

# Climate Factors of Vapour Pressure and Diurnal Temperature Influenced on Radial Growth of Scots Pine in Northeastern Mongolia

Sumaira Yasmeen<sup>1\*</sup>, Farah Perveen<sup>2</sup>, Inam Ullah<sup>3</sup>

<sup>1</sup>Center for Ecological Research, Northeast Forestry University, Harbin, China

<sup>2</sup>College of Economics and Management Northeast Forestry University, Harbin, China

<sup>3</sup>College of Wildlife and Protected Area, Northeast Forestry University, Harbin, China

Email: \*sumairagul@foxmail.com

**How to cite this paper:** Yasmeen, S., Perveen, F. and Ullah, I. (2019) Climate Factors of Vapour Pressure and Diurnal Temperature Influenced on Radial Growth of Scots Pine in Northeastern Mongolia. *Open Journal of Ecology*, 9, 401-412.  
<https://doi.org/10.4236/oje.2019.99026>

**Received:** August 18, 2019

**Accepted:** September 13, 2019

**Published:** September 16, 2019

Copyright © 2019 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

To find out the optimum conditions of growth in Scots pine (*Pinus sylvestris* var. *mongolica*), we analyzed the radial growth response relationship to climate factors in boreal forests. We present growth response from 3-sites Mg (Mangui), KYH (kheyihe), NM (Nanmu) from central Daxing'an mountains. Drought observed in 1920s-1930s years. We analyzed growth response from 1920-2016. Results specified that growth of scots pine did not vary with variation in sites. We measure the influence of vapour pressure and mean maximum and mean minimum diurnal temperature have been shown by correlations of different growing seasons. Most of warm temperature during June to September and growth of Scots pine show a significantly positive increase during winter season. Overall inconsistency in climate conditions of Daxing'an mountains due to Atlantic and Pacific oceans, affects the Asian monsoon and alternatively changes the local temperature and precipitation and vapour pressure and increases the drought severity.

## Keywords

Climate Variables, Scots Pine, Vapour Pressure, Radial Growth, Diurnal Temperature

## 1. Introduction

The forest tree mechanism to response to atmospheric drought and soil is poorly known, especially in relation to carbon allocation, how the trees modified their architecture above and below ground in response to variations in climate condi-

tions. *Pinus sylvestris* var. *mongolica* is the most extensive conifer as it can be spread throughout Eurasia as on the western Mediterranean to the Russian Far East. Such huge distribution includes a wide array of climates, with the severe and frequent summer drought of southern Iberian Peninsula and extremely cold winters of north eastern Siberia [1]. World climate conditions are placing greater pressure on forests ecosystems from almost all over the globe [2]. In case of Scots pine, growth can be endorsed by increased temperature in northern and upper areas where production is basically cold-limited [3] [4]. However, there is most evidence that indicates Scots pine growth is also influenced in cold constrained sites due to aggravated soil moisture deficit which linked to increasing demand for evapotranspiration or decreased in precipitation during growing season [5] [6]. Such contrasting influence of minimum temperature and drought brings uncertainty about productivity and vigor of species throughout the range and specifically in cold-dry environment [7], besides other dry environments, particularly warmer areas of Mediterranean, where Scots pine also subjected to winter and warm climate [8].

In this consideration, the comparison of low temperature (*i.e.*, Siberian forest-steppe) and warm climate (*i.e.*, Mediterranean mountains) has a simultaneous effect on Scots pine growth which is of particular interest to predict the climate change influences on conifer species [9]. A variety of range of methodological approaches are used to determine tree growth climate relations, but dendroclimatological techniques are valuable in determining long term variations in forest productivity in perspective of climate relationship with variables like precipitations and warmer temperature [10].

Mongolian Scots pine (*Pinus sylvestris* var. *mongolica*), an environmental diversity of Scots pine, is naturally dispersed in the Daxing'anling mountains of China ( $>50^{\circ}10'_{-}$  -  $53^{\circ}33'_{N}$ ,  $121^{\circ}11'_{-}$  -  $127^{\circ}10'_{E}$ ), in Honghuaerji of the Hulunbeier sandy plains of China ( $47^{\circ}35'_{-}$  -  $48^{\circ}36'_{N}$ ,  $118^{\circ}58'_{-}$  -  $120^{\circ}32'_{E}$ ) and parts of Russia and Mongolia ( $46^{\circ}30'_{-}$  -  $53^{\circ}59'_{N}$ ,  $118^{\circ}00'_{-}$  -  $130^{\circ}08'_{E}$ ) (Zhu *et al.*, 2008; Zheng *et al.*, 2012). As of its strong nature and ability to tolerate dry environment, so in 1950 it is first time introduced to condense wind speed and increase sand fixation in the Zhanggutai region, the south east sandy land. So, it becomes the most important species for reforestation in north east China [11] [12]. Tree rings are widely used to evaluate the climate variation effects on forests [13]. Most dendrochronological studies focus on radial growth patterns to infer the long-term variations in tree performance. There is a remarkable expansion in desertification across Mongolia due to climate warming at global scale, and it has potential influence on Mongolian environmental health and economy conditions in current years. So Mongolian government has applied reforestation plans. *Pinus sylvestris* L. *mongolica* has a significant role in ecology and Mongolian economy [14] [15].

