven with four IPCC AR4 SRES scenarios. The using of climate variables should give an overview of the sensitivity of the methodology for modelling of plant distribution according to climate models. Also, the future climate change is highly depending on the anthropogenic emission of the green house gases (GHG). To consider that aspects SRES scenarios were developed for investigations of the interaction between the GHGs and the climate. The using of the climate variables of four IPCC AR4 SRES scenarios in this study allows the scientists the investigation of the sensitivity of the plant distribution by considering the different emission scenarios on global scale up to 2100 and 2300, respectively. Because of the missing the dynamic vegetation data and dynamic soil unit data for 2300, only the climate parameter were dynamic changed in the ADM for predicting of potential distribution of alder species in 2300. 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 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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Although clearly dynamic datasets for soil units and vegetation groups are needed for a testimonial evidence, the simple requirements of the ADM methodology might make it suitable for use in other biogeochemical models and other modelling systems.

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References

Aiba, H., Takafumi, H., and Hiura, T.: Interspecific differences in determinants plant species distribution and relationships with functional traits, J. Ecol., 100, 950–957, doi:10.1111/j.1365-2745.2012.01959.x, 2012. 835

Bartlein, P. J., Whitlock, C., and Shafer, S. L.: Future climate in the Yellowstone National Park Region and its potential impact on vegetation, Conserv. Biol., 11, 782–792, 1997. 817

Bean, W.: Trees and Shrubs Hardy in Great Britain, Vol. 1–4 and Supplement. A classic with a wealth of information on the plants, but poor on pictures, Royal Botanic Garden, London, Great Britain, 1989. 834

Behling, H.: Late quaternary cegetation, climate and fire history of the *Araucaria* Forest and Campos Region from Serra Campos Gerais, Parana State (South Brazil), Rev. Palaeobot. Palyno., 97, 109–121, 1997.

Binkley, D., Cromack, K., and Baker, D. D.: Nitrogen fixation by red alder: biology, rates, and controls, in: The Biology and Management of Red Alder, edited by: Hibbs, D. E., DeBell, D. S., and Tarrant, R. F., Oregon State University Press, Corvallis, 57–72, 1994. 818

Breckle, S. W.: Walter's Vegetation of the Earth. The Ecological Systems of the Geo-Biosphere, 4th edn., Springer-Verlag, Berlin, Heidelberg, New York, 87 pp., 2002. 834

Brooker, R. W.: Plant–plant interactions and environmental change, New Phytol., 171, 271–284, doi:10.1111/j.1469-8137.2006.01752.x, 2006. 819

Brovkin, V., Ganopolski, A., and Svirezhev, Y.: A continuous climate–vegetation classification for use in climate–biosphere studies, Ecol. Model., 101, 201–261, 1997. 833

Brown, J. H.: On the relationship between abundance and distribution of species, Am. Nat., 124, 255–279, 1984. 819

Chen, Z.-D.: Phylogeny and phytogeography of the betulaceae, Acta Phytotaxon. Sin., 32, 1–31, 1994. 837

Chen, Z. and Li, J.: Phylogenetics and biogeography of *Alnus* (*Betulaceae*) inferred from sequences of nuclear ribosomal DNA its region, Int. J. Plant Sci., 165, 325–335, 1994. 837

Claessens, H., Oosterbaan, A., Savill, P., and Rondeux, J.: A review of the characteristics of Black Alder (*Alnus glutinosa* (L.) Gaertn.) and their implications for silvicultural practices, Forestry, 83, 163–175, 2010. 834

Cramer, W. and Leemans, R.: The IIASA Database for Mean Monthly Values of Temperature, Precipitation and Cloudiness of a Global Terrestrial Grid, International Institute for Applied Systems Analysis (IIASA), RR–91–18, Laxenburg, Austria, 1991. 820, 859

Czerepanov, S. K.: Vascular Plants of Russia and Adjacent States (former USSR). ISBN–10: 0521450063, New York, USA, 1995. 837

Dai, Y. M., He, X. Y., and Zhang, Z. Z.: Characterization of genetic diversity of *Frankia* strains in nodules of *Alnus nepalensis* D. Don from the Hengduan Mountains on the basis of PCR–RFLP analysis of the nifD–nifK IGS, Plant Soil, 267, 207–212, 2004. 819

Davis, M. and Zabinski, C.: Changes in geographical range resulting from greenhouse warming: effects on biodiversity in forests, in: Global Warming and Biological Diversity, edited by: Peters, R. L. and Lovejoy, T. E., Yale University Press, New Haven (CT), 297–308, 1992. 816

Dorthe, J.: *Alnus nepalensis*, Danida Forest Seed Centre, Humlebaek, Denmark, 2 pp., 2000. 837

Dukes, J. S. and Mooney, H. A.: Does global change increase the success of biological invaders?, Trends Ecol. Evol., 14, 135–139, 1999. 819

eFloras: Missouri Botanical Garden, St. Louis, MO, Harvard University Herbaria, Cambridge, MA, available at: http://www.efloras.org (last access: 4 December 2010), 2010. 821, 859

