**Abstract:** Concerns have been raised about the negative impacts of global warming on the hydrological climate change and ecosystems of Asia. Research on the high-altitude mountainous regions of Asia with relatively short meteorological and hydrological records relies on paleoclimate proxy data with long time scales. The stable isotopes of tree-rings are insightful agents that provide information on pre-instrumental climatic and hydrological fluctuations, yet the variability of these data from different regions along the Tianshan Mountains has not been fully explored. Herein, we related climate data with tree-ring width (TRW) chronologies and δ¹³C (stable carbon isotope discrimination) series to discern if the *Picea schrenkiana* in the Ili and Manas River Basins are sensitive to climatic factors and baseflow (BF). The results show significant correlations between temperature and TRW chronologies, temperature and δ¹³C, relative humidity and TRW chronologies, and BF and δ¹³C. Temperature, particularly the mean late summer to early winter temperature, is a pronounced limiting factor for the tree-ring and the δ¹³C series in the Manas River Basin, located in the middle of the North Tianshan Mountains. Meanwhile, mean early spring to early autumn temperature is a limiting factor for that of the Ili River Basin, located on the southern slope of the North Tianshan Mountains. We conclude that different seasonal variations in temperature and precipitation of the two river basins exerted significant control on tree growth dynamics. Tree-ring width and tree-ring δ¹³C differ in their sensitivity to climate and hydrological parameters to which tree-ring δ¹³C is more sensitive. δ¹³C showed significant lag with precipitation, and the lag correlation showed that BF, temperature, and precipitation were the most affected factors that are often associated with source water environments. δ¹³C series correlated positively to winter precipitation, suggesting baseflow was controlling the length of the growing season. The tree-ring δ¹³C provided information that coincided with TRW chronologies, and supplied some indications that were different from TRW chronologies. The carbon stable isotopes of tree-rings have proven to be powerful evidence of climatic signals and source water variations.

**Keywords:** stable isotopes; climate change; tree-rings; baseflow; Tianshan Mountains

1. Introduction

Global warming is exacerbating direct and negative impacts on the hydrological climate change and ecosystems of Asia and is threatening the livelihoods of billions of people [1–5]. The North Tianshan...
Mountains are located in the inland of Central Asia, far from the sea; however, the contradiction between the supply and demand of water resources is an important factor restricting its social and economic sustainable development. The water resources in the arid area of the North Tianshan Mountains mainly originate in mountainous areas, and the runoff of the inland rivers is mainly supplied by glacial meltwater, baseflow (BF), and precipitation. The form of three source-recharged types of rivers is greatly affected by climate change; what is more, BF is an important part of river runoff, which is the main source of runoff in the dry season. A large number of studies have shown that BF is closely related to watershed (catchment area (km²), total length of stream network (km), catchment relief (km), elevation of catchment centroid (m), length of mainstream (km) and climatic characteristics [6–11]. Concerns have been raised about the continued supply of fresh water to meet the growing demand of water consumption, as global warming accelerates the retreat of glaciers in high-altitude mountainous regions of Asia [12–17]. Since many international rivers (that cross political boundaries) in Central Asia provide fresh water for adjacent countries, fluctuations in the regional climate, glaciers, and streamflow can have broad geopolitical consequences. However, the hydraulic records that provide information on hydraulic variability are short [18], especially in river basins that cross political boundaries, such as the Ili River. Therefore, climatic and hydrological information and their proxy records for international river basins are thus of critical significance for evaluating the variability in regional water resources, and are fundamental to understand how they will respond under different forest management schemes and under a changing climate. At present, the meteorological and hydrological records in the North Tianshan Mountains area are relatively short; most of the areas only have approximately 50 years of observation records, and the study of dry and wet changes over long time scales can only rely on paleoclimate proxy data.

