Postprint: Changes in the Potential Distribution Pattern of Sea Buckthorn in Xinjiang under Climate Change

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Abstract

This study employs the MaxEnt model, integrating sea buckthorn distribution point data in Xinjiang with climate data from historical periods (Last Glacial Maximum, mid-Holocene), present, and future periods (2050s, 2070s), as well as altitude data, to simulate the potential geographic distribution areas of sea buckthorn under different climate scenarios. It analyzes the main climatic and environmental factors influencing the natural distribution of sea buckthorn in Xinjiang and elucidates the migration patterns of its distribution areas. The results indicate that the primary environmental factors for suitable sea buckthorn habitats include a mean annual temperature of -1~8 °C, precipitation in the warmest quarter of 48~120 mm, maximum temperature of the warmest month of 22~32 °C, precipitation in the driest month of 2~15 mm, and suitable altitudes primarily ranging from 500 m to 3500 m. Under current climate conditions, sea buckthorn is distributed in both northern and southern Xinjiang, mainly in the northern and southwestern regions. Research on the centroid migration of sea buckthorn distribution areas under future climate scenarios reveals that the centroids migrate toward the northeast. The findings can provide theoretical data support for the development planning of sea buckthorn resources.

Full Text

Abstract

This study employs the MaxEnt model to simulate the potential geographic distribution of *Hippophae rhamnoides* in Xinjiang under different climate scenarios, integrating distribution point data for sea buckthorn in Xinjiang with historical (Last Glacial Maximum, mid-Holocene), current, and future (2050s, 2070s) climate data as well as altitude data. The main climatic and environmental factors influencing the natural distribution of sea buckthorn in Xinjiang were analyzed, and the migration patterns of its distribution range were elucidated. The results indicate that the suitable environmental conditions for sea buckthorn include an annual average temperature of -1~8 °C, precipitation in the wettest quarter of 50~110 mm, maximum temperature in the warmest month of 22~32 °C, precipitation in the driest month of 5~13 mm, and an altitude range of 500~1000 m. Under current climate conditions, sea buckthorn is distributed in both northern and southern Xinjiang, primarily concentrated in the northern and southwestern regions of the province. Under future climate scenarios, the centroid of the sea buckthorn distribution area migrates toward the northeast. These findings can provide theoretical data support for the development planning of sea buckthorn resources.

Keywords: *Hippophae rhamnoides*; maximum entropy model; climate change; suitable area; Xinjiang

Introduction

Climate change significantly impacts ecosystems, species composition, and species distribution, and is closely related to species growth, development, and adaptability. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), global average surface temperature will increase by 0.3~4.8 °C by the end of the 21st century. Climate change directly affects species' geographic distribution patterns, and species often adapt by migrating to seek and occupy new habitats. Ecological niche models are commonly used to study species distribution, with current popular models including Genetic Algorithm for Rule-set Prediction (GARP), Climate Analysis and Prediction System (CLIMEX), Random Forest, BIOCLIM, and Ecological Niche Factor Analysis (ENFA). The Maximum Entropy Model (MaxEnt) offers advantages of high accuracy, short runtime, and stable prediction results, and has been applied to predict suitable habitats for various plant species, animal distributions, and risk assessments for pests and invasive species. Sea buckthorn (*Hippophae rhamnoides*), a species in the Elaeagnaceae family, is a medicinal and edible tree with rich nutritional value and strong ecological functions. It has promising development prospects in Xinjiang, and climate change will affect its suitable habitat distribution. Therefore, investigating whether climate change will impact the geographic distribution of sea buckthorn in Xinjiang in the future holds scientific significance for guiding industrial development planning. This study uses MaxEnt to simulate the potential distribution of sea buckthorn in Xinjiang during historical periods (Last Glacial Maximum, mid-Holocene), current conditions, and under four greenhouse gas emission scenarios for the 2050s and 2070s, providing scientific data support for long-term development planning and promoting sustainable, healthy development of Xinjiang' s sea buckthorn industry.