Esser, G.: Nitrogen Carbon Interaction Model – NCIM, Documentation: Model Version 3.00, Mitteilungen aus dem Institut für Pflanzenökologie der Justus-Liebig-Universität Giessen, Volume 5, 57 pages (in English), 2007. 818

Esser, G., Kattge, J., and Sakalli, A.: Feedback of carbon and nitrogen cycles enhances carbon sequestration in the terrestrial biosphere, Glob. Change Biol., 17, 819–842, 2011. 817, 818, 819, 838

Flinn, K. M., Gouhier, T. C., Lechowicz, M. J., and Waterway, M. J.: The role of dispersal in shaping plant community composition of wetlands within and old growth forest, J. Ecol., 98, 1292–1299, doi:10.1111/j.1365-2745.2010.01708x, 2010. 835

Furlow, J. J.: The Systematics of the American species of *Alnus* (*Betulaceae*), Rhodora, 81, 1–121, 1979. 837

Galloway, J. N. and Cowling, E. B.: Reactive nitrogen and the world: 200 years of change, Ambio, 31, 64–71, 2002. 817, 818

Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., Asner, G. P., Cleveland, C. C., Green, P. A., Holland, E. A., Karl, D. M., Michaels, A. F., Porter, J. H., Townsend, A. R., Vöosmarty, C. J.: Nitrogen cycles: past, present, and future, Biogeochemistry, 70, 153–226, 2004. 817, 818

GBIF: Bioiversity occurrence data provided by: Botanical Society of the British Isles – Vascular Plants Database, Environment and Heritage Service – EHS Species Datasets, Plants (GBIF–SE: Artdatenbanken), Vascular Plants, Field notes, Oslo (O), Observations du Conservatoire Botanique National du Bassin Parisien, Bundesamt für Naturschutz/NetzIrk Phytodiversität Deutschland etc. 102.066 records, GBIF Data Portal, available at: http://www.gbif.net, (last access: 4 December 2010), 2010. 825, 854, 856, 861

GTOPO30: Global Digital Elevation Model (GTOPO30), The U.S. Geological Survey, EROS Data Center Distributed Active Archive Center (EDC DAAC), Redlands, California, USA, 2010. 822

FAO-Unesco: Soil Map of the World, vol. I–X, Paris, 1974. 820, 823, 830, 831

Hagenstein, R. and Rickets, T.: Beringia lowland tundra, available at: http://www.worldwildlife.org/wildworld/profiles/terrestrial/na/na1106_full.html (last access: on 14 October 2004), 2001. 819

Harrington, C. A.: *Alnus rubra* BONG.: Red Alder, in: Silvics of North America: Volume 2: Hardwoods, edited by: Burns, R. M. and Honkala, B. H., USDA Forest Service, Washington D. C., 654 116–123, 1991. 819

Harrington, C. A., Zasada, J. C., and Allen, E. A.: Biology of Red Alder (*Alnus rubra* BONG., in: The Biology and Management of Red Alder, edited by: Hibbs, D. E., DeBell, D. S., and Tarrant, R. E., Oregon Sate University Press, Corvallis, OR, 3–22, 1994.

Hnatiuk, R. J.: “Census of Australian Vascular Plants”, Australian Flora and Fauna Series No. 11, Bureau of Flora and Fauna, Australian Government Publishing Service, Canberra, 1990.

Iverson, L. R. and Prasad, A. M.: Potential redistribution of tree species habitat under five climate change scenarios in the eastern US, Forest Ecol. Manag., 155, 205–222, 2002. 816

Jackson, J. K.: Manual of Afforestation in Nepal, Nepal–United Kingdom Forestry Research Project, Forest Survey and Research Office, Dept. of Forest, UK, 402 pp., Kathmandu, Nepal, 1994. 837

Jones, M. M., Tuomisto, H., Borcard, D., Legendre, P., Clark, D. B., and Olivas, P. C.: Explaining variation in tropical plant community composition: influence of environmental and spatial data quality, Oecologia, 155, 593–604, doi:10.1007/s00442-007-0923-8, 2008. 835

Kajba, D. and Gracan, J.: EUFORGEN Technical Guidelines for genetic conservation and use for Black Alder (*Alnus glutinosa*), International Plant Genetic Resources Institute, Rome, Italy, 6 pp., 2003. 836

Kamruzzahan, S.: Is *Alnus viridis* a glacial relict in the Black Forest? Inaugural-Dissertation zur Erlangung der Doktorwürde der Fakultät für Biologie der Albert-Ludwigs-Universität Freiburg im Breisgau, 2003. 827

Kurz, W. A. and Apps, M. J.: A 70 year retrospective analysis of carbon fluxes in the Canadian forest sector, Ecol. Appl., 9, 526–547, 1999. 817

Lantz, T. C., Gergel, S. E., and Henry, G. H. R.: Response of green alder (*Alnus viridis* subsp. *fruticosa*) patch dynamics and plant community composition to fire and regional temperature in north-western Canada, J. Biogeogr., 37, 1597–1610, 2010. 833

Ledru, M.-P., Salatino, M. L. F., Ceccantini, G., Salatino, A., Pinheiro, F., and Pintaud, J.-C.: Regional assessment of the impact of climatic change on the distribution of a tropical conifer in the lowlands of South America, Divers. Distrib., 13, 761–771, doi:10.1111/j.1472-4642.2007.00389.x, 2007.