The objective of this study was to measure the climate influence on long term changes in tree radial growth, to investigate tree survival in drought conditions, and to check the influence of diurnal temperature and potential vapor pressure

effects on tree growth. It is anticipated that the results of this study might be useful for management of forest plantation with respect to growth conditions of *Pinus Sylvestris L. mongolica*.

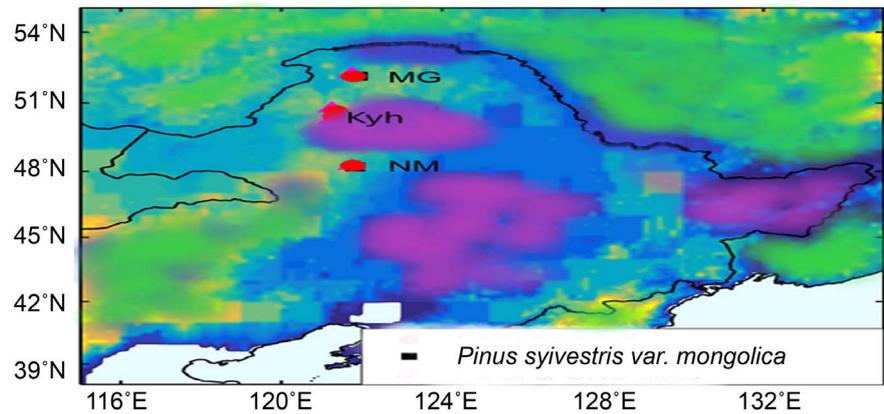
## 2. Material and Methods

### 2.1. Study Sites

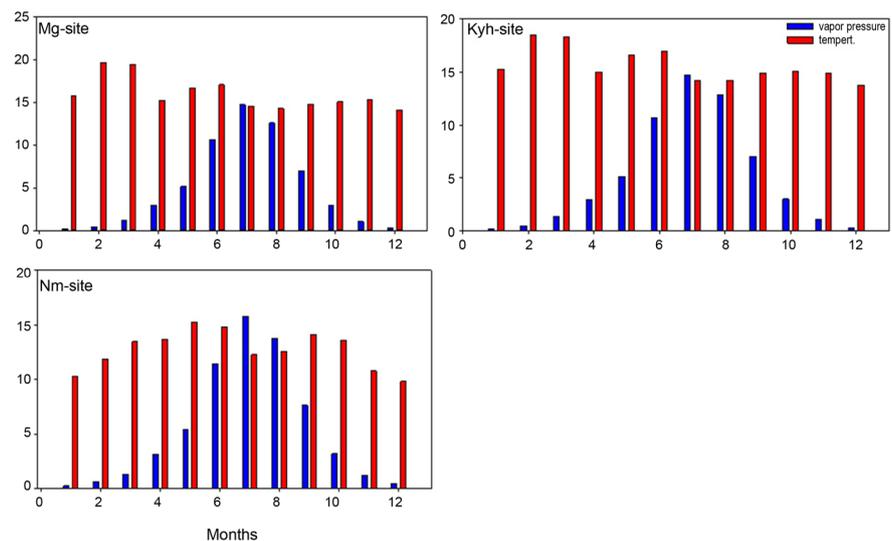
The Daxing'an Mountain is an important natural geographic barrier, in north east inner Mongolia and northwest Heilongjiang province, it is the middle part between semiarid inland area on northwest side and the Pacific Ocean. It is also known to be the transition zone semi-arid region to semi humid [16]. South east side of this area is blocked by mountains so, the summer monsoon cannot enter in this area. The eastern side of this region is humid and western side is more dried. Summer climate is explained by periodic invasions of warm and humid air from low elevation oceans, while winter season is invaded cold air masses on high latitudes. This study was done on high latitude in Daxing'an mountains. The forests are most dominant by Dahurian larch and Scots pines. Soils are mostly brown coniferous and dark brown forest peat [17]. Meteorological data were collected from KNMI 3.01. The annual mean vapor pressure (59.4, 59.8, 64.1) respectively at Mg, Kyh, and Nm sites and annual mean diurnal temperature (16, 15.6, 12.7) respectively at 3-sites. The coldest month is January and maximum hotness in Month of July. Annual rainfall accounts for 68% in June to August. Relative humidity high in growing season. Spring and early summer face severe drought conditions frequently. This area also has an average high burning rate in China [18].

