SIMULATION OF POTENTIAL DISTRIBUTION AND MIGRATION OF *ALNUS SPP.* UNDER CLIMATE CHANGE

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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 (Alnus-Distribution-Model (ADM)) 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 up to 2300. Results of the study showed that the potential distribution of *Alnus spp.* not only depending on solitary use of climate variables, soil types and vegetation groups but on combined effect of all tree influencing variables. The ADM also presented that the *Alnus spp.* potentially will migrate mainly northwards in the northern hemisphere. This study covered basic approaches to understand the combine effect of climate, soil and vegetation on modelling of plant distribution and migration.

Keywords: *Alnus, plant distribution, plant migration, nitrogen fixation, climate change, RCP scenarios*

Introduction

Since the nitrogen is 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 in the ecosystems. Numerous biogeochemical and biome models use empirical or statistical methods to predict the nitrogen fixation by N_2 fixing plants (Prentice et al., 1992; Vitousek et al., 2002; Galloway et al., 2004; Esser et al., 2011). 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 fixation process in biogeochemical, biome models to investigate the interactions between the carbon and nitrogen biogeochemical cycles. It is well known that plants can change their distribution with time, when environmental conditions (i.e. soil, climate etc.) and biological factors (i.e. plant–plant interaction) change in their distributed regions (Sauer, 1988; Dawis and Zabinski, 1992; Iverson and Prasad, 2002). Overpeck et al. (1991) and Bartlein et al. (1997) published new data about widening capability of trees due to the change in environmental conditions. Climate change in the 21st and 23rd centuries that mainly driven by emission change and its impacts on different sectors has been addressed by numerous studies and projects. It is also documented that rapid climate change may put some species at risk of extinction, and possibly reduce the functionality of ecosystems, which could have consequences for ecosystem processes such as global

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carbon storage and biodiversity (Thomas et al., 2003). Furthermore, a change in the land cover due to migration of plant species can also affect greenhouse gas concentration in the atmosphere, since for instance a migration of nitrogen fixing plants can influence 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 into phytomass. If 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 free-living or symbiotic cyanobacteria, actinomycetes, and bacteria in roots of host plants (Galloway, 2002). Not only N_2-fixing bacteria but also host plants that supply 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 plays a key role in earth system and ecosystem modelling. 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 fixed nitrogen under global climate change conditions, it is indispensable to have a mechanistic description of the N_2 fixation. And also, 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 are needed. For instance, the density of alders in their native locations in Europe is mainly between 0 and 40% of total plant biomass (Skjøth et al., 2008). These percentage provide a possibility for a modelling the distribution and 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 can 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 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. cordata* (Loisel.) Duby. (Quézel 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 ºC to more than 20 ºC (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. & Zucc. and *A. crispa* (Dryand. in Ait.) Pursh are distribute steep slopes. Several studies show that the main factors that 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 plant distribution, but also the soil units via their different physical or/and chemical conditions can influence 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 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 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 *Alnus* 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 was tested for the correctness of the predicted distribution. This work should be 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 information for implementation of N_2-fixation by alders in biogeochemical and ecosystem models since N_2 fixation is directly depending on the occurrence of N_2-fixing plants in the terrestrial ecosystem.

Materials and methods

In this paper, a new model based on four progress steps was developed for the predicting of the potential distribution of alder spp. on the 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 0.5º 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 0.5º resolution on the global scale. In the second step, the climate based ADM was extended with soil units by using the 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 database from the “Atlas for Biogeography” after Schmithüşsen (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 the ADM. The used climate, soil, and vegetation data sets are on identical global grid resolution, i.e. half degree longitude and latitude as commonly used by global vegetation models. 62483 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.

Distribution data for alders

For the construction of ADM, the global distribution data for of the *Alnus spp*. were extracted from seven databases (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 alder occurrence is very unevenly distributed worldwide. 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. of *Table 1* are represented in the 308 locations. The lifespan of alders ranges between 40-100 years (Harrington et al., 1994; Claessens et al., 2010). It is assumed that a change in the 30-year annual average of climate conditions (i.e. temperature and precipitation) can change the suitable climate conditions in the distribution area and force the migration of alder species. Unfortunately, there is data for validation of this assumption in the academic literature databases. Therefore the 30-year period was used for the prediction of alder distribution and migration. This is a weak point of the model, and may be changed in the future by long-term observation studies.

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 and Li (2004).*

Species name	**Species name**
***A. acuminata* HBK**	*A. matsumurae* Callier
***A. barbata* C. A. Mey**	*A. maximowiczii* Callier
***A. cordata* (Loisel.) Duby.**	*A. nepalensis* D. Don
***A. cremastogyne* Burkill**	*A. nitida* (Spach) Endl.
***A. crispa* (Dryand. in Ait.) Pursh**	*A. oblongifolia* Torr
***A. fernandi-coburgii* C.K. Schneider**	*A. orientalis* Decne
***A. firma* Sieb. and Zucc.**	*A. pendula* Matsum
***A. formasana* (Burkill) Makino**	*A. rhombifolia* Nutt.
***A. fruticosa* (Du Roi) Spreng.**	*A. rubra* Bong.
***A. glutinosa* (L.) Gaerten**	*A. rugosa* (Du Roi) Spreng.
***A. hirsuta* (Fischer) C.K. Schneider**	*A. serrulata* (Ait.) Willd
***A. incana* (L.) Moench**	*A. sieboldiana* Matsum
***A. inokumae* S. Murai and Kusaka.**	*A. sinuata* (Regel) Rydb.

A. japonica **(Thunb.) Steud.**	*A. subcordata* C.A. Mey
A. jorullensis **Kunth**	*A. tenuifolia* Nutt.
A. mandshurica **C. K. Schneider**	*A. trabeculosa* Hand. and Mazz
A. maritima **(Marsh.) Nutt.**	*A. viridis* (Chaix) D. C.