Lepper, M. G., and Fleschner, M.: Nitrogen fixation by *Cercocarpus iedifolius* (*Rosaceae*) in pioneer habitats, Oecologia, 27, 333–338, 1977. 817

Li, P.-C. and Skvortsov, A. K.: Betulaceae, in: Flora of China, vol. 4, Science Press, Beijing and Missouri Botanical Garden Press, St. Louis, 301–304, 1999. 821, 859

Lin, G., Stralberg, D., Gong, G., Huang, Z., Ye, W., and Wu, L.: Separating the effects of environment and space on tree species distribution: from population to community, PloS ONE, 8, 1–10, doi:10.1371/journal.pone.0056171, 2013. 835

Marchant, R., Almeida, L., Behling, H., Berrio, J. C., Bush, M., Cleef, A., Duivenvoorden, J., Kappelle, M., De Oliveira, P., de Oliveira, A. T., Lozano-Garcia, S., Hooghiemstra, H., Ledru, M. P., Ludlow-Wiechers, B., Markgraf, V., Mancini, V., Paez, M., Prieto, A., Rangel, O., and Salgado-Labouriau, M. L.: Distribution and ecology of parent taxa of pollen lodged within the Latin American Pollen Database, Rev. Palaeobot. Palyno., 121, 1–75, 2002.

Martínez-Meyer, E. and Peterson, A.: Conservatism of ecological niche characteristics in North American plant species over the Pleistocene-to-Recent transition, J. Biogeogr., 33, 1779–1789, 2006.

Meyen, F. J. F.: Outlines of the Geography of Plants: with Particular Enquiries Concerning the Native Country, the Culture, and the Uses of the Principal Cultivated Plants on the which the Prosperity of Nations in Based, Ray Society, London, 1846. 833

Min, B. M. and Kim, J.-H.: Plant distribution in relation to soil properties of reclaimed lands on the Ist Coast Korea, J. Plant Biol., 42, 279–286, 1999. 819

Mitchell, T. D. and Jones, D.: An improved method of constructing a database of monthly climate observations and associated high-resolution grids, Int. J. Climatol., 25, 693–712, 2005. 822

Müller, M. J.: Selected Climatic Data for a Global Set of Standard Stations for Vegetation Science, Tasks for Vegetation Science, 5, Junk Publishers, The Hague, 1982. 822

Murai, S.: Biology of Alder, USDA Portland, Oregon, 23–36, 1968. 836

Muthuri, C. W., Ong, C. K., Craigon, J., Mati, B. M., Ngumi, V. W., and Black, C. R.: Gas exchange and water use efficiency of trees and maize in agroforestry systems in semi-arid Kenya, Agr. Ecosyst. Environ., 129, 497–507, doi:10.1016/j.agee.2008.11.001, 2009. 837

Myrold, D. D. and Huss-Dannel, K.: Population dynamics of alder-invective *Frankia* in a forest soil with and without host trees, Soil Biol. Biochem., 26, 533–540, 1994. 818

NACS: Advisory Committee on Technology Innovation (1980) Firewood Crops: Shrub and Tree Species for Energy Production, vol. 1. National Academy of Sciences, Washington, D. C., PB 81–150716 (NTIS), 1980. 819

Nasir, Y. J.: Flora of Pakistan, Missouri Botanical Garden Press, St. Louis, MO, 1975. 819

Niang, A., Ugizil, J., Styger, E., and Ghamanyi, A.: Forage potential of eight woody species: intake and growth rates of local young goats in the highland region of Rwanda, Agroforest. Syst., 34, 171–178, 1996.

Overpeck, J. T., Bartlein, P. J., and Webb III, T.: Potential magnitude of future vegetation change in Eastern North America: comparisons with the past, Science, 254, 692–695,1991. 817

Prentice, I. C., Cramer, W., Harrison, S. P., Leemans, R., Monserud, R. A., and Solomon, A. M.: A global biome model based on Plant Physiol. and dominance, soil properties and climate, J. Biogeogr., 19, 117–134, 1992. 833

Pyke, D. A. and Archer, S.: Plant–plant interactions affecting plant establishment and persistence on revegetated rangeland, J. Range Manage., 44, 550–557, 1991. 819

Quézel, P., Médail, F., Loisel, R., and Barbero, M.: Biodiversity and conservation of forest species in the Mediterranean basin, FAO, available at: http://www.fao.org/docrep/x1880e/x1880e05.htm (last access: 10 January 2009), 1999. 819