1.1 Study Area Overview

Xinjiang is located in northwestern China, between 34°25 ~48°10 N and 73°40 ~96°18 E. The region' s topography is characterized by "three mountains surrounding two basins," with the Altai Mountains to the north, Kunlun Mountains to the south, and the Tianshan Mountains in the center dividing Xinjiang into southern and northern parts. Northern Xinjiang contains the Junggar Basin, while southern Xinjiang contains the Tarim Basin. Xinjiang has a temperate continental climate, with southern Xinjiang being warmer than northern Xinjiang, having an annual average temperature of 4~14 °C. The total solar radiation reaches 5440 $MJ \cdot m^{-2}$, with annual sunshine hours exceeding 2500 h, providing abundant light and heat resources. Precipitation is higher in the north than in the south, higher in the northwest than in the southeast, and higher in mountainous areas than in plains. This special geographic and climatic environment creates favorable conditions for forest and fruit tree growth. Sea buckthorn is distributed across northern, northwestern, and southwestern China, thriving in temperate regions that can tolerate large temperature variations. It commonly grows at altitudes of 800~3600 m in mountainous areas, valleys, and dry riverbeds. Sea buckthorn has low soil requirements and can grow in various soil types, including gravel soil, mildly saline-alkali soil, and sandy soil, but does not adapt well to heavy clay soils. It requires moderate precipitation, with annual rainfall above 400 mm, but cannot tolerate waterlogging. Sea buckthorn can adapt to extreme temperatures, surviving in environments with minimum temperatures of -50 °C and maximum temperatures of 40 °C.

1.2 Data Acquisition

Sea buckthorn distribution data in Xinjiang were obtained from field surveys of forest fruit resources conducted in 2022, totaling 156 distribution points. Climate data were downloaded from the WorldClim global climate database (http://www.worldclim.org/), including 19 bioclimatic variables for the Last Glacial Maximum (approximately 22,000 years ago), mid-Holocene (approximately 6,000 years ago), current conditions, and future scenarios (2050s, 2070s). The climate data were simulated using the Community Climate System Model version 4 (CCSM4) with Representative Concentration Pathways (RCPs), selecting four current mainstream greenhouse gas emission scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. All bioclimatic variable data had a spatial resolution of 2.5 minutes. Elevation data were also downloaded from WorldClim at 2.5-minute resolution.

1.3 Data Processing

Since selected environmental variables have certain correlations, to prevent multicollinearity from affecting modeling results, variables in the study area were screened to ensure independence and model accuracy. Pearson correlation analysis was used for variable selection; when correlation between two meteorological variables exceeded 0.8, the variable with higher contribution rate was retained for modeling. This screening process selected four bioclimatic variables (bio10, bio14, bio16, bio18) for MaxEnt model operation [Figure 2: see original paper]. Sea buckthorn distribution point data, climate data, and elevation data were imported into the MaxEnt model. The Jackknife method was used for calculation, with 75% of sea buckthorn distribution points as the training set and 25% as the test set. Other model parameters remained at default values to predict suitable distribution areas. Receiver Operating Characteristic (ROC) curve analysis was performed, yielding the Area Under the Curve (AUC) value to evaluate model accuracy and effectiveness, while simultaneously obtaining suitability thresholds for each factor.

Results

2.1 Distribution of Sea Buckthorn Suitable Areas Under Different Climate Scenarios

The AUC values for all climate scenarios exceeded 0.9 , indicating high model accuracy suitable for predicting sea buckthorn distribution. Based on the MaxEnt model calculations, suitable indices were reclassified into four levels: non-suitable area [0~0.06), low-suitable area [0.06~0.23), medium-suitable area [0.23~0.47), and high-suitable area [0.47~1.00). Suitable area distributions were analyzed for the Last Glacial Maximum, mid-Holocene, current, 2050s, and 2070s climate scenarios.

2.1.1 Historical Climate Scenarios During the Last Glacial Maximum and mid-Holocene, sea buckthorn distribution in Xinjiang was primarily located north of the Tianshan Mountains and around the northwestern edge of the Tarim Basin, particularly concentrated in the Altay, Changji, and Tacheng regions [Figure 3: see original paper]. High-suitable areas during these periods were mainly distributed in the northwestern and eastern edge regions of Altay. The mid-Holocene showed some changes compared to the Last Glacial Maximum: western Habahe County in Altay decreased, while northern and eastern Jeminay County increased slightly, and eastern Fuyun County decreased significantly. In Aksu, southern Wushi County decreased, and Kalpin County was no longer within the high-suitable area. High-suitable areas in Tacheng and Bortala Mongol Autonomous Prefecture disappeared, with new small distributions appearing in southern and northeastern Qitai County.

