Research Article

Effect of Climatic Factors on Stem Biomass and Carbon Stock of *Larix gmelinii* and *Betula platyphylla* in Daxing'anling Mountain of Inner Mongolia, China

Dilawar Khan,¹ Muhammad Atif Muneer,² Zaib-Un- Nisa ,^{3,4} Sher Shah,¹ Muhammad Amir ,¹ Sajjad Saeed,¹ Saleem Uddin,³ Muhammad Zeeshan Munir,³ Gao Lushuang ,¹ and Huaguo Huang ¹

¹College of Forestry, Beijing Forestry University, No. 35 Qinghua East Road, Haidian District, 100083 Beijing, China

²College of Grassland Science, Beijing Forestry University, No. 35 Qinghua East Road, Haidian District, 100083 Beijing, China

³School of Biological Sciences and Technology, Beijing Forestry University, No. 35 Qinghua East Road, Haidian District, 100083 Beijing, China

⁴Sorghum Research Sub-Station, Dera Ghazi Khan, Punjab, Pakistan

Correspondence should be addressed to Gao Lushuang; gaolushuang@bjfu.edu.cn and Huaguo Huang; huaguo_huang@bjfu.edu.cn

Received 23 May 2019; Revised 27 July 2019; Accepted 27 August 2019; Published 3 October 2019

Academic Editor: Herminia García Mozo

Copyright © 2019 Dilawar Khan et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Climate change has become a global concern for scientists as it is affecting almost every ecosystem. *Larix gmelinii* and *Betula platyphylla* are native and dominant forest species in the Daxing'anling Mountains of Inner Mongolia, playing a major role in carbon sequestration of this region. This study was carried out to assess the effect of climate variables including precipitation and temperature on the biomass of *Larix gmelinii* and *Betula platyphylla* forests. For this purpose, we used the climate-sensitive stem biomass allometric model for both species separately to find out accurate stem biomass along with climatic factors from 1950 to 2016. A total of 66 random plots were taken to attain the data from this study area. *Larix gmelinii* and *Betula platyphylla* stem biomass have a strong correlation with annual precipitation ($R^2 = 0.86$, $R^2 = 0.71$, $R^2 = 0.79$, and $R^2 = 0.59$) and maximum temperature ($R^2 = 0.76$, $R^2 = 0.64$, $R^2 = 0.67$, and $R^2 = 0.52$). However, annual minimum temperature ($R^2 = 0.58$, $R^2 = 0.43$, $R^2 = 0.55$, and $R^2 = 0.46$) and annual mean temperature ($R^2 = 0.40$, $R^2 = 0.22$, $R^2 = 0.36$, and $R^2 = 0.19$) have a relatively negative impact on tree biomass. Therefore, we suggest that both species have a very strong adaptive nature with climatic variation and hence can survive under drought and high-temperature stress climatic conditions.

1. Introduction

Increasing carbon concentration in the atmosphere and its link with global warming has attracted worldwide attention of the scientists [1]. Previous studies have suggested that carbon sink in the terrestrial ecosystem has a crucial effect on global warming [2, 3]. Forest ecosystems cover more than 4.1×10^9 hectares of the total land and store approximately 638 billion tons of carbon [4]. Forest ecosystem stores approximately 80% of carbon in the aboveground biomass and 40% in the belowground biomass [5]. There is a strong relationship between the nature of the forest ecosystem and climatic factors

[6, 7]. It has been reported that forest carbon sink can mitigate the global warming that may affect the climate at daily, seasonal, and decades basis through carbon sequestration [8]. Forests play a key role in balancing global warming due to their carbon absorption capacity which exhibits spatial and temporal dynamics [9]. Forest carbon greatly influences the climatic variables and carbon sequestration potential [6, 10]. Therefore, the trend of forest carbon sequestration potential and its response to climate variables can provide a pure vision of ecosystem mechanism feedback to climate change.

Forest can provide a low-cost option to mitigate climate change [11]. However, the climatic factors, especially the

temperature and precipitation [12], have significantly influenced tree biomass [13] and composition of forest vegetation [14]. Climate change also affects the soil water content to regulate the process of reparation, decomposition of soil organic compound, photosynthesis, and tree growth [15, 16]. Therefore, it is necessary to study the dynamics of forest vegetation and its relationship with the climate factors including precipitation and temperature variables in order to understand the quality of a terrestrial forest ecosystem and maintain its optimal functioning [17, 18]. Numerous studies explored the carbon sink and tree biomass of forest trees with different models in China. Some of them used the mature forest to estimate stem biomass [19]. However, many others estimated the carbon storage and tree biomass from the logistic equation at the species level [20, 21]. *Larix gmelinii* and *Betula platyphylla* are native species of northeastern Daxing'anling Mountain, Inner Mongolia, China [22]. Other species of this area are *Mongolica*, *Pinus clausa*, and *Chilopsis linearis* [23]. During the previous decade, many research studies have predicted that *Larix gmelinii* population would decrease in China, in the context of future climate changes induced as a result of rise in the annual temperature [24], monthly temperatures [25, 26], and annual precipitation [27]. Forest biomass is influenced by both temperature and precipitation [22, 24]. High-intensity light and salinity also affect forest population growth negatively [28]. Tree ring is the study to predict future climate variation and perceive the longitudinal pattern of trees' biomass growth [26, 29]. As a result, tree growth examination and assessment can increase our understanding and can predict the possible fluctuations in forests biomass and carbon sequestration potential [30, 31].