Racine, C., Lichvar, R., and Duffy, M.: An inventory of the vascular flora of Fort Greely, interior Alaska, Technical Report No. A172983, 51 pp., U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, NH, 2001. 827

Reese, C. A.: Pollen dispersal and deposition in the high central Andes, South America, Dissertation to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Geography and Anthropology, Baton Rouge, USA, 2003. 819

Reich, P. B., Hobbie, S. E., Lee, T., Ellsworth, D. S., Ist, J. B., and Tilman, D.: Nitrogen limitation constrains sustainability of ecosystem response to CO_2, Nature, 440, 922–925, doi:10.1038/nature04486, 2006. 817

Saikia, S. P. and Jain, V.: Biological nitrogen fixation with non-legumes: an achievable target or a dogma?, Curr. Sci. India, 92, 317–322, 2007. 817

Sakalli, A. and Simpson, D.: Towards the use of dynamic growing seasons in a chemical transport model, Biogeosciences, 9, 5161–5179, doi:10.5194/bg-9-5161-2012, 2012. 833

Sauer, J. D.: Plant Migration the Dynamics of Geographic Patterning in Seed Plant Species, University of California Press, Berkeley and Los Angeles, California. 816

Schmithüsen, J.: Allgemeine Vegetationsgeographie, 3. Auflage, 12, Walter De Gruyter & Co., Berlin, 7 pp., 1968 (in German). 834

Schmithüsen, J.: Atlas zur Biogeographie (Meyers großer physischer Weltatlas, Bd. 3), Bibliographisches Institut, Mannheim, Wien, Zürich, 1976.

Schouw, J. F.: Grundzüge einer allgemeinen Pflanzengeographie, Berlin, De Gruyter, 1823. 833

Schwintzer, C. R. and Tjepkema, J. D.: The Biology of *Frankia* and Actinorhizal Plants, Academic Press, Inc., San Diego, California, USA, 1990. 818

Sharma, E., and Ambasht, R. S.: Biomass, productivity and energetics in Himalayan Alder Plantations, Ann. Bot.-London, 67, 285–293, 1991 837

Simpson, D., Benedictow, A., Berge, H., Bergström, R., Emberson, L. D., Fagerli, H., Flechard, C. R., Hayman, G. D., Gauss, M., Jonson, J. E., Jenkin, M. E., Nyíri, A., Richter, C., Semeena, V. S., Tsyro, S., Tuovinen, J.-P., Valdebenito, Á., and Wind, P.: The EMEP MSC-

W chemical transport model – technical description, Atmos. Chem. Phys., 12, 7825–7865, doi:10.5194/acp-12-7825-2012, 2012. 819

Siriri, D., Wilson, J., Coe, R., Tenywa, M. M., Bekunda, M. A., Ong, C. K., and Black, R. C.: Trees improve water storage and reduce soil evaporation in agroforestry systems on bench terraces in SW Uganda, Agroforest Syst., 87, 45–58, doi:10.1007/s10457-012-9520-x, 2013. 837

Skjøth, C. A., Geels, C., Hvidberg, M., Hertel, O., Brandt, J., Frohn, L. M., Hansen, K. M., Hedegaard, G. B., Christensen, J. H., and Moseholm, L.: An inventory of tree species in Europe – an essential data input for air pollution modelling, Ecol. Model., 217, 292–304, 2008. 818, 833

Smith, B., Prentice, I. C., and Sykes, M. T.: Representation of vegetation dynamics in the modelling of terrestrial ecosystems: comparing two contrasting approaches within European climate space, Global Ecol. Biogeogr., 10, 621–637, doi:10.1046/j.1466-822X.2001.t01-1-00256.x, 2001. 819, 833

Sykes, M. T., Prentice, I. C., and Cramer, W.: A bioclimatic model for the potential distributions of north European tree species under present and future climates RID B-8221-2008, J. Biogeogr., 23, 203–233, 1996.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., Erasmus, B. F. N., Ferreira de Siqueira, M., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A. S., Midgley, G. F., Miles, L., Ortega-Huerta, M. A., Peterson, A. T., Philips, O. L., and Williams, S. E.: Extinction risk from climate change, Nature, 427, 145–148, doi:10.1038/nature02121, 2003. 817

Tropicos.org.: Missouri Botanical Garden, available at: http://www.tropicos.org (last access: 14 May 2009), 2009. 821, 859

Tutin, T. G., Heywood, V. H., Burges, N. A., and Valentine, D.: Flora Europaea, Royal Botanical Garden Edinburgh, Vol. 1–5, Cambridge University Press, available at: http://www.rbg-lb2.rbge.org.uk/FE/fe.html (last access: 29 June 2009), 2001. 818, 821, 859

USDA-NRCS: The PLANTS Database, National Plant Data Center, Baton Rouge, LA 70874–4490, USA, available at: http://plants.usda.gov (last access: 14 May 2009), 2009. 821, 827, 859

U.S. Forest Service: Fire effects information system, available at: http://www.fs.fed.us/database/feis/plants/tree/index.html (last access: 4 December 2010), 2008. 821, 859

Van Miegroet, H., Cole, D. W., Binkley, D., and Sollins, P.: The effect of nitrogen accumulation and nitrification on soil chemical properties in alder forests, in: Effects of Air Pollution on Istern Forests, edited by: Olson, R. and Lefohn, A., Air and Waste Management Association, Pittsburgh, Pa. 515–528, 1989. 818

Van Minnen, J. G., Leemans, R., and Ihle, F.: Defining the importance of including transient ecosystem responses to simulate C-cycle dynamics in a global change model, Glob. Change Biol., 6, 595–611, 2000.

