Impacts of Climate Change on the Potential Geographic Distribution of Broad-Leaved Korean Pine Forests: Postprint

Authors: Jia Xiang, Ma Fangfang, Zhou Wangming, Zhou Li, Yu Dapao, Qin Jing, Dai Limin

Date: 2017-02-09T00:00:00+00:00

Abstract

The geographic distribution of species is primarily determined by its adaptability to environmental factors such as climate and topography. Based on 22 environmental variables and geographic distribution data of four main constructive tree species in broadleaved Korean pine forests—Korean pine, Amur linden, Manchurian ash, and Mongolian oak—the MaxEnt model was employed to simulate the potential distribution areas of broadleaved Korean pine forests, analyze the primary climatic and topographic factors determining their geographic distribution, and finally predict future potential distribution areas using climate data for 2020, 2050, and 2080 under three emission scenarios (SRES-A2, SRES-A1B, SRES-B1) released by the Intergovernmental Panel on Climate Change (IPCC). The results indicate that the area under the receiver operating characteristic curve (AUC value) for each tree species exceeds 0.8, demonstrating strong predictive capability of the model; the dominant environmental factors influencing the distribution of broadleaved Korean pine forests are annual precipitation, seasonal precipitation, elevation, mean annual temperature, and mean temperature of the wettest quarter. Under baseline climate conditions, the highly suitable distribution areas of broadleaved Korean pine forests are mainly located in the Changbai Mountains and Lesser Khingan Range regions, accounting for 11.69% of the total study area, while the moderately suitable and unsuitable areas constitute 23% and 65.31% of the total study area, respectively. Model projections reveal that under future climate scenarios A2, A1B, and B1, both the southern and northern boundaries of the highly suitable areas for broadleaved Korean pine forests will shift northward, with a trend of decreasing area, while the area of moderately suitable zones shows an increasing trend.

Full Text

Preamble

ACTA ECOLOGICA SINICA
ChinaXiv Partner Journal
Vol. 37, No. 2, Jan. 2017
DOI: 10.5846/stxb201508101680

Impacts of Climate Change on the Potential Geographical Distribution of Broadleaved Korean Pine (*Pinus koraiensis*) Forests

Jia Xiang[1], Ma Fangfang[1,2], Zhou Wangming[1], Zhou Li[1], Yu Dapao[1], Qin Jing[3], Dai Limin[1]*

[1]Key Laboratory of Forest Ecology and Management, Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, China
[2]University of Chinese Academy of Sciences, Beijing 100049, China
[3]Liaoning Provincial Forest Seed and Seedling Management Station, Shenyang 110036, China

*Corresponding author. E-mail: lmdai@iae.ac.cn

Abstract

Species-environment relationships have always been a central issue in ecology and biogeography. The geographic distribution of a species is primarily determined by its adaptation to environmental factors such as climate and topography. Northeast China has experienced the greatest temperature increase since the 1950s, which has profoundly affected species distributions in this region. Broadleaved Korean pine mixed forest (BKF) is the native forest type in the southern part of Northeast China, but its distribution area has shrunk substantially due to historical overexploitation. For forest managers, predicting the potential geographic distribution of BKF based on species-environment relationships is crucial for ecological restoration and sustainable management. Although previous studies have reported the potential distributions of individual BKF species such as *Pinus koraiensis*, *Quercus mongolica*, *Tilia amurensis*, and *Fraxinus mandshurica*, few have focused on the entire BKF community. This study employed the maximum entropy model (MaxEnt) to simulate the potential distribution of BKF and identify the dominant climatic and topographic factors controlling its distribution. We selected four dominant tree species that together account for more than 80% of the growing stock in primary BKF. Nineteen climatic and three topographic variables considered most likely to influence tree species distribution in Northeast China were selected as environmental factors. Geographic distribution records of the four dominant species were compiled from herbarium databases and literature. The model showed excellent predictive performance, with area under the curve (AUC) values exceeding 0.8 for all four species. The dominant environmental factors affecting BKF distribution were annual precipitation, precipitation seasonality, elevation, annual mean temperature, and mean temperature of the wettest quarter. Under baseline climate conditions, the highly suitable distribution area for BKF was mainly concentrated in the Changbai Mountains and Xiaoxing' anling region, covering 11.69% of the total study area, while low-suitability and unsuitable areas accounted for 23.00% and 65.31%, respectively. Future projections based on three IPCC emission scenarios (SRES-A2, SRES-A1B, SRES-B1) for the 2020s, 2050s, and 2080s indicated that both the southern and northern boundaries of the highly suitable area will shift northward, with a decreasing trend in area. Under the A2 and A1B scenarios, the highly suitable area is projected to be less than 1% of the region by the 2080s. These results suggest that without effective climate change mitigation measures, BKF may disappear from Northeast China.

