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Interspecific Differences of Stem Diameter Variations in Response to Water Conditions for Six Tree Species in Northeast China

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Abstract: It is important to understand the response of stem diameter variations in dominant tree species to water conditions in Northeast China. The results will provide basic information for scientific predictions of the future development trend of temperate forests in the eastern mountainous area of northeast China. We employed a high-precision dendrometer to continuously monitor the stem radial changes of six dominant tree species in temperate forests in northeast China from 15 April to 24 October in 2021. Precipitation significantly promoted the tree stem diameter increment. The increment of stem diameter in *Juglans mandshurica* Maxim., *Quercus mongolica* Fisch. and *Betula platyphylla* Suk. had a significantly positive correlation with cumulative precipitation. Correlation analysis revealed that the stem radial change (SRC) of six tree species was positively correlated with precipitation (Pre) and relative humidity (RH), and negatively correlated with water vapor pressure deficit (VPD), indicating that the diameter growth of the six tree species was mainly restricted by water conditions. Under drought stress, the stem radial growth rate of the six tree species slowed down, the growth duration decreased and the tree water deficit (TWD) value increased, while there were obvious interspecific differences. Therefore, water conditions limited the stem radial growth of the six tree species, while each tree species had a different response to drought stress.

Keywords: dendrometer; drought stress; stem radial variation; tree water deficit; water conditions

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1. Introduction

In recent years, the climate in the northern hemisphere has shown a warming and drying trend [1]. Changes in global radiation, precipitation and temperature caused by climate change have affected forest tree species composition and forest productivity [2,3]. Temperate forests absorb about 400 Tg C per year and are important terrestrial carbon sinks [4]. However, this carbon sink role has become uncertain for the future due to the unknown effects of climate change on stem growth [5]. The area of temperate forest in northeast China accounts for more than 1/3 of the national total [6]. Therefore, it is essential to monitor the stem growth of tree species in northeastern temperate forests.

The decrease in stem diameter is due to a water deficit, and an increase in stem diameter can be induced by supplementing the water of cell tissues or by newly formed cells [7], so the water availability to the tree species will have a great impact on the change in stem diameter. Under the condition of sufficient soil moisture and drought stress, the diurnal variation pattern of the stem radial is quite different, and it will change more dramatically in a period of continuous drought [8]. A number of studies have found that tree growth is mainly restricted by precipitation and relative humidity [9–12]. However, the response of the stem diameter variations of dominant tree species to water conditions in northeast China is not clear.

Dendrometers have been widely used in recent years due to their high temporal and spatial resolution, the ability to continuously monitor changes in stem radials, lower damage to trees, and better correlation with environmental factors [13–15]. This study presents high-resolution dendrometer measurements on six dominant tree species of northeastern temperate forest of China. The aims of this study were (i) to identify the relationship between the stem radial growth and water conditions of each tree species and (ii) to explore the response and adaptation characteristics of different tree species under drought stress. We tested the hypotheses that (i) the radial growth of the tree stem is limited by water conditions, and precipitation has a pulse effect on the growth of the tree stem diameter, and (ii) there were obvious interspecific differences in the response of stem radial changes to seasonal drought.

2. Materials and Methods

2.1. Study Area and Species Selection

This study was conducted at the Maoershan Forest Ecosystem Research Station of Northeast Forestry University, Heilongjiang Province, Northeast China (45°240 N, 127°400 E, 400 m a.s.l.). The climate is a continental monsoon climate. The main soil type is dark brown soil. The mean annual precipitation is 629 mm; the mean annual potential evaporation is 864 mm. The mean annual air temperature is 3.1 °C, and the mean January and July air temperatures are −18.5 °C and 22.0 °C, respectively. The frost-free period is between 120 and 140 days, with early frosts in September and late frosts in May of the next year [16].

We defined the effective precipitation day as the day when there was precipitation on two consecutive days and the cumulative precipitation exceeded 5 mm. The average precipitation in July from 1980 to 2017 was 177.9 mm [17], and that in July 2021 was 150.23 mm. However, 74% of the precipitation was concentrated in the first week (DOY182-189), and there was no rainfall during DOY205-211, so we defined this period as seasonal drought. During DOY212-218, the precipitation was 116.15 mm, which was defined as a period of relatively sufficient water.

The current vegetation is naturally regenerated or in planted stands following large-scale industrial logging of the climax temperate mixed forest. The overstory of the forest is dominated by Korean pine (*Pinus koraiensis* Sieb.) mixed with deciduous species, such as *Betula* spp., *Larix* spp., *Populus* spp., *Quercus* spp., *Tilia* spp., *Acer* spp., etc. [18]; the shrubs are dominated by *Syinga reticulata* var. *mandshurica*.; the herbaceous layer is dominated by *Equisetum hyemale* [19].

In this study, we selected six tree species that represent the temperate forest species in the mountainous regions of northeastern China, and four dominant trees were selected for each species. These species have a similar stand age class (50–60 years old) under the same climate conditions but with various site conditions [20] (Table 1).

Table 1. Basic characteristics of the sampled trees for the six temperate tree species (*mean* ± *SE*, *n* = *4*).

Tree Species (Code)	Habitat	Wood Property	Leaf Habit	DBH (cm)
Pinus koraiensis Sieb. et Zucc. (PK)	Mid slope	Non-porous	Evergreen-coniferous	22.6 ± 0.7
Fraxinus mandshurica (FM)	Valley bottom	Ring-porous	Deciduous-broadleaved	35.4 ± 1.6
Juglans mandshurica Maxim. (JM)	Valley bottom	Ring-porous	Deciduous-broadleaved	37.7 ± 1.0
Quercus mongolica Fisch. (QM)	Upper slope	Ring-porous	Deciduous-broadleaved	34.0 ± 1.0
Populous davidiana Dode. (PD)	Upper slope	Diffuse-porous	Deciduous-broadleaved	49.6 ± 0.8
Betula platyphylla Suk. (BP)	Mid slope	Diffuse-porous	Deciduous-broadleaved	27.6 ± 1.1

2.2. Installation of the Measuring Instruments

In April 2021, we selected four well-grown trees of six species as experimental samples. An automatic band dendrometer (DRL26C, measurement range 64 mm, resolution: <1 µm, Czechia) was installed at a 1.3 m-height position for each sample to measure the variation of stem circumference. The circumference reading was automatically recorded at 15-min intervals from 15th April to 24th October (DOY105-297). In order to reduce the interference of the expansion and contraction process of bark due to the change in water conditions on the monitoring of the stem radial, the dead bark of the outer layer of the stem was removed without damaging the cambium.

