Impact of Climate Change on the Distribution of Major Zonal Vegetation Types in Northeast China: Postprint

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Abstract

Accurately delineating suitable areas for the distribution of zonal major vegetation types can provide valuable theoretical references for regional vegetation restoration and reconstruction, biodiversity conservation, and related endeavors. Based on detecting climate change tipping points in Northeast China from 1961-2013, and using thermal indices of major vegetation types in this region, this study investigates the impacts of climate change on suitable distribution areas of major vegetation types. Using land cover type data (MCD12Q1) from 2000 and 2013 to validate the estimated suitable distribution areas, the results show that: the temperature tipping point for the Greater Khingan Mountains was 1982, while for other regions it was 1988; no significant precipitation tipping points were identified in the various eco-geographical regions of Northeast China. After the temperature tipping point, the major vegetation species suitable for growth in Northeast China remained unchanged, but the distribution areas of each vegetation type were altered. Specifically, the suitable distribution areas of alpine tundra, subalpine dwarf bent forests, cold temperate coniferous forests, and temperate mixed coniferous-broadleaf forests decreased, while those of warm temperate deciduous broadleaf forests and temperate grasslands increased. The geographic centers of suitable distribution areas for all vegetation types shifted to varying degrees before and after the temperature tipping point, with the largest shift observed in subalpine dwarf bent forests in the southern region, which moved 135.44 km toward the northeast. Comparison with actual distributions of major vegetation types demonstrates that climate change may have already impacted vegetation type distribution in the study area.

Full Text

Preamble

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Effects of Climate Change on the Distribution of Main Zonal Vegetation Types in Northeast China

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Abstract

Accurately delineating suitable distribution areas for zonal vegetation types can provide valuable theoretical references for regional vegetation restoration, reconstruction, and biodiversity conservation. Based on thermal indices of main vegetation types in Northeast China, this study examines the impacts of climate change on suitable distribution areas of major vegetation types, building upon detection of climate change tipping points in the region between 1961 and 2013. Land cover data from NASA LPDAAC EOS (MCD12Q1) for 2000 and 2013 were used to validate the simulated distribution regions. The results showed that the temperature mutation point for the Daxing' an Mountains occurred in 1982, while other regions experienced mutation points in 1988. Annual precipitation showed no obvious mutation points across the various eco-geographical regions of Northeast China. After the temperature mutation points, the main vegetation types suitable for growth in Northeast China remained unchanged in terms of species composition; however, their distribution regions had shifted. The suitable distribution areas for alpine tundra, subalpine dwarf forest, cold-temperate coniferous forest, and temperate mixed forest decreased continuously, while those for warm-temperate deciduous broad-leaved forest and temperate grassland increased. The geographic centers of suitable distribution for each vegetation type moved to varying degrees before and after the temperature mutation points. Among them, the subalpine forest in the southern region showed the largest displacement, moving 135.44 km toward the northeast. Comparative analysis with actual vegetation distributions demonstrated that climate change may have already impacted vegetation type distribution in the study area.

Keywords: zonal vegetation; climate change; Northeast China; suitable distribution

Introduction

Global climate change and its impacts have received widespread attention. The IPCC Fifth Assessment Report indicates that the average annual temperature increased by 0.78°C from 2003–2012 compared to 1951–1980, with precipitation differences increasing across regions and seasons, and the probability of future extreme weather and climate events likely to increase further. China' s climate change trends are consistent with global patterns, with warming rates higher than global or Northern Hemisphere averages, particularly evident in northern China and the Qinghai-Tibet Plateau. Precipitation trends show significant regional differences, with decreasing trends in Northeast China and western regions.

Climate, as a critical controlling factor of ecosystem evolution, affects ecosystems through any changes that occur, subsequently influencing the distribution of constructive species in zonal vegetation. Zonal vegetation refers to large-scale vegetation types whose distribution generally aligns with climate zone boundaries, comprehensively reflecting macro-climatic characteristics and specific eco-geographical spaces. Scholars have used Kira' s warmth index (WI) and coldness index (CI) to classify zonal vegetation, with subsequent expansions introducing humidity indices (HI). All these methods are based on the principle that climate is the primary factor influencing zonal vegetation distribution.