Keywords: broadleaved Korean pine mixed forest; climate change; MaxEnt model; potential geographic distribution; climate change scenarios

1. Introduction

The relationship between species and environment has become a focal issue in ecology and biogeography. Every species has a temporary geographic distribution range under the combined effects of various biotic and abiotic factors, with climate being particularly important for forest community dominants. Many atmospheric circulation models predict that global warming will significantly impact species distributions, with surface temperatures projected to rise by 1.1-6.4°C. Species distribution models (SDMs) have emerged as a popular research method, using species occurrence data and environmental variables to estimate ecological niches and project them onto landscapes as probability surfaces reflecting habitat suitability. Among all SDMs, the maximum entropy model (MaxEnt) demonstrates superior predictive performance.

Broadleaved Korean pine mixed forest is the typical zonal vegetation in the mountainous regions of eastern Northeast China and represents a well-preserved remnant plant community from the post-Quaternary glacial period. *Pinus koraiensis* is the main canopy species, forming mixed coniferous-broadleaved forests with other species such as *Picea jezoensis*, *Abies nephrolepis*, *Tilia amurensis*, *Fraxinus mandshurica*, and *Quercus mongolica*. Due to historical overexploitation, BKF has been severely damaged and its distribution area has shrunk dramatically. Understanding its potential distribution under future climate change is essential for ecological restoration and sustainable management. Previous studies have been limited to single species and explored only a few environmental factors such as growing degree days (GDD) and potential evapotranspiration rate (PER). This study uses four dominant BKF species (*P. koraiensis*, *Q. mongolica*, *T. amurensis*, *F. mandshurica*) to analyze key climatic and topographic factors controlling BKF distribution, models their potential distributions, and defines BKF distribution as the overlapping area of all four species. Future climate data are then used to predict BKF' s future potential distribution.

2. Materials and Methods

2.1 Study Area

BKF is mainly distributed in Northeast China, including Heilongjiang, Jilin, and Liaoning provinces, as well as Hulunbuir City in eastern Inner Mongolia. The region is located on the eastern margin of the Eurasian continent, bordered by Russia to the northeast, the Democratic People' s Republic of Korea across the Yalu River to the southeast, the Yellow Sea and Bohai Sea to the south, and Inner Mongolia to the west. Geographic coordinates range from 38°43 -53°23 N, 118°50 -135°05 E.

2.2 Species Distribution Data

Geographic distribution data were obtained from the Chinese Virtual Herbarium (http://www.cvh.org.cn/), the China Nature Reserve Specimen Resource Sharing Platform (http://www.papc.cn/), the Teaching Specimen Resource Platform (http://mnh.scu.edu.cn/), and provincial floras of the three northeastern provinces. Detailed collection records were used to determine distribution point coordinates via the Baidu coordinate picking system (http://api.map.baidu.com/lbsapi/getpoint/index.html). To improve prediction reliability, we removed fuzzy records and cultivated species distribution points, resulting in 85 distribution points for *P. koraiensis*, 78 for *Q. mongolica*, 45 for *T. amurensis*, and 72 for *F. mandshurica*.