“Clim”

I determined the grid elements, in which alders occur in 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. Therefore, corrections of the gridded climate data were sometimes necessary. For this purpose, the altitude of the site that was given in the original databases was used. If altitudes were lacking, it was determined from the GTOPO30 global elevation dataset (GTOPO30, 2010). If the altitude could not be determined, the side was eliminated. The nearby climate stations were selected from Walter and Lieth (1961–1967), Müller (1982) and Mitchell and Jones (2005). The arrays of T_{ann} and P_{ann} were plotted 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 F1–F3 were fitted to the six cardinal points P1–P6:

F1(P1, P2); F2(P3, P4); F3(P5, P6). The three linear functions that form the borderlines of alder distribution in the temperature–precipitation matrix are:

$$F_1(x) = -2.04 * x + 172.58 \quad \text{(Eq. 1)}$$

$$F_2(x) = -561.58 * x + 16141.87 \quad \text{(Eq. 2)}$$

$$F_3(x) = 110.67 * x + 1658.64 \quad \text{(Eq. 3)}$$

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

To determine the potential distribution areas for alders, the following climate based method was used:

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

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

“Soil”

For this aim, the FAO soil units from the “Soil Types of the World” database, which includes 129 soil units for the 0.5º grid cells of the terrestrial biosphere (excl. Antarctic) (FAO-Unesco, 1974) were used to enhance the climate based ADM for prediction of potential alders distribution. The soil units of the 308 study sites, in which the alders natively occur were recorded as suitable soil types for the alder distribution. Thereby, the soil units were used as additional determinants for the alder occurrence. If a soil unit were present in only one grid element, it was not considered in the modelling study. Grid elements were marked as potential alder habitats, if they were 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:

$$D_{Soil,i} = \begin{cases} true, if \begin{cases} Soil_i = Soil_a \\ D_{Clim,i} = true \end{cases} \\ false, else \end{cases} \qquad \text{(Eq. 5)}$$

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.

“Veg”

In this step, the 31 potential natural vegetation groups according to the study from Esser et al. (2011) were used to investigate the correlation between the alder distribution and climate–vegetation aspect in this study. The potential natural vegetation groups, in which alders occur natively were marked as suitable vegetation groups for alder distribution. Thereby, these potential natural vegetation groups were used as additional determinants for alder distribution. If a vegetation group was recorded in only one grid element, it was not considered in the modelling study. Grid elements were marked as potential alder habitats if they were 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:

$$\mathrm{D_{Veg,i}} = \begin{cases} \mathrm{true, if} \begin{cases} \mathrm{Veg_i = Veg_a} \\ \mathrm{D_{Clim,i} = true} \end{cases} \\ \mathrm{false, else} \end{cases} \qquad \text{(Eq. 6)}$$

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.

“All”

In this step, all three method were combined 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:

$$D_{All,i} = \begin{cases} true, if \begin{cases} D_{Clim,i} = true \\ D_{Soil,i} = true \\ D_{Veg,i} = true \end{cases} \\ false, else \end{cases} \qquad \text{(Eq. 7)}$$

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

Migration of alder species in 2100 and 2300

To predict the migration of alder species up to 2300, data for T_{ann} and P_{ann} were needed. For this step, the mean annual value of temperature and precipitation of four RCP (Representative Concentration Pathway) 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 period between 2000 and 2300. The climate data of the four different RCP scenarios was used for checking the potential effect of variability in temperature and precipitation on plant distribution (i.e. *Alnus spp*.) due to change in anthropogenic emission of greenhouse gases, technology and population density according to the RCP scenarios. Since the used climate data for the prediction of alder distribution in the “Clim” stage were the 30-year annual average data from Leemans and Cramer data base, 30-year annual average value of T_{ann} and P_{ann} from 2071 to 2100, and from 2271 to 2300 were used for prediction of alder distribution in 2100 and 2300, respectively. The 30-year periods give 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), it is also assumed that the alder cannot migrate to a grid cell if at least one of the neighbor grid cell was not marked as a potential distribution grid cell.

Observations and statistical analyses

The Global Biodiversity Occurrence Data Base (GBIF) (GBIF, 2010) was used for the evaluation of the model results. The database includes 237178 data records about the alder occurrence worldwide. 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 a global distribution map as well as the opportunity to download information 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*, 49 countries were presented, which were extracted from the database with data records about the alder distribution. 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, 215444 of 237178 were selected as useful data records in the 49 countries (see *Table 4*).

The prediction of the ADM model was validated with the data from the GBIF database for each step as well as for analyzing correlations between the observed and predicted data 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. The used *MAE* and d equations are:

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |P_i - O_i| \qquad \text{(Eq. 8)}$$

$$d = 1 - \frac{\sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}((|P_i - \bar{O}_i|)+(|O_i - \bar{O}|))} \qquad \text{(Eq. 9)}$$

where *P* is the number of the simulated grid cells with potential alder distribution in related locations and *O* is the number of the observed grid cells with alder distribution, *i* a sample, *n* the number of samples, overbar represents mean values, and *d* is the index of agreement, respectively.