Among all kinds of paleoclimatic substitute data, tree-rings offer a great advantage in the research of paleoclimatic information archives, with the benefits of accurate annual resolution, a large number of replications, and easy access. Long-scale hydrological and climate change chronologies obtained from tree-ring data have unparalleled advantages and great potential in this respect. Since the 1970s, tree-ring climatologists have carried out plenty of tree-ring research work in the Tianshan Mountains area and numerous reconstructions of streamflow, precipitation, and drought have been developed based on tree-ring data [19–28]. Such achievements include research on the reconstruction and analysis of the precipitation in the Ili River Basin in the west of the Tianshan Mountains over 314 years [29], the relationship between the climate growth volume and the climate of the spruce rings in the west of the Tianshan Mountains [30], and changes in the cold and warm characteristics in the Ili River Basin in Xinjiang over the past 250 years [31]. Moreover, research on tree-rings in the Manas River Basin has only carried out the reconstruction of runoff [32] by using the tree-ring width (TRW) of the basin and the precipitation changes in the middle of the northern slope of the Tianshan Mountains. There are also some other tree-ring parameters available in tree-ring research in addition to ring width, including tree-ring density, cell structure, gray scale, and stable isotopes. Finding hydrological change information from more tree-ring parameters has now become one of the trends of tree-ring hydrology research [33,34]. In recent decades, research on the stable isotopes of tree-rings has made great progress, especially the development of tree-ring isotopes in the mechanism of interpretation and application in ecological environments [35]. The stable isotopes of tree-rings have become important basic data for the study of paleoclimate and source water environment changes because of their strong physiological explanation and high information resolution [36–42]. Tree-ring data from moisture-sensitive trees provide one of the best sources of recording tree growth environments, herein the composition of stable isotopes in tree-rings reflects the change of the source resources [43]. O’Leary (1988) and Bert et al. (1997) suggested that the characteristics of the carbon isotope ratios of tree-rings could be used to study the physiological and ecological responses of trees to past environmental changes, in addition to reflect past climate changes [44,45]. According to the analysis of tree-ring carbon isotopes and environmental factors, Han et al. (2000), Liu et al. (2002) found significant correlations between the average annual temperature and tree-ring carbon isotopes [46–48].
carbon isotopes is sensitive to seasonal temperature, precipitation, and relative humidity, with a lag effect [36]. Meanwhile, tree-ring carbon isotopes also reflect the relationship between tree growth and the water and heat environments to some extent [49–51]. In order to better understand the dynamics of forests and their interaction with climate, TRW and stable isotopes are insightful agents that provide information on pre-instrumental climatic and hydrological fluctuations, yet the variability of these data between different regions and different tree species has not been fully explored. Therefore, we carried out this study in an area with one of the best preserved *Picea schrenkiana* (known by the common name of Schrenk’s spruce) forests in different water resource recharge types of watershed along the Tianshan Mountains.

The aims of this study were to (1) analyze the long-term growth response of spruce forests to climate variability and changes in river BF and (2) determine if the climate is the driver of growth releases in the study area. We expect that (1) the tree-ring stable isotopes of spruce forest along the river are more sensitive to precipitation and river BF relative to TRW; and (2) the influence of climate on trees located at different slopes of the Tianshan Mountains is not the same due to different regional climatic backgrounds.

2. Study Area

The Tianshan Mountains, located in the inland of Asia, comprise the largest mountain system in Central Asia. This system runs west of the Kizilkum Desert of Uzbekistan and passes through Kazakhstan and Kyrgyzstan. The east–west length is approximately 2500 km, across the entire territory of Xinjiang and 1700 km of China’s territory, accounting for more than two-thirds of the total length with an area of approximately 570,000 km². The Tianshan Mountains divide Xinjiang into the Tarim Basin in the south and the Junggar Basin in the north, forming the unique geomorphologic features of the two basins. The climate of Xinjiang is affected by the mid-latitude westerly winds and subpolar air masses and characterized as arid continental. This study was conducted on the northern edges of the Tianshan Mountains area, and two areas (Figure 1) were chosen as representatives of extremely different climatic conditions. Schrenk spruce forests are the most dominant and widespread boreal forest type in the Tianshan Mountains and are one of the most important zonal vegetation types in the region [52,53].
Figure 1. Map of the climate station (blue triangle), hydrological station (white circle) and the sampling sites (red circle) on the North Tianshan Mountain, Xinjiang China (yellow abbreviations represent the site ID of stations).