2.3. Meteorological Data

Meteorological data were collected from the standard meteorological observation field at Maoershan Forest Ecosystem Research Station and the automatic environmental monitoring system set up in a typical forest stand. The meteorological factors considered include air temperature (Ta), relative humidity (RH), precipitation (Pre) and the volumetric water content of soil (VWC) at a 5-cm depth. The 15-min measured climate data were averaged to daily means for further analyses. The water vapor pressure deficit (VPD) can be calculated according to the relative humidity (RH) and air temperature (Ta) [21]. The calculation formula is as follows:

$$\mathrm{VPD} = 0.61078 \times e^{\frac{17.27 \times \mathrm{Ta}}{\mathrm{Ta}+237.3}} \times (1 - \mathrm{RH}) \quad (1)$$

2.4. Extraction of Stem Radial Variation and Statistical Analysis

Based on a stem-cycle approach, the typical diurnal cycle can be divided into three distinct phases as follows: (a) contraction phase, the period of shrinkage of the stem radius from a morning maximum to a daily minimum; (b) recovery phase, from the daily minimum to the position observed at that morning's maximum; (c) stem radial increment (SRI) phase, from when the stem radius exceeds the morning maximum until the subsequent maximum [22].

The change in stem diameter monitored by the dendrometer can be divided into growth-induced irreversible stem expansion (GRO) and tree water deficit-induced reversible stem shrinkage (TWD) [7]. In order to distinguish GRO from TWD, the zero-growth (ZG) model assumes that there is no growth during the period of stem contraction [7]. Radial growth occurs only when the stem is saturated with water, and the stem radial change below the previous maximum is caused by the water deficit. TWD is the difference value between the step-type growth curve and the actual radial growth curve. The increase in TWD indicates an increase in water loss under the condition of low water potential, and a value greater than zero indicates a water shortage of the stem. The higher the value, the more intense the water shortage. TWD can quantify the water loss from elastic tissues due to the imbalance between transpiration and water uptake, and it reflects the water deficit accumulated by plants during successive dry periods [23].

The data derived from the high-precision dendrometer reflected the stem circumference variation. We assumed the cross-section of the stem to be exactly circular, and the circumference was converted into diameter. We extracted the daily minimum values from tree stem diameter data using the "dendRoAnalyst" package in R software [24,25] for each tree. The data from four monitored trees were averaged to obtain the average growth condition of the species. The difference between the minimum values for two consecutive days was calculated as the stem radial change (SRC) of the trees. Based on the ZG approach, we extracted the growth duration and the growth rate of each tree species under different environmental conditions [25]. The growth process of the ZG model was calculated as follows:

$$\mathrm{GRO} = \begin{cases} \mathrm{SR(t)} - \max[\mathrm{SR}(<\mathrm{t})], \mathrm{SR(t)} \geq \max[\mathrm{SR}(<\mathrm{t})] \\ 0, \mathrm{SR(t)} < \max[\mathrm{SR}(<\mathrm{t})] \end{cases} \quad (2)$$

where t is the current moment; < t is from the beginning to the current moment; GRO is growth-induced irreversible stem expansion; SR is the stem radius fluctuation.

The relationships between changes in stem diameter and climatic variables were tested with linear correlations. We performed an ANOVA analysis to distinguish the significance of differences between groups. All statistical analyses were conducted with the R programming language.

3. Results

3.1. Relationship between Stem Radial Growth and Water Conditions

The variations in six tree species' stem diameter were all responsive to the changes in water conditions. Precipitation significantly promoted the tree stem diameter increment (Figure 1). The stem diameter of the six tree species had the same increasing trend but different increasing degrees in each precipitation period of the growing season. During the effective precipitation days, the total precipitation was 624.19 mm, and the cumulative increment of stem diameter of QM, PK, FM, PD, JM and BP accounted for 112.49%, 82.61%, 74.20%, 70.43%, 63.37% and 58.70% of the annual cumulative net growth, respectively (Table 2).

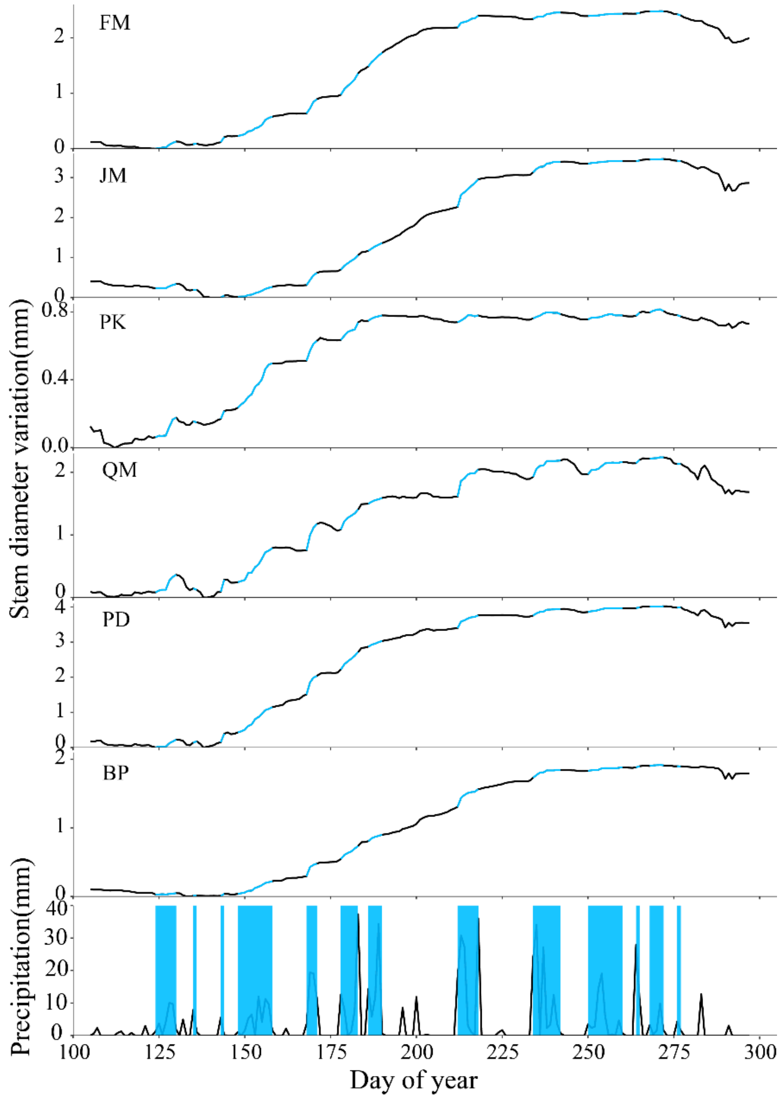

Figure 1. Stem diameter variation of six tree species and precipitation pattern in Northeast China. The shaded part is the time period with two consecutive days of precipitation where the precipitation accumulative amount was greater than 5 mm. The blue part of the annual growth curve is the corresponding stem diameter change during the effective precipitation days of six tree species. FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk.