### 2.2. Tree Ring Data

Tree ring cores of *Pinus Sylvestris var. mongolica* were selected from three-sites which are infrequently distributed across the Daxing'an Mountain. We collected two cores per tree in May-2016. Total of 160 cores was selected from living old trees from breast height at 1.3 m. Each tree which selected for sample collection tried to avoid influence of visible stand disturbances (including windstorm, animal and human disturbances or fire damage). The average distance is more than 100 km between selected sample sites. All cores were air dried, mounted, surfaced and cross-dated following standard techniques of dendrochronology [19] [20]. Ring widths were measured with a precision of 0.001 mm using a Velmex measuring system (Velmex, Inc., Bloomfield, NY, USA). The cross-dating quality was checked by COFECHA program (Holmes, 1983). Successively, the age-related trends were removed by fitting a cubic smoothing spline with a 50% frequency response cut-off at two-thirds of the series length using the ARSTAN program [19]. Autocorrelation was separated by autoregressive modeling, and each site chronology was measured using a bi-weighted robust mean [19]. In **Figure 1** map shows the distribution of *Pinus sylvestris v. mongolica* along the Daxing'an Mountain. **Figure 2** indicates the variation in monthly climate data of vapor



**Figure 1.** Sampling sites set up across the natural distribution area of *Pinus sylvestris* woodlands in Daxing'an Mountain north east China.

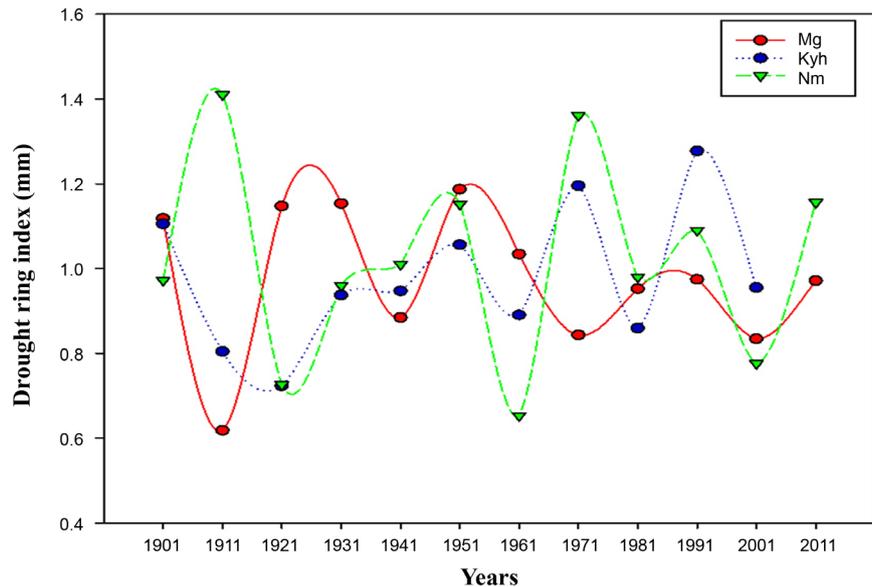


**Figure 2.** Variation in diurnal temperature and vapor pressure from 1901-2016. Monthly mean maximum-minimum temperature and vapor pressure along 3 sites Mangui (Mg), kheyihe (Kyh) and Nanmu (NM).

pressure and mean maximum and minimum diurnal temperature variations from period 1901-2016 along 3-sites Mangui (Mg) kheyihe (KYH) and nan (NM). There is higher diurnal temperature from Jan-Apr and maximum vapor pressure during May-Jul. In **Figure 3**, we make correlation between tree ring index and with the years there is a maximum increase in growth trend at Nm site during 1901-1911 and 1971-1980 the decline in growth trend.

### 2.3. Climate Data and Statistical Analyses

Large scale Climate data were used from 1901-2016 collected from the National Meteorological Information center e.g., gridded diurnal temperature and Vapor pressure, and soil moisture indices were downloaded from <http://climexp.knmi.nl/>. The gridded climate data has much coherency and homogeneity than station data. Pearson correlation was conducted to climate



**Figure 3.** The growth pattern of tree ring index series in Daxing'an mountain in north east China, comparison of 3 sites red color (Mg) site, blue line (Kyh) and green line indicates (Nm) site growth series from 1901-2016.