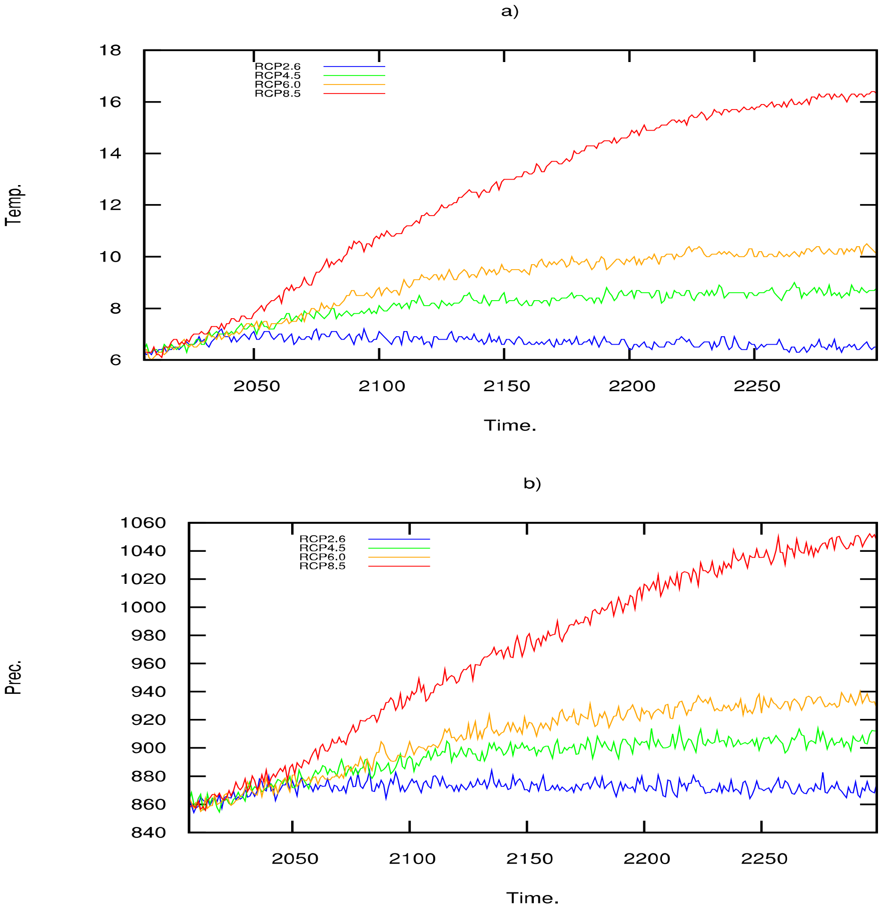


Figure 1. *The change in global average temperature and precipitation (2006–2300) of CCSM4 model which driven by four RCP emission scenarios.*

Results

Evaluation of distribution methods

In *Figure 2*, the distribution of the 308 data points in the field of T_{ann} and P_{ann} is shown. In the distribution regions, there is a lower limit of annual precipitation, which excludes the occurrence of alders. This lower limit depends also on T_{ann}. At the alder distribution sides, when the T_{ann} around −10 ºC or colder, P_{ann} limit is about at 190 mm. When T_{ann} is around 28ºC, the alders need about 115 mm annual precipitation for their existence. Since alders occur at low precipitation values mainly along rivers and brooks, it is assumed that the occurrence of alders in areas with low P_{ann} is due to the probability of the suitable soil water content.

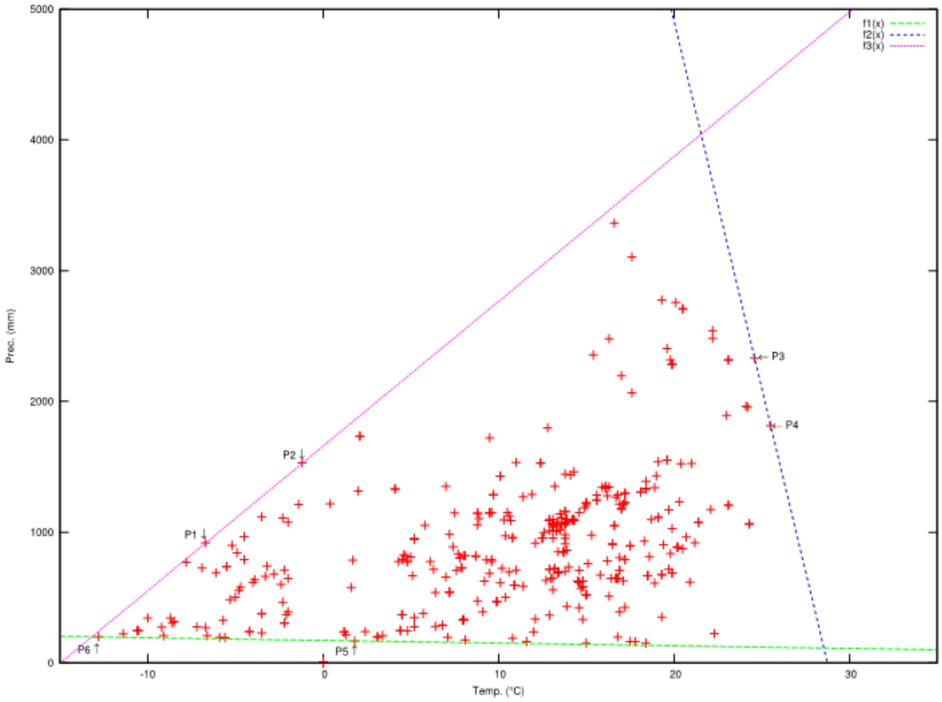


Figure 2. *The temperature–precipitation field of the 308 data points which were extracted from seven data bases (Tropicos.org, 2009; eFloras, 2008; WWF, 2009; Tutin et al., 2001; US Forest Service, 2008; USDA-NRCS, 2009; Li and Skvortsov, 1999) as sites of alder occurrence. The cardinal points P1,...,P6 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).*

From the selected six cardinal points P1...P6 to define the borderline of the alder distribution in a matrix (see *Figure 2*), the point P1, P2 and P6 refers to *Alnus viridis*, which occurs in the northern boreal regions of Asia, Europe, and North America. In temperate regions, *A. viridis* may occur at high elevations (Kamruzzahan, 2003). P_{ann} range for *A. viridis*. 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 *Alnus acuminata* the Andean alder, and *Alnus jorullensis* 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 ºC average annual temperature. In the regions, P_{ann} may range from 500 to 4000 mm yr^{-1}. The point P5 refers to *Alnus rhombifolia*, which occurs in the lower areas of the northern Pacific coast of North America from humid to per-humid climates (USDA-NRCS, 2009). The P_{ann} within the distribution areas of *A. rhombifolia* varies from 508 to 3175 mm per year, and the lowest temperature is −4.4ºC (USDA-NRCS, 2009).