Climate change generates a great deal of uncertainty, which remains a key factor in the regulation of the biomass of forests. Despite its impactful role in the carbon sink, very limited and basic research has been carried out to evaluate the response of potential biomass changes and carbon storage of *Larix gmelinii* and *Betula platyphylla* to the climate change [29, 31–33]. In this paper, we studied *Larix gmelinii* and *Betula platyphylla* forests stem along with the climatic factors in Daxing'anling Mountains, Inner Mongolia, China. The main objective of this study was to find out a correlation of climatic variables including annual precipitation and annual temperature variables with the stem biomass and carbon sequestration of *Larix gmelinii* and *Betula platyphylla* forest.

2. Materials and Methods

2.1. Study Area. This study was conducted in the mountains of Daxing'anling (E'71°18.19.10-W'126°41.52, N'47°48.35-S53°33.12) located in northeastern China and connected with Heilongjiang Provinces from east to west (Figure 1). This area exhibits the temperate continental climate of the climbing zone cold of the monsoon having long and cold winter, while hot and short summer. It has a total area of 83000 km² with an altitude of 3556 m (11667 ft.). Annual rainfall varies between 350 mm and 500 mm, mostly received from May to October [34]. Annual mean temperature varies

from January to July +20°C to −28°C with the wind speed of 1106 miles per hour. Forest ecosystem of this region has severe climatic conditions although there is still a difference between the northern and southern parts due to the adaptability of flora with climatic change.

2.2. Field Data Collection. Field surveys were conducted in 2017 to collect data from the study area using circular plots operation design. A total of 66 plots were randomly taken, and each plot has a radius of 17.84 m to find out biomass and carbon stock of *Larix gmelinii* and *Betula platyphylla*. Among the total, 39 plots have *Larix gmelinii* and 27 plots have *Betula platyphylla* species. Tree diameter at breast height (DBH) and tree height (H) was measured and recorded on the LINTAB5 and statistically verified COFECHA software.

2.3. Climatic Data Collection. We collected the climatic factors data like annual precipitation, annual maximum temperature, annual minimum temperature, and annual mean temperature from 1950 to 2016 (Figure 2). Data of these parameters were downloaded from the (0.5°) grid data using KNMI Climate Explorer (<https://climexp.knmi.nl>). These selected climate stations were uniformly distributed in the northeastern region of Inner Mongolia, China. Climatic data of each sample plot were downloaded from its coordinate with the help of the global positioning system (GPS) with an accuracy of 1 meter, which was used to extract geographical data of each sampling plot. To evaluate the accuracy of interpolated values, we use regression analysis between interpolated and measured temperature variables and precipitation. Climatic data were divided into two categories on the basis of precipitation such as <470 mm or >470 mm for *Larix gmelinii* and <430 mm or >430 mm *Betula platyphylla*.

2.4. Stem Biomass. Biomass is a very important part of the forest ecological system. Quantifying accurate tree biomass is essential to study carbon storage along with the effect of climatic gradients such as precipitation and temperature variables [35, 36]. Although directly measuring the actual weight of tree components such as branch, stem, root, and foliage is the perfect method, it is destructive, time-consuming, and a costly method. Therefore, stem biomass model is considered the best method to estimate tree biomass [37, 38]. To find out above tree biomass usually, tree models are used having a diameter at breast height and tree height [39–44]. In this paper, forest stem biomass and carbon storage for broadleaved and coniferous forests were calculated separately. The following common allometric equations were used:

$$\text{Larix gmelinii equation } W_s = 0.025(D^2H)^{0.96}, \quad (1)$$

$$\text{Betula platyphylla equation } W_s = 0.1193(D^2H)^{0.8372}, \quad (2)$$

FIGURE 1: Sketch plots map of geographic division of Daxing'anling Mountain, northeastern Mongolia, China.

