**Predicting the distribution of plant associations under climate change: A case study on *Larix gmelinii* in China**

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**Running title: Distribution prediction of plant associations**

**Abstract**

Association is the basic unit of plant community classification. Exploring the distribution of plant associations can help improve the understanding of biodiversity conservation. Different associations depend on different habitats. Studying the association level is significant for ecological restoration, regional ecological protection, regulating the ecological balance, and maintaining biodiversity. However, previous studies have focused only on the suitable distribution areas of species and not on the distribution of plant associations. *Larix gmelinii* is a sensitive and abundant species spread in the southern margin of Eurasian boreal forests, and its distribution is closely related to permafrost. In this study, 420 original plots of *L. gmelinii* forests were investigated. We used Maxent model and ArcGIS software to project the potential geographical distribution of *L. gmelinii* associations in the future (by 2050 and 2070) according to the climate scenarios RCP 2.6, RCP 4.5, and RCP 8.5. The causes for the changes in spatial distribution were analyzed using multinomial logistic regression analysis.

The results revealed that temperature is the most important factor affecting the distribution of *L. gmelinii* forests and most of its associations under different climate scenarios. Further, the suitable areas for each association type are shrinking by varying degrees, especially due to habitat loss at high altitudes in special terrains. For different *L. gmelinii* associations, management measures should also be different based on the different site conditions, composition structure, growth, development, and renewal succession trends. Furthermore, subsequent research should consider data on biological factors to obtain more accurate prediction results.

**Keywords:** Climate change,Temperature, *Larix gmelinii* associations, Maxent, Spatial distribution

1. **Introduction**

Climate change has far-reaching impacts on species range, leading to changes in species dominance, survival, succession, and community structure (Crase et al., 2015; Fei et al., 2017; Pires et al., 2018). The dominant species can alter the living conditions of other species and affect the entire community (Hickler et al., 2012). Biodiversity is indispensable for stabilizing biological communities (Loreau and de Mazancourt, 2013; Ma et al., 2017; Mougi and Kondoh, 2012). Rising temperatures disrupt seasonal species interactions, change the flowering period of plants, and affect insect pollination (Durant et al., 2007; Memmott et al., 2007). Some studies suggest that warm and dry environments are particularly prone to fires, droughts, and insect interferences, whereas warm and humid environments experience wind and pathogen interferences (Seidl et al., 2014, 2017; Abatzoglou and Williams, 2016).

The continuous emission of greenhouse gases is now widely credited for causing global warming (Meinshausen et al., 2009; Allen et al., 2010; Friend et al., 2014; Kamkeng et al., 2021). Forests play an important role in the global carbon cycle (Bonan, 2008; Pan et al., 2011; Schlosser et al., 2003), and the dominant effect of climate change on forest ecosystems is evident at low and high altitudes (He et al., 2005). At the community scale, forests are a mixture of tree species with different functional characteristics and growth behaviors that respond to different light, moisture, and nutrient regimes (Pan et al., 2013). Carbon storage in larch forests accounts for a large proportion of the forest community (Alexeyev et al., 1995). The Chinese boreal forests are located on the southern margin of the Eurasian boreal forests (Jia et al., 2021), and a particular concern is that the northern boundary of the broad-leaved forest is moving northwest (Chen, 2000).

Previous research has established that species in ecological communities reflect interactions among organisms and between organisms and their abiotic environments (Walther et al., 2002; Cardinaux et al., 2018; Koffel et al., 2021). Many scholars have focused on the response of communities to global changes, and an in-depth understanding of species interactions can help comprehensive prediction of their responses to climate change (Enquist, 2002; Gilman et al., 2010; Ovaskainen et al., 2013; Santos-Hernández et al., 2021). To a certain extent, climate change leads to inconsistencies in the phenology of species, which in turn leads to changes in communities (Ovaskainen et al., 2013). Through long-term observations, it has been found that with climate change, cold mountain habitats and the biological communities in high mountains are gradually decreasing (Gottfried et al., 2012).

*Larix gmelinii* is commonly found in the boreal forests of subalpine coniferous forests in Northeast China, and contributes to the high carbon storage capacity of forests (Fang et al., 2001; X. He et al., 2019). The range of *L. gmelinii* extends almost to the permafrost region (Larionova et al., 2004). Leng et al. (2008) predicted the current distributions of *L. gmelinii*using the random forest algorithm under the current climate conditions. Furthermore, Li et al. (2006) proved that the geographical distribution of *L. gmelinii*forests is decreasing and may even move northward from China. Yang et al. (2014) indicated that suitable high-altitude areas for larch forests are not available in China. Therefore, conserving the existing habitats and maintaining the general living conditions of this species is necessary, as larch habitats support a wide range of organisms, including endemic species, and any habitat change can affect their distribution (Rivas et al., 2020).

The Chinese vegetation classification system is separated into three levels: vegetation, alliance, and association (Fang and Wang, 2020; Wang et al., 2020). In other words, association is the basic unit of plant community classification (Jennings et al., 2009; Tansley, 1920). In this study, the following research questions were addressed: (1) Which climatic factors have the power to distribute the *L. gmelinii* associations more strongly? (2) Which association types control the movement of *L. gmelinii* forests under climate change scenarios?

Compared with field surveys, the study of plant communities by remote sensing methods is not sufficiently comprehensive; moreover, the spectral signal changes between communities are not evident, and the ability to interpret complex local terrains is insufficient (Westman et al., 1989; Chang et al., 2004). In this study, 420 original plots of *L. gmelinii* forests were investigated. The forest plot area was set to 30 × 30 m, and the sample plot survey data included the basic condition of the tree, shrub, and herb species in the plot. Maxent model and ArcGIS software can help determine the future (by 2050 and 2070) potential geographical distribution of different associations based on three different climate scenarios RCP 2.6, RCP 4.5, and RCP 8.5 (Dyderski et al., 2018; Tapiador et al., 2019). The reasons for the changes in spatial distribution can be analyzed using multinomial logistic regression analysis (Kwak and Clayton-Matthews, 2002; Fagerland et al., 2008; Friedman et al., 2010). Through this study, we seek to understand the current and future changes in the distribution of *L. gmelinii* associations to provide a scientific basis and useful reference for medium- and long-term management, biodiversity protection, and regional ecological planning.

**2. Materials and methods**

**2.1. Study area**

The study area was located in Northeast China, with a geographical range of 38°40′ N–53°30′ N and 115°05′ E–135°02′ E and covering an area of 1.26 million km2. The area of mountains and plains in Northeast China are roughly equal. The ridge height of the mountains is generally between 1000–2000 m **(Fig. 1)**.



**Fig. 1.** Geographical location of the research area. The blue part represents the research area, the red points represent the sampling points, and the black lines represent the provincial boundaries.

**2.2. Data analysis**

**2.2.1 Sample plot data**

Based on the regional distribution data of Northeast China, 420 plots of *L. gmelinii* forests were selected for this study. Next, we set a buffer radius of 1 km to screen the distribution points of the plots to avoid the influence of overfitting caused by excessive correlation. Ultimately, 337 distribution points were available. The data were classified using two-way indicator species analysis (Hill et al., 1975) and combined with the traditional community classification (Zhou, 1997, 1991) to remove transitional associations, and assign names. Subsequently, 13 association types were determined **(Table 1)**.

**Table 1 Association type**

|  |  |  |  |
| --- | --- | --- | --- |
| Code | Association | Quantity | Category |
| LRC1 | *Ass. Carex callitrichos, Rhododendron davuricum, Larix gmelinii* | 15 | mesogenic drought |
| LRD2 | *Ass. Deyeuxia pyramidalis, Rhododendron davuricum, Larix gmelinii* | 9 | mesogenic drought |
| LRV3 | *Ass. Vaccinium vitisidea, Rhododendron davuricum, Larix gmelinii* | 25 | mesogenic drought |
| LLC4 | *Ass. Carex callitrichos, Lespedeza bicolor, Larix gmelinii* | 7 | mesogenic drought |
| LH5 | *Ass. Herbage,Larix gmelinii* | 77 | mesogenic |
| LCC6 | *Ass. Carex lanceolata, Corylus mandshurica, Larix gmelinii* | 56 | mesogenic |
| LCC7 | *Ass. Carex callitrichos, Corylus heterophylla, Larix gmelinii* | 26 | mesogenic |
| LPV8 | *Ass. Vaccinium vitis-idaea, Pinus pumila, Larix gmelinii* | 18 | mesogenic |
| LLV9 | *Ass. Vaccinium vitis-idaea, Ledum palustre, Larix gmelinii* | 41 | mesogenic wet |
| LV10 | *Ass. Vaccinium vitis-idaea, Larix gmelinii* | 8 | mesogenic wet |
| LBC11 | *Ass. Carex schmidtii, Betula fruticosa, Larix gmelinii* | 52 | wet |
| LBV12 | *Ass. Vaccinium vitis-idaea, Betula fruticosa, Larix gmelinii* | 16 | wet |
| LBV13 | *Ass. Vaccinium vitis-idaea, Betula middendorfii, Larix gmelinii* | 6 | wet |

LRC1(*Ass. Carex callitrichos, Rhododendron davuricum,* and *L. gmelinii*) was present in the cold temperate coniferous forest area on the northeast and southeast slopes (1–28°) of the Huzhong National Nature Reserve, Duobukur National Nature Reserve, Nanwenghe National Nature Reserve, and Chuonahe National Nature Reserve. Such low and medium degree slopes are common at approximately 400–800 m. The main forest layer consisted of *L. gmelinii*, *Betula platyphylla,* and *Quercus mongolica*. The shrub layer was dominated by *Rhododendron dauricum* and *Vaccinium vitis-idaea*, and the herb layer was dominated by ferns and *C. callitrichos.*

LRD2(*Ass. Deyeuxia pyramidalis, R. davuricum,* and *L. gmelinii*) was present in the cold temperate coniferous forest area on the southeast, northeast, and middle–low slopes of the Huzhong National Nature Reserve and Da Hinggan Ling Hanma National Nature Reserve, at an altitude of approximately 500–1000 m. The main forest layer was dominated by *L. gmelinii* and included a sparse populationof *B. platyphylla*. The irrigated layer was dominated by *R. dauricum* and accompanied by a small population of *Spiraea salicifolia*. *Deyeuxia arundinacea* dominated the herb layer, accompanied by non-layered *V. vitis-idea* and *Ledum palustre*, and the lower layer included *Rosa davurica*, *Sorbaria sorbifolia*, *Pyrola asarifolia* subsp*. incarnata*, *Ribes janczewskii*, *Convallaria majalis* Linnaeus, *Maianthemum bifolium*, and *Deyeuxia purpurea*.