Further stages of the model

The climate based ADM was refined by means of the soil units. The soil units that 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 of the 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. Gleysols are wetland soils and categorized in FAO-UNESCO soil database as a hydromorphic soil group, which are influenced by groundwater for a long period to develop a characteristics gleyic pattern, and are mainly covered by swamp vegetation (FAO-Unesco, 1974). The soil units, which were present in only one grid element, were not considered in this work.

Table 2. *Soil units related to Soil Map of the World of FAO-UNESCO (1974) which dominate in the 0.5^o grid elements where alder species occur according to the GBIF database. The bold lines are the main groups of the related sub group for soil types according to FAO-UNESCO Soil Map of the World.*

Nr. of the grids	**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

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 was the potential natural vegetation group "Temperate deciduous forests" (68 of 308 grid elements). In 97 locations, the tropical and subtropical potential natural vegetation groups were recorded. In 32 locations, 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") were found. In those locations, the alders may distribute in moist areas along rivers and streams. For instance, the "drought-deciduous and part evergreen thorn bush formation" (7 sites) occurs on the east slopes of the Argentinian and southern Bolivian Andes, where a number 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.

Table 3. *The potential natural vegetation groups according to the study from Esser et al. (2011) (name with bold character) and the vegetation units according to Schmithüsen (1976) which occur in the 0.5^o grid elements which include the data records about alder occurrence. The left column gives the respective number of grid elements.*

Nr. of records	**Name of the 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
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
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

Observed alder distribution

In *Table 4*, data about the 49 countries with data records for alder distribution in GBIF database were presented. The 49 countries include 215444 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 208181 of 215444 in 1866 of 4098 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, these countries were not considered within the 20 countries. Countries with only one data record in GBIF data base were also not considered and not presented in this paper.

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.*

Contry	**Nr. of records**	**Nr. of 0.5 grids**	**Nr. of GBIF grid**
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
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

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.

Validation of the methods

Since the 20 countries had the most density for data records about the alder distribution in GBIF database, a statistical analysis between the observed and predicted alder distribution was done 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 *Figure 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 was found between the observed and "Clim" method based ADM results with r^2 = 6%. The d and *MAE* values of this correlation analysis were 0.36 and 117, respectively (see *Figure 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 *Figure 3b*). The correlation coefficients r^2 between this method and observed data were 11%. The value of d for this method was 0.5, where the *MAE* value was 86. The method "Veg" provided a better correlation with the observed data (see *Figure 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 *Figure 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, the "All" method based ADM was used to predict the potential alder distribution areas globally.

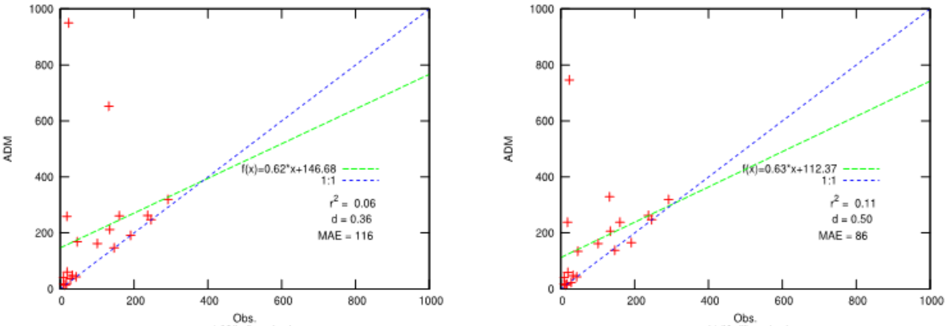
The figures in the *Appendix* give an overview about the statistical analyses between the results of ADM by using each single parameter and observation in the 20 countries, and about the results of "CLIM", "Soil" and "Veg" methods on global scale.

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.*

Country	Tot. 0.5 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

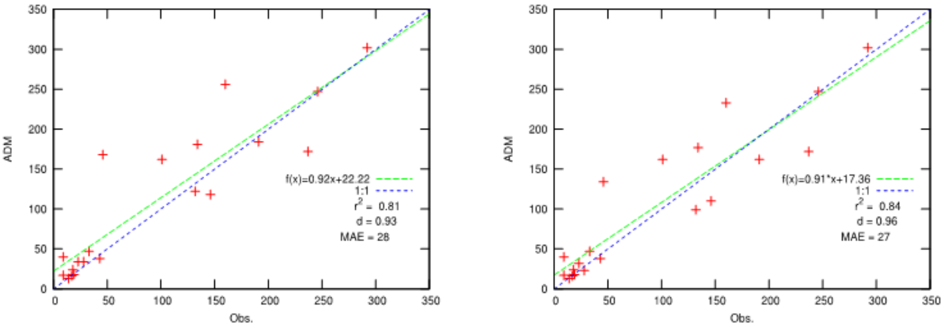
PT	33	48	48	47	47
KR	9	40	40	40	40
AR	23	950	746	34	32
BO	18	259	238	24	24
EC	19	60	59	18	18
US	1413	3925	2920	2130	1912
CA	555	4625	3139	3403	2168
RU	73	10 695	7952	7018	4881
CN	3	3070	2980	1411	1379
PE	30	240	233	53	53
CO	16	110	105	51	51
PA	2	5	5	4	4
DK	6	30	30	30	30
IT	14	143	134	137	129
CH	10	19	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

Meaning of the columns: (Country) name of the countries; (Tot. 0.5 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.