FIGURE 2: Spatial distribution of climatic factors for annual precipitation, annual maximum temperature, annual minimum temperature, and annual mean temperature from 1950 to 2010, from the sampling plots for *Larix gmelinii* and *Betula platyphylla* in Daxing'anling Mountain, Inner Mongolia, China.

where " W_s " is the stem biomass in kg, " D " is the tree diameter at breast height, and " H " is the height of the tree. The coefficient of determination (R^2) is 0.025 and 0.1193,

respectively. Total stem biomass per plot was summed for all plots to average biomass and carbon stock of the individual plot. Then, we converted it to tons per hectare (tons/ha).

TABLE 1: Mean and standard deviation of stem biomass, carbon stock, precipitation, and temperature variables on precipitation >470 mm and <470 mm of *Larix gmelinii* across the geographic regions of Daxing'anling Mountain of Inner Mongolia, China.

<i>Larix gmelinii</i>	Statistical variables	Biomass (tons/ha)	Carbon stock (tons/ha)	Precipitation (mm)	Maximum temperature	Minimum temperature
PPT <470	Mean	75	37.5	442.8	4.6	-8.4
	Standard deviation	50.2	25.1	25.5	1.5	3.5
PPT >430	Mean	33.51	16.76	483.74	3.43	-10.87
	Standard deviation	16.78	8.39	11.1	0.81	1.97

2.5. Data Analysis. During data analysis, the correlation analysis, one of the most common and important statistical method, was used to find out the relationship between two variables [45]. For both variables, x and y were used to find the correlation coefficient and calculated as follows:

$$r_{xy} = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^n (y_i - \bar{y})^2}}, \quad (3)$$

where x_i represents the value of x for sample I , y_i represents the value of y for sample I , and n is the number of samples. However, $\bar{x}$ is the average of all x_i and $\bar{y}$ is the average of all y_i . Commonly testing the significance of the correlation coefficient of variables uses the t distribution [45]. To find out the relation of variables (origin 2016), was used to detect the statistical difference between biomass and climatic gradients, such as temperature variables and precipitation. The coefficient of determination (R^2) and the probability level (P) were used to determine the fit quality of the curves. The level of the significant ($R^2 = 0.05$) was used in the analysis of variance (ANOVA). To check the variable relationship accuracy, we used linear regression analysis. All statistical analyses were done with Origin 2016 on Windows 10.

3. Results

3.1. Amount of Stem Biomass, Carbon Stock, and Climate Factor Parameters for *Larix gmelinii*. *Larix gmelinii* forests showed a huge variation in biomass and carbon stock at precipitation (<470 mm). The average stem biomass 75 ± 50.2 tons/ha, carbon stock 37.5 ± 25.1 tons/ha, precipitation 442.8 ± 25.5 mm, maximum temperature $4.6 \pm 1.5^\circ\text{C}$, and minimum temperature $-8.4 \pm 3.5^\circ\text{C}$, while the corresponding variation on precipitation at >470 mm, stem biomass ton/ha 33.51 ± 16.78 , carbon stock 16.76 ± 8.39 tons/ha, precipitation 483.74 ± 11.10 mm, maximum temperature $3.43 \pm 0.81^\circ\text{C}$, and minimum temperature $-10.87 \pm 1.97^\circ\text{C}$. The highest and lowest values of biomass and carbon stock along climatic factors found in the Inner Mongolia forests are presented in Table 1.

3.2. Correlations of Stem Biomass with Climatic Gradients, Temperature Variables, and Precipitation with *Larix gmelinii*. Stem biomass comparisons with 66-year period of climatic variables showed the strongest coefficient correlations ($p < 0.05$) (Figure 3). Stem biomass response of *Larix gmelinii* to precipitation at >470 mm with climatic variables was as follows: positively correlated with precipitation ($R^2 = 0.86$) and maximum temperature ($R^2 = 0.76$), as shown

in Figures 3(a) and 3(b), respectively, and negatively correlated with minimum temperature ($R^2 = 0.58$) and mean temperature ($R^2 = 0.40$), as shown in Figures 3(c) and 3(d), respectively.

In case of precipitation at <470 mm, stem biomass of *Larix gmelinii* had a strong significant correlation with annual precipitation and maximum temperature, i.e., $R^2 = 0.71$ and $R^2 = 0.64$, respectively (Figures 4(a) and 4(b)). However, biomass was negatively correlated with minimum temperature ($R^2 = 0.43$) and mean temperature ($R^2 = 0.22$) (Figures 4(c) and 4(d)).