LRV3 (*Ass. V. vitis-idea, R. davuricum,* and *L. gmelinii*) was found on the lower or middle regions of the southeast slopes of Genhe, Inner Mongolia, at an altitude of approximately 890–1100 m. The main forest layer consisted of *L. gmelinii*, with a small population of *B. platyphylla*. The shrub layer was dominated by *Rhododendron dauricum* and accompanied by a small population of *Pinus pumila*. The herb layer included *L. palustre* and *V. vitis-idea*, accompanied by a sparse populations of *D. purpurea, Vicia pseudo-orobus*, *Sanguisorba officinalis, Iris uniflora, Peucedanum terebinthaceum,* and *Juniperus davurica*.

LLC4(*Ass. C. callitrichos, Lespedeza bicolor,* and *L. gmelinii*) was found on the northeast and southwest slopes and located in the middle or lower parts of the slopes of the Chuonahe National Nature Reserve, at an altitude of approximately 400–600 m. The forest layer mainly consisted of *Q. mongolica* and *B. platyphylla*. The shrub layer was mainly populated by *Lespedeza bicolor,* accompanied by sparse populations of *Rhododendron dauricum* and *Vaccinium vitisidea*. The herb layer was dominated by *C. callitrichos*.

LH5 (*Ass. Herbage* and *L. gmelinii*) was mainly distributed on the sun and semi-sun slopes of the Ergun National Nature Reserve and Da Hinggan Ling Hanma National Nature Reserve of the cold temperate coniferous forest subzone. The slope is generally 2–10°. Most of these associations are derived from the forests of *Q. mongolica* and *Larix olgensis*. The main forest layer consisted of *L. gmelinii*, and the shrub layer included *Spiraea media*, *Vaccinium uliginosum* Linn., *Sorbaria sorbifolia*, and *Philadelphus schrenkii*. The herb layer mainly included *D. purpurea*, *Carex lanceolata*, *Carex ussuriensis*, *D. pyramidalis*, and *Pyrola rotundifolia*.

LCC6(*Ass. C. lanceolata, Corylus mandshurica,* and *L. gmelinii*) was derived from broad-leaved Korean pine forests of the Youhao National Nature Reserve and was distributed in terraces or second-level terraces at an altitude of 300–500 m. *L. gmelinii* was the dominant tree species, the main shrubs were *C. mandshurica* and *Aralia elata*, and the main herbs were *Bolboschoenus yagara* and *Filipendula palmata*.

LCC7(*Ass. C. callitrichos, Corylus heterophylla,* and *L. gmelinii*) was found in the middle or lower parts of the northeast and northwest slopes of the Duobukur National Nature Reserve, Nanwenghe National Nature Reserve, and Chuonahe National Nature Reserve, at approximately 200–500 m a.s.l. The trees primarily included *B. platyphylla*, *Populus davidiana*, and *L. gmelinii*. The shrub layer was mainly composedof *C. heterophylla* Fisch. The herb layer included *C. callitrichos* and was accompanied by sparse populations of *D. purpurea*, *F. palmata*, *Cimicifuga dahurica*, *S. officinalis*, and some ferns.

LPV8 (*Ass. V. vitis-idaea, Pinus pumila,* and *Larix gmelinii*) was the zonal vegetation of the cold temperate coniferous forest belt in the mountainous area of the Daxinganling Mountains, which was the highest altitude distribution of the *L. gmelinii* forest. LPV8 was mainly distributed at the mountain top, in the ridge, the upper part of the slope, and the broad watershed. The habitat temperature was low, the wind was high, and tree growth was affected. Only thick pines occupied the shrub layer. *Larix gmelinii* was the dominant species in the forest layer, and a small population of *B. platyphylla* was also present in the main forest layer. The shrub layer was dominated by *P. pumila*, with sparse populations of *Alnus mandshurica*, *Sorbus pohuashanensis,* and *R. dauricum*. *Vaccinium vitis-idaea* dominated the shrub layer, and *L. palustre* and *R. davurica* were randomly distributed in the shrub layer.

LLV9(*Ass. V. vitis-idaea, L. palustre,* and *L. gmelinii*) was sporadically distributed in the cold temperate coniferous forest subzone in the middle or lower part of the mountain area. It was mostly distributed in floodplains and terraced riverbank valleys, and the slope was gentle, mostly within 5° (Zhou, 1991). The tree layer mainly consisted of *L. gmelinii* as a mature, pure forest with an occasional occurrence of *B. platyphylla*. The shrub layer was dominated by *L. palustre* and *D. arundinacea*, and accompanied by sparse populations of *R. davurica*, *V. uliginosum* Linn., *V. vitis-idaea* Linn., *Betula middendorfii*, and *Equisetum pratense* Ehrh. The moss layer was extremely underdeveloped.

LV10 (*Ass. V. vitis-idaea* and *L. gmelinii*) represented cold and humid habitat conditions and was marginally distributed in the Daxinganling Mountains. It was concentrated in the subzone of the cold temperate coniferous forest in the middle of the mountain. The soil was the brown taiga forest soil and was moist and well-drained (Zhou, 1991). Leaves of deciduous conifers, consisting of *L. gmelinii*, were dominant among standing trees and sometimes mixed with populations of *B. platyphylla* and *Pinus sylvestris* var. *mongolica*. The evergreen shoots *of V. vitis-idaea* Linn.were the dominant layers in the shrub layer. *Carex lanceolata* Boott, *D. pyramidalis*, *F. palmata,* and *D. purpurea* were common in the shrub layer.

LBC11 (*Ass. Carex schmidtii, Betula fruticosa,* and *L. gmelinii*) was generally located in flat bottoms, valleys, and low-lying areas. The soil in this region was gleyed brown coniferous forest or swamp soil. The permafrost layer was deep and belonged to a continuous frozen soil area. This type of vegetation was characterized by distinct vegetation stratification. *Larix gmelinii* was the dominant species in the tree layer and was sometimes accompanied by *B. platyphylla*. The shrub layer was typically dominated by *B. fruticosa*. The second shrub layer was composed of *V. uliginosum* and *L. palustre*. The herb layer was mainly composed of *C. schmidtii*, and accompanied by sparse populations of *D. pyramidalis,* *F. palmata*, *Equisetum sylvaticum* L*.*, *D. purpurea*, *V. uliginosum*, *Saussurea neoserrata*, *V. vitis-idaea* Linn, *P. asarifolia* subsp*. incarnata*, *R. davurica*, and *S. officinalis*.

LBV12 **(***Ass. V. vitis-idaea, B. fruticosa,* and *L. gmelinii*) was located in plains, valleys, low-lying areas, and slope feet, at an elevation of 200–1000 m. The tree layer was mainly composed of *L. gmelinii*. The shrub layer was mainly composed of *B. fruticosa*, and accompanied by sparse populations of *L. palustre*, *D. pyramidalis*, *R. davurica*, *V. uliginosum*, and *Chamerion angustifolium*. The grass layer was mainly composed of *V. vitis-idaea* Linn., accompanied by sparse populations of *Ribes mandshuricum* and *Maianthemum trifolium*.

LBV13 (*Ass. V. vitis-idaea, B. middendorfii,* and *L. gmelinii*) was located on flat, middle, or lower slopes at an elevation of 800–1000 m. The main forest layer was dominated by *L. gmelinii*. The first shrub layer was dominated by *B. middendorfii* and occasionally by *B. fruticosa*. The second shrub layer was dominated by *L. palustre* and occasionally by *R. davurica*, *C. angustifolium*, *L. gmelinii*, *Carex karoi,* and *D. pyramidalis*. The herb layer was dominated by *V. vitis-idaea* Linn., and the moss layer was not well-developed.