Vitousek, P. M., Hättenschwiler, S., Olander, L., and Allison, S.: Nitrogen and nature, Ambio, 31, 97–101, 2002. 817, 818

von Humboldt, A.: Ideen zu einer Geographie der Pflanzen nebst einem Naturgemälde der Tropenländer, Tübingen, Dem Erstern, Cotta, 1807 (in German). 833

Wajja-Musukwe, T. N., Wilson, J., and Sprent, J. I.: Tree growth and management in Ugandan agroforestry systems: effects of root pruning on tree growth and crop yield, Tree Physiol., 28, 233–242, 2008. 837

Walter, H. and Lieth, H.: Climate Diagram World Atlas, Fischer Verlag, Jena, 1961–1967. 822

Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., Fromentin, J.-M., Hoegh-Guldberg, O., and Bairlein, F.: Ecological responses to recent climate change, Nature, 416, 389–394, 2002. 819

Wang, Y. P., Houlton, B. Z., and Field, C. B.: A model of bio-geochemical cycles of carbon, nitrogen, and phosphorus including symbiotic nitrogen fixation and phosphatase production, *Global Bio-geochemical Cycles*, 21, GB1018, doi:10.1029/2006GB002797, 2007. 817, 818

Wheeler, C. T. and Miller, I. M.: Current and potential uses of actinorhizal plants in Europe, in: The Biology of *Frankia* and Actinorhizal Plants, edited by: Schwintzer, C. R. and Tjepkema, J. D., Academic Press, San Diego, CA 365–489, 1990. 834

Wiedmer, E. and Senn-Irlet, B.: Biomass and primary productivity of an *Alnus viridis* stand: a case study from the Schächental valley, Switzerland, Bot. Helv., 116, 55–64, 2006. 818

Willmott, C. J.: Some comments on the evaluation of model performance, B. Am. Meteorol. Soc., 63, 1309–1313, 1982. 826

Woodward, F. I.: Climate and Plant Distribution, Cambridge University Press, UK, 177 pp., Cambridge, Great Britain, 1996. 819

Woodward, F. I. and Williams, B. G.: Climate and plant distribution at global and local scales, Vegetatio, 69, 189–197, 1987.

WRCC: Istern Regional Climate Center, Climate of Alaska, available at: http://www.wrcc.dri.edu/narratives/ALASKA.htm, (last access: 10 October 2009), 2009. 819

Wu, T., Wu, M., Yu, M., and Xiao, J.: Plant distribution in relation to soil conditions in Hangzhou by coastal Itlands, China, Pak. J. Bot., 43, 2331–2335, 2011. 819

WWF: World Wildlife Fund. Online database of species distributions, version January-06, available at: http://www.worldwildlife.org (last access: 10 October 2009), 2009. 821, 859

Table 1. The global distributed 34 alder species, which were used for selection of the locations and the relevant climate, soil, and vegetation parameters. The species names are according to the publication from Chen und Li (2004).

A. acuminata HBK
A. barbata C. A. Mey
A. cordata (Loisel.) Duby.
A. cremastogyne Burkill
A. crispa (Dryand. in Ait.) Pursh
A. fernandi-coburgii C.K. Schneider
A. firma Sieb. and Zucc.
A. formasana (Burkill) Makino
A. fruticosa (Du Roi) Spreng.
A. glutinosa (L.) Gaerten
A. hirsuta (Fischer) C.K. Schneider
A. incana (L.) Moench
A. inokumae S. Murai and Kusaka.
A. japonica (Thunb.) Steud.
A. jorullensis Kunth
A. mandshurica C. K. Schneider
A. maritima (Marsh.) Nutt.
A. matsumurae Callier
A. maximowiczii Callier
A. nepalensis D. Don
A. nitida (Spach) Endl.
A. oblongifolia Torr
A. orientalis Decne
A. pendula Matsum
A. rhombifolia Nutt.
A. rubra Bong.
A. rugosa (Du Roi) Spreng.
A. serrulata (Ait.) Willd
A. sieboldiana Matsum
A. sinuata (Regel) Rydb.
A. subcordata C.A. Mey
A. tenuifolia Nutt.
A. trabeculosa Hand. and Mazz
A. viridis (Chaix) D. C.

Table 2. Soil units after Soil Map of the World of FAO-UNESCO (1974) 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**
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**

Table 3. 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-deciduous 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

Table 3. Continued.