2.1.2 Current Climate Scenario Analysis of environmental factors affecting sea buckthorn distribution revealed variable contribution rates and permutation importance . The highest contribution rates were for precipitation in the driest month (44.50%), mean temperature in the warmest quarter (25.80%), temperature seasonality (22.00%), maximum temperature in the warmest month (10.30%), and altitude (8.50%). The highest permutation importance values were for precipitation in the driest month (18.30%), maximum temperature in the warmest month (13.10%), mean temperature in the wettest quarter (10.90%), and altitude (3.90%). Individual variable analysis showed that regularized training gain was highest for maximum temperature in the warmest month, mean temperature in the wettest quarter, and precipitation in the driest month, while test gain was highest for mean temperature in the wettest quarter, mean temperature in the warmest quarter, and maximum temperature in the warmest month [Figure 4: see original paper]. These results demonstrate that temperature, precipitation, and altitude are the main factors influencing sea buckthorn distribution in Xinjiang. The suitable climate ranges for sea buckthorn growth are: annual average temperature of -1~8 °C, maximum temperature in the warmest month of 22~32 °C, temperature seasonality of 15~25 °C, mean temperature in the wettest quarter of 14~23 °C, mean temperature in the warmest quarter of 15~24 °C, precipitation in the driest month of 5~13 mm, precipitation in the wettest quarter of 50~110 mm, and altitude of 500~1000 m [Figure 5: see original paper].

Under current climate conditions, sea buckthorn is mainly distributed in northern and southwestern Xinjiang (primarily north of the Tianshan Mountains and west of the Tarim Basin). The suitable areas were classified into non-suitable, low-suitable, medium-suitable, and high-suitable zones [Figure 6: see original paper]. High-suitable areas are concentrated in central Altay and slightly in western Aksu, with medium-suitable areas diffusing outward from high-suitable centers. The area proportions of high-, medium-, and low-suitable zones are 2.03%, 9.91%, and 4.78% respectively, with non-suitable areas accounting for 83.28%.

2.1.3 Future Climate Scenarios Under the four emission scenarios for the 2050s and 2070s, sea buckthorn suitable areas are distributed across the northern Tianshan slope planting zone, Ili River Valley fruit planting zone, Turpan-Hami Basin fruit planting zone, and the area surrounding the Tarim Basin. These are mainly located in Altay, Changji Hui Autonomous Prefecture, Tacheng, Karamay, Bortala Mongol Autonomous Prefecture, Ili Kazakh Autonomous Prefecture, Urumqi, Hami, Aksu, and Kizilsu Kirghiz Autonomous Prefecture, with scattered distribution in Bayingolin Mongol Autonomous Prefecture, Turpan, and Kashgar. High-suitable areas are primarily in Altay, with small portions in Tacheng, Aksu, and Kizilsu, and very limited distribution in Bortala and Changji [Figure 7: see original paper].

2.2 Changes in Sea Buckthorn Suitable Areas

2.2.1 Area Changes From the Last Glacial Maximum to the present, the total suitable area and low-suitable area for sea buckthorn showed a gradual decreasing trend, declining by 19.80% and 20.98% respectively. Medium- and high-suitable areas showed a trend of first decreasing then increasing. The medium-suitable area was largest during the Last Glacial Maximum, while the high-suitable area reached its maximum during the current period, with the medium-suitable area decreasing by 15.14% compared to the Last Glacial Maximum .

Under future climate scenarios, changes vary by emission pathway. In RCP2.6, total suitable area first increases then decreases, peaking in the 2050s. Low-suitable area increases at an average rate of 2.11 km^2, while high-suitable area decreases at 0.18%. In RCP4.5, total and low-suitable areas show an overall upward trend, increasing by 26.66% and 13.54% respectively compared to current conditions. In RCP6.0, total, low-, and medium-suitable areas first increase then decrease, with high-suitable area reaching its minimum in the 2050s at 2.57 km^2, then increasing to 2.48 km^2 in the 2070s. In RCP8.5, total, low-, and high-suitable areas first increase then decrease, with high-suitable area decreasing by 0.3 km^2 overall, while medium-suitable area continues increasing at 0.28% .