3.3. Amount of Stem Biomass, Carbon Stock, and Climate Factor Parameters for *Betula platyphylla*. *Betula platyphylla* forests presented huge variation in their biomass and carbon stock at precipitation <430. The average stem biomass is 126 ± 31.8 tons/ha, carbon stock 67 tons/ha 66.9 ± 25.0 , annual precipitation 384.6 ± 40.4 mm, annual maximum temperature $4.5 \pm 1.3^\circ\text{C}$, and annual minimum temperature $-9.5 \pm 1.9^\circ\text{C}$. While the corresponding variation at the precipitation is >430 mm, the average stem biomass was 140.9 ± 43.7 tons/ha, carbon stock 70.5 ± 21.9 , annual precipitation 452.3 ± 15.3 mm, annual maximum temperature $2.7 \pm 0.3^\circ\text{C}$, and annual minimum temperature $-13.1 \pm 0.7^\circ\text{C}$. The highest and lowest values of biomass and carbon stock along climatic factors found in the Inner Mongolia forests are presented in Table 2.

3.4. Correlations of Stem Biomass with Climatic Gradients, Temperature Variables, and Precipitation with *Betula platyphylla*. Stem biomass response of *Betula platyphylla* to climatic factors from 1950 to 2016 was calculated to determine the correlation along with climatic factors (Figure 5). In case of precipitation at >430 mm, stem biomass of *Betula platyphylla* had a strong significant correlation with annual precipitation and maximum temperature, i.e., $R^2 = 0.79$ and $R^2 = 0.67$, respectively (Figures 5(a) and 5(b)). However, biomass was negatively correlated with minimum temperature ($R^2 = 0.55$) and mean temperature ($R^2 = 0.36$) (Figures 5(c) and 5(d)).

In addition to the correlation of *Betula platyphylla* stem biomass with <430 mm precipitation, positive correlation was found for biomass with annual precipitation ($R^2 = 0.59$) and annual maximum temperature ($R^2 = 0.52$) (Figures 6(a) and 6(b)), while negative correlation was found with annual minimum temperature ($R^2 = 0.46$) and annual mean temperature ($R^2 = 0.19$) (Figures 6(c) and 6(d)).

FIGURE 3: Relationship between *Larix gmelinii* stem biomass (SB) with >470 mm (PPT) along climatic gradients from 1950 to 2016: (a) annual precipitation; (b) annual maximum temperature; (c) annual minimum temperature; (d) annual mean temperature.

FIGURE 4: Continued.

FIGURE 4: Relationship between *Larix gmelinii* stem biomass (SB) with <470 mm (PPT) along with climatic gradients from 1950 to 2016: (a) annual precipitation; (b) annual maximum temperature; (c) annual minimum temperature; (d) annual mean temperature.

TABLE 2: Mean and standard deviation of stem biomass, carbon stock, precipitation, and temperature variables on precipitation >430 mm and <430 mm of *Betula platyphylla* across the geographic regions of Daxing'anling Mountain of Inner Mongolia, China.

<i>Betula platyphylla</i>	Statistical variables	Biomass (tons/ha)	Carbon stock (tons/ha)	Precipitation (mm)	Maximum temperature	Minimum temperature
PPT <470	Mean	126	66.9	384.6	4.5	-9.5
	Standard deviation	31.8	25	40.4	1.3	1.9
PPT >430	Mean	140.9	70.5	452.3	2.7	-13.1
	Standard deviation	43.7	21.9	15.3	0.3	0.7

FIGURE 5: Continued.

FIGURE 5: Relationship between *Betula platyphylla* stem biomass (SB) with >430 mm (PPT) along climatic gradients since 1950–2016: (a) annual precipitation; (b) annual maximum temperature; (c) annual minimum temperature; (d) annual mean temperature.

FIGURE 6: Relationship between *Betula platyphylla* stem biomass (SB) with >430 mm (PPT) along climatic gradients from 1950 to 2016: (a) annual precipitation; (b) annual maximum temperature; (c) annual minimum temperature; (d) annual mean temperature.

4. Discussion

The cold and temperate forests were extensively harvested in Daxing'anling Mountain of China from 1960 to 2000. Now young- and middle-aged strands of *Larix gmelinii* and *Betula platyphylla* are dominating trees in this region. These trees play not only an important role in the carbon budget but also host rich biodiversity. Our results showed that the biomass of *Larix gmelinii* and *Betula platyphylla* is positively correlated with the annual maximum temperature and annual precipitation. Similar results were reported in the previous finding [46] acknowledging the important role of the temperature and precipitation in the tree growth.

The concentration of carbon storage and stem biomass was not similar to climatic factors in *Larix gmelinii* and *Betula platyphylla*. This resulted in dissimilarity in the growth of the individual tree species. Long and sunny summer days increase the rate of photosynthesis, which eventually affect the tree biomass positively. Moreover, the high temperature and precipitation also increase the rate of litter decomposition and nitrogen mineralization which improve the nutrient availability [47, 48]. Annual precipitation affects the air and soil, while maximum temperature influences the water content and soil through evaporation [49]. It shows a positive relation between biomass, annual precipitation, and annual maximum temperature [50]. High temperature and precipitation in the growing season increase tree biomass value [51]. In addition, more sugar is stored in the tree for winter, which is available for tree growth until next following summer [52]. Besides this, the maximum temperature at the beginning of the growing season in the northeastern China could accelerate the snow melting process, due to which more soil water content is available for tree growth [53].