The first area is Ili River Basin (the southern slope of the North Tianshan Mountains, 42°12′–44°48′ N and 80°10′–85°02′ E). The basin area is approximately 56,700 km², and the annual average runoff is 2.28 × 10¹⁰ m³. After 400 km in China’s territory, the Ili River flows out of the border and into Kazakhstan’s Balkhash Lake. The northern and southern branches of the Tianshan Mountains hinder the dry and hot air current from the Gurbantunggut Desert and the Taklamakan Desert, as well as the dry and cold current from Siberia. Thus, a humid and temperate climate is formed in the Ili River Valley, which becomes the precipitation center of the Tianshan Mountains and Central Asia. The runoff formation types of the watershed are ice/snow meltwater and mixed rainfall. Snow cover, precipitation in spring and summer, and temperature change are the main limiting factors of river runoff.

The second area is the Manas River Basin (the northern slope of mid-North Tianshan Mountain, 84°43′–86°35′ E and 43°21′–45°20′ N), 198.7 km in length from east to west and 260.8 km in width.
from south to north. The watershed area is 31,000 km², and the annual average runoff is 2.30 × 10⁹ m³. The landform of the basin is of a typical mountain structure—a basin system, with a hilly area (south), an oasis plain area (middle), and a desert area (north) [32]. Given its mid-continental location, Manas is characterized by a typical continental climate. The area is situated far from oceans, so ocean water vapor rarely reaches this region. The runoff formation types of the watershed are mixed rainfall and seasonal snow meltwater. Precipitation in spring and temperature changes are the main limiting factors of river runoff. Manas River is the largest river in the Manas River Basin of the northern Tianshan Mountains, with an annual average runoff of 1.27 × 10⁹ m³, which accounts for 55.2% of the whole basin’s runoff.

3. Materials and Methods

3.1. Field Sampling

The tree cores were collected following the Sveriges Lantbruksuniversitet (SLU, the Swedish national forest inventory, Department of Forest Resource Management) standards for tree core collection. Two cores per tree were extracted using an increment borer (Swedish Haglof, 12 mm) during September to October (the tree-rings of the year 2016 and 2012 were complete). The sampling only considered isolated, mature, and healthy individuals to avoid competition-influenced plant structures. In total, four sites provided 102 samples from 51 trees in the Ili River Basin, which were located on the south slope of the North Tianshan Mountains, with an altitude between 1698 and 2739 m; and 54 samples were collected from Xiao Baiyang Gou (XBY) in the Manas region, located at the tree line under the forest, with an altitude between 1745 and 1803 m. The information of sampling sites is summarized in Table 1.

| Location | Site ID | Longitude | Latitude | Elevation | Aspect | Slope |
|----------|---------|-----------|----------|-----------|--------|-------|
| Ili      | GS3     | 43°17′13.72″ | 84°18′47.16″ | 1698–1770 m | NW     | 40    |
|          | WS1     | 43°27′43.38″ | 81°7′16.84″ | 2150–2580 m | NE     | 30    |
|          | WS2     | 43°25′40.17″ | 81°3′25.47″ | 2552–2739 m | NW     | 10    |
|          | AH2     | 42°41′26.65″ | 81°4′54.47″ | 1950–2685 m | NE     | 35    |
| Manas    | XBY     | 85°59′ | 43°50′ | 1745–1803 m | NW     | 55.6  |

Note: NW is Northwest; NE is Northeast.

3.2. Dendrochronological Dataset and Chronology Building

All cores were taken back to the Key Laboratory of Tree-ring Physical and Chemical Research of China Meteorological Administration, Institute of Desert Meteorology, China Meteorological Administration. Following standard dendrochronological techniques [54], the sampled tree-ring cores were airdried, sanded to a high polish in preparation for ring-width measurements. After a rigorous visual cross-dating of the tree-ring cores, TRW was measured with a LINTAB measuring table with 0.001 mm precision, equipped with OLYMPUS binoculars and a polarized light source. A final cross-dating of samples was completed both visually and using the TSAP-Win™ dendrochronological software (Version 4.6x, http://www.rinntech.de). Cross-dating quality was verified using COFECHA (program written by Richard Holmes, LTRR-University of Arizona) [55] and used to check the consistency of TRW series among trees from the same site. Several methods (negative exponential curve, spline method, Tukey’s biweight robust mean) were used. The mean TRW chronologies computed by ARSTAN _41d program (2003, Dendrochronology Program Library) [56] were visualized by using plotting functions in the dplR package for R [57]. Principal component analysis (PCA) [58] was applied to explore the common variance of the site TRW chronologies and obtain the composite TRW chronologies (Table 2). Consequently, we combined all of the series from the four sites into an
average TRW chronology of Ili River Basin and combined all of the series from the XBY sites into an average TRW chronology of Manas River Basin.