2.2.2 Spatial Changes Using the current climate scenario as a reference, future climate scenarios show expansion of sea buckthorn distribution, mainly in central and southern Altay, western and eastern Tacheng, western Karamay, central and eastern Hami, most of northern and scattered southern Changji, central Bortala, western and central Ili, southern Urumqi, northern Turpan, northwestern Aksu, southwestern Kizilsu, and very limited areas of Bayingolin [Figure 8: see original paper]. The regions with the most significant area fluctuations are Tacheng, Hami, Ili, and Changji. Stable suitable area varies by emission scenario, following the pattern RCP4.5 > RCP8.5 > RCP6.0 > RCP2.6, indicating that temperature is a major factor affecting sea buckthorn distribution. As environmental temperature changes, sea buckthorn adjusts its temperature adaptation, altering its suitable habitat.

2.2.3 Centroid Migration The current distribution centroid of sea buckthorn suitable areas in Xinjiang is located at 43°38 33.68 N, 84°57 54.82 E, within Shawan County. Under future climate scenarios, the centroid migrates to 44°0 ~44°38 N, 85°1 ~85°57 E [Figure 10: see original paper]. All future emission scenarios show northeastward migration . Migration distances vary by scenario, with higher emission scenarios showing more pronounced northward shifts, indicating that greenhouse gas emissions and temperature increases drive sea buckthorn to seek new suitable habitats in cooler northern regions.

Discussion

3.1 Climate Change Impacts on Sea Buckthorn Distribution

The main factors affecting global climate change are rising atmospheric CO_2 concentration and environmental temperature, which impact agricultural systems. CO_2 concentration has increased from 280 ppm in the 19th century to 330 ppm in the 1980s, reaching approximately 417 ppm by 2022, and is projected to reach 550 ppm by mid-century and 700 ppm by the end of the century. These changes force species to adjust their environmental temperature adaptation for survival. The IPCC Fifth Assessment Report indicates that temperature increases of 0.3~4.8 °C by the end of the 21st century will affect species distribution patterns, causing range shifts, expansions, or contractions based on species-specific adaptability.

This study found that under the four RCP scenarios for the 2050s and 2070s, RCP8.5 consistently shows larger high-suitable areas than the other three scenarios. This occurs because higher emission scenarios increase environmental temperatures, expanding the suitable temperature range for sea buckthorn and consequently enlarging the high-suitable area.

3.2 Climate Change Impacts on Centroid Migration

Previous studies have documented northward shifts of temperature zones under future climate scenarios, particularly for subtropical, warm temperate, and plateau temperate zones. Research on various species, including *Corydalis*, wild *Cymbidium faberi*, and *Kandelia obovata*, has shown similar northward or northwestward range shifts. This study demonstrates that sea buckthorn suitable area centroids migrate northeastward (to higher latitudes and longitudes) under all future scenarios, with more pronounced northward shifts under higher emission scenarios. As sea buckthorn requires an annual average temperature of -1~8 °C, maximum temperature in the warmest month of 22~32 °C, and precipitation in the warmest quarter of 48~120 mm, rising temperatures drive the species to migrate northward to find suitable habitats. This migration pattern is thus linked to human activities, greenhouse gas emission concentrations, and carbon emissions.

Conclusion

This study used the MaxEnt model to analyze suitable areas for sea buckthorn in Xinjiang. The current suitable range is primarily north of the Tianshan Mountains and west of the Tarim Basin, with high-suitable areas in northern Altay and slightly along the western border of Aksu. Over time, under different greenhouse gas emission scenarios, sea buckthorn suitable areas migrate northeastward to varying degrees. The main environmental variables determining suitable ranges are annual average temperature of -1~8 °C, precipitation in the wettest quarter of 50~110 mm, maximum temperature in the warmest month of 22~32 °C, precipitation in the driest month of 5~13 mm, and altitude of 500~1000 m. These results provide data support for sea buckthorn resource development and scientific reference for distribution protection.

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