Table 2. Proportion of the corresponding increment of six tree species in each precipitation period to the annual net growth. "/" indicates that the growth period is not within the annual net growth period or the diameter change in this period is negative.

Period of Precipitation	Cumulative Precipitation (mm)	Proportion of Net Annual Growth (%)					
		FM	JM	PK	QM	PD	BP
DOY 124-130	30.98	5.00	/	15.10	/	/	/
DOY 135-136	8.95	0.31	/	/	/	/	0.14
DOY 143-144	5.58	3.56	1.38	5.86	8.22	5.99	1.38
DOY 148-158	52.82	13.82	7.03	34.16	23.44	17.84	9.70
DOY 168-171	53.55	10.12	8.79	15.10	18.10	13.07	9.65
DOY 178-183	66.76	14.11	9.56	13.09	13.74	11.79	9.80
DOY 186-190	66.67	9.56	5.48	4.07	3.93	3.94	4.88
DOY 212-218	116.15	8.29	20.13	5.26	18.65	8.97	13.52
DOY 234-242	107.56	4.46	7.76	3.26	11.43	4.63	5.94
DOY 250-260	53.39	1.73	1.85	2.87	8.34	2.83	2.56
DOY 264-265	39.46	0.49	0.41	2.51	2.13	0.50	0.95
DOY 268-272	16.42	0.26	0.48	1.14	0.77	0.30	0.44

The stem diameter increment of the six tree species was correlated with cumulative precipitation, but the significance of the correlation varied with tree species (Figure 2). The results of correlation analysis showed that the increment of stem diameter of JM ($R^2 = 0.71$, $p < 0.001$), QM ($R^2 = 0.33$, $p = 0.038$) and BP ($R^2 = 0.61$, $p = 0.002$) had a significantly positive correlation with cumulative precipitation, while FM ($R^2 = 0.27$, $p = 0.071$), PK ($R^2 = 0.02$, $p = 0.617$) and PD ($R^2 = 0.16$, $p = 0.181$) was not significantly correlated.

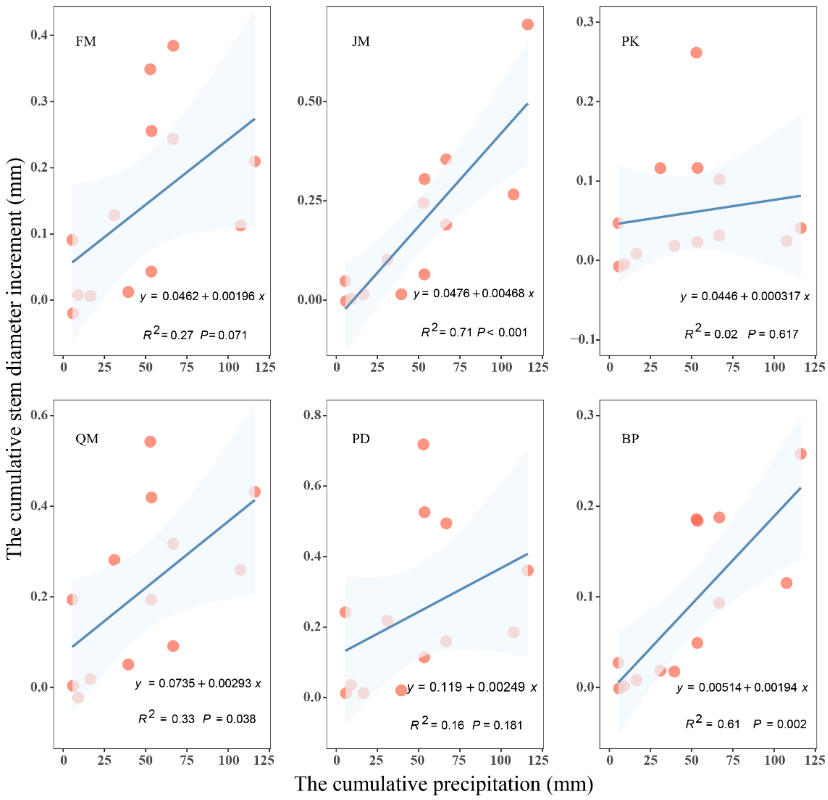

Figure 2. The relationship between the stem diameter increment and the cumulative precipitation of six tree species. The light blue area is the 95% confidence interval. FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk.

There was significant correlation between the stem radial variation (SRC) of stems and the water condition characteristics (Figure 3). The results showed that the stem radial change (SRC) of six tree species during the growing season (DOY121-273) had a significant positive correlation with precipitation ($p < 0.001$) and relative humidity ($p < 0.001$) and had a significant negative correlation with VPD ($p < 0.001$).