Rec.	Vegetation group
10	**Temperate evergreen forests**
7	Temperate conif. rain forest
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 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. 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. The first 20 countries have in the GBIF grid cells minimum 100 data records and five data records per grid.

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
TW	480	14	13
AT	393	36	28
PT	169	48	33
KR	132	40	9
AR	117	1138	23
BO	112	365	10
EC	106	83	19

Table 4. Continued.

Country	Rec.	Grid 0.5	GBIF 0.5
US	5166	4469	1413
CA	1439	7004	555
RU	143	14 283	73
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

Table 5. 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
TW	14	14	14	13	13
AT	28	36	23	34	23
PT	33	48	48	47	47
KR	9	40	40	40	40
AR	23	950	746	34	32
BO	18	259	238	24	24
EC	19	60	59	18	18

Table 5. Continued.

Country	Grid	Clim	Soil	Veg	All
US	1413	3925	2920	2130	1912
CA	555	4625	3139	3403	2168
RU	73	10 695	7952	7018	4881
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

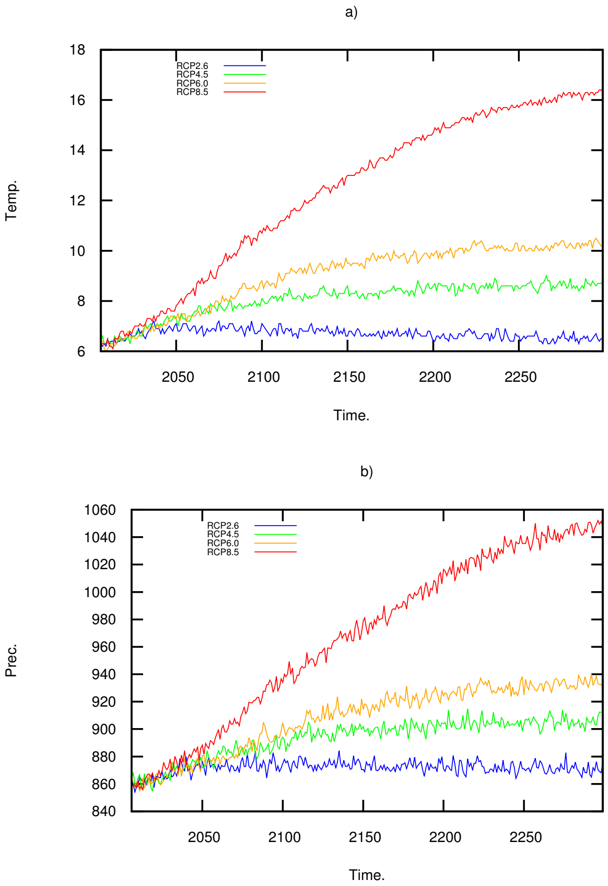


Figure 1. The change in global average temperature and precipitation (2006–2300) of CCSM4 model which driven by four RCP emission scenarios.

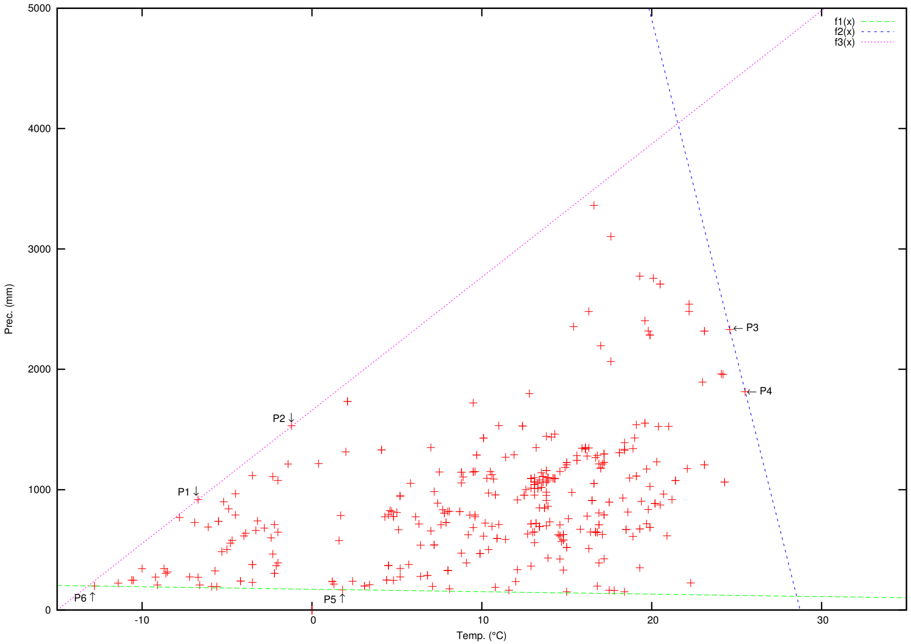
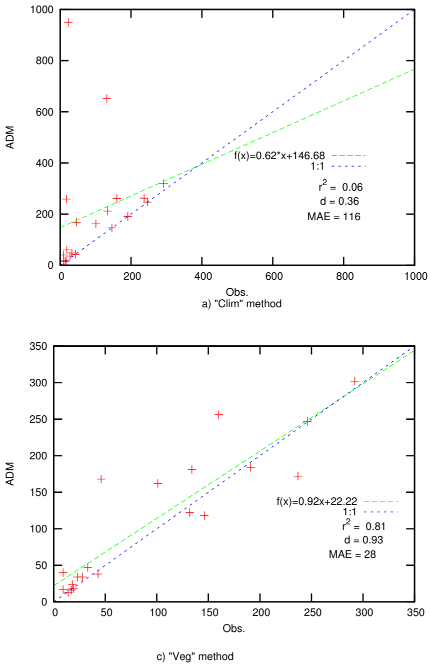