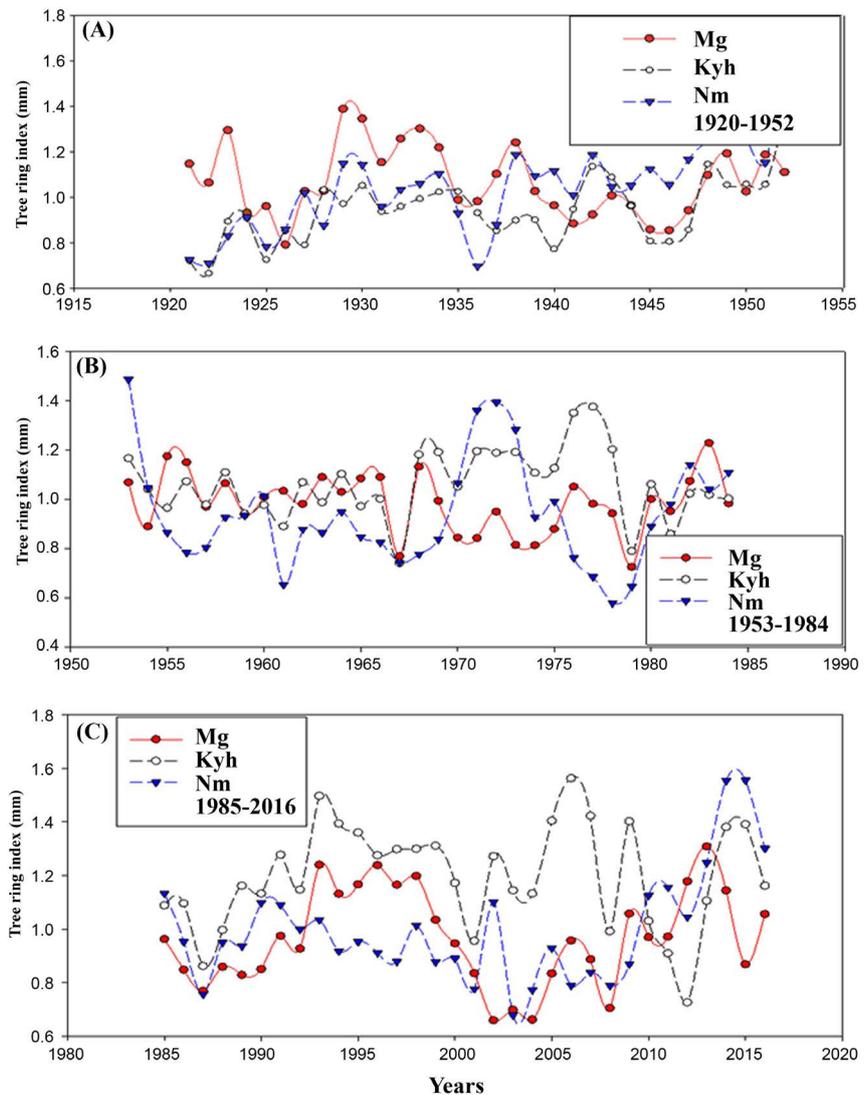
growth relationship. And used growth trends of summer and winter diurnal temperature were made. To determine climatic variables that control the radial growth of *P. sylvestris* mean monthly vapor pressure and mean diurnal temperature were compared with the local chronologies for each sampling sites. The sampled chronologies make correlations with the meteorological chronologies which neare to the analyzed sites. The periods were explored in Summer from June-September and winter season from November-January in **Figure 4**. Stem diameter at breast height was measured by using scattered plot with latitude. **Table 1** indicates the sampling site information, along with latitude.

### 3. Results

When building up a large chronology it is most important to reminisce the fluctuation in growth with the climate conditions in chronology when large area being summarized by different growing conditions. The Daxing'an mountains tree chronologies along 3-elevations have various ranging gradients, its highest peak range 2035-meters. It was formed about 200 - 145 million years ago. The site information is given in **Table 1**. **Figure 2** indicates the spatiotemporal variations and drought patterns in Daxing'an mountains and north inner Mongolia. The relevant chronology and statistic information's are listed in **Table 2**. **Figure 3** represents the tree growth of *Pinus Sylvestris var. mongolica* from 1901-2016. We clearly observed variations in growth trends there is a significant increase in growth 1920-1930 and then decline in curve 2<sup>nd</sup> growth increase interval from 1991-2001. **Figure 4** represents the growth trend of *Pinus Sylvestris var. mongolica*. We divide it into 3-periods 1921-1952, 1953-1984, 1985-2016. There is an obvious increase in growth trend during 1925 in Mg site in **Figure 4(A)** and

**Table 1.** Site description and statistical characteristic of the *Pinus sylvestris* var. *mongolica* dendrochronology in the Daxing'an Mountains.

	Sites	Elevation (m)	Latitude (°E)	Longitude (°N)	Annual mean diurnal temperature (°C)	Annual meant total vapour pressure (hpa)
<i>P. sylvestris</i>	MG	699.9	52.14	121.79	16	59.4
<i>var. mongolica</i>	KYH	719.4	50.48	122.4	15.6	59.8
	NM	652.7	48.26	121.83	12.7	64.1



**Figure 4.** Mean intra-annual course of the DRI for three periods in the 20th century. At all 3 sites (A) represents 1921-1952, (B) from 1953-1984 and (C) represents the 1985-2016 growth trends.