Northeast China's natural vegetation belongs to the Eurasian forest-steppe plant subregion and the China-Japan forest plant subregion, with main zonal vegetation types including cold-temperate coniferous forest, temperate coniferous-broadleaved mixed forest, and warm-temperate deciduous broad-leaved forest. Located in a region sensitive to global climate change with high variability, Northeast China has been the subject of numerous studies on climate change impacts on vegetation distribution. For example, Leng Wenfang et al. used logistic regression models to predict spatial distribution changes of main constructive tree species in Northeast forests under climate scenarios, finding most species coverage might decrease. Cheng Xiaoxia also predicted that climate warming would be unfavorable for main forest types in Northeast China, with proportions of major coniferous species decreasing while broad-leaved species increase. However, these studies were based on climate projections, while current research confirms that climate change in Northeast China is already an established fact. Whether and to what extent this change has already affected the distribution of main constructive tree species remains underreported. This study addresses this question by examining impacts of climate change on forest vegetation geographical distribution in the three Northeast provinces from an eco-climatological perspective, based on thermal index ranges of zonal constructive and common species. This research benefits regional forest vegetation restoration and reconstruction and provides theoretical references for rational utilization of natural resources and biodiversity protection.

The three Northeast provinces (Heilongjiang, Jilin, and Liaoning) are bounded by the Yalu, Ussuri, and Heilongjiang rivers to the east and north, border Inner Mongolia to the west, and neighbor the Yellow Sea and Bohai Sea to the south. The region spans 118.83°–135.09°E and 53.56°–38.72°N, covering the Changbai Mountain system and Northeast Plain (including Songnen, Liaohe, and Sanjiang plains). The area has a temperate monsoon climate, with the northern Daxing' an region belonging to cold-temperate climate and other areas to temperate climate. Elevation ranges from 2-2,667 m, with mean annual temperature of -4.15-10.99°C, annual precipitation of 366.90-1,080.47 mm, and daily average sunshine hours of 5.22-8.10 h.

1. Geographic Information Data

The Digital Elevation Model (DEM) data with 90 m spatial resolution were obtained from the International Scientific Data Mirror Site of the Computer Network Information Center, Chinese Academy of Sciences (http://www.gscloud.cn). County and provincial administrative boundary data required for the study were obtained from the 1:250,000 basic geographic information data issued by the China Meteorological Administration, with topological processing to remove gaps between provincial and county boundaries. Ground observation station location data were vector data issued by the China Meteorological Administration.

2. Land Cover Type Data

Land cover type data (MCD12Q1) were obtained from NASA LPDAAC EOS (The Land Processes Distributed Active Archive Center) at 500 m spatial resolution. This product uses Terra satellite observations to describe land characteristics, with primary information extraction based on supervised decision tree classification. The dataset includes classification results from 17 different land cover classification schemes and corresponding quality information. This study selected the IGBP global vegetation classification scheme, which classifies based on the International Geosphere-Biosphere Programme (IGBP) protocol. Data for 2000 and 2013 were used, with images mosaicked and reprojected to a unified 500 m spatial resolution and geographic coordinate projection using MODIS Reprojection Tool software (MRT V4.0).

3. Meteorological Data Preprocessing

Meteorological data were obtained from daily compiled records of 98 meteorological stations in Heilongjiang, Jilin, and Liaoning provinces, including daily mean temperature and precipitation, along with station geographic locations and elevations. Climate change research must be based on reliable data; however, data inhomogeneity can arise from station relocations, observation errors, missing data, and urban heat island effects, necessitating preprocessing to minimize errors affecting analysis accuracy.

Since errors may be introduced by observation instruments, data processing, and transmission, we employed Zhai Panmao' s method for meteorological data quality control. Karl et al. noted that missing data related to time can cause errors in climate trend analysis. This study excluded stations with more than 10 days of missing data in a year (approximately >3% of annual observations).

Normality tests were conducted on daily temperature and relative humidity data for each climate zone using SPSS software, with 98.7% of daily temperature data showing approximate normal distribution (p 0.05), allowing analysis without standardization. Unlike temperature data, daily precipitation lacks gradual, continuous characteristics, so normality tests were conducted using monthly data, with most following normal distribution.

The IPCC Third Assessment Report suggests urbanization has minimal impact on global mean surface temperature records, with effects an order of magnitude smaller than observed warming values. However, Wang et al. and Zhao Zongci argued urban heat island effects do impact long-term temperature series. This study analyzed urban heat island effects by removing temperature data from cities with populations 1 million and 0.5 million based on statistical yearbook data. The resulting annual mean temperature change rates were 0.0149, 0.0126, and 0.0145°C/a respectively—differences an order of magnitude smaller than warming values—so urban heat island effects were not considered further. Missing meteorological data were interpolated using the Newton interpolation method.