Figure 2. The temperature–precipitation field of the 308 data points which were extracted from seven data bases (Tropicos.org, 2009; eFloras, 2008; WWF, 2009; Tutin et al., 2001; US Forest Service, 2008; USDA-NRCS, 2009; Li and Skvortsov, 1999) as sites of alder occurrence. The cardinal points $P_1, \ldots, P_6$ define the borderline of the distribution of alder in this field. They define the three linear functions 1 through 3 which were used to select appropriate grid elements from a global 0.5° grid of climate data (Cramer and Leemans, 1991).



a) "Clim" method

b) "Soil" method

c) "Veg" method

d) "All" method

Figure 3. The correlation between the observed and predicted alder distribution in half degree grid elements in 20 countries. Countries from the Table 4 with minimum 100 data records and five data records per each noted half degree grid cell were considered. The regression and 1 : 1 lines are shown along with correlation coefficient (*r*), index of agreement (*d*), mean absolute error (MAE).

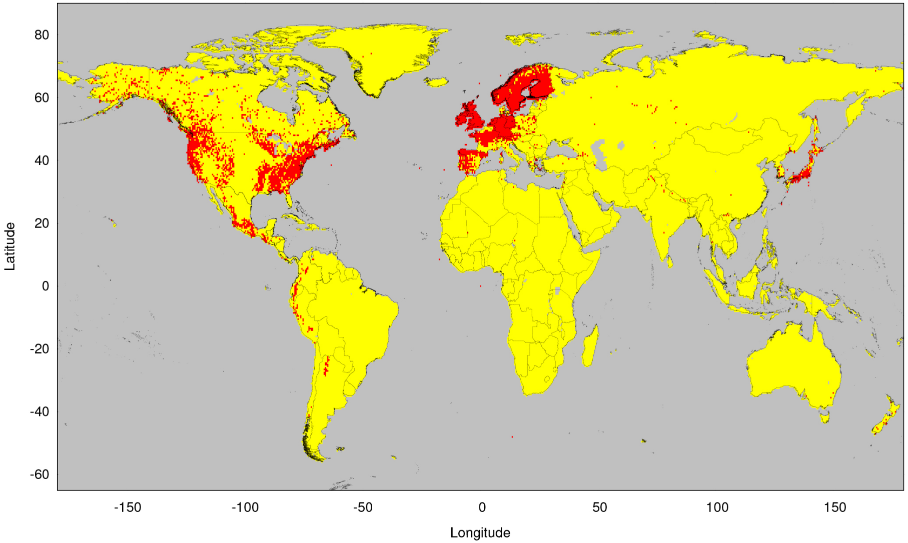


Figure 4. Distribution of alders (red) according to the GBIF database (GBIF, 2010). For the locations with yellow colour there is no data record in the database.