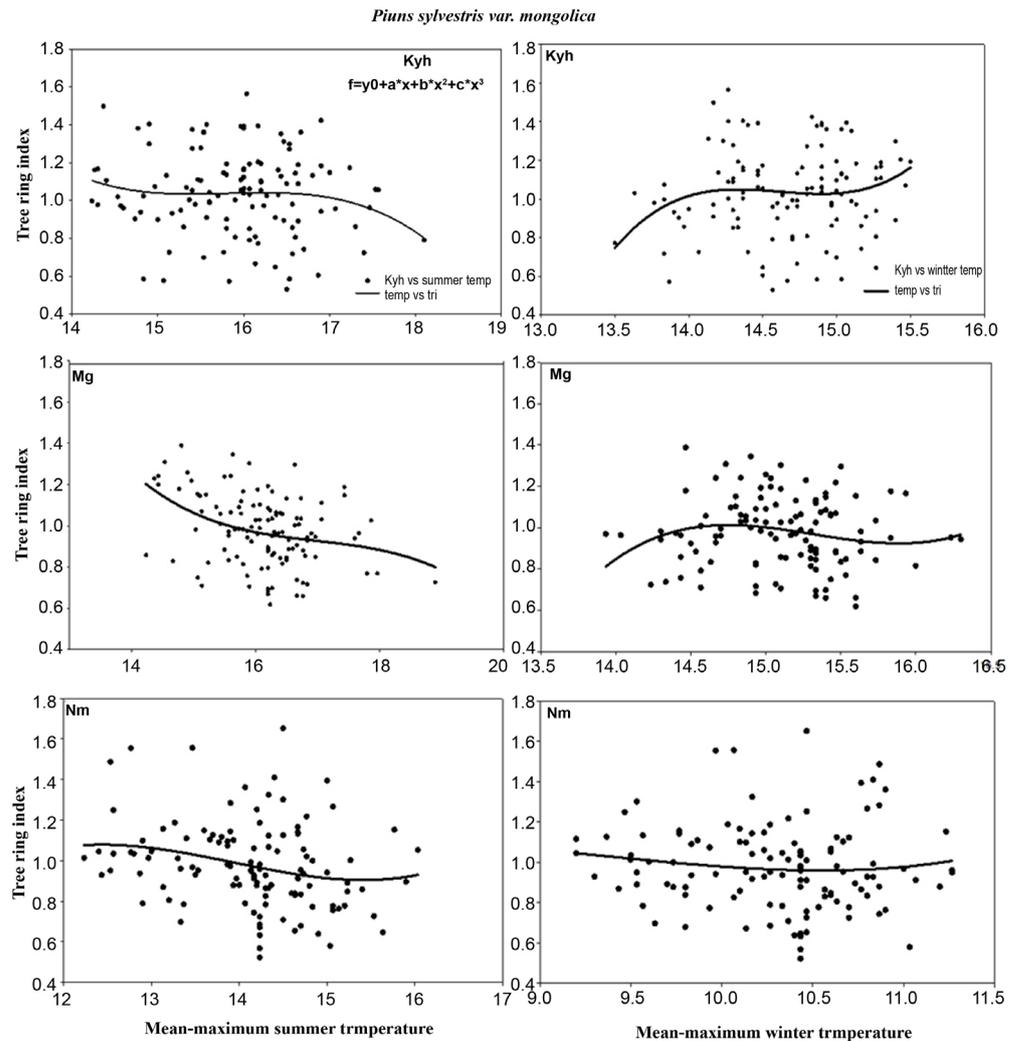
1952 period at Nm site in **Figure 4(C)**. During 1975-1980 increasing trend of growth for MG and Kyh in **Figure 4 (B)** but decline in growth trend at Nm site.

**Figure 5** we explain the scatter plot with diurnal temperature of summer and winter seasons and we use growth trends to indicate the growth rate at 3-sites.

**Table 2.** Internal statistic properties of scots pine along with region differences at 3-sites Mg, Kyh, Nm along Daxing'an Mountain, alphabetic letter indicates the LSD-significant differences by multiple comparison.

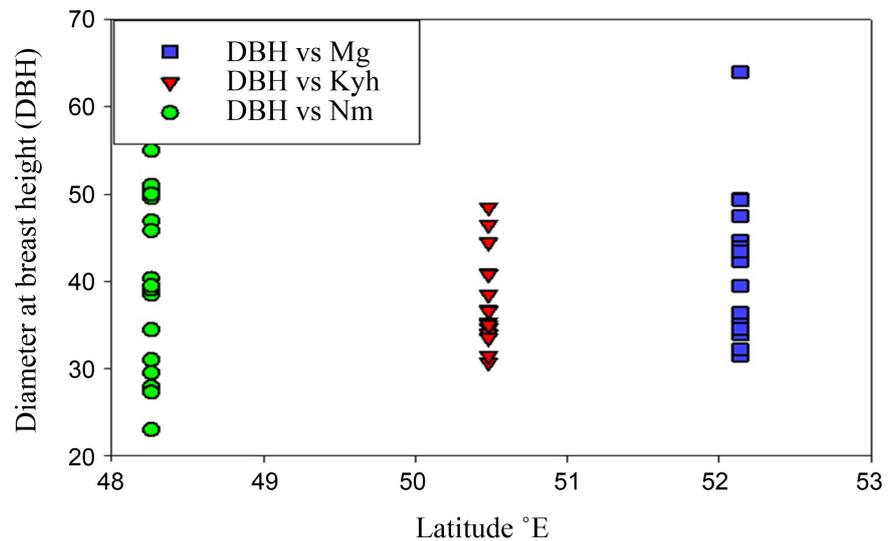
Sites	Species	Mean	Std. Deviation	Minimum	Maximum	Significant.
Mg	Pinus	0.9761	0.17055	0.62	1.39	a
Kyh	sylvestris	1.0353	0.22060	0.53	1.56	ac
Nm	Var. mongolica	0.9771	0.21450	0.52	1.65	c

Letter a' and c' represents the significance level between groups.