We also found that annual minimum temperatures and annual mean temperatures negatively affected the tree growth of *Larix gmelinii* and *Betula platyphylla* across climatic factors, particularly during the cold and short seasons. Our study further showed that the annual minimum temperature and annual mean temperature during cold season were the main factors that limit the growth of *Larix gmelinii* and *Betula platyphylla* species. Our results consistently matched with the previous findings [46]. A study indicated that annual minimum temperature and annual mean temperature of the previous year and current year had a negative effect on tree biomass. Tree growth is regulated by many factors, such as water, temperature, and nutrients, and it was also found that biomass was well influenced by the current soil moisture regime and amount of storage compound [54] same like that at the end of winter hot months when temperature starts increasing, which also increases the utilization of stored carbohydrates [55]. This study showed that wet winters annual minimum temperature and annual mean temperature have a relatively weak negative impact on tree biomass. The possible reason for that is high snowfall weather during the winter season, which slows the snow melting process affecting tree growth and biomass [56]. This is probably because the quantity of precipitation and mean temperature in the humid climatic region is very appropriate

for tree growth in the drought-resistant tree species particularly in the wettest quarter of growing season [57]. The study also predicts that tree height also decreases the uncertainty of the stem biomass estimation [58]. The spontaneous change of humidity, soil, species composition, and solar radiations also affect biomass growth [59, 60].

In northeastern Daxing'anling Mountains, Inner Mongolia, China, the annual maximum temperature of the wettest season is moderately high and it has a high amount of precipitation in the growing season. This supports tree growth as well and has a positive relation with tree biomass [57]. Our result also showed that the annual precipitation and maximum temperature have a positive correlation on the growth of *Larix gmelinii* and *Betula platyphylla*. *Betula platyphylla* and *Larix gmelinii* are naturally drought-resistant tree species growing in northeastern China [57]. Therefore, they can easily maintain their survival at high temperature and precipitation. Such condition cannot inhibit the physiological processes of the tree and stem biomass [61].

In addition, a high quantity of rainfall and humidity can cause loss of nutrients overflowing [62]. For more accurate precision of tree biomass prediction, incorporating different stand levels of the tree and climate variables could be better [63, 64]. That is why in the current study, we select only a simple tree biomass model along with two climatic factors for final stem biomass prediction.

5. Conclusion

We divided precipitation of Daxing'anling Mountains, Inner Mongolia, from 1950 to 2016, into two parts on basis of precipitation for *Betula platyphylla* and *Larix gmelinii* species and then checked the effect of precipitation and temperature variables. The result of our study indicates that the annual maximum temperature and annual precipitation had a positive correlation with stem biomass. However, the distribution of *Betula platyphylla* along with the most predominant species *Larix gmelinii* has a negative correlation with the annual minimum temperature and annual mean temperature. In the overall influence of the last 66 years, climate factors predict that *Betula platyphylla* and *Larix gmelinii* have more tolerance to future climate change.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors would like to thank the Key Project of National Key Research and Development Plan (2017YFC0504003-1) and Beijing Forestry University for supporting this study.