4. Meteorological Data Mutation Detection

To explore potential climate change impacts on zonal vegetation distribution, we tested for temperature and precipitation mutation points in Northeast China from 1961-2014.

(1) Mann-Kendall Test: A commonly used climate mutation detection method. For original time series y, under random independence assumptions, define statistic d_k where m_i represents the count of y_i > y_j (1 j i). The mean and variance are E(d_k) and Var(d_k). Standardizing d_k yields UF_k values forming a UF curve. Applying this to the reversed series yields a UB curve; intersection points within confidence intervals indicate mutation points.

(2) Moving t-test: Tests significant differences between two random sample means. A continuous variable x of length n is divided into subsets x_1 and x_2, testing mean differences between post-year n_1 and pre-year n_2 periods. The t-statistic uses pooled variance S_p^2 as unbiased estimate. Given significance level , if |t| > t_ , the null hypothesis is rejected, indicating significant difference. Peak and valley years are identified as mutation years.

(3) Cumulative Anomaly Test: For sequence x_t, cumulative anomaly at time t is calculated as Σ(x_i - x̄). Plotting these values yields curves for trend analysis.

5. Study Area Division

Spanning cold-temperate, mid-temperate, and warm-temperate zones with complex terrain alternating between hills and plains and elevation differences up to 2,665 m, Northeast China' s three provinces may exhibit different climate trends and mutation points. Referencing China' s eco-geographical regionalization data from the Chinese Academy of Sciences' Resource and Environmental Science Data Center (http://www.resdc.cn), we tested mutation points for mean annual temperature and precipitation across seven eco-geographical subregions. This regionalization divides China into 49 eco-geographical zones based on temperature and moisture indices; the three Northeast provinces occupy seven of these zones.

6. Mutation Point Detection

Temperature: All seven eco-geographical subregions showed significant warming trends. For subregion I, UF and UB curves intersected in 1983, with cumulative anomaly tests also identifying 1983 as the mutation year. Subregion II' s temperature mutation year was 1988, consistent with previous research.

Precipitation: Unlike temperature, subregions II, III, and V showed UF values within [-1.96, 1.96], indicating no significant precipitation changes. Subregion I showed significant decline from 1966, while subregion IV showed significant increase from 1988. Overall, no obvious precipitation mutation points were detected, so this study focused only on temperature mutation impacts on vegetation distribution.

7. Vegetation Distribution Heat Index (WI)

Following Xu Wenduo's method, WI was calculated as the sum of monthly mean temperatures above 5°C. Based on species geographical distribution data, the probabilistic weighting method determined each species' thermal distribution range: PWH = 2.354X - 3.132S, where X is the mean WI and S is the standard deviation, ensuring approximately 95% of species distribution falls within the optimal thermal range.

Using detected climate mutation points as boundaries, we calculated pre- and post-mutation WI averages for each meteorological station. For subregion I (1982 mutation), 1961–1982 data calculated pre-mutation WI means; 1983–2013 data calculated post-mutation means. Subregion II (1988 mutation) used similar methods with 1961–1988 and 1989–2013 periods.

Given sparse and unevenly distributed meteorological stations, especially in mountainous terrain, limited stations cannot represent distant areas, reducing WI representativeness. To address this, we interpolated WI data using multiple linear regression with longitude, latitude, and altitude as independent variables, given their strong correlation with temperature. The regression model WI = f(long, lat, alt) was fitted (Table 2), then used to calculate WI values for all stations. Differences between fitted and actual values were interpolated to create correction surfaces, producing corrected WI values closer to actual calculations (standard error reduced by 0.13, standard deviation by 0.12).

8. Vegetation Type Distribution Changes

Pre-mutation: Temperate mixed forest had the largest suitable distribution area (55.89×10 km^2), distributed in the Songnen Plain, Xiaoxing' anling, and Changbai Mountains below 1,100 m. Post-mutation suitable area decreased to 47.22×10 km^2 (15.63% reduction), mainly contracting in the Liaohe Plain and expanding in eastern/southern Daxing' anling and Xiaoxing' anling at 400–500 m elevations.