**Figure 5.** Influences of the mean max-mini diurnal temperature during winter and summer season on cambial growth of scots pine.

There is an obvious difference at Kyh site between winter and summer season and growth trends in summer season there is growth trend first remain stable then start to decline but in winter season there is an obvious increase in growth. at Mg site also increase in trend in winter diurnal temperature. at Nm site its growth remains stable in winter season. In **Figure 6**, we measured diameter at breast height along elevation latitude at 3-sites Mg, Kyh, Nm.



**Figure 6.** Correlation between latitude and stem diameter at breast (DBH) height in Daxing'an Mountains.

#### 4. Discussion

Scots pine is an under the effects of drought stress and considered to be a drought tolerant, so it is thought to be a main climate limiting factors which reduce its growth in semi humid and semi-arid regions such as in Mongolian Plateau Daxing'an Mountains [21] [22] [23]. In previous studies, it also suggests that radial growth of scots pine is influenced by humidity, precipitation in these regions, and most of dendroclimatic studies based on reconstruction of hydroclimatic history [21] [24]. In these areas' radial growth for growing season mostly in July-September as in **Figure 1**. On the other hand, a significant increase in radial growth of non-growing season due to temperature also observed. It is probable protect of dormant buds in winter high temperature from frost damage [25]. The positive growth response with spring temperature could be due to early snow melting process, which supply the early spring water, and eventual tree growth rate stimulated [26] [27]. This infrequent drought response relatively due to humid climate and might be northern study site, where positive effect is strongly greater than negative effect [28]. Similar drought response also visible in most of reconstruction studies in Qilian Mountains (Sun and Liu, 2013) and also same case of drought stress in western Tian Shan Mountain, China [29].

Scots pine usually has usually typical drought response patterns, it shows positive response to precipitation and negative response to temperature increasing [21] [22]. Actually, this typical response to drought patterns also found in other drought or wetness tree ring analysis in other studies [30] [31]. In this study correlation between tree ring index and diurnal (Maximum-Minimum) temperature it clearly indicates that summer temperature shows negative or decline in growth response and winter temperature indicates the positive growth response in **Figure 4**. A significant positive growth response in winter temperature supported moisture as the main limiting factor for *Pinus Sylvestris* growth.

The climate (drought) response also observed in Dahurian larch a most important conifer specie in this area [32]. Late summer temperature influence on nutrient storage capacity which affects the sprouting in next spring. This alternatively affects the growing ratio of sprouting and tree ring diameter in next year's [33]. The results of the analysis revealed that *Pinus Sylvestris* revealed the consistent increase in growth pattern in moist conditions. These relationships recommended that specific drivers which affect variation in dry-wet conditions in Daxing'an mountains. Among these differences the most prominent differences in Daxing'an mountain in central Mongolia. Similar studies were investigated by [34] which reported that different patterns of dry and wet conditions under global warming using models and observations. [35] found that increase in moisture related to quick warming. Though the reasons for divergence should be further studied, it might be associated to the diverse response to phase shift [36] [37].

## 5. Conclusion

Drought severity conditions most obvious during 1920-1930 in Daxing'an Mountains rather than other areas. In addition, most of growth series indicates that Daxing'an Mountain has gotten more warm and wet since the late 1970s. This is not only the case of Daxing'an Mountain especially in all transit zones. Our results may be not accurate due to in-adequate spatiotemporal distribution of tree ring data collection in this area. Overall, drought inconsistency in Daxing'an mountains and its consequential affects on surrounding areas due to climate oscillations of the Atlantic and Pacific oceans (e.g., AMO, NAO, PDO, and SNAO ENSO). These climate oscillations at large scale occur due to variations in Asian monsoon and lead to dry and wet fluctuations in the Daxing'an mountains.

## Acknowledgements

This work was supported by the National Key Research and Development Program of China (2016YFA0600800), the National Natural Science Foundation of China (41877426), the Fundamental Research Funds for the Central Universities (2572019CP15), and the Open Fund of Ecological-Meteorological Innovation Laboratory of China Meteorological Administration (stqx2018zd02). We thank Jinsheng Han, Zhenjing Sun and Zecheng Chen for their help in sampling. We also thank the staff of the sampled Forestry Bureaus for their assistance in the field.