References

- [1] D. S. Schimel, J. I. House, K. A. Hibbard et al., "Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems," *Nature*, vol. 414, no. 6860, pp. 169–172, 2001.
- [2] R. A. Houghton, "Balancing the global carbon budget," *Annual Review of Earth and Planetary Sciences*, vol. 35, no. 1, pp. 313–347, 2007.
- [3] S. Piao, J. Fang, P. Ciais et al., "The carbon balance of terrestrial ecosystems in China," *Nature*, vol. 458, no. 7241, pp. 1009–1013, 2009.
- [4] J.F.W.E.C.O.F.A. Meeting and World Health Organization, *Safety Evaluation of Certain Food Additives*, World Health Organization, Geneva, Switzerland, 2006.
- [5] R. K. Dixon, A. M. Solomon, S. Brown, R. A. Houghton, M. C. Trexler, and J. Wisniewski, "Carbon pools and flux of global forest ecosystems," *Science*, vol. 263, no. 5144, pp. 185–190, 1994.
- [6] M. Cao and F. I. Woodward, "Dynamic responses of terrestrial ecosystem carbon cycling to global climate change," *Nature*, vol. 393, no. 6682, pp. 249–252, 1998.
- [7] R. A. Pielke Jr., C. Landsea, M. Mayfield, J. Layer, and R. Pasch, "Hurricanes and global warming," *Bulletin of the American Meteorological Society*, vol. 86, no. 11, pp. 1571–1576, 2005.
- [8] A. Käb, V. Kaufmann, R. Ladstädter, and T. Eiken, "Rock glacier dynamics: implications from high-resolution measurements of surface velocity fields," in *Proceedings of the 8th International Conference on Permafrost*, Zurich, Switzerland, July 2003.
- [9] V. Bellassen and S. Luyssaert, "Carbon sequestration: managing forests in uncertain times," *Nature*, vol. 506, no. 7487, pp. 153–155, 2014.
- [10] Z. Ma, C. Peng, Q. Zhu et al., "Regional drought-induced reduction in the biomass carbon sink of Canada's boreal forests," *Proceedings of the National Academy of Sciences*, vol. 109, no. 7, pp. 2423–2427, 2012.
- [11] M. Amir, X. Liu, A. Ahmad, S. Saeed, A. Mannan, and M. A. Muneer, "Patterns of biomass and carbon allocation across chronosequence of chir pine (*Pinus roxburghii*) forest in Pakistan: inventory-based estimate," *Advances in Meteorology*, vol. 2018, Article ID 3095891, 8 pages, 2018.
- [12] R. Zhou, W. Li, Y. Zhang et al., "Responses of the carbon storage and sequestration potential of forest vegetation to temperature increases in yunnan province, SW China," *Forests*, vol. 9, no. 5, p. 227, 2018.
- [13] E.-S. Weng and G.-S. Zhou, "Modeling distribution changes of vegetation in China under future climate change," *Environmental Modeling & Assessment*, vol. 11, no. 1, pp. 45–58, 2006.
- [14] R. T. Watson, M. C. Zinyowera, and R. H. Moss, "Climate Change 1995," *Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*, 1996.
- [15] C. Y. Miao, L. Yang, X. H. Chen, and Y. Gao, "The vegetation cover dynamics (1982–2006) in different erosion regions of the Yellow River Basin, China," *Land Degradation & Development*, vol. 23, no. 1, pp. 62–71, 2012.
- [16] S. Yang, Y. Cornet, M. Erpicum, and B. Tychon, "Studying interactions between climate variability and vegetation dynamic using a phenology based approach," *International Journal of Applied Earth Observation and Geoinformation*, vol. 20, pp. 20–32, 2013.
- [17] D. D. Breshears, N. S. Cobb, P. M. Rich et al., "Regional vegetation die-off in response to global-change-type drought," *Proceedings of the National Academy of Sciences*, vol. 102, no. 42, pp. 15144–15148, 2005.