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).*

Global potential alder distribution

The predicted alder distribution by using "All" method based ADM was shown in *Figure 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 *Figure 4*) the ADM also predicted the potential distribution in several grid elements of South America, Africa, and Australia (see *Figure 5*). The ADM predicted the alder distribution in 1898 grid elements in the 20 countries where the GBIF database has records in 2066 grid elements (see *Table 5* columns "Grid" and "All"). Most of the eliminated grid elements have suitable soil units but not vegetation types for the potential alder distribution in these countries. For example, eliminated grid elements in Norway have the soil unit "Lithosols" and the vegetation type "Mountain vegetation above the tree line". "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. Most eliminated grid elements in the 20 countries after using "Soil" and "Veg" methods in ADM were found in Mexico. The dominant soil units in Mexico are "Leptosols", "Regrosols", and "Calcisols" (FAO-Unesco, 1974). Only "Regrosols" were presented in 308 evaluation's grid elements (see *Table 2*). Also, the dominated vegetation types are "Shrub desert", "Thorn savanna", and 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 has shown the potential alder distribution in 67, and 460 times more grid elements than the GBIF database records. In Russia, 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, same vegetation types are also the dominant vegetation types in potential distribution areas. However, the mostly coming soil units in those areas are the “Cambisols”, “Gleysols” and “Acrisols”. The 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 the regions, “Lithosols”, “Podzols”, “Luvisols”, and “Phaozems” are mostly recorded soil units (FAO-Unesco, 1974). The potential natural vegetation groups are mainly “Temperate deciduous forests”, and “Mediterranean sclerophyll formations” in the US, “Boreal evergreen conif. forests” in Canada.

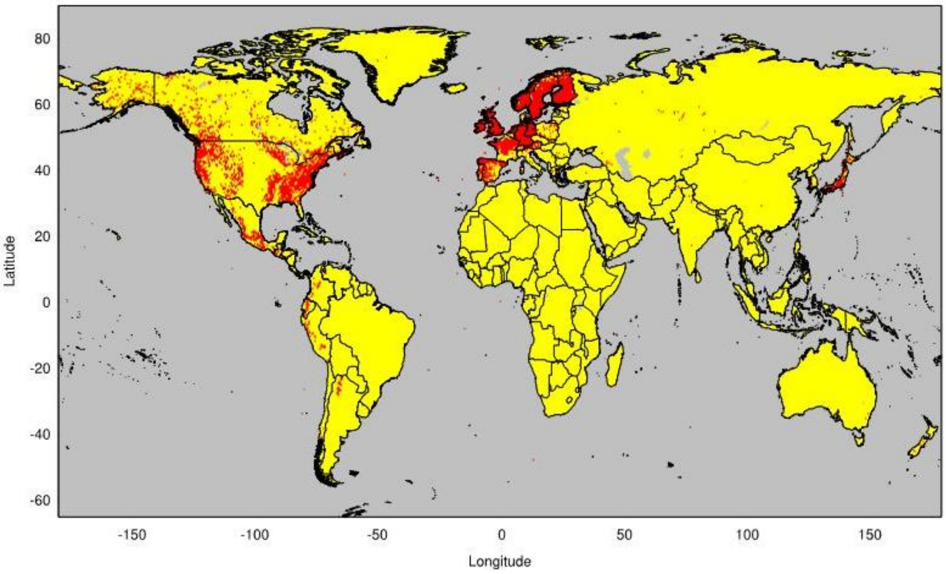


Figure 4. *Distribution of alders (red) according to the GBIF database (GBIF, 2010). For the locations with yellow colour there is no data record in the database.*

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 potential distribution of alders mainly occurs in Northern Hemisphere, but also occurs in quite few locations in south hemisphere with adequate climate conditions, soil types and vegetation units (see *Figure 5*). Since the alders can fix atmospheric nitrogen, consideration of the nitrogen fixation by alders in their distributional areas in ecosystem and biogeochemical models gives the opportunity to investigate and predict the nitrogen fixation impacts on CO_2 uptake, and carbon storage in the.