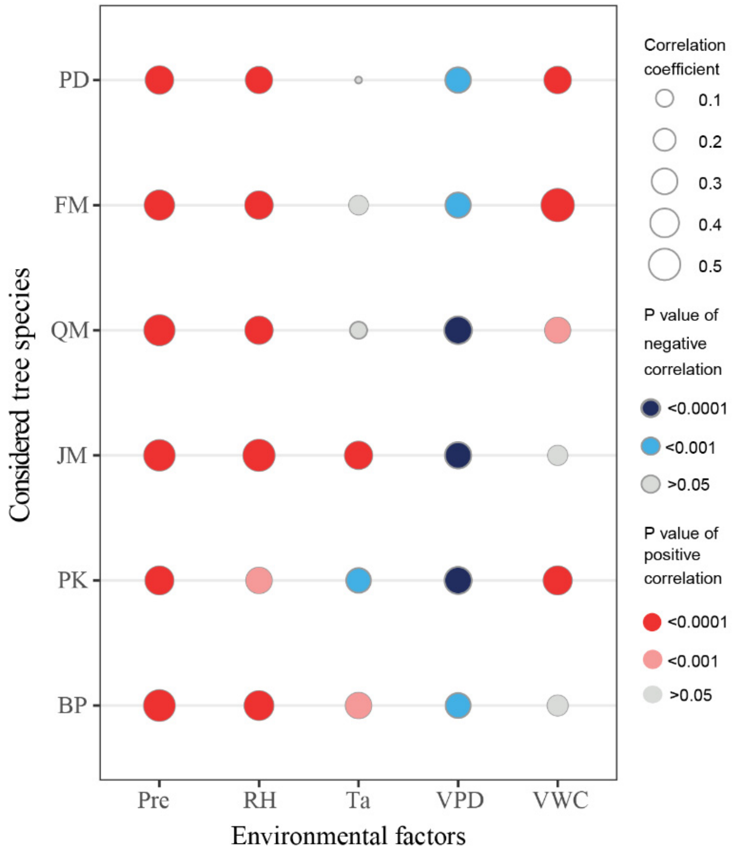

Figure 3. Relationship between stem radial change (SRC) of six tree species and environmental factors. The data are from the growth seasons of the six tree species (DOY121-273). FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk. Pre: precipitation; RH: relative humidity; Ta: air temperature; VPD: water vapor pressure deficit; VWC: volumetric water content of soil.

3.2. Interspecific Differences in Stem Diameter Variation Patterns under Drought Stress

There were obvious interspecific differences in stem diameter variation under drought stress (Figure 4). The stem diameter of QM and PK showed a strong stem contraction trend during the seasonal drought (DOY205-211), and the diameter decreased by 0.04 mm and 0.03 mm, respectively. However, the other four tree species showed an increasing trend: the stem diameter of FM and PD increased by 0.01 mm and 0.03 mm, respectively. The stem diameter of JM and BP showed consistently rhythmic growth, increasing by 0.14 mm and 0.12 mm, respectively. The stem diameters of the six tree species showed continuous recovery or growth after precipitation (DOY212-218). The stem diameters of JM, QM, PD, BP, FM and PK increased by 0.72 mm, 0.44 mm, 0.38 mm, 0.27 mm, 0.22 mm and 0.04 mm, respectively. During DOY215-217, the precipitation was less, the moisture content decreased, and the growth slope of the stem diameter decreased. Until DOY218, the precipitation increased again, and the growth range of the stem diameter of the six tree species increased.

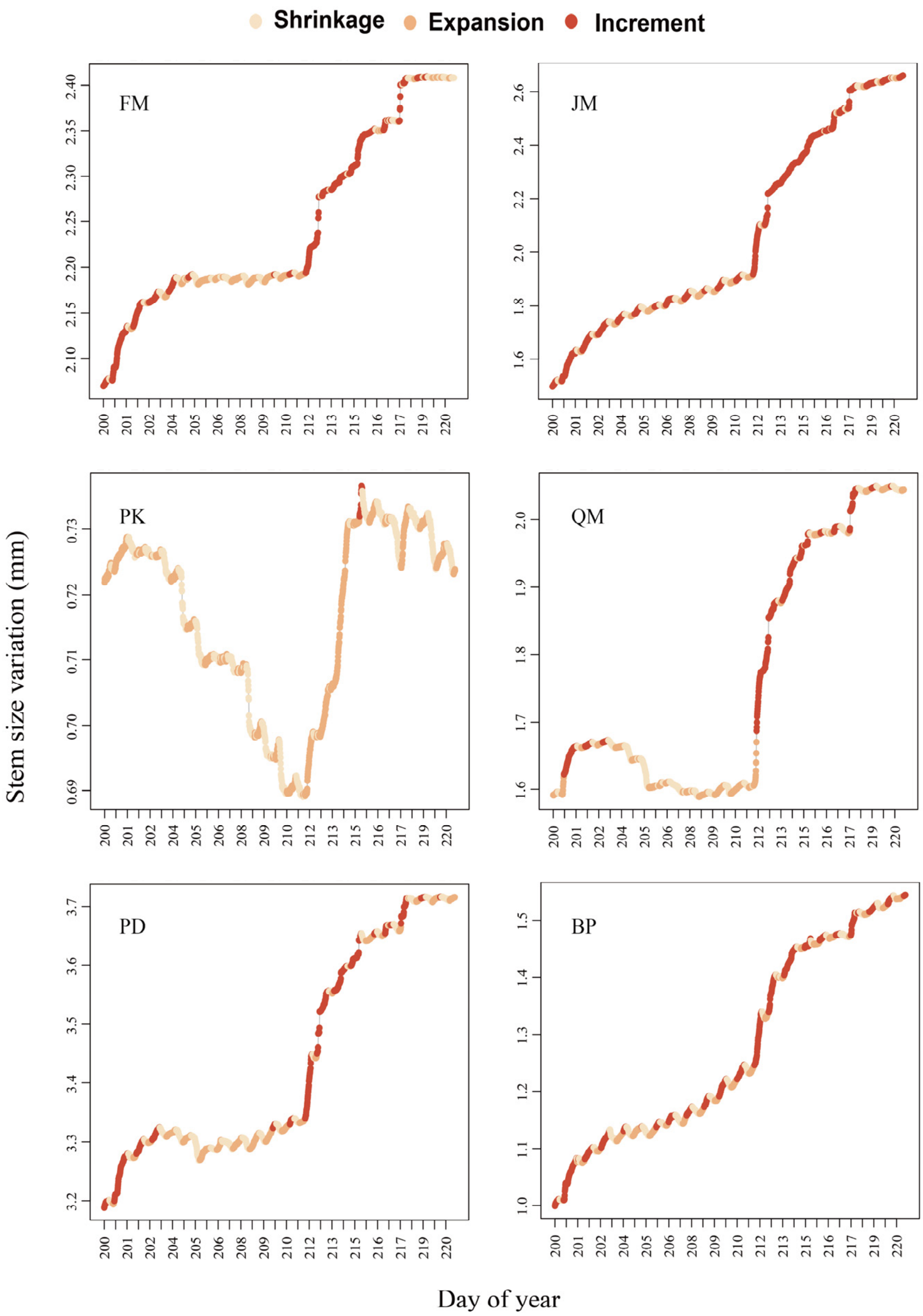

Figure 4. Stem diameter variation of six tree species during DOY200-220. The "shrinkage, expansion, increment" represent the three phases of the stem-cycle approach. The data are available at 15-min intervals. FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk.