- [18] X. Chen and H. Wang, "Spatial and temporal variations of vegetation belts and vegetation cover degrees in Inner Mongolia from 1982 to 2003," *Acta Geographica Sinica*, vol. 64, no. 1, pp. 84–94, 2009, in Chinese.
- [19] Y. Liu, G. Yu, Q. Wang, Y. Zhang, and Z. Xu, "Carbon carry capacity and carbon sequestration potential in China based on an integrated analysis of mature forest biomass," *Science China Life Sciences*, vol. 57, no. 12, pp. 1218–1229, 2014.
- [20] B. Xu, Z. Guo, S. Piao, and J. Fang, "Biomass carbon stocks in China's forests between 2000 and 2050: a prediction based on forest biomass-age relationships," *Science China Life Sciences*, vol. 53, no. 7, pp. 776–783, 2010.
- [21] N. Guo, D. Wen, J. Zhu et al., "Vegetation carbon sequestration in Chinese forests from 2010 to 2050," *Global Change Biology*, vol. 23, no. 4, pp. 1575–1584, 2017.
- [22] J. Zhang, Y. Zhou, G. Zhou, and C. Xiao, "Structure and composition of natural gmelin larch (*Larix gmelinii* var. *gmelinii*) forests in response to spatial climatic changes," *PLoS One*, vol. 8, no. 6, Article ID e66668, 2013.
- [23] R.-E. Fan, K. W. Chang, C.-J. Hsieh, X.-R. Wang, and C.-J. Lin, "LIBLINEAR: a library for large linear classification," *Journal of Machine Learning Research*, vol. 9, pp. 1871–1874, 2008.
- [24] F. Li, "Responses of Betula geographical distribution to future climate change: a simulation study," *The Journal of Applied Ecology*, vol. 17, no. 12, pp. 2255–2260, 2006.
- [25] X. Cheng and X. Yan, "Effects of global climate change on forest succession in Daxing'anling of Northeast China," *Chinese Journal of Ecology*, vol. 26, no. 8, pp. 1277–1284, 2007.
- [26] X. Cheng and X. Yan, "Effects of climate change on typical forest in the northeast of China," *Acta Ecologica Sinica*, vol. 28, pp. 534–543, 2008.
- [27] W. Leng, H.-S. He, R.-C. Bu, and Y.-M. Hu, "Sensitivity analysis of the impacts of climate change on potential distribution of three larch (*Larix*) species in Northeastern China," *Chinese Journal of Plant Ecology*, vol. 31, no. 5, pp. 825–833, 2007.
- [28] J. Dong, M. Sun, J. E. Purcell, Y. Chai, Y. Zhao, and A. Wang, "Effect of salinity and light intensity on somatic growth and podocyst production in polyps of the giant jellyfish *Nemopilema nomurai* (Scyphozoa: rhizostomeae)," *Hydrobiologia*, vol. 754, no. 1, pp. 75–83, 2015.
- [29] V. I. Kharuk, K. J. Ranson, S. T. Im, and M. L. Dvinskaya, "Response of *Pinus sibirica* and *Larix sibirica* climate change in southern Siberian alpine forest-tundra ecotone," *Scandinavian Journal of Forest Research*, vol. 24, no. 2, pp. 130–139, 2009.
- [30] H. E. Ranson, W. K. Lauenroth, I. C. Burke, and D. P. Coffin, "Ecological responses of dominant grasses along two climatic gradients in the Great Plains of the United States," *Journal of Vegetation Science*, vol. 7, no. 6, pp. 777–788, 1996.
- [31] C. Dulamsuren, M. Hauck, M. Khishigjargal, H. H. Leuschner, and C. Leuschner, "Diverging climate trends in Mongolian taiga forests influence growth and regeneration of *Larix sibirica*," *Oecologia*, vol. 163, no. 4, pp. 1091–1102, 2010.
- [32] N. Devi, F. Hagedorn, P. Moiseev et al., "Expanding forests and changing growth forms of Siberian larch at the Polar Urals treeline during the 20th century," *Global Change Biology*, vol. 14, no. 7, pp. 1581–1591, 2008.
- [33] A. H. Lloyd, A. G. Bunn, and L. Berner, "A latitudinal gradient in tree growth response to climate warming in the Siberian