### Table 2. Site information (site ID, longitude, latitude, and elevation) and average climate eigenvalue of the meteorological stations in the study area for the common period of 1950–2016. Long-term climatic data of each station contain mean temperature, mean air humidity, mean precipitation, and mean snow per year.

| Location | Site ID | Longitude/N | Latitude/E | Elevation/m | Mean a Temperature/°C | Mean b Air Humidity/% | Mean c Precipitation /mm | Mean d Snow/mm |
|----------|--------|-------------|------------|-------------|----------------------|----------------------|------------------------|----------------|
| Ili      | CB     | 43.80       | 80.78      | 600         | 8.8                  | 68.6                 | 226.1                  | 27.5          |
|          | YN     | 43.92       | 81.28      | 670         | 9.0                  | 64.8                 | 279.2                  | 33.8          |
|          | NLK    | 43.80       | 82.57      | 1200        | 6.5                  | 68.1                 | 382.6                  | 35.3          |
|          | YNX    | 44.12       | 81.65      | 800         | 9.7                  | 61.0                 | 354.7                  | 40.4          |
|          | GL     | 43.47       | 82.13      | 800         | 8.3                  | 70.0                 | 279.0                  | 24.8          |
|          | XY     | 43.45       | 83.13      | 900         | 9.0                  | 62.5                 | 508.0                  | 34.5          |
|          | ZS     | 43.13       | 81.00      | 1837        | 3.4                  | 67.4                 | 501.7                  | 26.9          |
|          | TKS    | 43.18       | 81.77      | 1210.4      | 6.1                  | 66.7                 | 396.1                  | 18.4          |
|          | HGS    | 44.20       | 80.42      | 770.9       | 9.9                  | 58.3                 | 248.3                  | 26.2          |
|          | HC     | 44.05       | 80.85      | 640         | 9.7                  | 63.3                 | 244.0                  | 28.1          |
| Manas    | SHZ    | 44.32       | 86.05      | 442.9       | 7.4                  | 64.1                 | 214.5                  | 24.4          |
|          | SW     | 44.35       | 85.62      | 533         | 7.8                  | 59.3                 | 198.5                  | 25.7          |
|          | MNS    | 44.30       | 86.22      | 471.4       | 7.1                  | 63.9                 | 200.4                  | 25.8          |
|          | HTB    | 44.12       | 86.82      | 522.1       | 7.1                  | 61.0                 | 184.4                  | 23.5          |

#### 3.3. Stable Carbon Isotope Analysis

The sample cores with no obvious difference in width growth, a normal growth, fewer missing rings, and a more obvious ring boundary were selected for isotope analysis. Tree cores from different trees at WS1 (six), WS2 (five), GS3 (five), AH2 (four) and XBY (seven) for isotope sample subsampling were prepared for each site individually and at an annual resolution. [59,60]. Samples of different cores for the same year were packed into the same centrifuge tube and dried at 75 °C for 24 h. The dried samples were crushed to 60 mesh (300 Lm) using a high centrifugal ball mill. Leavitt [61] proposed that the representative information of isotopic composition can be obtained by mixing the sample cores of different trees of the same year and then analyzing their δ13C (stable carbon isotope discrimination) values. Treydte [62] showed that the results obtained by mixed multi-core analysis are similar to those obtained by separate analysis. Barbour [63] compared and analyzed the isotope values of whole wood and the cellulose of oak and pine trees all over the world, and concluded that both the whole wood and the cellulose isotope records the same climate information, and that analysis of whole wood alone does not lose climate information. Indeed, many tree-ring isotope studies have adopted a multi-core mixing method [64,65]. Considering the often very narrow tree-rings of ca. 0.1 mm and their small portions of latewood, we mixed the sample cores of different trees among one site from the same year, and analyzed the whole wood isotope.