The variation patterns of stem diameter shrinkage of the six tree species under different water conditions were inconsistent (Figure 5). The TWD of the six tree species during seasonal drought (DOY205-211) was significantly higher than that during periods with sufficient water (DOY212-218). The maximum TWD value of QM, PD, PK, JM, BP and FM was 0.26 mm, 0.17 mm, 0.12 mm, 0.06 mm, 0.06 mm and 0.03 mm, respectively.

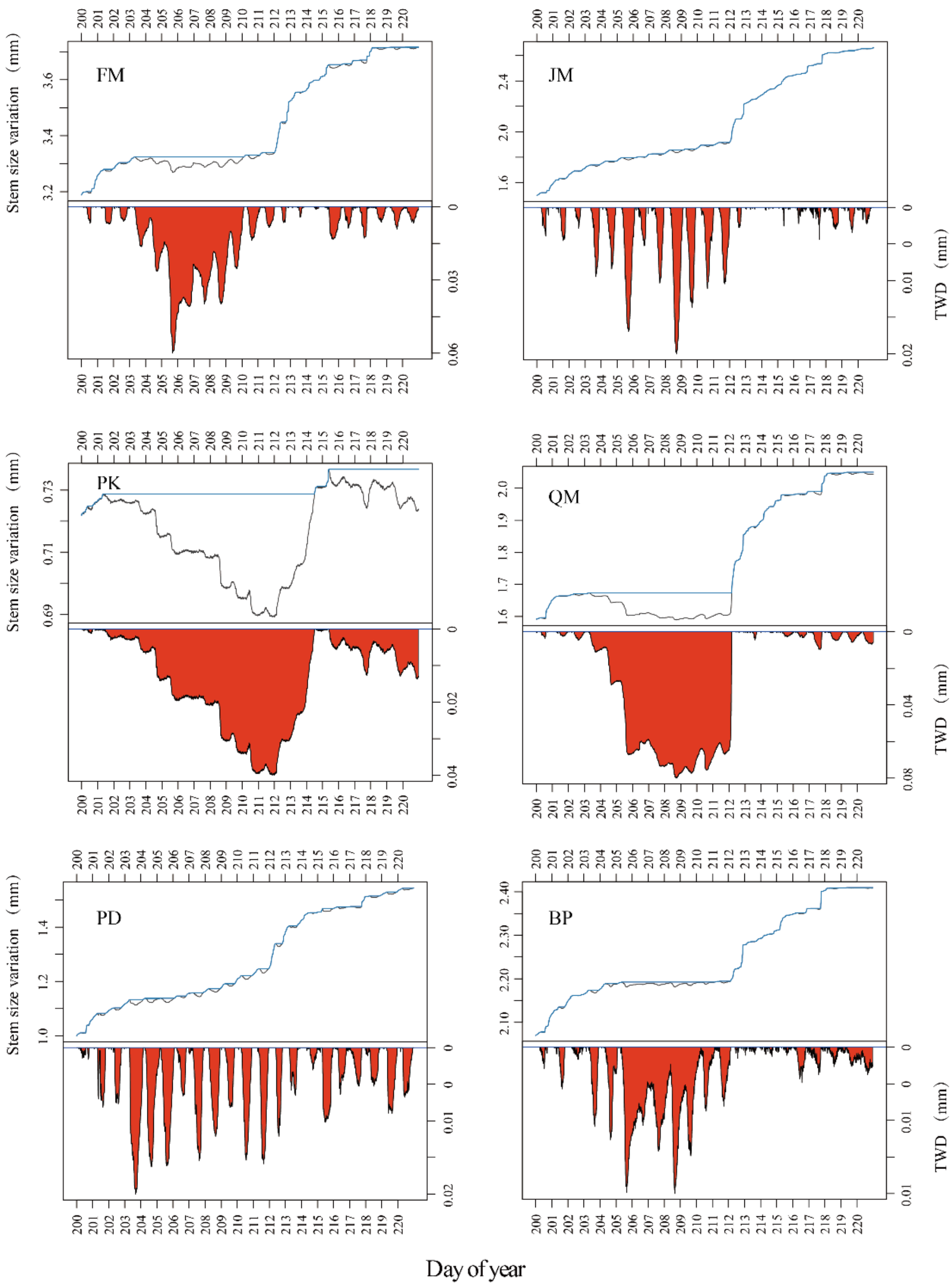

Figure 5. TWD changes in tree stem diameter of six tree species during DOY200-220. The data are available at 15-min intervals. The black line is the true value of tree stem diameter change, and the blue line is the ZG model of tree stem growth. FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk.

Seasonal drought events affected the growth duration and the growth rate of stem diameter (Figure 6). The growth duration of FM ($p < 0.001$), JM ($p < 0.001$), PD ($p < 0.01$), PK ($p < 0.001$) and QM ($p < 0.001$) had significant differences between the period of seasonal drought and the period of sufficient moisture, while BP ($p = 0.368$) had none. The growth rate of FM ($p < 0.05$), JM ($p < 0.05$), and QM ($p < 0.01$) had significant differences between the period of seasonal drought and the period of sufficient moisture, while PK ($p = 0.796$), BP ($p = 0.083$) and PD ($p = 0.067$) had none.