Post-mutation increases: Warm-temperate deciduous broad-leaved forest and temperate grassland showed increased suitable areas. Warm-temperate deciduous broad-leaved forest expanded from 55.39 to 60.90×10 km^2, becoming the most widely distributed type, contracting in southern coastal areas but expanding in northern Songnen Plain and mountain slopes (Xiaoxing' anling 300–400 m, Changbai 600–800 m). Temperate grassland showed the largest increase (50.47 to 53.46×10 km^2), expanding in western/northern Liaohe Plain and southern Changbai Mountains.

Post-mutation decreases: Cold-temperate coniferous forest showed the largest reduction (46.54 to 30.91×10 km^2), contracting in northern Songnen and Sanjiang plains while expanding in Daxing' anling at 700–900 m. Alpine tundra had the smallest suitable area, decreasing from 27.91 to 11.71 km^2. Subalpine dwarf forest decreased from 104.79 to 71.80 km^2, mainly in Daxing' anling at 700–900 m.

9. Geographic Center Changes

All vegetation types' geographic centers shifted pre- to post-mutation. Alpine tundra and cold-temperate coniferous forest moved northwest; others moved northeast. The largest displacement was subalpine dwarf forest in the southern region (135.44 km northeast). The smallest was southern alpine tundra (1.39 km). Temperate mixed forest moved 71.80 km; other types moved 22.20–71.47 km.

10. Projected vs. Actual Distribution Comparison

Lacking field survey data, we compared projected distributions with MCD12Q1 classifications: evergreen coniferous forest vs. MCD12Q1 needleleaf forest, temperate mixed forest vs. mixed forest, warm-temperate deciduous broad-leaved forest vs. broadleaf forest, and temperate grassland vs. grassland. We extracted overlapping areas between 2000 and 2013 classifications, calculating areas of increase, decrease, and stability.

Results: Cold-temperate coniferous forest and temperate mixed forest showed no common decrease areas. Their common increase areas (4.82% and 21.46% respectively) were in eastern Daxing' anling and mountain slopes. Warm-temperate deciduous broad-leaved forest had no common decrease area; its 20.23% increase area was in northern Songnen Plain and mountain slopes.

Temperate grassland increased 8.03% in Xiaoxing' anling and Changbai Mountains, while decreasing 18.72% in western/northern Liaohe Plain. Most area (70.24%) remained stable, but climate change has clearly impacted vegetation distribution.

11. Conclusions

Using Northeast China as the study area, we investigated climate change impacts on suitable distribution areas of zonal vegetation based on thermal indices. Using 98 meteorological stations' daily data and MCD12Q1 land cover data for validation, we found: (1) Temperature mutation points were 1982 for Daxing' anling and 1988 for other regions; no precipitation mutation points were detected. (2) A linear regression equation between WI and longitude, latitude, and altitude effectively interpolated data for areas lacking observations. (3) Post-mutation vegetation types remained unchanged, but suitable distribution areas shifted significantly.

12. Discussion

Post-mutation, temperate mixed forest' s suitable area decreased, contracting in Liaohe Plain while expanding in Daxing' anling and Xiaoxing' anling slopes. Warm-temperate deciduous broad-leaved forest became the most extensive type, expanding in northern Songnen Plain and mountain slopes. Cold-temperate coniferous forest showed the largest decrease. Temperate grassland had the greatest increase. Comparison with actual distributions showed 4.82–21.46% of areas matched projected increases, confirming climate change impacts.

These results align with previous studies: Cheng Xiaoxia predicted climate warming would reduce coniferous and increase broad-leaved species proportions, consistent with our findings. Our detection of temperate mixed forest encroaching into eastern Daxing' anling validates predictions that climate change may transform Daxing' anling forests to mixed forest dominance. Leng Wenfang' s prediction of decreased coverage for cold-temperate coniferous species matches our results. Yan Hanbing' s prediction of northwestward drift for larch and birch aligns with our finding of northwestward center shifts for cold-temperate coniferous forest.

Limitations: (1) Our conclusions are based on temperature as the primary factor, though precipitation, human activities, and other factors also influence vegetation. However, temperature dominates vegetation dynamics in Northeast China, giving our single-factor approach reference value. (2) MCD12Q1 classification accuracy without ground validation affects results. (3) Species migration lags behind climate change and is affected by dispersal capacity and human intervention, which we didn' t consider—likely explaining why only 4.82–21.46% of projected changes matched actual distributions.

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