## Conflicts of Interest

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

## References

- [1] Carlisle, A. and Brown, A.H.F. (1968) *Pinus sylvestris* L. *Journal of Ecology*, **56**, 269-307. <https://doi.org/10.2307/2258078>

- [2] Allen, C.D., Breshears, D.D. and McDowell, N.G. (2016) On Underestimation of Global Vulnerability to Tree Mortality and Forest Die-Off from Hotter Drought in the Anthropocene. *Ecosphere*, **6**, 1-55. <https://doi.org/10.1890/ES15-00203.1>
- [3] Kullman, L. and Kjällgren, L. (2010) Holocene Pine Tree-Line Evolution in the Swedish Scandes: Recent Tree-Line Rise and Climate Change in a Long-Term Perspective. *Boreas*, **35**, 159-168. <https://doi.org/10.1080/03009480500359137>
- [4] Briffa, K.R., *et al.* (2008) Trends in Recent Temperature and Radial Tree Growth Spanning 2000 Years across Northwest Eurasia. *Philosophical Transactions of the Royal Society of London*, **363**, 2271-2284. <https://doi.org/10.1098/rstb.2007.2199>
- [5] Lloyd, A.H. and Bunn, A.G. (2007) Responses of the Circumpolar Boreal Forest to 20th Century Climate Variability. *Environmental Research Letters*, **2**, Article ID: 045013. <https://doi.org/10.1088/1748-9326/2/4/045013>
- [6] Dũthorn, E., *et al.* (2016) Ecological and Climatological Signals in Tree-Ring Width and Density Chronologies along a Latitudinal Boreal Transect. *Scandinavian Journal of Forest Research*, **31**, 1-26. <https://doi.org/10.1080/02827581.2016.1181201>
- [7] Matías, L. and Jump, A.S. (2012) Interactions between Growth, Demography and Biotic Interactions in Determining Species Range Limits in a Warming World: The Case of *Pinus sylvestris*. *Forest Ecology & Management*, **282**, 10-22. <https://doi.org/10.1016/j.foreco.2012.06.053>
- [8] Julio Camarero, J., *et al.* (2015) Know Your Limits? Climate Extremes Impact the Range of Scots Pine in Unexpected Places. *Annals of Botany*, **116**, 917. <https://doi.org/10.1093/aob/mcv124>
- [9] Babst, F., *et al.* (2017) Improved Tree-Ring Archives Will Support Earth-System Science. *Nature Ecology & Evolution*, **1**, Article ID: 0008. <https://doi.org/10.1038/s41559-016-0008>
- [10] Andreu, L., *et al.* (2010) Climate Increases Regional Tree-Growth Variability in Iberian Pine Forests. *Global Change Biology*, **13**, 804-815.
- [11] Jiao, S. (1989) Structure and Function of Mongolian Pine Plantation for Sand Fixation in Zhanggutai. Liaoning Science and Technology Press, Shenyang. (In Chinese)
- [12] Zhu, J.-J., *et al.* (2003) Comparison of Stand Structure and Growth between Artificial and Natural Forests of *Pinus sylvestris* var. *mongolica* on Sandy Land. *Journal of Forestry Research*, **14**, 103-111. <https://doi.org/10.1007/BF02856774>
- [13] Shestakova, T., *et al.* (2017) Warming Effects on *Pinus sylvestris* in the Cold-Dry Siberian Forest-Steppe: Positive or Negative Balance of Trade? *Forests*, **8**, 490. <https://doi.org/10.3390/f8120490>
- [14] Sternberg, T. (2008) Environmental Challenges in Mongolia's Dryland Pastoral Landscape. *Journal of Arid Environments*, **72**, 1294-1304. <https://doi.org/10.1016/j.jaridenv.2007.12.016>
- [15] Sukhbaatar, G. (2011) Growth of Scotch Pine (*Pinus sylvestris* L.) Plantation in Northern Mongolia. *Journal of Agricultural Science and Technology*, **1**, 1205-1210.
- [16] Zhao, H.L., *et al.* (2002) Boundary Line on Agro-Pasture Zigzag Zone in North China and Its Problems on Eco-Environment. *Advance in Earth Sciences*, **17**, 739-747.
- [17] Xu, H. (1998) Daxing'an Mountains Forests in China. Science Press, Beijing.
- [18] Li, W.L., Zhang, D.Y. and Zhang, L.J. (2009) Risk Assessment and Zoning of Meteorological Disaster in Heilongjiang Province. *Arid Land Geography*, **32**, 754-760.
- [19] Cook, E. and Kairiukstis, L. (1990) Methods of Dendrochronology: Applications in

the Environmental Sciences. Kluwer Academic Publishers, Dordrecht.