**2.2.2 Environmental data**

The WorldClim database (<http://worldclim.org>) can describe the climatic conditions by specifying annual and seasonal changes in temperature and precipitation. We used the “WorldClim 2” dataset at a spatial resolution of 30 arcs, commonly referred to as “1-km” spatial resolution (Fick and Hijmans, 2017). We then separated the future period into two parts: 2050 and 2070. Four scenarios (RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5) described the change curves of different greenhouse gas concentrations in response to different increases in radiative forcing (IPCC, 2013). In terms of global warming, RCP 8.5 showed the most pessimistic condition, RCP 2.6 showed the most optimistic condition, whereas RCP 4.5 showed moderate conditions. Based on previous research (Dyderski et al., 2018; Yu et al., 2019; Tapiador et al., 2019), we selected three climate change scenarios (RCP 2.6, RCP 4.5, and RCP 8.5) for prediction and analysis using Maxent. Soil data were obtained from the World Soil Database at a spatial resolution of 1 km (Science Data Center for Cold and Dry Areas, Chinese Academy of Sciences, Lanzhou, China; <http://westdc.westgis.ac.cn/>). Topographic data were obtained at an altitudinal spatial resolution of 90 m (Resource and Environmental Science Data Center, Chinese Academy of Sciences, Beijing, China; <http://www.resdc.cn/>).

To increase the accuracy of the model results, selected environmental variables were subjected to multiple collinearity tests. First, we submitted the climate and soil variables into the Maxent model as input data for initial operation and calculated the contribution values of 19 climate variables and 32 soil variables. Subsequently, we extracted the charge values of environmental factors by the “'Extract Multi Values to Points” tool in ArcGIS10.2.2 software (https://www.esri.com/) and conducted Pearson’s correlation analysis. Based on the environmental contribution rate in the initial model, if the correlation coefficient of the two variables was greater than 0.8, the environmental variable with a large contribution rate was selected, the actual distribution of species was determined, and relevant research results were examined (Yang et al., 2014). The factors with ecological significance were saved by referring to the relevant research results. Finally, ten climatic variables, three topographic factors, and seven soil factors were selected **(Appendix Tables 1 and 2; Table 2)**. Environmental variables have been proven to affect the distribution and physiology of plant species across different spatial extents (from local to global scales) and are widely used to project the distributions of plant species.

**Table 2 Contribution rate of major environmental factors**

|  |  |  |  |
| --- | --- | --- | --- |
| Variables | Description | Unit | Category |
| bio01 | Annual Mean Temperature | ℃ | Temperature |
| bio03 | Isothermality（bio2/bio7）（\*100） | ℃ |
| bio04 | Temperature Seasonality (Standard deviation\*100) | ℃ |
| bio06 | Min. Temperature of Coldest Month | ℃ |
| bio07 | Temperature Annual Range（bio5-bio6） | ℃ |
| bio09 | Mean Temperature of Driest Quarter | ℃ |
| bio12 | Annual Precipitation | mm | Precipitation |
| bio13 | Precipitation of Wettest Month | mm |
| bio15 | Precipitation Seasonality (Coefficient of variation:  mean/SD\*100) | % |
| bio17 | Precipitation of Driest Quarter | mm |
| cate1 | SU\_SYM90(Soil name in FAO90 soil classification system) | - | Soil type |
| cate4 | T\_USDA\_TEX: Real (USDA soil texture classification) | - |
| cate5 | S\_USDA\_TEX: Real (USDA soil texture classification) | - |
| cate6 | SWR (soil moisture content) | % |
| cont16 | T\_CACO3: Real (Surface carbonate or lime content) | % | Soil physical and chemical properties |
| cont30 | S\_BS: Real (Basic saturation of bottom layer) | % |
| cont32 | S\_CACO3: Real (Bottom carbonate or lime content) | % |
| dem | altitude | m | Terrain |
| slope | slope | ° |
| aspect | slope aspect | - |

**2.2.3 Model analysis**

Species distribution models (SDMs) provide comprehensive distribution statements of future possible occurrences by connecting the existence of species with condition predictors (Despland and Houle, 1997; Zhao et al., 2020; Zhong et al., 2021). Maxent shows higher performance and accuracy than other SDM tools (Carnaval and Moritz, 2008). Moreover, it has good prediction ability for small sample datasets (Elith et al., 2011; Pearson et al., 2006; Phillips et al., 2006). It also identifies areas where sensitive species currently exist or may exist (Li et al., 2020; Qin et al., 2017). The Maxent model indirectly describes how ecological processes shape ecological communities in the form of constraints (Bertram et al., 2019), and simulates the sample and environmental data of vegetation on a local and regional scale (Merow et al., 2013; Radosavljevic and Anderson, 2014; Phillips et al., 2017; Comino et al., 2021).

Considering the association as a species, we used the Maxent model to quantitatively prove its association with environmental factors and explore the response of association distribution to climate change. We randomly selected 75% of the distribution data as the training set to establish a prediction model, and the remaining 25% were used as the test set for model validation (Zhang et al., 2016). The maximum number of iterations was 1000, and the number of model repetitions was four (Salako et al., 2019). Jackknife analysis using Maxent was performed to determine the weight of each variable (Zhang et al., 2016). The receiver operating characteristic curve analysis method was used to verify the accuracy of the Maxent model prediction results (Hanley and McNeil, 1982). In this method, the prediction accuracy of the model is determined by calculating the area under the curve (AUC) value (Swets, 1988). Generally, when the AUC value is greater than 0.9, the prediction accuracy is high, and the prediction results can be used. We selected the minimum existence threshold to distinguish between suitable and unsuitable regions of species and to visualize the model results (Pearson et al., 2006) (**Fig. 2)**. To further quantitatively analyze the changes in the spatial pattern of the *L. gmelinii* alliance and associations, we defined four types of conditions: suitable areas increased, unsuitable areas unchanged, suitable areas unchanged, and suitable areas decreased. The SDM toolbox (Brown, 2014) (<http://www.sdmtoolbox.org/downloads>) was used to determine the spatial pattern change ofthe *L. gmelinii* alliance and associations under different future climate scenarios (**Fig. 3)**.

**2.2.4** **Multinomial logistic regression analysis**

The dependent variable consisted of disordered multi-classification data, which were suitable for the multinomial logistic regression model (Kwak and Clayton-Matthews, 2002; Fagerland et al., 2008; Friedman et al., 2010).

where β0 is a constant, I = 1, 2, …, k; j = 1, 2, …, J − 1, and Xi is an explanatory variable

We randomly selected 800 pixels in the study area, and the distribution changes and climatic factors of the associations were extracted as modeling data. Considering the change in distribution in pixels as the dependent variable *J*, range expansion (suitable areas increased) was considered as -1, no occupancy (unsuitable areas unchanged) as 0, no change (suitable areas unchanged) as 1, and range contraction (suitable areas decreased) as 2 (**Fig. 3)**. The amplitude of the main climatic factors’ output determined by the Maxent model was considered as the independent variable *Xi*. The climatic factors that dominated the change in *L. gmelinii* association distribution were analyzed using a multinomial logistic regression model **(Table 3; Appendix Table 3)**, which was more conducive to an in-depth analysis of the relationship between changes in suitable areas and climatic factors.

**3. Results**

**3.1 Current potential geographical distribution of *Larix gmelinii* alliance and associations**

The prediction accuracy was tested, and the mean AUC value of the test dataset was greater than 0.9, which showed that the simulation accuracy of the potentially suitable area using Maxent was high, and the prediction results were reliable. The distribution of *L. gmelinii* forests and associations based on Maxent were visualized **(Fig. 2)**. The distribution area of LH5 was the largest, followed by that of LRC1, while that of LBV13 was the smallest.



**Fig. 2.** Current potential geographical distribution of *Larix gmelinii* alliance and associations. The blue area represents the unsuitable area and the yellow area represents the suitable area.

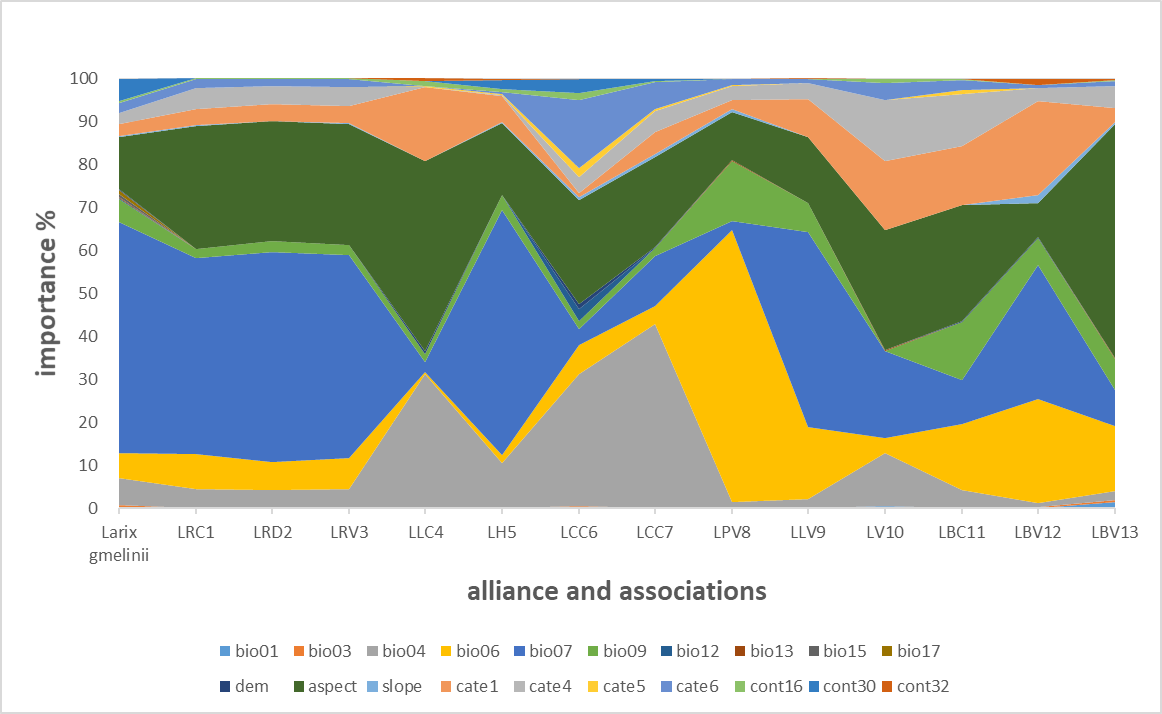
**3.2 Future potential geographical distribution of *Larix gmelinii* alliance and associations**