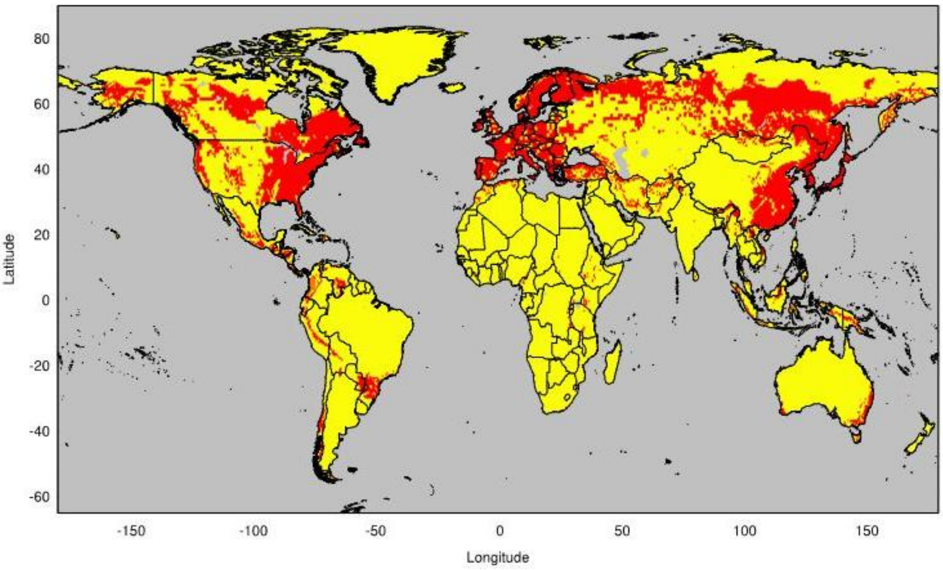


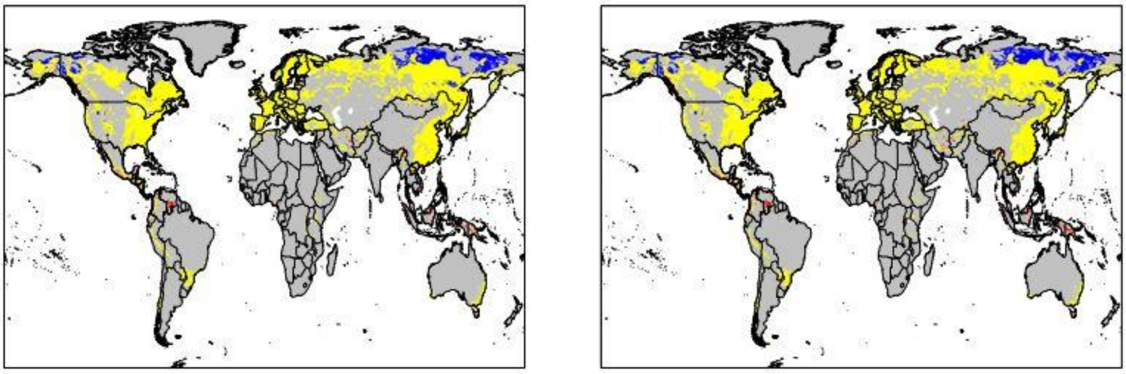
Figure 5. *Distribution of grid elements (red) that were identified as potential sites with alder based on the climate functions 1...3 (see also Figure 2). In this version of the model, restriction by vegetation types (see Table 3) and by soil units as found in Table 2 was applied. Yellow: grid elements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

Potential distribution and migration of alder in 2100 and 2300

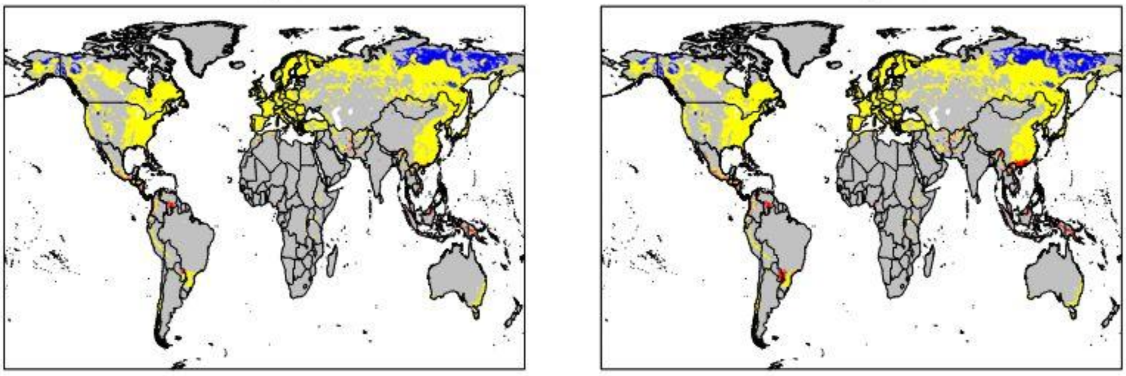
The absence of alders in the natural ecosystems can also cause an extreme decrease in nitrogen input by N_2 fixation of this plants group, and as a result can have gravely consequences for the nitrogen availability in soil of the areas. Therefore, it is important to model the migration of the N_2 fixing 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). An increase in CO_2 in the atmosphere can also influence plant distribution by e.g. CO_2 fertilization, CO_2 partial pressure, water use efficiency (Johnson et al., 1993; Collatz et al., 1998). In this study, this type of impacts from CO_2 on the alder distribution was not considered.

For this step of the study, it was 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 *Figures 6* and 7. The results show that the alders can extend its distribution northwards. Especially the alder species may be frequently occurring furthermore in Northern Russia and Alaska at all scenarios of the climate models (see the blue areas in *Figure 6*). 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 in 2300 (see the red areas in *Figure 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 and 2300.

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).