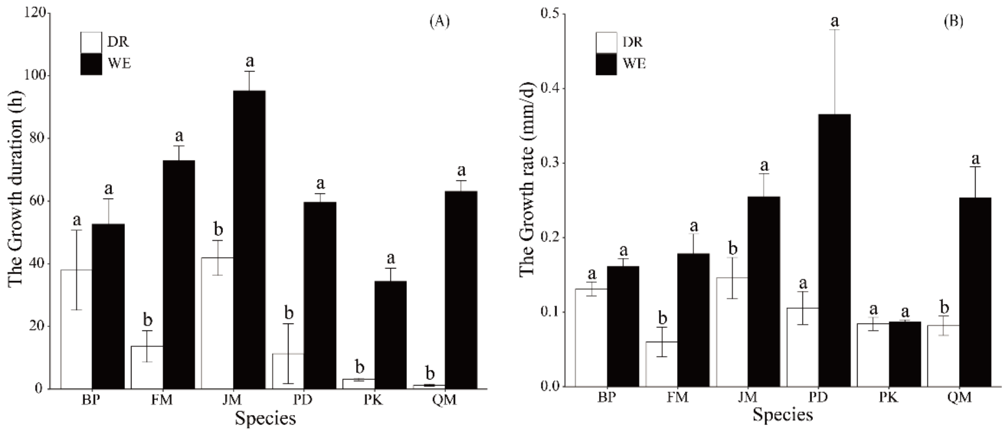

Figure 6. Comparison of growth duration (**A**) and growth rate (**B**) of six tree species during different periods. DR represents the period of seasonal drought (DOY205-211) and WE represents the period of sufficient moisture (DOY212-218). FM: *Fraxinus mandshurica*; JM: *Juglans Mandshurica* Maxim.; PK: *Pinus koraiensis* Sieb. et Zucc.; QM: *Quercus mongolica* Fisch.; PD: *Populus davidiana* Dode.; BP: *Betula platyphylla* Suk. Different lowercase letters indicated significant difference at 0.05 level.

4. Discussion

4.1. Water Conditions Affect Stem Radial Growth

The radial growth of tree stems is limited by water conditions, and precipitation has a certain pulse effect on the growth of tree stem diameter (Figure 1). The results of this study showed that the diurnal variation in stem diameter of six tree species was significantly positively correlated with relative humidity (RH) and precipitation (Pre), and negatively correlated with water vapor pressure deficit (VPD) (Figure 3). These factors were all correlated with the water conditions required for radial growth of the stem, indicating that radial growth of the stem was limited by water. This is consistent with the experimental results observed in tropical rainforests [26]. After precipitation, the tree stem diameter of the six tree species showed an obvious increasing trend, while after several days of precipitation, the tree stem growth trend slowed down significantly (Figure 1). In addition, by analyzing the influence of representative precipitation events on the change in stem diameter, we showed that during the short-term drought event of DOY205-211, except for BP and JM, the growth duration of the other tree species significantly decreased but recovered rapidly after the precipitation of DOY212-218 (Figure 4). Continuous sunny days with strong transpiration would lead to a decrease in the daily maximum diameter of the stem, which would return to a higher level after the precipitation, which was consistent with the decrease in the water vapor pressure deficit (VPD) and the weak transpiration on rainy days. At the same time, the root system can obtain further water supply from the soil moisture improved by precipitation, so that the stem water content can be restored [27,28]. The plant physiology demonstrated that water affects cell division and cell elongation by affecting cell turgor [29]. Since cell division and expansion depend on cell expansion, a water deficit may directly affect xylem cambium differentiation and cell growth [30].

Our results showed that the six tree species were affected to different degrees during the seasonal drought period. The tree stem growth rate decreased due to water deficiency, and the tree stem growth rate during drought stress was lower than that during water sufficiency (Figure 6). During the period of DOY200-212, there was a continuous absence of precipitation, and the water available to the trees decreased, which induced stem contraction, that is, an increase in TWD. Drought stress slows down the radial growth rate of tree stems and reduces the growth duration and increment, which is consistent with the experimental results of temperate montane forest [31]. In this study, tree stems shrank more during the drought stress period than the sufficient water period (Figure 3), which is also consistent with the results of Steppe et al. [8]. Experimental results from tropical rainforests indicate that tree species with different life types may reduce their stem diameters after experiencing seasonal drought, and two deciduous broadleaved tree species exhibited the largest shrinkage of their stems after drying for ten consecutive days, reaching 2 mm [32]. Among the six tree species selected in this study, QM had the largest shrinkage of stem diameter (0.26 mm) and stopped growing completely during seasonal drought. However, the stem diameter of JM and BP continued to increase without stopping growth, and the daily cycles were more obvious when compared with the period of sufficient water (Figure 4). The reason for this phenomenon may be that the living habits of the tree species selected in the two studies exhibit extreme variation. Tropical rainforest is more moist than temperate forests, so the tree species respond more strongly to drought events.

4.2. *Species-Specific Drought Response*

Tree species with different growth phenology [33–35], site conditions [12,36] and wood properties [37–39] have different drought resistances. Hence, the six tree species of this study adopted different strategies to respond to drought stress. PD and BP are pioneer species of forest succession in this region, with early leaf-out, beginning growth in mid-May. PK is a temperate evergreen conifer species, while FM, JM and QM are typical broadleaved species in northeast China. The responses of the six tree species to precipitation in different periods were inconsistent. During the precipitation period in late May and early June, the growth of PK, QM and PD reached the maximum proportion of cumulative growth during the annual precipitation period, indicating that these three species began to grow earlier. However, the end of June and beginning of July were the active growth periods for FM, while JM and BP still had a strong growth ability in early August (Figure 1, Table 2).

The six tree species selected in this study were scattered in four forest types: Mongolian oak forest (dominated by QM) from arid infertile steep upper slopes, aspen–birch forest (dominated by BP and PD) and Korean pine plantations (PK) from well-drained fertile gentle mid-slopes and hardwood forest (dominated by FM, JM) from moist fertile gentle toe slopes. Trees growing on sites with good water conditions have a higher leaf hydraulic conductivity and embolization resistance, while trees growing on sites with poor water conditions have a lower leaf hydraulic conductivity and embolization resistance [40–42]. Tree species with a high leaf conductivity are suitable for growing on wet sites, are more competitive for light and nutrients and have higher photosynthetic and growth rates. In contrast, tree species with a low leaf conductivity often have a high embolic resistance and can survive under drought conditions but the leaves simultaneously reduce their competitive ability in resource-rich areas [42]. Site conditions are the result of the interaction between trees and the environment, which can not only reflect the differences in drought tolerance of different tree species but can also explain the causes of such differences.

Under the same climate conditions, the six species have different rates of stem shrinkage/growth and require different recovery times after a prolonged drought [32]. In this study, the growth of all tree species under drought stress was affected to some extent, but the drought tolerance of different tree species was different, which is consistent with the results of other studies [32]. We assume that the maximum TWD value reached by trees after several days of continuous drought is used to measure the drought tolerance level of trees [43], the drought tolerance order of the six tree species selected in this study was QM > PD > PK > JM > BP > FM. The drought tolerance of five tree species was previously evaluated by water index in the Maoershan area [44]. The results showed that the drought tolerance of five tree species was in the order of PK > QM > JM > BP > FM, which is similar to our results.