- [20] Lamb, H.H. and Gray, B.M. (1978) Tree Rings and Climate. By H. C. Fritts. London, New York and San Francisco, Academic Press, 1976. Pp. xiii+567 (Including 19 pp. Bibliography, 15 pp. Glossary of Terms + Author and Subject Indexes), 12 Photographs, 161 Diagrams and Maps, 28 Tables. Price £16.00 (\$35.00). *Quarterly Journal of the Royal Meteorological Society*, **104**, 236-237.  
<https://doi.org/10.1002/qj.49710443923>
- [21] Bao, G., *et al.* (2015) Drought Variability in Eastern Mongolian Plateau and Its Linkages to the Large-Scale Climate Forcing. *Climate Dynamics*, **44**, 717-733.  
<https://doi.org/10.1007/s00382-014-2273-7>
- [22] Davi, N.K., *et al.* (2006) Extension of Drought Records for Central Asia Using Tree Rings: West-Central Mongolia. *Journal of Climate*, **19**, 288-299.  
<https://doi.org/10.1175/JCLI3621.1>
- [23] Pederson, N., *et al.* (2013) Three Centuries of Shifting Hydroclimatic Regimes across the Mongolian Breadbasket. *Agricultural & Forest Meteorology*, **178-179**, 10-20. <https://doi.org/10.1016/j.agrformet.2012.07.003>
- [24] Liu, Y., *et al.* (2009) Precipitation Reconstruction from Hailar Pine (*Pinus sylvestris* var. *mongolica*) Tree Rings in the Hailar Region, Inner Mongolia, China Back to 1865 AD. *Palaeogeography Palaeoclimatology Palaeoecology*, **282**, 81-87.  
<https://doi.org/10.1016/j.palaeo.2009.08.012>
- [25] Chen, F., *et al.* (2012) Tree Ring-Based Winter Temperature Reconstruction for Changting, Fujian, Subtropical Region of Southeast China, since 1850: Linkages to the Pacific Ocean. *Theoretical & Applied Climatology*, **1092**, 141-151.  
<https://doi.org/10.1007/s00704-011-0563-0>
- [26] J'rgen, H., *et al.* (2015) Winter Warming as an Important Co-Driver for *Betula Nana* Growth in Western Greenland during the Past Century. *Global Change Biology*, **21**, 2410-2423. <https://doi.org/10.1111/gcb.12913>
- [27] Zhu, L., *et al.* (2017) A 211-Year Growing Season Temperature Reconstruction Using Tree-Ring Width in Zhangguangcai Mountains, Northeast China: Linkages to the Pacific and Atlantic Oceans. *International Journal of Climatology*, **37**, 3145-3153.  
<https://doi.org/10.1002/joc.4906>
- [28] Wang, X.C. and Song, L.P. (2011) Climate-Tree Growth Relationships of *Pinus sylvestris* var. *mongolica* in the Northern Daxing'an Mountains, China. *Chinese Journal of Plant Ecology*, **35**, 294-302. <https://doi.org/10.3724/SP.J.1258.2011.00294>
- [29] Feng, C., *et al.* (2015) Tree-Ring Recorded Hydroclimatic Change in Tianshan Mountains during the Past 500 Years. *Quaternary International*, **358**, 35-41.  
<https://doi.org/10.1016/j.quaint.2014.09.057>
- [30] Li, J., *et al.* (2017) Moisture Increase in Response to High-Altitude Warming Evidenced by Tree-Rings on the Southeastern Tibetan Plateau. *Climate Dynamics*, **48**, 649-660. <https://doi.org/10.1007/s00382-016-3101-z>
- [31] Liu, Y., *et al.* (2017) Tree-Ring-Width-Based PDSI Reconstruction for Central Inner Mongolia, China over the Past 333 Years. *Climate Dynamics*, **48**, 867-879.  
<https://doi.org/10.1007/s00382-016-3115-6>
- [32] Wang, X.C. and Lv, S.-N. (2012) Tree-Ring Reconstructions of January-March Streamflow in the Upper Nenjiang River since 1804, China. *Arid Land Geography*, **4**, 002.
- [33] Henttonen, H. (1984) The Dependence of Annual Ring Indices on Some Climatic Factors. *Suomen Metsätieteellinen Seura*, **186**, 1-38.

<https://doi.org/10.14214/aff.7633>

- [34] Dai, A. (2013) Increasing Drought under Global Warming in Observations and Models. *Nature Climate Change*, **3**, 52-58. <https://doi.org/10.1038/nclimate1633>
- [35] Qiang, L., *et al.* (2015) Divergence of Tree-Ring-Based Drought Reconstruction between the Individual Sampling Site and the Monsoon Asia Drought Atlas: An Example from Guancen Mountain. *Science Bulletin*, **19**, 1688-1697. <https://doi.org/10.1007/s11434-015-0889-6>
- [36] Ma, Z. (2007) The Interdecadal Trend and Shift of Dry/Wet over the Central Part of North China and Their Relationship to the Pacific Decadal Oscillation (PDO). *Chinese Science Bulletin*, **52**, 2130-2139. <https://doi.org/10.1007/s11434-007-0284-z>
- [37] Wang, X., Li, Z. and Ma, K. (2014) Decreased Sensitivity of Tree Growth to Temperature in Southeast China after the 1976/77 Regime Shift in Pacific Climate. *Sains Malaysiana*, **43**, 9-19.