The suitable areas for the *L. gmelinii* alliance and associations under future climate conditions were predicted **(Fig. 3)**. Generally, under the three future climate scenarios, the boundary of the suitable area of *L. gmelinii* forests will migrate by different degrees by 2050 and 2070. It is predicted that the southern boundary will move northward, the eastern boundary will move slightly westward, the western and northern boundaries will not change significantly, and the centroid will move northwestward. The main change in the distribution area was the decrease in the suitable area with a loss rate of 15.06–38.87%. These results corroborated that the suitable areas of *L. gmelinii* associations in the future distribution will also decrease. LRC1 and LRV3 will move north under future climatic conditions. Moreover, the main distribution in the scattered areas of LRD2 and LLC4 will decrease further. In the high-emission scenario, the habitat loss rate of LCC6 will be more than 50%, but this type will occupy a new habitat northward. Although LH5 experienced some habitat loss, the impact of future climate change was relatively small. The habitat loss of LCC7 and LPV8 at high altitudes was the most serious in different scenarios. Under various climate scenarios, the habitat loss of cold and wet LLV9 was extremely serious (average > 90%). The loss rate of LV10, with better light transmittance, will be more than 50% in the 2070s. Although the suitable area of LBC11, which was mainly distributed in permafrost wetlands, was reduced in some areas, there was an increase in the new suitable area. LBV12 had slightly low water content and humidity conditions, which supported the habitat of *V. uliginosum*. The habitat loss rate of LBV12 under different scenarios will be more than 50%, which requires immediate attention. LBV13, which was located in the flatwater accumulation position of large slope land, was more likely to lose water due to high temperatures and drought. Under the different scenarios, the habitat loss rate was close to 100%.

**Fig. 3.** Future (2050 and 2070) potential geographical distribution of *Larix gmelinii* alliance and associations based on the climate scenarios RCP 2.6, RCP 4.5, and RCP 8.5.

**3.3 Importance of environmental factors in *Larix gmelinii* alliance and associations**

The output results of the three climate scenario models for the two periods were comprehensively analyzed, and the contribution rates of each environmental factor involved in the modeling were statistically analyzed according to the jackknife method provided by the model. The statistical results for the contribution rates are shown in **Fig. 4**. The results showed that among the environmental factors assessed in the modeling, bio07 had the highest contribution rate (53.76%), indicating that the average annual temperature difference was the most important environmental factor affecting the distribution of *L. gmelinii* forests. Simultaneously, the contribution rate of slope aspect was more than 10%, while that of bio06, bio04, and bio09 was 5.79%, 6.37%, and 5.41%, respectively. These five environmental factors contributed 83.36% to the distribution of *L. gmelinii* forests. The environmental factors were divided into four categories: temperature, precipitation, topography, and soil. The main factors affecting the distribution of associations LRC1, LRD2, LRV3, LH5, LCC7, LPV8, and LLV9 were in the order: temperature, terrain, soil, and precipitation. The dominant factors affecting the distribution of associations LCC6, LV10, LBC11, and LBV12 were in the order: temperature, soil, terrain, and precipitation. The dominant factors affecting the distribution of the associations LLC4 and LBV13 were in the order: terrain, temperature, soil, and precipitation.



**Fig. 4.** Importance of environmental factors in *Larix gmelinii* alliance and associations. The colors represent the percentage change from bio01 to cont32. Bio07 had the highest contribution rate affecting the distribution of *L. gmelinii* forests (53.76%), LRC1 (45.72%), LRD2 (48.98%), LRV3 (47.35%), LH5 (56.95%), LLV9 (45.22%), and LBV12 (31.25%). Slope aspect had the highest contribution rate affecting the distribution of LLC4 (44.25%), LV10 (27.95%), LBC11 (27.02%), and LBV13 (54.53%). Bio04 had the highest contribution rate affecting the distribution of LCC6 (30.82%) and LCC7 (42.87%). Bio06 had the highest contribution rate affecting the distribution of LPV8 (63.30%). Bio01: Annual Mean Temperature; bio03: Isothermality; bio04: Temperature Seasonality; bio06: Minimum Temperature of the Coldest Month; bio07: Temperature Annual Range; bio09: Mean Temperature of the Driest Quarter; bio12: Annual Precipitation; bio13: Precipitation of the Wettest Month; bio15: Precipitation Seasonality; bio17: Precipitation of the Driest Quarter; dem: Altitude; cate1: SU\_SYM90 (Soil name in FAO90 soil classification system); cate4: T\_USDA\_TEX: Real (USDA soil texture classification); cate5: S\_USDA\_TEX: Real (USDA soil texture classification); cate6: SWR (soil moisture content); cont16:T\_CACO3: Real (Surface carbonate or lime content); cont30: S\_BS: Real (Basic saturation of bottom layer); cont32: S\_CACO3: Real (Bottom carbonate or lime content).

**3.4 Response of the spatial distribution of *Larix gmelinii* alliance and associations to climate change**

In this study, we used the unchanged suitable area as a reference and aimed to analyze the extent of reduction in the suitable area. A multinomial logistic regression model was used to determine the climatic factors that have an impact on *L. gmelinii* forests and their spatial change associations. As the expansion of suitable areas was small, the spatial distribution pattern of the suitable area reduction of *L. gmelinii* forests and its associations was analyzed. Considering the suitable area unchanged as the reference group, the results of the model operation were statistically significant. The distribution pattern of suitable area reduction of the *L. gmelinii* alliance and associations under different climate scenarios was screened using various factors of the visibility test. The corresponding results are shown in **Table 3 and Appendix Table 3**.

The response of the spatial distribution of the *L. gmelinii* alliance to climate change was analyzed as follows: In the RCP2.6 scenario, by 2050, the change in bio07 would have the greatest impact on the reduction of the suitable area. For each unit increase in bio07, the probability of the reduction of the suitable area would decrease by 0.382 times. By 2070, the change in bio17 had would have the greatest impact on the decrease in the suitable area of larch, and the probability of shrinkage of the suitable area will increase by 0.189 times for every unit decrease in bio17. Under the RCP 4.5 scenario, the change in bio15 would have the greatest impact on the reduction of the suitable area by 2050. For every unit reduction of bio15, the probability of reduction of the suitable area would increase by 0.307 times. By 2070, the change in bio04 would have the greatest influence on the decrease in the suitable area, and the probability of the decrease in the suitable area will increase 0.948 times for every unit decrease in bio04. Under the RCP 8.5 scenario, by 2050, the change in bio06 would have the greatest impact on the reduction of the suitable area, and for every unit reduction in bio06, the probability of the reduction of the suitable area would increase by 0.155 times. By 2070, the change in bio13 will have the greatest impact on the reduction of the suitable area. For every unit reduction in bio13, the probability of suitable area reduction would increase by 0.795 times.

**Table 3 Response of spatial distribution of** ***Larix gmelinii* alliance to climate change**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Climate Change Scenario | Variables | B | Std. Error | Sig. | Exp(B) |
| RCP2.6-2050 | bio07 | -0.962 | 0.363 | 0.008 | 0.382 |
| RCP2.6-2070 | bio04 | 0.044 | 0.015 | 0.004 | 1.045 |
|  | bio12 | 0.179 | 0.073 | 0.014 | 1.196 |
| bio17 | -1.667 | 0.676 | 0.014 | 0.189 |
| RCP4.5-2050 | bio12 | 0.203 | 0.083 | 0.015 | 1.225 |
| bio15 | -1.181 | 0.477 | 0.013 | 0.307 |
| RCP4.5-2070 | bio04 | -0.053 | 0.013 | 0 | 0.948 |
| RCP8.5-2050 | bio01 | -0.89 | 0.349 | 0.011 | 0.41 |
| bio04 | -0.025 | 0.007 | 0 | 0.976 |
| bio06 | -1.867 | 0.407 | 0 | 0.155 |
| bio07 | -1.476 | 0.313 | 0 | 0.229 |
| bio13 | -0.17 | 0.059 | 0.004 | 0.844 |
| RCP8.5-2070 | bio09 | -0.034 | 0.015 | 0.027 | 0.967 |
| bio13 | -0.229 | 0.082 | 0.005 | 0.795 |

For most associations, annual mean temperature (bio01), temperature seasonality (bio04), minimum temperature in the coldest month (bio06), annual temperature range (bio07), and mean temperature in the driest quarter (bio09) could impact the expansion or contraction of the suitable area. In other words, temperature could significantly affect the shrinkage of suitable areas. For example, in future climate scenarios, changes in bio06 and bio09 would cause the greatest impact on the reduction of the suitable area distribution of LLC4. Under the future climate scenario, changes in bio06, bio07, and bio01 would have the greatest impact on the shrinkage of the suitable area for LLV9. In some associations (LCC6, LPV8, LBC11, and LBV13), precipitation also would play an important role in the reduction of suitable areas. The changes in the climate factors would affect the distribution of LCC6 under future climate scenarios. Under the RCP 2.6 scenario, by 2070, bio15 would have the greatest impact on the reduction in the suitable area, and the correlation was negative. Under the RCP4.5 scenario, by 2050, bio01 and bio15 would have the greatest impact on the reduction of the suitable area, and the correlation was negative. In future climate scenarios, the loss rate of suitable areas for LPV8 will be relatively high. As LPV8 requires low-temperature habitats, the increase in temperature may impact the suitable areas for LPV8. For LBC11, in the future climate scenario, changing precipitation factors, such as bio12, would have a greater impact on the reduction or expansion of suitable areas. Under future climate scenarios, most suitable areas for LBV13 would disappear, and only a few suitable areas would remain; therefore, changes in the climate factors will have a severe impact on its distribution.