5. Conclusions

In this study, a dendrometer was used to continuously monitor the stem diameter variation of six tree species in the eastern mountainous area of Northeast China. We demonstrated that stem growth was significantly correlated with the change in water conditions. Seasonal drought events affected the growth of the stem diameter, and the responses of different tree species were inconsistent. Our results are fundamental to the evolution of temperate forests and the sustainable management of forest ecosystems in northeast China under climate change. Further long-term monitoring of the stem radial changes of different tree species is of great significance to explore both the regularity and differences in inter-annual growth.

Author Contributions: Idea and experimental design, Q.Z.; experimental implementation, X.W.; statistical data analyses, X.W.; manuscript writing, X.W.; discussion and provision of amended advice, Q.Z. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. IPCC. *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
2. Boisvenue, C.; Running, S.W. Impacts of climate change on natural forest productivity—Evidence since the middle of the 20th century. *Glob. Chang. Biol.* **2006**, *12*, 862–882. [CrossRef]
3. Choat, B.; Jansen, S.; Brodribb, T.J.; Cochard, H.; Delzon, S.; Bhaskar, R.; Bucci, S.J.; Feild, T.S.; Gleason, S.M.; Hacke, U.G.; et al. Global convergence in the vulnerability of forests to drought. *Nature* **2012**, *491*, 752–755. [CrossRef] [PubMed]
4. Pan, Y.; Birdsey, R.A.; Fang, J.; Houghton, R.; Kauppi, P.E.; Kurz, W.A.; Phillips, O.L.; Shvidenko, A.; Lewis, S.L.; Canadell, J.G.; et al. A Large and Persistent Carbon Sink in the World's Forests. *Science* **2011**, *333*, 988–993. [CrossRef]
5. Pugh, T.A.M.; Lindeskog, M.; Smith, B.; Poulter, B.; Arneth, A.; Haverd, V.; Calle, L. Role of forest regrowth in global carbon sink dynamics. *Proc. Natl. Acad. Sci. USA* **2019**, *116*, 4382–4387. [CrossRef] [PubMed]
6. Wang, C. Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. *For. Ecol. Manag.* **2006**, *222*, 9–16. [CrossRef]
7. Zweifel, R.; Haeni, M.; Buchmann, N.; Eugster, W. Are trees able to grow in periods of stem shrinkage? *New Phytol.* **2016**, *211*, 839–849. [CrossRef]
8. Steppe, K.; Sterck, F.J.; Deslauriers, A. Diel growth dynamics in tree stems: Linking anatomy and ecophysiology. *Trends Plant Sci.* **2015**, *20*, 335–343. [CrossRef] [PubMed]
9. Zhang, R.; Yuan, Y.; Gou, X.; Zhang, T.; Zou, C.; Ji, C.; Fan, Z.; Qin, L.; Shang, H.; Li, X. Intra-annual radial growth of Schrenk spruce (*Picea schrenkiana* Fisch. et Mey) and its response to climate on the northern slopes of the Tianshan Mountains. *Dendrochronologia* **2016**, *40*, 36–42. [CrossRef]
10. Wu, L.; Kaewmano, A.; Fu, P.; Wang, W.; Fan, Z. Intra-annual Radial Growth of *Melia azedarach* in a Tropical Moist Seasonal Forest and its Response to Environmental Factors in Xishuangbanna, Southwest China. *Acta Ecol. Sin.* **2020**, *40*, 6831–6840. [CrossRef]
11. Deslauriers, A.; Morin, H.; Urbinati, C.; Carrer, M. Daily weather response of balsam fir (*Abies balsamea* (L.) Mill.) stem radius increment from dendrometer analysis in the boreal forests of Quebec (Canada). *Trees-Struct. Funct.* **2003**, *17*, 477–484. [CrossRef]
12. Martin, J.; Looker, N.; Hoylman, Z.; Jencso, K.; Hu, J. Hydrometeorology organizes intra-annual patterns of tree growth across time, space and species in a montane watershed. *New Phytol.* **2017**, *215*, 1387–1398. [CrossRef]
13. Aldea, J.; Bravo, F.; Vazquez-Pique, J.; Ruiz-Peinado, R.; del Rio, M. Differences in stem radial variation between *Pinus pinaster* Ait. and *Quercus pyrenaica* Willd. may release inter-specific competition. *For. Ecol. Manag.* **2021**, *481*, 118779. [CrossRef]
14. Etzold, S.; Sterck, F.; Bose, A.K.; Braun, S.; Buchmann, N.; Eugster, W.; Gessler, A.; Kahmen, A.; Peters, R.L.; Vitasse, Y.; et al. Number of growth days and not length of the growth period determines radial stem growth of temperate trees. *Ecol. Lett.* **2022**, *25*, 427–439. [CrossRef]
15. Meng, S.-W.; Yang, F.-T.; Dai, X.-Q.; Wang, H.-M. Radial growth dynamics of Chinese fir and its response to seasonal drought. *Chin. J. Appl. Ecol.* **2021**, *32*, 3521–3530. [CrossRef]
16. Sang, Y.; Wang, C.; Huo, H. Inter-specific and seasonal variations in photosynthetic capacity and water use efficiency of five temperate tree species in Northeastern China. *Scand. J. For. Res.* **2011**, *26*, 21–29. [CrossRef]
17. Zhang, Q.Z.; Wang, C.K. *Chinese Ecosystem Long-Term Observation and Research Dataset. Forest Ecosystem: Heilongjiang Maoershan Station (1979–2017)*; China Agriculture Press: Beijing, China, 2022.
18. Wang, C.; Yang, J.; Zhang, Q. Soil respiration in six temperate forests in China. *Glob. Chang. Biol.* **2006**, *12*, 2103–2114. [CrossRef]
19. Liu, F.; Wang, C.; Wang, X.; Zhang, J.; Zhang, Z.; Wang, J. Spatial patterns of biomass in the temperate broadleaved deciduous forest within the fetch of the Maoershan flux tower. *Acta Ecol. Sin.* **2016**, *36*, 6506–6519. [CrossRef]
20. Zhang, Q.Z.; Wang, C.K.; Zhou, Z.H. Does the net primary production converge across six temperate forest types under the same climate? *For. Ecol. Manag.* **2019**, *448*, 535–542. [CrossRef]