2.3 Environmental Variables

2.3.1 Climate Data Baseline climate data (1961–1990) were obtained from WorldClim (http://www.worldclim.org/), which uses interpolation to generate global climate raster data from monthly meteorological station records. Nineteen bioclimatic variables (Bio1–Bio19) were extracted at 30 arc-second (~1 km) resolution. Future climate data for three emission scenarios (SRES-A2, SRES-A1B, SRES-B1) and three time periods (2020s, 2050s, 2080s) were derived from the HadCM3 atmospheric circulation model, obtained from the International Center for Tropical Agriculture (CIAT, http://www.ccafs-climate.org). The A2 scenario represents high-speed economic growth with continuous population increase; A1B describes a convergent world with rapid economic growth and balanced energy use; B1 represents a convergent world with service/information economy and clean technologies.

2.3.2 Topographic Data Topographic data were obtained from the International Scientific Data Mirror Site of the Chinese Academy of Sciences Computer Network Information Center. A 90 m resolution digital elevation model (DEM) was resampled to 1 km resolution to extract elevation, slope, and aspect layers. Chinese administrative boundary maps were obtained from the National Fundamental Geographic Information System (http://nfgis.nsdi.gov.cn/).

2.4 Environmental Factor Screening

Since environmental factors are often correlated, direct application can cause overfitting. We performed Pearson correlation analysis using SPSS 19.0, retaining only one factor from any pair with correlation coefficient 0.8. Following Moreno et al.' s methodology, we also conducted multicollinearity analysis. The final model included eight climate factors (Bio1, Bio2, Bio3, Bio4, Bio8, Bio12, Bio15, Bio19) and three topographic factors (elevation, slope, aspect). Studies have shown that MaxEnt model accuracy is not sensitive to sample size, confirming our data were adequate for modeling.

2.5 Species Distribution Modeling

MaxEnt (http://www.cs.princeton.edu/~schapire/maxent/) is a widely used SDM that requires only environmental layers and species occurrence data. We ran MaxEnt V3.3.3.k with default parameters, using 75% of distribution points for training and 25% for testing. The model was run 10 times, and the iteration with highest test AUC was selected. Model performance was evaluated using receiver operating characteristic (ROC) curves and area under the curve (AUC) values, where 0.5–0.6 indicates poor fit, 0.6–0.7 average, 0.7–0.8 good, 0.8–0.9 excellent, and 0.9–1.0 outstanding. Jackknife tests assessed variable importance. Outputs were converted to raster format and classified into four suitability levels based on IPCC probability standards: unsuitable, low suitability, moderate suitability, and high suitability. BKF distribution was defined as the intersection of high-suitability areas for all four species, while unsuitable areas represented the union of unsuitable zones for each species.

3. Results

3.1 Model Performance

ROC analysis demonstrated strong predictive capability for all four species (Table 2). AUC values were 0.925 for *P. koraiensis*, 0.890 for *F. mandshurica*, 0.859 for *T. amurensis*, and 0.847 for *Q. mongolica*, all exceeding the 0.8 threshold and indicating excellent model performance.

Table 2. AUC values of MaxEnt models for the four dominant species

Species	AUC Value
Pinus koraiensis	0.925
Fraxinus mandshurica	0.890
Tilia amurensis	0.859
Quercus mongolica	0.847

3.2 Dominant Environmental Factors

Jackknife tests and contribution percentage analysis revealed that annual precipitation (Bio12), precipitation seasonality (Bio15), elevation (ELE), annual mean temperature (Bio1), and mean temperature of the wettest quarter (Bio8) were the primary factors controlling BKF distribution, with cumulative contributions exceeding 85%. Annual precipitation was the most important factor.

[Figure 2: see original paper]
Figure 2. Percentage contribution of environmental variables to species distribution models

3.3 Current Potential Distribution

Under baseline climate conditions, BKF' s highly suitable area is mainly distributed in the Changbai Mountains and Xiaoxing'anling region, extending from Heihe City in Heilongjiang southward through Yichun, Hada Ridge in Jilin, to Xiuyan and Fengcheng in Liaoning. The highly suitable area covers 11.69% of the study region, low-suitability area 23.00%, and unsuitable area 65.31%.