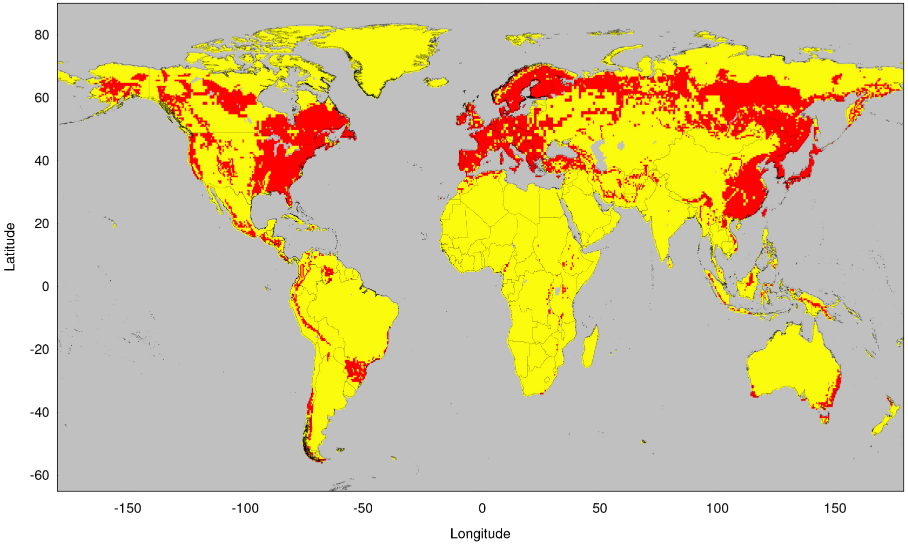
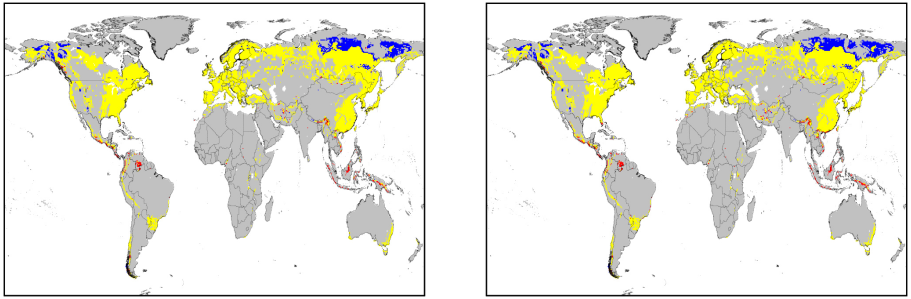
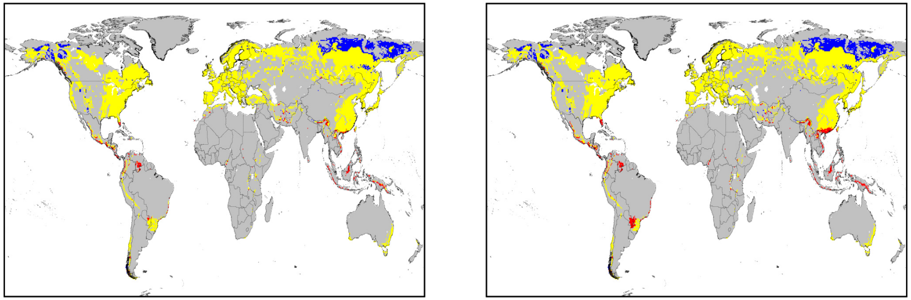


Figure 5. Distribution of grid elements (red) which were identified as potential sites with alder based on the climate functions 1…3 (see also Fig. 2). In this version of the model, restriction by vegetation types (see Table 3) and by soil units as found in table 2 was applied. Yellow: grid elements were not identified as potential distribution area for alder.



a) RCP2.6

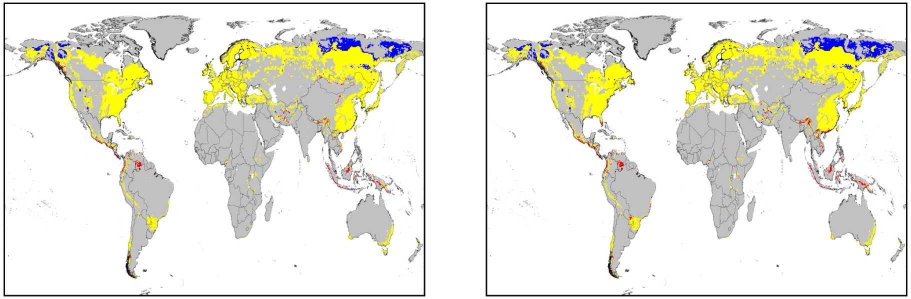
b) RCP4.5



c) RCP6.0

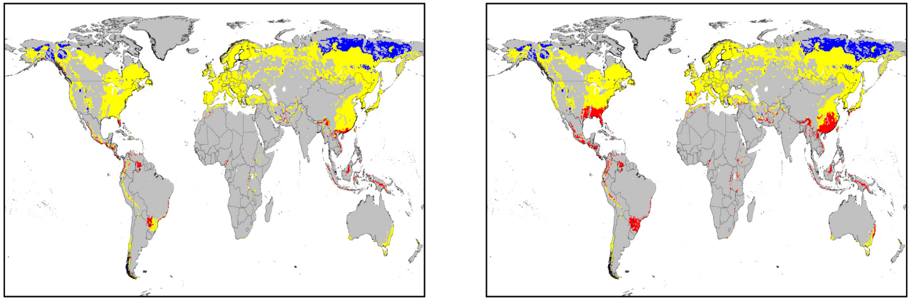
d) RCP8.5

Figure 6. 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 CCSM4 data model which was driven by four RCPs emission scenarios. The colour "yellow" represents the potential distribution areas both present and in 2100, where the colour "red" shows the grid elements with present potential distribution but not in 2100, and also the colour "blue" the grid elements with potential distribution in 2100 but not present.



a) RCP2.6

b) RCP4.5



c) RCP6.0

d) RCP8.5

Figure 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 CCSM4 data model which was driven by four RCPs emissions scenarios. The colour “yellow” represents the potential distribution areas both present and in 2100, where the colour “red” shows the grid elements with present potential distribution but not in 2100, and also the colour “blue” the grid elements with potential distribution in 2100 but not present.