21. Campbell, G.S.; Norman, J.M. *An Introduction to Environmental Biophysics*, 2nd ed.; Springer: New York, NY, USA, 1998.
22. Downes, G.; Beadle, C.; Worledge, D. Daily stem growth patterns in irrigated *Eucalyptus globulus* and *E. nitens* in relation to climate. *Trees* **1999**, *14*, 102–111. [CrossRef]
23. Dietrich, L.; Zweifel, R.; Kahmen, A. Daily stem diameter variations can predict the canopy water status of mature temperate trees. *Tree Physiol.* **2018**, *38*, 941–952. [CrossRef]
24. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2020.
25. Aryal, S.; Husser, M.; Grieinger, J.; Fan, Z.X.; Bruning, A. "dendRoAnalyst": A tool for processing and analysing dendrometer data. *Dendrochronologia* **2020**, *64*, 125772. [CrossRef]
26. Hu, L.; Fan, Z. Stem radial growth in response to microclimate in an Asian tropical dry karst forest. *Acta Ecol. Sin.* **2016**, *36*, 401–409. [CrossRef]
27. Liu, C.; Kang, S. Assessment of trunk diameter fluctuation for irrigation schedule in apple trees. *Acta Ecol. Sin.* **2015**, *35*, 4754–4762. [CrossRef]
28. Zweifel, R.; Zimmermann, L.; Zeugin, F.; Newbery, D.M. Intra-annual radial growth and water relations of trees: Implications towards a growth mechanism. *J. Exp. Bot.* **2006**, *57*, 1445–1459. [CrossRef]
29. Muller, B.; Pantin, F.; Genard, M.; Turc, O.; Freixes, S.; Piques, M.; Gibon, Y. Water deficits uncouple growth from photosynthesis, increase C content, and modify the relationships between C and growth in sink organs. *J. Exp. Bot.* **2011**, *62*, 1715–1729. [CrossRef]
30. Rossi, S.; Anfodillo, T.; Cufar, K.; Cuny, H.E.; Deslauriers, A.; Fonti, P.; Frank, D.; Gricar, J.; Gruber, A.; King, G.M.; et al. A meta-analysis of cambium phenology and growth: Linear and non-linear patterns in conifers of the northern hemisphere. *Ann. Bot.* **2013**, *112*, 1911–1920. [CrossRef]
31. Gao, J.; Yang, B.; Qin, C. Response of intra-annual stem radial growth to drought events: A case study of *Pinus tabuliformis* in the Helan Mountains, China. *Chin. J. Appl. Ecol.* **2021**, *32*, 3505–3511. [CrossRef]
32. Raffelsbauer, V.; Spannl, S.; Peña, K.; Pucha-Cofrep, D.; Steppe, K.; Bräuning, A. Tree Circumference Changes and Species-Specific Growth Recovery after Extreme Dry Events in a Montane Rainforest in Southern Ecuador. *Front. Plant Sci.* **2019**, *10*, 342. [CrossRef]
33. Aldea, J.; Bravo, F.; Vazquez-Pique, J.; Rubio-Cuadrado, A.; del Rio, M. Species-specific weather response in the daily stem variation cycles of Mediterranean pine-oak mixed stands. *Agric. For. Meteorol.* **2018**, *256*, 220–230. [CrossRef]
34. Ernst, V.D.M.; Jonas, P.; Marieke, V.D.M.-T.; Tobias, S.; Marko, S.; Roberto, C.-G.; Martin, W. Distinct growth phenology but similar daily stem dynamics in three co-occurring broadleaved tree species. *Tree Physiol.* **2018**, *38*, 1820–1828. [CrossRef]
35. Alday, J.G.; Julio Camarero, J.; Revilla, J.; Resco de Dios, V. Similar diurnal, Seasonal and annual rhythems in radial root expansion across two coexiting Mediterranean oak species. *Tree Physiol.* **2020**, *40*, 956–968. [CrossRef] [PubMed]
36. Obojes, N.; Meurer, A.; Newesely, C.; Tasser, E.; Oberhuber, W.; Mayr, S.; Tappeiner, U. Water stress limits transpiration and growth of European larch up to the lower subalpine belt in an inner-alpine dry valley. *New Phytol.* **2018**, *220*, 460–475. [CrossRef]
37. Jin, Y.; Wang, C. Leaf hydraulic traits and their trade-offs for nine Chinese temperate tree species with different wood properties. *Chin. J. Plant Ecol.* **2016**, *40*, 702–710. [CrossRef]
38. Brodribb, T.J.; Holbrook, N.M.; Zwieniecki, M.A.; Palma, B. Leaf hydraulic capacity in ferns, conifers and angiosperms: Impacts on photosynthetic maxima. *New Phytol.* **2005**, *165*, 839–846. [CrossRef]
39. Li, J.; Zhai, H. Hydraulic architecture and drought resistance of woody plants. *Chin. J. Appl. Ecol.* **2000**, *11*, 301–305. [CrossRef]
40. Bucci, S.J.; Scholz, F.G.; Goldstein, G.; Meinzer, F.C.; Sternberg, L.D.L. Dynamic changes in hydraulic conductivity in petioles of two savanna tree species: Factors and mechanisms contributing to the refilling of embolized vessels. *Plant Cell Environ.* **2003**, *26*, 1633–1645. [CrossRef]
41. Nardini, A.; Salleo, S.; Raimondo, F. Changes in leaf hydraulic conductance correlate with leaf vein embolism in *Cercis siliquastrum* L. *Trees-Struct. Funct.* **2003**, *17*, 529–534. [CrossRef]
42. Nardini, A.; Peda, G.; La Rocca, N. Trade-offs between leaf hydraulic capacity and drought vulnerability: Morpho-anatomical bases, carbon costs and ecological consequences. *New Phytol.* **2012**, *196*, 788–798. [CrossRef]
43. Gueney, A.; Zweifel, R.; Turkan, S.; Zimmermann, R.; Wachendorf, M.; Guney, C.O. Drought responses and their effects on radial stem growth of two co-occurring conifer species in the Mediterranean mountain range. *Ann. For. Sci.* **2020**, *77*, 105. [CrossRef]
44. Duan, R.; Sun, H. Evaluation on Drought Tolerance of the Major Tree Species in the Eastern Mountain Region of Northeast China. *Acta Bot. Boreali-Occident. Sin.* **2019**, *39*, 156–163. [CrossRef]