**4. Discussion**

The associations in our study were divided into four categories based on the type of vegetation: mesogenic drought, mesogenic, mesogenic wet, and wet associations. For example, *R. davuricum* is suitable for survival in the upper part of a dry, sunny slope, *L. palustre* grows in a humid place, and *B. fruticosa* tends to survive in swamp forests. Shrub species, such as *L. bicolor*, dominated the shrub layer in areas with a high human disturbance at the edge of the forest. When the lower part of the slope and the soil layer were thick, the shrubs were often unstratified owing to the high canopy density of the arbor layer, and the richness of the herbaceous plants was extremely high, resulting in the formation of *Ass. Herbage* and *L. gmelinii*. If the soil layer was thin and few tall shrubs existed, *Ass. V. vitis-idaea* and *L. gmelinii* formed. The changes in the different association types were inconsistent. In our study, we found that the temperature and terrain type were the most important factors influencing *L. gmelinii*, followed by the soil type. Soil type considerably influences the distribution of LV10, which is related to the growth of such associations in brown taiga soils (Zhou, 1991).

Our study revealed that temperature was the most important factor affecting the distribution of *L. gmelinii* forests and most of its associations, and *L. gmelinii* forests are mainly distributed in the northern part of the Greater Khingan Range and in the Lesser Khingan Range. These findings were consistent with the findings of previous studies (Li et al., 2006; Yang et al., 2014). However, future predictions are based on the relationship between the distribution of species and the environment, and because of different models, environmental factors, and future climate scenarios, the prediction results of our study differed from those of previous studies (Chen, 2001; Li et al., 2006; Mu et al., 2021; Yang et al., 2014). For example, Li et al. (2006) studied the response of the spatial distribution of *L. gmelinii* to climate change from a statistical perspective by considering environmental variables, such as temperature, humidity, and precipitation, as factors, while in the present study, we classified different associations by humidity and then selected temperature and precipitation as factors. Furthermore, Yang et al. (2014) demonstrated that temperature is the decisive factor for the potential distribution of *L. gmelinii* forests and that water conditions have a marginal limiting effect. However, terrain has a greater impact than temperature on the distribution of some species. For example, Mu et al. (2021) reported that the order of importance of environmental factors is terrain, climate, soil, and elevation, which are the main factors affecting the distribution of *Larix principis*-*rupprechtii* plantations. In our research, terrain had a greater influence on the association (LLC4 and LBV13) distribution than temperature. We also found that precipitation had a large effect on some *L. gmelinii* associations (LCC6, LPV8, LBC11, and LBV13) under future climate scenarios.

We analyzed the response of the *L. gmelinii* alliance and associations of suitable area reduction to climate change under different climate scenarios. Increasing temperature, precipitation increase, and precipitation seasonal dispersion are the main causes for the reduction in the suitable area for *Larix gmelinii* alliance. Moreover, increasing temperature, decreasing annual temperature difference, gradual increase in the cold season, and rising temperature in spring are the main driving forces that affect *L. gmelinii* associations. In terms of clump physiology, *L. gmelinii* has a strong drought resistance ability and can grow under mild drought conditions (Sugimoto et al., 2002). Under climate warming, the distribution of plant species tends to shift to habitats at high latitudes or altitudes (He et al., 2019). In the future, suitable areas for each association are expected to shrink by varying degrees. Using a logistic regression model, Leng et al. (2006) predicted that *L. gmelinii* would retreat 200 km northward by 2050 and 300 km northward by 2100. LCC6 and LBC11 showed an obvious northward shift trend under future climate change simulations, which was in agreement with the results of previous studies (Chen, 2000; He et al., 2019; Yang et al., 2014). Although the expansion of the area is relatively small, associations shift during the transition of the area and thus, require attention. Under such circumstances, it is recommended to reduce human disturbance. Alternatively, the sensitivity of some species to climate change may be overlooked when the range of observations is limited to *L. gmelinii*. When the general living conditions support multiple species with similar functions, or some species contribute relatively less to the characteristics of the general living conditions, or when the characteristics are controlled mainly by the abiotic environment, the characteristics of the ecosystem will be insensitive to species loss (Hooper et al., 2005).

For different *L. gmelinii* associations, different management measures are required for each association because of different habitat conditions, composition structure, growth, development, and renewal succession trends (Estrada Valdés et al., 2021; González de Andrés et al., 2018; Jia et al., 2016). Areas with good site conditions should be selected for performing thinning, and the forest spatial structure should be adjusted and optimized through thinning (Zhang et al., 2018). As far as possible, continuous conditions should be artificially created for climate-sensitive association types, such as creating wet and moist conditions for LBV13. Previous studies have demonstrated the effects of fixed conditions on plants and animal communities, such as long-term absence of rain (Vicente-Serrano et al., 2020). Furthermore, the recovery of forests after a fire is generally due to undamaged or slightly damaged trees (Oreshkova et al., 2013). Therefore, it is necessary to increase the number of LPV8 samples that face the most serious fire loss (Chen et al., 2015; Makoto et al., 2011). LPV8 is also critical as an important net resource for maintaining the economic development of the community. In terms of environmental data selection, our study considered climate factors as dynamic variables and terrain and soil factors as static variables. However, terrain and soil factors will also change in future climate scenarios (Richter and Markewitz, 2003). Moreover, subsequent research should consider data on biological factors to obtain more accurate prediction results.

**5. Conclusions**

Temperature is the most important factor affecting the distribution of *L. gmelinii* forests and their associations under different climate scenarios. Regardless of the climate scenario, different association types showed a decrease in suitable areas. The decline in the suitable areas was particularly evident in the case of habitat loss of *Ass. V. vitis-idaea, P. pumila,* and *L. gmelinii* at high altitudes, and *Ass. V. vitis-idaea, B. middendorfii,* and *L. gmelinii*in special terrain under different climate scenarios. In the case of habitat loss, associations, such as *Ass. C. lanceolata, C. mandshurica,* and *L. gmelinii*, and *Ass. C. schmidtii, B. fruticosa,* and *L. gmelinii* can occupy new habitats. The main cause for the retreat of *L. gmelinii* forests northwestward was the exit of *Ass. D. pyramidalis, R. davuricum,* and *L. gmelinii*; *Ass. V. vitis-idaea, P. pumila,* and *L. gmelinii*; *Ass. V. vitis-idaea, L. palustre,* and *L. gmelinii*; and *Ass. V. vitis-idaea, B. middendorfii,* and *L. gmelinii* from their original habitats. Future studies will consider both different species and focus on conserving *L. gmelinii* after relocation and its associated economic species to sustain different forest ecosystems and their associations under the backdrop of global climate warming.

**Data Accessibility Statement**

All datasets utilized in this study are available in the tables present in the main text and appendix.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

**Author Contributions**

Jing-hua Yu: Conceptualization (lead); Funding Acquisition (lead); Project administration (lead); Supervision (lead); Investigation (equal); Writing–review & editing (equal). Chen Chen: writing–original draft (lead); Formal analysis (supporting); Visualization (lead); Writing–review & editing (equal). Xi-juan Zhang: writing–original draft (supporting); Formal analysis (lead); Writing–review & editing (equal). Ji-zhong Wan: Supervision (supporting); Writing–review & editing (equal). Fei-fei Gao: Formal analysis (supporting); Writing–review & editing (equal). Shu-sheng Yuan: Investigation (equal); Writing–review & editing (equal). Tian-tian Sun: Writing–review & editing (equal). Zhen-dong Ni: Data curation (supporting).