a) RCP2.6 b) RCP4.5

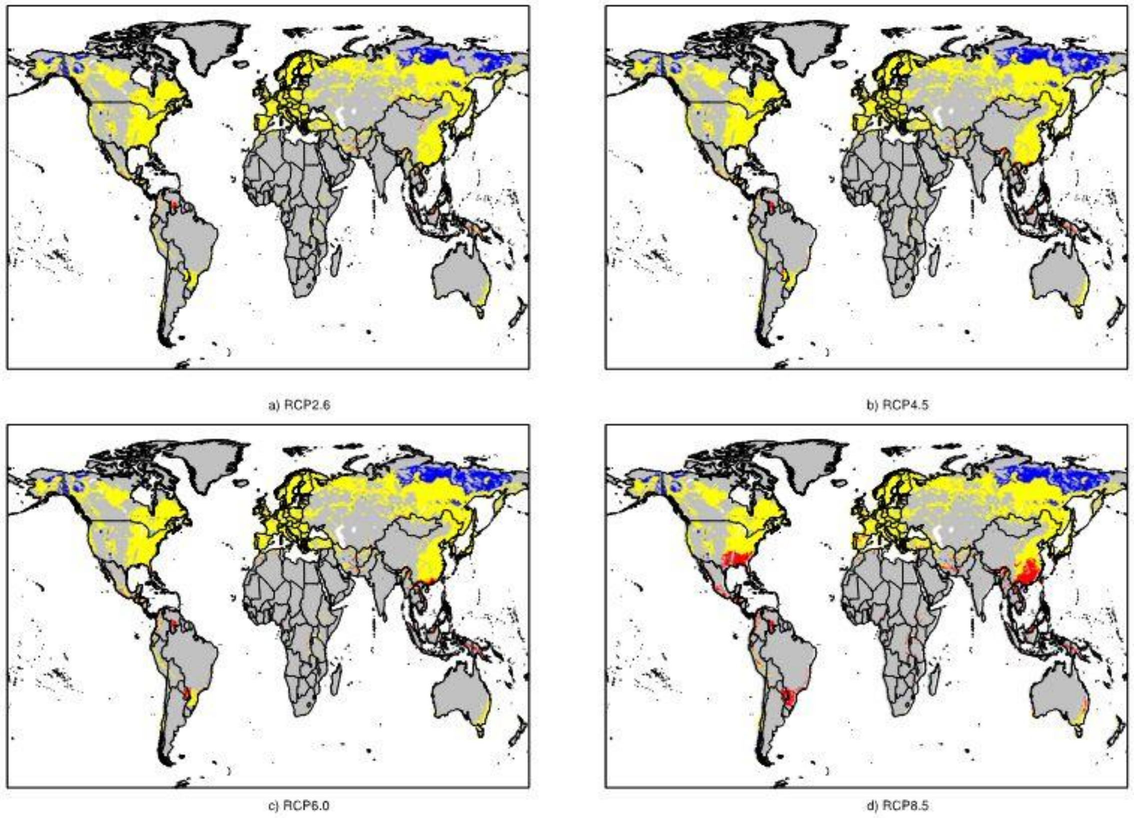


c) RCP6.0 d) RCP8.5

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.*

The results indicated that only a change in two climate parameters (i.e. T_{ann} and P_{ann}) can affect 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 should be considered in modelling studies about plant distribution.

The changes of the climate parameters within the four RCP scenarios have quite similar impacts on the alder distribution at global level in 2100 (see *Figure 6 a*, *b*, *c* and *d*). In 2300, the alder distribution was more affected by the change of the climate parameters in RCP8.5 scenario in the tropical and sub-tropical regions than other three RCP scenarios (see *Figure 7-d*).



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 2300, and also the colour "blue" the grid elements with potential distribution in 2300 but not present.*

Discussion

The records for the distribution of the world's vegetation types was started by foundations of plant geography 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 plant species distribution, and for the modelling of phenological processes of 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 impacts 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 *Figure 3* in the paper). The using of only climate parameter in ADM predicted the distribution of all alder species almost in whole Australia, Middle and South Africa, where there is no or very poor record about the distribution of alder (see *Appendix Figure 1*). 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 plants was not only depending on the climate factors but also the soil conditions could play a crucial role in the prediction. Like most of the models, the bioclimatic model could 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 impacts 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 *Figure 4* and *Appendix Figure 2*). Also, the statistical analysis between the observed and predicted data in the 20 countries resulted a rare correlation (see *Figure 3b*).

In the natural ecosystems 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 plant communities, and the using of the relations were quite important in modelling of distribution of plant species. Woodward and Williams (1987) investigated the effect of climate on plant distribution on global and local scales. Their predictions of the distribution of the vegetation 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 vegetation or species, and in such modelling studies, the population dynamics (plant–plant interactions) should be also considered. Therefore, 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. Although the statistical of the results in the 20 countries showed quite good correlation with the observed data from the GBIF database (see *Figure 3c*), on the global scale, the comparing of the results (see *Appendix Figure 3*) with the distribution map from GBIF database (see *Figure 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 plant species in plant communities, and 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) pointed out that 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 annual average temperature and sum of the precipitation as determinant in their studies. The used parameters (Wind, NO3, soil humus content etc.) were also dynamic parameters, which can have strong seasonality. The ADM considered the average of 30 years of the climate data (1961–1990). That eliminated the uncertainties regarding to the dynamic seasonality of climate parameters.

Although, only 6% of the alder distribution can be explained by using the climate data in this study (see *Figure 3*), results of this study showed that the distribution of plant species was 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, all determinants were merged in one method 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 *Figure 3d*). The predicted potential distribution areas for alder species using the “All” method was presented in the *Figure 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 are 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 be restricted under the alkaline or neutral conditions. “Lithosols” are typical soil unit in temperate climate zone under coniferous forests, and the “Camsbisols” are well represented in boreal and temperate regions. The two soil units are well represented 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 shows 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 showed that *A. glutinosa* also distribute in several locations in Russia. These maps confirm that the results of ADM prediction for Russia are acceptable. Furthermore, the GBIF database does not indicate the absence of alders. Therefore, 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). Globally, 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 such 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 1376 grid elements more than the GBIF database. Likewise, it is well known that *A. nepalensiss* distributes in 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. Furthermore, some regions in Central Africa and southeast Australia still remain. The regions in Central Africa are known to be suitable for alder cultivation, however, 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 1500 mm and the annual mean temperature is 14.6 ºC in the study site. The values of the climate parameters are in the climate field (see *Figure 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 type 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 ºC and 500–1100 mm, respectively. The dominant vegetation unit is “Laurel mountain forests” as well as “Laurel forest w. conf. trees”, and “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 *Figure 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 an 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 *Figure 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 show 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 certainly influence 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 alder distribution and migration in the future. As it presented in *Figure 1*, CCSM4 provides variously T_{ann} and P_{ann} by using four IPCC RCP scenarios. There is quite difference between the values of the T_{ann} as well as P_{ann} of the models, and the difference between the four scenarios of the models are quite large (ca. 16 ºC for T_{ann} and ca. 250 mm for P_{ann} in 2300). Though, the effects of the climate parameter of the models, and scenarios on the alder distribution on global scale are quite similar (see *Figure 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. Therefore, it is assumed that the prediction of the potential alder distribution (migration) in the future is quite reasonable according to the results of this study.

Conclusion

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 using simplified approaches as in “All” method of the model allows the scientist to understand the functionality of plant distribution by considering the environmental and geological factors. The model shows that combine effect of the all three parameters (i.e. climate, soil, vegetation) is the predictor for the identification of potential habitats for the alders. 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. In this paper, the temporal and spatial change of alder distribution was modeled by using the climate variables from the CCSM4, which was driven with four RCP scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) up to 2300. The using of climate variables should give an overview of the sensitivity of the methodology for modelling of plant distribution according to climate models. The using of the climate variables of four RCP scenarios in this study allows the scientists the investigation of the sensitivity of plant distribution by considering the different emission scenarios on global scale up to 2100 and 2300, respectively. Because of the missing dynamic vegetation data and dynamic soil unit data for 2300, only the climate parameters were dynamically changed in the ADM for predicting the potential distribution of alder species in 2300. The results of the ADM show that numerous regions 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 not be suitable for alder occurrence.