The measurement of carbon isotopes was carried out using a continuous flow isotope ratio mass spectrometer coupled with an elemental analyzer (EA-CF-IRMS, Isoprime Ltd, Hanau, Germany). The stable carbon isotope compositions of the samples were determined using an IsoPrime elemental analyzer/continuous flow isotope ratio mass spectrometer (IsoPrime100 mass spectrometer) at the State Key Laboratory of Desert and Oasis Ecology, Chinese Academy of Sciences. In order to determine the δ13C values, the samples were encapsulated in a tin. The samples were combusted at temperatures of 1120 °C and 850 °C in the elemental analyzer. The δ13C values were calibrated relative to the C-3 and C-5 international standards, and the results are reported in values relative to Vienna Pee Dee Belemnite (VPDB).

The isotopic values are reported in standard notation as delta:

\[
\delta = \frac{R_{\text{Sample}} - R_{\text{Standard}}}{R_{\text{Standard}}}.
\]
$R$ represents the ratio of the heavy to light isotopes in the sample and in the standard. Quality control was needed in the process of isotope analysis: each sample was tested more than twice. At the same time, every laboratory standard sample with a known isotopic composition was inserted in 10 sample intervals. A retest was required when the difference between the two measurements became large (0.5%). By using annual values for atmospheric $\delta^{13}C$, tree-ring $\delta^{13}C$ values can be translated into values that represent discrimination against $^{13}C$ ($\Delta$) using the equation [51]:

$$\Delta = \frac{(\delta^{13}C_a - \delta^{13}C_p)}{(1 + \delta^{13}C_p/1000)}$$  \hspace{1cm} (2)

where $\delta^{13}C_a$ is the carbon isotopic ratio of the air (the source) and $\delta^{13}C_p$ is the raw carbon isotopic ratio of the tree-ring. Annual resolution atmospheric $\delta^{13}C$ data were determined by taking the yearly values of the 6th order polynomial curve fit of measurements and Antarctic ice core. There is a significant correlation between atmospheric $\delta^{13}C$ and tree-ring $\delta^{13}C$ (Ili: $r = -0.785, p < 0.01$; Manas: $r = -0.541, p < 0.01$). The results show that the new sequence retains all the information of high frequency changes on the premise of eliminating the influence of low frequency of atmospheric $\delta^{13}C$ as much as possible.

### 3.4. Meteorological and Hydrological Data

Instrumental climate records of 14 meteorological stations near sample sites were obtained from the China National Climatic Data Center (http://data.cma.cn), including monthly mean temperature, monthly minimum temperature, monthly maximum temperature, relative humidity, and total monthly precipitation (Figure 2, Table 2). The Manas River Basin is located in the middle of the North Tianshan Mountains and the southern margin of the Junggar Basin. Drought and less rain, large evaporation, and the same period of rain and heat, belonging to the typical continental climate, characterize the climate of the Manas River Basin. The annual mean temperature of the basin is ~4.7–5.7 $^\circ$C, the annual precipitation is ~115–200 mm, and the annual evaporation is 1500–2100 mm. The Ili River Basin is located in the west of the North Tianshan Mountains; the annual precipitation in its plain area is different from in its mountainous area. The mean precipitation in plain area is 250–300 mm, which of the alpine plain area is 500–1000 mm. In particular, the max precipitation occurs at an altitude of 1000–2000 m in the mid-mountainous area. The annual average precipitation is 320.5 mm, while the annual average temperature is 6.3–9.6 $^\circ$C. The monthly average precipitation appears to have “double peaks”. From January, the precipitation increases month by month and is most concentrated in May, June, and July, while the minimum precipitation appears in August and September and then shows a second peak in November. The monthly average temperature shows an obvious “single peak”, reaching a maximum in July and August. The rare precipitation and high temperature in August and September form the hot and dry climate, characteristic of summer.