- taiga," *Global Change Biology*, vol. 17, no. 5, pp. 1935–1945, 2011.
- [34] T. Kajimoto, Y. Matsuura, A. Osawa et al., "Size-mass allometry and biomass allocation of two larch species growing on the continuous permafrost region in Siberia," *Forest Ecology and Management*, vol. 222, no. 1–3, pp. 314–325, 2006.
- [35] D. A. Clark, S. Brown, D. W. Kicklighter, J. Q. Chambers, J. R. Thomlinson, and J. Ni, "Measuring net primary production in forests: concepts and field methods," *Ecological Applications*, vol. 11, no. 2, pp. 356–370, 2001.
- [36] X. Wang, H. Bi, F. Ximenes, J. Ramos, and Y. Li, "Product and residue biomass equations for individual trees in rotation age *Pinus radiata* stands under three thinning regimes in new south wales, Australia," *Forests*, vol. 8, no. 11, p. 439, 2017.
- [37] H. Bi, J. Turner, and M. J. Lambert, "Additive biomass equations for native eucalypt forest trees of temperate Australia," *Trees*, vol. 18, no. 4, pp. 467–479, 2004.
- [38] L. Dong, L. Zhang, and F. Li, "Developing additive systems of biomass equations for nine hardwood species in Northeast China," *Trees*, vol. 29, no. 4, pp. 1149–1163, 2015.
- [39] S. Chen and S. A. Billings, "Representations of non-linear systems: the NARMAX model," *International Journal of Control*, vol. 49, no. 3, pp. 1013–1032, 1989.
- [40] D. K. Cheng, *Field and Wave Electromagnetics*, Pearson Education India, Delhi, India, 1989.
- [41] R. G. Wagner and M. T. Ter-Mikaelian, "Comparison of biomass component equations for four species of northern coniferous tree seedlings," *Annals of Forest Science*, vol. 56, no. 3, pp. 193–199, 1999.
- [42] B. R. Parresol, "Additivity of nonlinear biomass equations," *Canadian Journal of Forest Research*, vol. 31, no. 5, pp. 865–878, 2001.
- [43] J. Wirth, "Solution representations for a wave equation with weak dissipation," *Mathematical Methods in the Applied Sciences*, vol. 27, no. 1, pp. 101–124, 2004.
- [44] R. R.-P. Gertrudix, G. Montero, and M. D. Rio, "Biomass models to estimate carbon stocks for hardwood tree species," *Forest Systems*, vol. 21, no. 1, pp. 42–52, 2012.
- [45] R. Watts and J. Zimmerman, "Positive accounting theory," Prentice-Hall, New Jersey, NJ, USA, 1986.
- [46] W. Qian and A. Qin, "Spatial-temporal characteristics of temperature variation in China," *Meteorology and Atmospheric Physics*, vol. 93, no. 1–2, pp. 1–16, 2006.
- [47] J. Huang, J. C. Jacques, Y. Bergeron, B. Dennele, F. Berninger, and M. P. Girardin, "Radial growth response of four dominant boreal tree species to climate along a latitudinal gradient in the eastern Canadian boreal forest," *Global Change Biology*, vol. 16, no. 2, pp. 711–731, 2010.
- [48] X. Zhang, M. X. Cui, Y. J. Ma, T. Wu, Z. J. Chen, and W. H. Ding, "Larix gmelinii tree-ring width chronology and its responses to climate change in Kuduer, Great Xing'an Mountains," *The Journal of Applied Ecology*, vol. 21, no. 10, pp. 2501–2507, 2010.
- [49] Y.-F. Zheng and J. Hoefs, "Effects of mineral precipitation on the sulfur isotope composition of hydrothermal solutions," *Chemical Geology*, vol. 105, no. 4, pp. 259–269, 1993.
- [50] J. Wu, *Theory and Applications of Partial Functional Differential Equations*, Springer Science & Business Media, Berlin, Germany, 2012.
- [51] P. Zhou, B. W. Ang, and K. L. Poh, "A survey of data envelopment analysis in energy and environmental studies," *European Journal of Operational Research*, vol. 189, no. 1, pp. 1–18, 2008.
- [52] V. C. LaMarche, "Paleoclimatic Inferences from Long Tree-Ring Records: intersite comparison shows climatic anomalies that may be linked to features of the general circulation," *Science*, vol. 183, no. 4129, pp. 1043–1048, 1974.
- [53] K. Yu, A. H. Y. Wong, K. W. Y. Yau, Y. S. Wong, and N. F. Y. Tam, "Natural attenuation, biostimulation and bioaugmentation on biodegradation of polycyclic aromatic hydrocarbons (PAHs) in mangrove sediments," *Marine Pollution Bulletin*, vol. 51, no. 8–12, pp. 1071–1077, 2005.
- [54] H. C. Fritts, D. G. Smith, J. W. Cardis, and C. A. Budelsky, "Tree-ring characteristics along a vegetation gradient in northern Arizona," *Ecology*, vol. 46, no. 4, pp. 393–401, 1965.
- [55] H. Su, J. C. Axmacher, B. Yang, and W. Sang, "Differential radial growth response of three coexisting dominant tree species to local and large-scale climate variability in a subtropical evergreen broad-leaved forest of China," *Ecological Research*, vol. 30, no. 4, pp. 745–754, 2015.
- [56] E. A. Vaganov, M. K. Hughes, A. V. Kirdyanov, F. H. Schweingruber, and P. P. Silkin, "Influence of snowfall and melt timing on tree growth in subarctic Eurasia," *Nature*, vol. 400, no. 6740, pp. 149–151, 1999.
- [57] L. Fu, W. Sun, and G. Wang, "A climate-sensitive above-ground biomass model for three larch species in northeastern and northern China," *Trees*, vol. 31, no. 2, pp. 557–573, 2017.
- [58] T. R. Feldpausch, J. Lloyd, S. L. Lewis et al., "Tree height integrated into pantropical forest biomass estimates," *Biogeosciences*, vol. 9, no. 8, pp. 3381–3403, 2012.
- [59] J. Nascimbene, R. Benesperi, G. Brunialti et al., "Patterns and drivers of β -diversity and similarity of *Lobaria pulmonaria* communities in Italian forests," *Journal of Ecology*, vol. 101, no. 2, pp. 493–505, 2013.
- [60] Z. Ma, B. Sandel, and J.-C. Svenning, "Phylogenetic assemblage structure of North American trees is more strongly shaped by glacial-interglacial climate variability in gymnosperms than in angiosperms," *Ecology and Evolution*, vol. 6, no. 10, pp. 3092–3106, 2016.
- [61] W. Xiao-Ying, Z. Chun-Yu, and J. Qing-Yu, "Impacts of climate change on forest ecosystems in Northeast China," *Advances in Climate Change Research*, vol. 4, no. 4, pp. 230–241, 2013.
- [62] Y. Chen, X. Song, Z. Zhang, P. Shi, and F. Tao, "Simulating the impact of flooding events on non-point source pollution and the effects of filter strips in an intensive agricultural watershed in China," *Limnology*, vol. 16, no. 2, pp. 91–101, 2015.
- [63] W.-S. Zeng and S.-Z. Tang, "Modeling compatible single-tree aboveground biomass equations for masson pine (*Pinus massoniana*) in southern China," *Journal of Forestry Research*, vol. 23, no. 4, pp. 593–598, 2012.
- [64] L. Dong, L. Zhang, and F. Li, "Developing two additive biomass equations for three coniferous plantation species in Northeast China," *Forests*, vol. 7, no. 7, p. 136, 2016.