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**Appendix Table 1 Bioclimatic correlation matrix**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | bio01 | bio02 | bio03 | bio04 | bio05 | bio06 | bio07 | bio08 | bio09 | bio10 | bio11 | bio12 | bio13 | bio14 | bio15 | bio16 | bio17 | bio18 | bio19 |
| bio01 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio02 | -.899 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio03 | -.836 | .961 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio04 | -.408 | .237 | 0.038 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio05 | .912 | -.833 | -.849 | -0.021 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio06 | .985 | -.920 | -.836 | -.455 | .873 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| bio07 | -.805 | .771 | .608 | .777 | -.520 | -.870 | 1 |  |  |  |  |  |  |  |  |  |  |  |  |
| bio08 | .965 | -.905 | -.892 | -.158 | .982 | .939 | -.653 | 1 |  |  |  |  |  |  |  |  |  |  |  |
| bio09 | .909 | -.804 | -.726 | -.489 | .786 | .904 | -.790 | .844 | 1 |  |  |  |  |  |  |  |  |  |  |
| bio10 | .965 | -.905 | -.892 | -.158 | .982 | .939 | -.653 | 1.000 | .844 | 1 |  |  |  |  |  |  |  |  |  |
| bio11 | .976 | -.844 | -.742 | -.591 | .814 | .977 | -.890 | .889 | .918 | .889 | 1 |  |  |  |  |  |  |  |  |
| bio12 | .580 | -.596 | -.490 | -.667 | .291 | .573 | -.710 | .428 | .602 | .428 | .655 | 1 |  |  |  |  |  |  |  |
| bio13 | .358 | -.299 | -.136 | -.854 | -0.014 | .378 | -.676 | .139 | .426 | .139 | .506 | .878 | 1 |  |  |  |  |  |  |
| bio14 | .344 | -.351 | -.306 | -.485 | .134 | .313 | -.412 | .222 | .443 | .222 | .408 | .833 | .678 | 1 |  |  |  |  |  |
| bio15 | -.476 | .686 | .771 | -.295 | -.603 | -.451 | .181 | -.597 | -.421 | -.597 | -.352 | -.399 | 0.024 | -.414 | 1 |  |  |  |  |
| bio16 | .478 | -.451 | -.317 | -.788 | .134 | .480 | -.706 | .284 | .515 | .284 | .593 | .972 | .951 | .791 | -.182 | 1 |  |  |  |
| bio17 | .367 | -.446 | -.438 | -.315 | .217 | .327 | -.353 | .293 | .463 | .293 | .385 | .807 | .559 | .922 | -.592 | .717 | 1 |  |  |
| bio18 | .478 | -.451 | -.317 | -.788 | .134 | .480 | -.706 | .284 | .515 | .284 | .593 | .972 | .951 | .791 | -.182 | 1.000 | .717 | 1 |  |
| bio19 | .367 | -.446 | -.438 | -.315 | .217 | .327 | -.353 | .293 | .463 | .293 | .385 | .807 | .559 | .922 | -.592 | .717 | 1.000 | .717 | 1 |

**Appendix Table 2 Correlation matrix of soil factors**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | cate1 | cate2 | cate4 | cate5 | cate6 | cont2 | cont4 | cont5 | cont6 | cont7 | cont8 | cont9 | cont10 | cont11 | cont12 | cont13 | cont14 | cont15 | cont16 | cont18 | cont20 | cont21 | cont22 | cont23 | cont24 | cont25 | cont26 | cont27 | cont28 | cont29 | cont30 | cont31 | cont32 | cont33 |
| cate1 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cate2 | -0.24 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cate4 | -0.03 | -0.74 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cate5 | 0.22 | -0.99 | 0.73 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cate6 | 0.33 | -0.52 | -0.01 | 0.49 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont2 | -0.24 | 1.00 | -0.74 | -0.99 | -0.52 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont4 | 0.37 | -0.43 | -0.04 | 0.45 | 0.86 | -0.43 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont5 | 0.27 | -0.94 | 0.75 | 0.96 | 0.41 | -0.94 | 0.37 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont6 | 0.07 | -0.40 | 0.26 | 0.40 | 0.30 | -0.40 | 0.17 | 0.24 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont7 | -0.10 | 0.81 | -0.79 | -0.86 | -0.31 | 0.81 | -0.42 | -0.84 | -0.26 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont8 | -0.66 | 0.79 | -0.45 | -0.80 | -0.59 | 0.79 | -0.61 | -0.77 | -0.21 | 0.73 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont9 | 0.65 | -0.20 | 0.14 | 0.18 | -0.18 | -0.20 | -0.20 | 0.18 | 0.30 | -0.04 | -0.40 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont10 | -0.17 | 0.21 | -0.58 | -0.23 | 0.55 | 0.21 | 0.52 | -0.37 | 0.23 | 0.37 | 0.22 | -0.37 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont11 | 0.57 | 0.35 | -0.39 | -0.35 | 0.18 | 0.35 | 0.13 | -0.23 | 0.09 | 0.36 | 0.05 | 0.14 | 0.15 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont12 | -0.46 | 0.23 | -0.30 | -0.24 | -0.07 | 0.23 | -0.08 | -0.42 | 0.59 | 0.35 | 0.50 | -0.09 | 0.61 | -0.13 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont13 | -0.47 | 0.56 | -0.55 | -0.55 | -0.19 | 0.56 | -0.06 | -0.74 | 0.12 | 0.46 | 0.54 | -0.17 | 0.60 | -0.23 | 0.75 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont14 | 0.13 | -0.16 | 0.30 | 0.19 | -0.13 | -0.16 | 0.09 | 0.35 | -0.72 | -0.40 | -0.31 | -0.22 | -0.59 | -0.18 | -0.82 | -0.54 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont15 | -0.10 | 0.15 | -0.45 | -0.14 | 0.53 | 0.15 | 0.56 | -0.29 | 0.49 | 0.21 | 0.15 | -0.31 | 0.91 | 0.28 | 0.69 | 0.56 | -0.64 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont16 | 0.01 | -0.01 | 0.39 | -0.07 | 0.00 | -0.01 | -0.03 | -0.12 | -0.03 | -0.06 | -0.02 | -0.08 | -0.11 | -0.05 | -0.15 | -0.02 | 0.09 | -0.10 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont18 | -0.84 | 0.21 | -0.06 | -0.19 | -0.30 | 0.21 | -0.15 | -0.35 | -0.04 | 0.04 | 0.48 | -0.48 | 0.26 | -0.73 | 0.55 | 0.73 | -0.12 | 0.20 | 0.05 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont20 | 0.14 | -0.80 | 0.50 | 0.80 | 0.68 | -0.80 | 0.42 | 0.79 | 0.53 | -0.57 | -0.55 | -0.02 | 0.05 | 0.04 | -0.09 | -0.57 | -0.12 | 0.14 | -0.15 | -0.37 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| cont21 | 0.18 | 0.30 | -0.55 | -0.30 | 0.50 | 0.30 | 0.53 | -0.33 | 0.24 | 0.36 | 0.17 | -0.33 | 0.76 | 0.68 | 0.36 | 0.24 | -0.39 | 0.85 | -0.06 | -0.19 | 0.08 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |  |
| cont22 | -0.54 | 0.36 | -0.58 | -0.38 | 0.05 | 0.36 | 0.00 | -0.56 | 0.13 | 0.55 | 0.55 | -0.41 | 0.72 | -0.25 | 0.77 | 0.77 | -0.54 | 0.60 | -0.16 | 0.64 | -0.23 | 0.36 | 1.00 |  |  |  |  |  |  |  |  |  |  |  |
| cont23 | 0.62 | 0.48 | -0.55 | -0.49 | 0.05 | 0.48 | 0.11 | -0.40 | -0.03 | 0.54 | 0.12 | 0.28 | 0.23 | 0.90 | -0.01 | -0.02 | -0.20 | 0.30 | -0.05 | -0.61 | -0.25 | 0.66 | -0.11 | 1.00 |  |  |  |  |  |  |  |  |  |  |
| cont24 | 0.00 | 0.85 | -0.86 | -0.85 | -0.17 | 0.85 | -0.07 | -0.91 | -0.20 | 0.74 | 0.49 | -0.02 | 0.48 | 0.33 | 0.33 | 0.74 | -0.34 | 0.41 | -0.01 | 0.20 | -0.74 | 0.43 | 0.48 | 0.52 | 1.00 |  |  |  |  |  |  |  |  |  |
| cont25 | 0.39 | 0.43 | -0.52 | -0.46 | 0.06 | 0.43 | 0.02 | -0.47 | 0.33 | 0.60 | 0.26 | 0.38 | 0.47 | 0.71 | 0.43 | 0.28 | -0.67 | 0.53 | -0.05 | -0.37 | -0.16 | 0.65 | 0.17 | 0.84 | 0.55 | 1.00 |  |  |  |  |  |  |  |  |
| cont26 | -0.36 | 0.23 | -0.33 | -0.21 | 0.37 | 0.23 | 0.36 | -0.29 | 0.41 | 0.20 | 0.39 | -0.55 | 0.78 | 0.31 | 0.64 | 0.43 | -0.55 | 0.89 | -0.09 | 0.24 | 0.20 | 0.81 | 0.52 | 0.21 | 0.26 | 0.41 | 1.00 |  |  |  |  |  |  |  |
| cont27 | -0.32 | 0.22 | -0.55 | -0.23 | 0.38 | 0.22 | 0.33 | -0.42 | 0.37 | 0.40 | 0.33 | -0.43 | 0.87 | 0.04 | 0.77 | 0.65 | -0.63 | 0.86 | -0.13 | 0.42 | 0.03 | 0.67 | 0.89 | 0.08 | 0.43 | 0.33 | 0.76 | 1.00 |  |  |  |  |  |  |
| cont28 | -0.78 | 0.41 | -0.19 | -0.38 | -0.50 | 0.41 | -0.43 | -0.50 | 0.01 | 0.23 | 0.60 | -0.18 | 0.19 | -0.59 | 0.60 | 0.80 | -0.33 | 0.12 | -0.11 | 0.88 | -0.48 | -0.27 | 0.57 | -0.45 | 0.37 | -0.13 | 0.16 | 0.29 | 1.00 |  |  |  |  |  |
| cont29 | -0.78 | 0.46 | -0.29 | -0.43 | -0.46 | 0.46 | -0.44 | -0.56 | -0.01 | 0.32 | 0.64 | -0.22 | 0.25 | -0.55 | 0.62 | 0.82 | -0.37 | 0.15 | -0.14 | 0.87 | -0.48 | -0.22 | 0.65 | -0.42 | 0.43 | -0.10 | 0.19 | 0.37 | 0.99 | 1.00 |  |  |  |  |
| cont30 | 0.41 | 0.04 | 0.07 | 0.01 | -0.09 | 0.04 | 0.24 | 0.15 | -0.54 | -0.25 | -0.29 | -0.12 | -0.44 | 0.23 | -0.69 | -0.44 | 0.85 | -0.35 | 0.11 | -0.30 | -0.24 | 0.00 | -0.52 | 0.24 | -0.07 | -0.29 | -0.34 | -0.45 | -0.49 | -0.53 | 1.00 |  |  |  |
| cont31 | -0.12 | 0.18 | -0.51 | -0.20 | 0.50 | 0.18 | 0.47 | -0.35 | 0.43 | 0.37 | 0.24 | -0.26 | 0.96 | 0.24 | 0.73 | 0.58 | -0.71 | 0.96 | -0.08 | 0.20 | 0.11 | 0.81 | 0.70 | 0.31 | 0.43 | 0.60 | 0.84 | 0.89 | 0.14 | 0.19 | -0.49 | 1.00 |  |  |
| cont32 | -0.51 | -0.21 | -0.06 | 0.22 | 0.41 | -0.21 | 0.52 | 0.04 | 0.12 | -0.21 | -0.01 | -0.56 | 0.62 | -0.58 | 0.45 | 0.51 | -0.12 | 0.55 | -0.04 | 0.72 | 0.12 | 0.18 | 0.63 | -0.52 | 0.01 | -0.32 | 0.46 | 0.64 | 0.43 | 0.43 | -0.24 | 0.53 | 1.00 |  |
| cont34 | 0.05 | 0.65 | -0.51 | -0.63 | -0.40 | 0.65 | -0.10 | -0.72 | -0.21 | 0.40 | 0.29 | 0.16 | 0.15 | 0.01 | 0.24 | 0.71 | -0.09 | 0.16 | 0.15 | 0.36 | -0.88 | 0.09 | 0.26 | 0.30 | 0.82 | 0.30 | -0.06 | 0.15 | 0.46 | 0.45 | 0.17 | 0.12 | 0.05 | 1.00 |