Streamflow can be divided into quickflow (QF) and baseflow (BF). In arid inland areas, such as Xinjiang, a vast arid region located in Northwestern China, BF becomes an important water source to support ecosystem and economic development in the region [66]. As a result, changes in BF would greatly affect the quantity and quality of the water resources of the study area, and considerably impact the natural ecological environment in the region, particularly trees along the lower reaches of the river. The BFI (baseflow index) is one of the most important low flow indexes, which is the long-term ratio of BF volume to total streamflow volume and affected by a number of climatic and topographic factors. We selected the Gongnais River of Ili River Basin and Manas River for our BF analysis due to their location (Gongnais River is the main tributary of the Ili River), just upstream of the study area, making them representative of the BF into their respective basins. Gaged calendar year BF data were obtained from the hydrologic station at the Gongnais and Manas rivers, covering the period 1936–2008. The influence of human activities on the streamflow recorded at the gauging location is very limited. The Manas River is of a rain/snow/glacier meltwater recharge type; the glacier area accounts for 14.3% of the whole basin, the rate of contribution of meltwater is 34.6%, and the BF index is 60%.
The Gongnais River of Ili River Basin is of a snow meltwater recharge type; the glacier area accounts for 1.3% of the whole basin, the rate of contribution of meltwater is 2.9%, and the BFI is 79% [67].

3.5. Statistic Analysis

Standard dendrochronological statistical parameters were computed for each chronology. From the TRW chronologies, the parameters were mean sensitivity (MS), standard deviation (Std.Dev), first-order autocorrelation (AC1), a signal-to-noise ratio (SNR), variance in first eigenvector (VFE), expressed population signal (EPS), and mean correlation between all trees or series (MCS) [68]. We used the Mann–Kendall test [69] to detect the monotonic trend of TRW chronologies and carbon isotope series. The highest values were defined as higher than the mean + σ (standard deviation), and the lowest values were defined as lower than the mean – σ. Detrending was conducted to remove frequency variability as a consequence of the biological age effect and standardization was completed on individual TRW series.

In order to examine the correlations between climatic variables and tree-ring parameters, we first determined the correlations between a number of annual climate variables (including temperature, precipitation, relative humidity) and the TRW chronologies, as well as tree-ring δ13C series, by using Pearson’s correlation tests. Analysis was performed for the period of 1952–2016 (Ili) and 1952–2012 (Manas) (determined by the meteorological observation records in the North Tianshan area and quality of data). We used partial correlation to evaluate the relationships between tree-ring parameters and climate parameters. When evaluating the relationship between a tree-ring parameter and a climate parameter (e.g., precipitation), we considered the other climate parameter (e.g., temperature) as the third factor in the partial correlation calculation. Due to the strong biological lag effect, climate data taken from the prior January to the current December of the sample year were used for the monthly correlation analysis.

To investigate the correlation between weather and growth, the R package “treeclim” was used [70]. Seasonal correlation analysis was undertaken for a 95% significance level for different season durations from 1 to 6 months in monthly increments. Partial correlation with primary and secondary climate variables and tree-ring data was calculated for seasons of different lengths; in this study, monthly temperature was set as the primary variable and monthly precipitation as the secondary variable. To evaluate the temporal stability of climate–growth relationships, we compared climate data and composite TRW chronologies and δ13C series using a univariate moving window correlation analysis. The 8 month dendroclimatic window was set from March to October with an 18 year moving interval and a 2 year offset.

Figure 2. Long-term trend of mean annual climate data (temperature, precipitation, average relative humidity) of (a) Manas River Basin in the middle of the Northern Tianshan Mountain; (b) Ili River Basin in the west of the Northern Tianshan Mountain. Bars indicate annual precipitation anomaly (in mm), and curves with red color represent annual temperature anomaly (in °C), dashed lines with a hollow circle represent trends in annual average relative humidity anomaly (in %).
To detect statistical relationships between time series of BF and tree-ring variables, we conducted cross-correlation analysis (C-C analysis) to determine lagged effects of them. All data series were pre-whitened to eliminate autocorrelations existing in the data series by using the best fitting autoregressive integrated moving average (ARIMA) models [71]. Model residuals were then applied for cross-correlation analysis. Here, we used the Morlet wavelet to decompose the series to explore the relationships between the tree-ring parameters and BF [72]. The cross-wavelet transform (XWT) and wavelet coherence (WTC) of the BF and δ¹³C series could be obtained after using the continuous wavelet transform tool. The relative phase relationship is shown as arrows (with in-phase pointing right and antiphase pointing left). Both the XWT and WTC analyses can reveal the resonance signals of two time series. The XWT exposes regions with high common power and further reveals information about the phase relationship.