[Figure 3: see original paper]
Figure 3. Potential distribution of broadleaved Korean pine forest under current climate

3.4 Future Projections

Projections for 2020, 2050, and 2080 under three climate scenarios show that both southern and northern boundaries of the highly suitable area will shift northward, with overall area reduction (Figure 4). Under A2 and A1B scenarios, the highly suitable area fluctuates: decreasing to 4.77% by 2020, increasing to 5.66% by 2050, then dropping dramatically to 0.60% by 2080. The low-suitability area shows an increasing trend from 23.00% to 37.18%. Under the B1 scenario, the highly suitable area decreases more gradually to 4.71% by 2080, while low-suitability area increases to 28.01%.

[Figure 4: see original paper]
Figure 4. Predicted potential distribution of broadleaved Korean pine forest under different climate change scenarios

Table 3. Habitat suitability class area percentages for broadleaved Korean pine forest

Scenario	Unsuitable Area (%)	Low Suitability (%)	High Suitability (%)
Current	65.31	23.00	11.69
A2 2020	70.88	24.35	4.77
A2 2050	61.91	32.44	5.66
A2 2080	62.22	37.18	0.60

Scenario	Unsuitable Area (%)	Low Suitability (%)	High Suitability (%)
A1B 2020	67.27	28.57	4.17
A1B 2050	69.26	28.22	2.52
A1B 2080	71.32	28.47	0.21
B1 2020	63.32	30.10	6.58
B1 2050	63.09	30.34	6.57
B1 2080	65.30	30.34	4.36

4. Discussion

Previous research indicates that plant cold hardiness, heat supply for life cycle completion, and water availability are the main factors limiting plant geographic distribution. Our finding that annual precipitation is the primary factor for *Q. mongolica* aligns with Yin et al.' s results. However, our results differ from some studies that identified temperature differences between coldest and hottest months as the primary factor for *P. koraiensis* distribution, likely due to our inclusion of topographic variables and different factor screening methods.

Climate projections for Northeast China under the three emission scenarios show increasing temperature and precipitation trends, with A2 showing the greatest change and B1 the least. While precipitation increases, it cannot offset the effects of rising temperatures, leading to a warmer and drier climate in eastern mountainous regions. This climatic trend reduces BKF' s ecological suitability and distribution area. Cheng et al. suggested that *P. koraiensis* could become dominant in the Greater Khingan Mountains under warming and wetting conditions. Our projections show BKF' s low-suitability area expanding northward into the Greater Khingan region, with some areas becoming highly suitable under A2 and A1B scenarios by 2080. However, for the Xiaoxing' anling region, forest gap models predict BKF will be replaced by broadleaved forests dominated by *Q. mongolica*, *T. amurensis*, and *Ulmus laciniata* when temperature increases exceed precipitation gains.

Differences between species distribution models arise from multiple sources of uncertainty, including model selection, environmental factor choice, and climate scenarios. Our approach of overlaying four species distributions may accumulate errors. Species distribution patterns represent complex expressions of ecological and evolutionary history, controlled by multiple factors at different spatiotemporal scales, including dispersal capacity and evolutionary potential. This study considered only partial environmental factors, indicating the need for further research incorporating additional determinants.

5. Conclusion

Broadleaved Korean pine forest is currently distributed mainly in the Changbai Mountains and Xiaoxing' anling region. Under A2, A1B, and B1 climate scenarios, BKF distribution boundaries will shift northward, with highly suitable areas decreasing in size and becoming more concentrated in the Changbai Mountain Nature Reserve. The more severe the climate change, the greater the impact on BKF distribution. Under A2 and A1B scenarios, the highly suitable area will be less than 1% of the study region by the 2080s, suggesting BKF may gradually disappear from Northeast China without effective climate mitigation. The dominant environmental factors controlling BKF distribution are annual precipitation, precipitation seasonality, elevation, annual mean temperature, and mean temperature of the wettest quarter.

References

[1] Yang X Q, Kushwaha S P S, Saran S, Xu J C, Roy P S. Maxent modeling for predicting the potential distribution of medicinal plant, *Justicia adhatoda* L. in Lesser Himalayan foothills. *Ecological Engineering*, 2013, 51: 83–87.

[2] IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2007: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge: Cambridge University Press, 2007.

[3] Elith J, Graham C H, Anderson R P, et al. Novel methods improve prediction of species' distributions from occurrence data. *Ecography*, 2006, 29(2): 129–151.