**Appendix Table 3 Response of Associations to climate change**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Number and Association | Climate Change Scenario | Variables | B | Std. Error | Sig. | Exp(B) |
| *1 Ass. Carex callitrichos, Rhododendron davuricum, Larix gmelinii* | RCP2.6-2050 | bio04 | 0.017 | 0.008 | 0.028 | 1.017 |
| bio06 | -1.394 | 0.565 | 0.014 | 0.248 |
| bio07 | -1.732 | 0.42 | 0 | 0.177 |
| bio09 | 0.031 | 0.009 | 0.001 | 1.032 |
| RCP2.6-2070 | bio06 | -1.682 | 0.549 | 0.002 | 0.186 |
| RCP4.5-2050 | bio06 | -0.326 | 0.138 | 0.018 | 0.722 |
| bio07 | -0.511 | 0.209 | 0.014 | 0.6 |
| RCP4.5-2070 | bio04 | -0.009 | 0.004 | 0.018 | 0.991 |
| bio06 | -1.609 | 0.341 | 0 | 0.2 |
| bio07 | -0.941 | 0.337 | 0.005 | 0.39 |
| RCP8.5-2050 | bio04 | -0.019 | 0.008 | 0.014 | 0.981 |
| bio06 | -1.912 | 0.406 | 0 | 0.148 |
| bio07 | -1.994 | 0.436 | 0 | 0.136 |
| RCP8.5-2070 | bio04 | -0.015 | 0.007 | 0.025 | 0.985 |
| *2* *Ass. Deyeuxia pyramidalis, Rhododendron davuricum, Larix gmelinii* | RCP2.6-2050 | bio06 | 5.246 | 2.455 | 0.033 | 189.754 |
| RCP2.6-2070 | bio06 | -1.865 | 0.934 | 0.046 | 0.155 |
| bio07 | -1.848 | 0.739 | 0.012 | 0.157 |
| RCP4.5-2050 | bio01 | -2.487 | 1.073 | 0.02 | 0.083 |
| bio09 | 0.107 | 0.029 | 0 | 1.113 |
| RCP8.5-2050 | bio01 | 1.356 | 0.458 | 0.003 | 3.88 |
| bio04 | 0.029 | 0.007 | 0 | 1.03 |
| bio06 | 2.053 | 0.429 | 0 | 7.793 |
| bio07 | 1.348 | 0.361 | 0 | 3.85 |
| RCP8.5-2070 | bio01 | 0.859 | 0.218 | 0 | 2.361 |
| bio04 | 0.009 | 0.004 | 0.017 | 1.009 |
| bio06 | 0.839 | 0.271 | 0.002 | 2.314 |
| bio07 | 0.881 | 0.183 | 0 | 2.414 |
| *3 Ass. Vaccinium vitisidea, Rhododendron davuricum, Larix gmelinii* | RCP2.6-2050 | bio06 | -2.594 | 0.608 | 0 | 0.075 |
| bio07 | -2.466 | 0.424 | 0 | 0.085 |
| bio09 | 0.073 | 0.011 | 0 | 1.076 |
| RCP2.6-2070 | bio06 | -0.844 | 0.398 | 0.034 | 0.43 |
| RCP4.5-2050 | bio07 | -0.511 | 0.208 | 0.014 | 0.6 |
| RCP4.5-2070 | bio09 | 0.122 | 0.061 | 0.047 | 1.13 |
| RCP8.5-2050 | bio06 | -1.671 | 0.49 | 0.001 | 0.188 |
| bio07 | -1.392 | 0.402 | 0.001 | 0.249 |
| bio09 | 0.032 | 0.01 | 0.002 | 1.032 |
| bio01 | -1.201 | 0.392 | 0.002 | 0.301 |
| RCP8.5-2070 | bio01 | -9.933 | 0 | 0 | 4.86E-05 |
| *4 Ass. Carex callitrichos, Lespedeza bicolor, Larix gmelinii* | RCP2.6-2050 | bio09 | 0.039 | 0.013 | 0.003 | 1.039 |
| RCP2.6-2070 | bio06 | -2.713 | 0.757 | 0 | 0.066 |
| bio09 | 0.059 | 0.019 | 0.002 | 1.06 |
| RCP4.5-2050 | bio09 | 0.107 | 0.029 | 0 | 1.113 |
| bio01 | -2.487 | 1.073 | 0.02 | 0.083 |
| RCP8.5-2050 | bio06 | -3.007 | 0.858 | 0 | 0.049 |
| bio09 | 0.105 | 0.023 | 0 | 1.111 |
| RCP8.5-2070 | bio06 | 4.269 | 0 | 0 | 71.453 |
| *5 Ass. Herbage,Larix gmelinii* | RCP2.6-2050 | bio06 | 4.88 | 2.291 | 0.033 | 131.634 |
| RCP2.6-2070 | bio06 | -2.365 | 0.474 | 0 | 0.094 |
| bio07 | -2.831 | 0.451 | 0 | 0.059 |
| RCP4.5-2050 | bio09 | 0.114 | 0.027 | 0 | 1.121 |
| RCP4.5-2070 | bio06 | -1.33 | 0.598 | 0.026 | 0.264 |
| bio09 | 0.131 | 0.053 | 0.014 | 1.139 |
| RCP8.5-2050 | bio06 | -2.379 | 0.657 | 0 | 0.093 |
| bio09 | 0.109 | 0.021 | 0 | 1.115 |
| RCP8.5-2070 | bio07 | -343.058 | 0 | 0 | 1.03E-149 |
| *6 Ass. Carex lanceolata, Corylus mandshurica, Larix gmelinii* | RCP2.6-2050 | bio07 | -0.931 | 0.333 | 0.005 | 0.394 |
| bio01 | 0.73 | 0.361 | 0.043 | 2.076 |
| RCP2.6-2070 | bio15 | -0.317 | 0.126 | 0.012 | 0.728 |
| RCP4.5-2050 | bio09 | 0.139 | 0.038 | 0 | 1.149 |
| bio01 | -2.649 | 1.217 | 0.03 | 0.071 |
| bio15 | -0.861 | 0.419 | 0.04 | 0.423 |
| RCP4.5-2070 | bio06 | -0.893 | 0.421 | 0.034 | 0.409 |
| bio07 | -0.791 | 0.298 | 0.008 | 0.454 |
| RCP8.5-2050 | bio06 | -3.603 | 1.06 | 0.001 | 0.027 |
| bio09 | 0.09 | 0.024 | 0 | 1.094 |
| bio01 | 2.292 | 1.036 | 0.027 | 9.891 |
| RCP8.5-2070 | bio07 | 68.902 | 0 | 0 | 8.39E+29 |
| *7 Ass. Carex callitrichos, Corylus heterophylla, Larix gmelinii* | RCP2.6-2050 | bio04 | 0.081 | 0.026 | 0.002 | 1.084 |
| RCP2.6-2070 | bio04 | 0.031 | 0.015 | 0.049 | 1.031 |
| bio07 | 1.503 | 0.741 | 0.043 | 4.496 |
| bio09 | 0.099 | 0.026 | 0 | 1.105 |
| bio01 | -1.573 | 0.791 | 0.047 | 0.208 |
| RCP4.5-2050 | bio09 | 0.11 | 0.029 | 0 | 1.117 |
| bio01 | -2.72 | 1.072 | 0.011 | 0.066 |
| RCP4.5-2070 | bio09 | 0.091 | 0.044 | 0.036 | 1.096 |
| RCP8.5-2050 | bio06 | -2.977 | 0.831 | 0 | 0.051 |
| bio09 | 0.11 | 0.024 | 0 | 1.117 |
| RCP8.5-2070 | bio04 | -0.035 | 0.012 | 0.004 | 0.966 |
| bio06 | -1.876 | 0.581 | 0.001 | 0.153 |