4. Results

4.1. Tree Growth

4.1.1. Statistical Characteristics of the TRW Chronologies

The averaged TRW chronology (STD, standard version) from the Ili River Basin consisted of 102 tree-ring series from 51 trees, and Manas consisted of 46 tree-ring series from 24 trees (Table 3). This is after discarding those series that were not datable. The common period of the Ili tree-ring width chronology is from 1860 to 2016, and Manas tree-ring width chronology is from 1859 to 2012 (Figures 3a and 4a). The wavelet-based spectral analysis of TRW chronologies of Ili showed a significant periodicity of eight to sixteen years during 1910–1950 (Figure 3b), and TRW chronologies of Manas showed a significant periodicity of eight years during 1938–1956 (Figure 4b). The largest sample size was the AH2 site of the Ili River Basin. The mean correlations between the TRW chronologies of the four sites of Ili are high, with correlation coefficients of 0.69 (p < 0.01), 0.56 (p < 0.01), 0.54 (p < 0.01), 0.66 (p < 0.01), 0.62 (p < 0.01), and 0.66 (p < 0.01), respectively, indicating that the ring-width changes of spruces from the different sites were controlled by similar factors. The mean correlation within series of Manas TRW chronology is 0.69 (p < 0.01), indicating the strength of the common signal among the series (Table 3).

Table 3. Summary statistics for site tree-ring width (TRW) chronologies used in this study.

| Location | Site | Core/Tree Number | Length of TRW Chronology | MS | AC1 | SNR | VFE | EPS | Std.Dev | MCS |
|----------|------|------------------|--------------------------|----|-----|-----|-----|-----|---------|-----|
| Ili      | GS3  | 24/12            | 1860–2016                | 0.11 | 0.47 | 14.6 | 35.8% | 0.95 | 0.18 | 0.68  |
|          | WS1  | 32/16            | 1641–2016                | 0.12 | 0.45 | 22.6 | 42.6% | 0.96 | 0.015 | 0.72  |
|          | WS2  | 30/15            | 1624–2016                | 0.12 | 0.45 | 16.7 | 36.4% | 0.96 | 0.13 | 0.66  |
|          | AH2  | 16/8             | 1784–2016                | 0.15 | 0.50 | 16.5 | 36.2% | 0.96 | 0.17 | 0.65  |
| Manas    | XBY  | 46/24            | 1859–2012                | 0.21 | 0.45 | 22.4 | 65.5% | 0.93 | 0.25 | 0.69  |

Note: MS is the mean sensitivity; AC1 is the first-order autocorrelation; SNR is the signal-to-noise ratio; VFE is the variance in first eigenvector; EPS is the expressed population signal, first year EPS > 0.85; Std.Dev is the standard deviation; MCS is mean correlation between all trees (Ili) or series (Manas).

Table 3 shows the statistics of the TRW chronology. The MS and Std.Dev of the Ili TRW chronology are 0.12 and 0.13, respectively, which are similar to other TRW chronologies near the Ili River Basin in Northwest China [73]. The relatively minor inter-annual variability implies that the conifers grew in relatively stable environments. The SNR and the VFE of Ili are 37.7 and 38.7%. The AC1 of the TRW chronology is from 0.45–0.50, suggesting that climate conditions in one year can influence ring width in the following year. The Manas TRW chronology has a MS of 0.21, and a higher MS indicates high variability between adjacent ring widths, which is more likely related to climate variability. The results indicate the existence of strong climatic information in the Manas TRW chronology. The SNR and
the VFE of Manas are 22.4 and 65.5%. The AC1 of 0.45 for the Manas TRW chronology also indicates that the climate conditions of the previous year affect the tree growth of the current year. In general, the higher EPS and SNR are believed to indicate a greater climatic influence on tree growth [56]. The EPS calculated for Ili and Manas are 0.96 and 0.93. This exceeds the commonly accepted threshold of 0.85 for sufficient signal strength of a TRW chronology [58], indicating a high consistency between individual trees’ width series. According to the above analysis results of TRW chronologies, trees in Manas are likely to be more sensitive to regional climate change relative to Ili. We used principal components analysis to extract variability in common between the site tree-ring chronologies (Table 4). The first principal component has high positive high weights on all chronologies, whereas the PC2 mainly contrasts WS1 with the other chronologies. This contrast is likely due to high SNR of WS1 relative to the arid and cold regions.