[4] Elith J, Graham C H. Do they? How do they? Why do they differ? On finding reasons for differing performances of species distribution models. *Ecography*, 2009, 32(1): 66–77.

[5] Woodward F I. *Climate and Plant Distribution*. Cambridge: Cambridge University Press, 1987.

[6] Qü J, Jin H J. IPCC-AR4 model data-based projections of climate and available water resources in Northeast China. *Journal of Natural Resources*, 2009, 24(9): 1647–1656.

[7] Cheng X X, He H S. Impacts of climate change on forest succession dynamics in Greater Khingan Mountains, Northeast China. *Chinese Journal of Ecology*, 2007, 26(8): 1277–1284.

[8] Xu D Y, Yan H. A study of the impacts of climate change on the geographic distribution of *Pinus koraiensis* in China. *Environment International*, 2001, 27(2/3): 201–205.

[9] Brown J H. *Macroecology*. Chicago: University of Chicago Press, 1995.

[10] Franklin J. *Mapping Species Distributions: Spatial Inference and Prediction*. Cambridge: Cambridge University Press, 2009.

[11] Soberón J, Peterson A T. Interpretation of models of fundamental ecological niches and species' distributional areas. *Biodiversity Informatics*, 2005, 2: 1-10.

[12] Soberón J, Nakamura M. Niches and distributional areas: concepts, methods, and assumptions. *Proceedings of the National Academy of Sciences*, 2009, 106(S2): 19644–19650.

[13] Soberón J M. Niche and area of distribution modeling: a population ecology perspective. *Ecography*, 2010, 33(1): 159–167.

[14] Sillero N. What does ecological modeling model? A proposed classification of ecological niche models based on their underlying methods. *Ecological Modelling*, 2011, 222(8): 1343–1346.

[15] Moreno R, Zamora R, Molina J R, Vasquez A, Herrera M A. Predictive modeling of microhabitats for endemic birds in South Chilean temperate forests using Maximum entropy (Maxent). *Ecological Informatics*, 2011, 6(6): 364–370.

[16] Chen X M, et al. Study on sample size requirements for MaxEnt model predictions. *Scientia Silvae Sinicae*, 2012, 48(1): 53–59.

[17] Fitzpatrick M C, Gove A D, Sanders N J, Dunn R R. Climate change, plant migration, and range collapse in a global biodiversity hotspot: the *Banksia* (Proteaceae) of Western Australia. *Global Change Biology*, 2008, 14(6): 1337-1352.

[18] IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the IPCC. Cambridge: Cambridge University Press, 2007.

[19] Yang X Q. Research on the relationship between geographic distribution of *Pinus koraiensis* and climate in China. *Graduate University of Chinese Academy of Sciences*, 2011.

[20] Yin X J, et al. Dominant climatic factors and thresholds for *Quercus mongolica* geographic distribution. *Acta Ecologica Sinica*, 2013, 33(1): 103-109.

[21] Zhang Y D, et al. Ecoclimatic suitability and impact assessment of global climate change on BKF distribution in Northeast China. *Chinese Journal of Applied Ecology*, 2003, 14(5): 771–775.

[22] Zhao S D. Simulation analysis of terrestrial carbon cycle balance in Northeast China. *Geographical Research*, 2001, 56(4): 390–400.

[23] Wang S Q, et al. Spatial distribution pattern of forest ecosystem carbon storage in Northeast China. *Graduate University of Chinese Academy of Sciences*, 2011.

[24] Qu J F, et al. Detection and assessment of anthropogenic impacts on climate change in East Asia. *Journal of Applied Meteorological Science*, 2002, 13(5): 513–525.

[25] Dai L M, et al. Latest understanding of climate change science. *Advances in Climate Change Research*, 2007, 3(2): 63-73.

[26] Cheng X X, et al. Dynamic simulation of climate change impacts on BKF in Xiaoxing' anling. *Chinese Journal of Applied Ecology*, 2000, 11(1): 43-46.

[27] Wang X A, et al. Potential responses of different-aged stands to climate change in Xiaoxing' anling. *Journal of Beijing Forestry University*, 2007, 29(4): 110-117.

Note: Figure translations are in progress. See original paper for figures.