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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APPENDIX

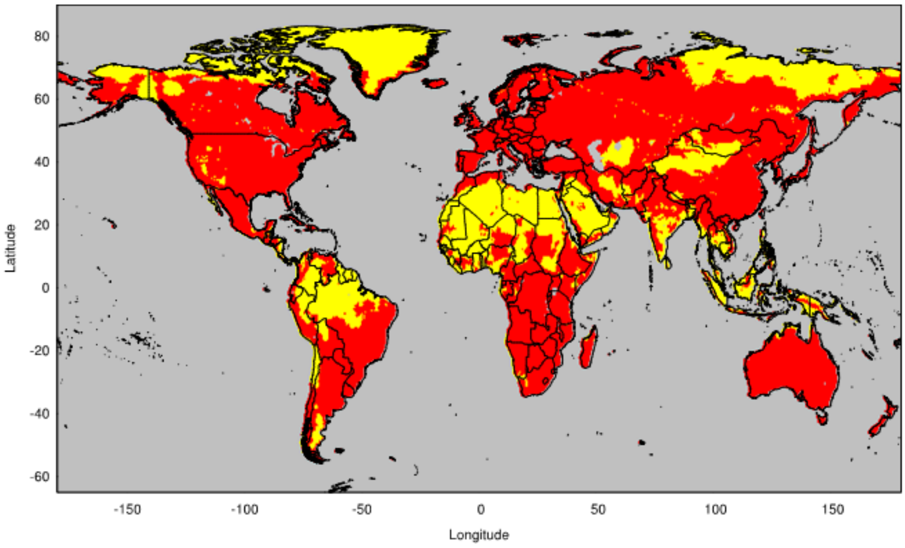

Figure A1. *Distribution of grid elements (red) which were identified as potential sites with alder based on the climate functions 1…3 (see Fig. 3). Yellow: grid elements were not identified as potential distribution area for alder.*

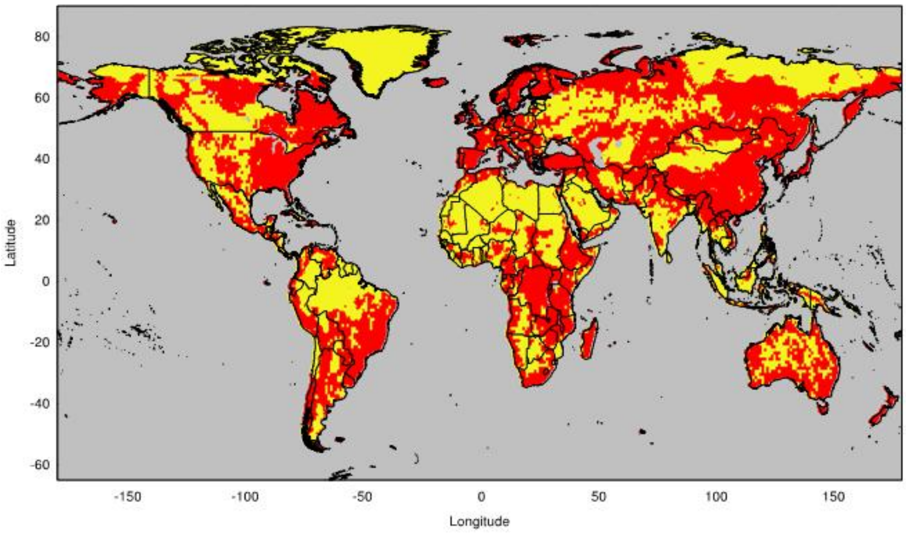

Figure A2. *Distribution of grid elements (red) which were identified as potential sites with alder based on the climate functions 1…3 (see Fig. 3). In this version of the model, restriction by soil units as found in Tab. 1 was applied. Yellow: grid elements were not identified as potential distribution area for alder.*

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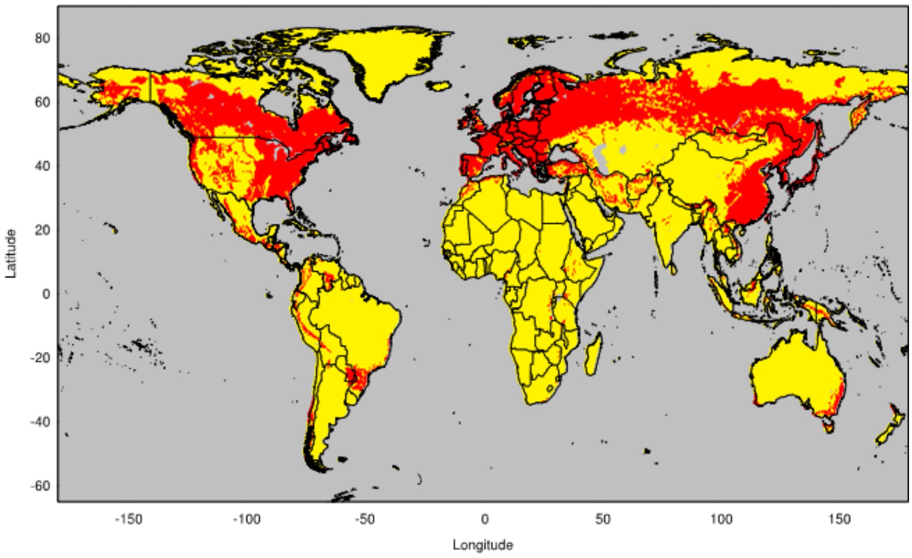

Figure A3. *Distribution of grid elements (red) which were identified as potential sites with alder based on the climate functions 1…3 (see Fig. 3). In this version of the model, restriction by vegetation types (see Tab. 2) was applied. Yellow: grid elements were not identified as potential distribution area for alder.*

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