| bio01 | -0.978 | 0.43 | 0.023 | 0.376 |
| *8 Ass. Vaccinium vitis-idaea, Pinus pumila, Larix gmelinii* | RCP2.6-2070 | bio04 | 0.142 | 0.07 | 0.043 | 1.153 |
| RCP4.5-2070 | bio01 | 1.235 | 0.55 | 0.025 | 3.439 |
| bio03 | -1.906 | 0.644 | 0.003 | 0.149 |
| bio04 | 0.072 | 0.014 | 0 | 1.074 |
| bio06 | 4.413 | 0.789 | 0 | 82.511 |
| bio07 | 2.713 | 0.573 | 0 | 15.08 |
| bio09 | -0.055 | 0.025 | 0.029 | 0.946 |
| bio12 | 0.407 | 0.096 | 0 | 1.502 |
| bio13 | -1.066 | 0.198 | 0 | 0.344 |
| bio15 | 0.261 | 0.226 | 0.247 | 1.299 |
| bio17 | 0.07 | 0.4 | 0.86 | 1.073 |
| RCP8.5-2050 | bio01 | 3.454 | 1.282 | 0.007 | 31.626 |
| bio06 | -3.746 | 1.091 | 0.001 | 0.024 |
| bio09 | 0.059 | 0.026 | 0.026 | 1.061 |
| bio12 | -0.378 | 0.117 | 0.001 | 0.685 |
| bio13 | 0.389 | 0.144 | 0.007 | 1.475 |
| RCP8.5-2070 | bio01 | 1.988 | 0.436 | 0 | 7.301 |
| bio03 | -0.886 | 0.57 | 0.12 | 0.412 |
| bio04 | 0.031 | 0.008 | 0 | 1.031 |
| bio06 | 1.69 | 0.687 | 0.014 | 5.422 |
| bio07 | 1.11 | 0.517 | 0.032 | 3.033 |
| bio09 | -0.033 | 0.016 | 0.042 | 0.968 |
| bio12 | 0.431 | 0.072 | 0 | 1.539 |
| bio13 | -0.162 | 0.084 | 0.054 | 0.85 |
| bio15 | 0.02 | 0.231 | 0.93 | 1.021 |
| bio17 | 0.809 | 0.255 | 0.002 | 2.245 |
| *9 Ass. Vaccinium vitis-idaea, Ledum palustre, Larix gmelinii* | RCP2.6-2050 | bio07 | -0.988 | 0.414 | 0.017 | 0.372 |
| RCP2.6-2070 | bio04 | -0.027 | 0.009 | 0.003 | 0.973 |
| bio06 | -1.908 | 0.652 | 0.003 | 0.148 |
| bio07 | -1.044 | 0.461 | 0.023 | 0.352 |
| RCP4.5-2050 | bio04 | -0.034 | 0.016 | 0.035 | 0.967 |
| bio07 | -1.205 | 0.593 | 0.042 | 0.3 |
| RCP8.5-2050 | bio09 | 0.037 | 0.018 | 0.041 | 1.037 |
| bio01 | -1.315 | 0.623 | 0.035 | 0.269 |
| RCP8.5-2070 | bio04 | 0.011 | 0.003 | 0.001 | 1.011 |
| bio07 | -42.587 | 0 | 0 | 3.20E-19 |
| bio01 | 1.445 | 0.153 | 0 | 4.244 |
| *10 Ass. Vaccinium vitis-idaea, Larix gmelinii* | RCP2.6-2050 | bio06 | 8.809 | 4.087 | 0.031 | 6691.628 |
| RCP2.6-2070 | bio07 | 0.767 | 0.346 | 0.027 | 2.153 |
| RCP4.5-2050 | bio04 | 0.019 | 0.006 | 0.001 | 1.02 |
| bio06 | 0.562 | 0.272 | 0.039 | 1.754 |
| bio01 | -0.659 | 0.327 | 0.044 | 0.517 |
| bio03 | 1.114 | 0.44 | 0.011 | 3.047 |
| RCP4.5-2070 | bio01 | -1.507 | 0.749 | 0.044 | 0.222 |
| RCP8.5-2050 | bio06 | -3.33 | 0.867 | 0 | 0.036 |
| bio09 | 0.096 | 0.024 | 0 | 1.1 |
| RCP8.5-2070 | bio01 | -1.862 | 0 | 0 | 0.155 |
| *11 Ass. Carex schmidtii, Betula fruticosa, Larix gmelinii* | RCP2.6-2050 | bio12 | -0.205 | 0.082 | 0.013 | 0.815 |
| RCP2.6-2070 | bio09 | 0.056 | 0.025 | 0.024 | 1.058 |
| bio12 | -0.209 | 0.085 | 0.014 | 0.812 |
| RCP4.5-2050 | bio07 | -0.719 | 0.342 | 0.036 | 0.487 |
| bio13 | 0.219 | 0.093 | 0.019 | 1.244 |
| RCP4.5-2070 | bio01 | 2.116 | 0.926 | 0.022 | 8.298 |
| bio12 | 0.448 | 0.155 | 0.004 | 1.565 |
| bio13 | -0.842 | 0.384 | 0.028 | 0.431 |
| bio15 | 0.764 | 0.313 | 0.015 | 2.146 |
| RCP8.5-2070 | bio04 | -0.016 | 0.008 | 0.04 | 0.984 |
| bio06 | -1.427 | 0.598 | 0.017 | 0.24 |
| bio07 | -0.931 | 0.469 | 0.047 | 0.394 |
| bio12 | -0.178 | 0.075 | 0.018 | 0.837 |
| bio17 | -0.96 | 0.301 | 0.001 | 0.383 |
| *12 Ass. Vaccinium vitis-idaea, Betula fruticosa, Larix gmelinii* | RCP2.6-2050 | bio06 | 4.982 | 2.479 | 0.044 | 145.816 |
| RCP2.6-2070 | bio06 | -1.634 | 0.588 | 0.005 | 0.195 |
| bio07 | -0.911 | 0.443 | 0.04 | 0.402 |
| RCP4.5-2050 | bio09 | 0.107 | 0.029 | 0 | 1.113 |
| bio01 | -2.487 | 1.073 | 0.02 | 0.083 |
| RCP8.5-2050 | bio06 | -3.007 | 0.858 | 0 | 0.049 |
| bio09 | 0.105 | 0.023 | 0 | 1.111 |
| RCP8.5-2070 | bio01 | -0.126 | 0 | 0 | 0.882 |
| *13 Ass. Vaccinium vitis-idaea, Betula middendorfii, Larix gmelinii* | RCP2.6-2070 | bio06 | -1.885 | 0.702 | 0.007 | 0.152 |
| bio07 | -3.039 | 0.582 | 0 | 0.048 |
| bio17 | -1.135 | 0.454 | 0.012 | 0.321 |
| RCP4.5-2050 | bio17 | 5.098 | 2.303 | 0.027 | 163.716 |
| RCP4.5-2070 | bio04 | 0.054 | 0.013 | 0 | 1.056 |
| bio06 | 4.526 | 1.147 | 0 | 92.425 |
| bio07 | 2.579 | 0.893 | 0.004 | 13.178 |
| bio13 | -0.715 | 0.238 | 0.003 | 0.489 |
| bio17 | -1.521 | 0.526 | 0.004 | 0.219 |
| RCP8.5-2050 | bio04 | 0.11 | 0.025 | 0 | 1.116 |
| bio06 | 4.396 | 1.605 | 0.006 | 81.145 |
| bio07 | 3.07 | 1.524 | 0.044 | 21.543 |
| bio09 | -0.059 | 0.021 | 0.004 | 0.943 |
| bio12 | 0.611 | 0.154 | 0 | 1.842 |
| RCP8.5-2070 | bio01 | 1.976 | 0.693 | 0.004 | 7.212 |
| bio06 | 2.565 | 1.023 | 0.012 | 12.994 |
| bio09 | -0.092 | 0.031 | 0.003 | 0.912 |
| bio12 | 0.648 | 0.154 | 0 | 1.912 |
| bio17 | 1.75 | 0.589 | 0.003 | 5.757 |