![Figure 3](image)

**Figure 3.** (a) Ili TRW chronology (standard (STD)) detrended using a 30-spline curve and the sample depths with respect to time (red line); the green line represents the expressed population signal (EPS) > 0.85. (b) The wavelet power spectrum. The contour levels were chosen so that 75%, 50%, 25% and 5% of the wavelet power is above each level, respectively. The black contour is the 1% significance level with a red noise (autoregressive lag1) background spectrum. RWI refers to ring width index.

**Table 4.** Factor loadings of principal components from PCA of the TRW chronologies of the Ili River Basin.

| Chronology | Total | % of Variance | Cumulative % | Factor 1 | Factor 2 |
|------------|-------|---------------|--------------|----------|----------|
| GS3        | 2.263 | 56.586        | 56.586       | 0.769    | −0.365   |
| WS1        | 1.024 | 25.602        | 82.187       | 0.405    | 0.891    |
| WS2        | 0.468 | 11.702        | 93.889       | 0.907    | 0.156    |
| AH2        | 0.244 | 6.111         | 100.000      | 0.828    | −0.268   |

Note: PCA was run on the correlation matrix 1860-2016.
The detrended tree-ring δ13C series of Manas shows continuously increasing trends, with a rate of 6.5% (Z0 = 1.645, H0 = A). The detrended tree-ring δ13C series of Ili shows a decreasing rate of –0.24‰ (Z0 = 1.96, H0 = R). The tree-ring δ13C series of Manas shows continuously increasing trends, with a rate of 6.5% (Z0 = 1.645, H0 = A). The detrended tree-ring δ13C series are shown in Figure 5. The δ13C series of Ili showed higher carbon isotope values during the 1940s to 1980s, and the stable carbon isotope ratios are constantly above the long-term mean, indicating generally drier climate conditions in Ili River Basin. Since the early 1960s, a steady trend in δ13C series values of Manas could be observed.

Table 5. Site information and Pearson’s correlation coefficients for the common period of 1921–2016 for tree-ring δ13C chronologies of *Picea schrenkiana* (spruce) from the Ili region.

| No. | Site | Time Span | Correlation Coefficients |
|-----|------|-----------|--------------------------|
|     |      |           | 2   | 3   | 4   |
| 1   | GS3  | 1940–2016 | 0.470 ** | 0.466 ** | 0.546 ** |
| 2   | WS1  | 1921–2010 | /   | 0.228 ** | 0.680 ** |
| 3   | WS2  | 1921–2016 | /   | /   | 0.744 ** |
| 4   | AH2  | 1939–2016 | /   | /   | /   |

** Significance at the level of p < 0.01 (2-tailed).
The AC1 of Ili and Manas δ parameters relative to the preceding years and formed in the following year, so lag effect may contribute to the isotope signal of the whole tree-ring. BF over one growing season can carry the climate signal of the preceding year along with the actual climate signal. Moreover, memory effects the changing climatic factors on tree-rings taken up during the previous year on the isotopic composition of the current tree-ring. The δ13C series of Manas were 0.62 and 0.56, indicating a significant influence of the climatic parameters and that the tree-ring isotopes may contain more climate information. Our resulting δ13C series of Ili extends from 1921 to 2016, and δ13C series of Manas extends from 1962 to 2012. The mean δ13C value of the Ili series is –23.78‰ ± 0.88, with a range of δ13C values between –26.37‰ and –21.56‰, respectively. In addition, the mean δ13C value of Manas series is –25.54‰ ± 0.27, with a range of δ13C values between –26.45‰ and –25.20‰, respectively (Table 6). The AC1 of Ili and δ13C series of Manas were 0.62 and 0.56, indicating a significant influence of the previous year on the isotopic composition of the current tree-ring. The δ13C series of Ili have higher values of Std.Dev and variance, which means the δ13C series of Ili are more sensitive to climate parameters relative to the δ13C series of Manas. Trees with the access to ice-snow meltwater and stable BF over one growing season can carry the climate signal of the preceding year along with the actual climate signal. Moreover, memory effects the changing climatic factors on tree-rings taken up during the preceding years and formed in the following year, so lag effect may contribute to the isotope signal of the whole tree-ring.

![Graph of δ13C series](image)

**Figure 5.** Tree-ring δ13C series of Ili (a) and Manas (b). The thick line represents the 10 year moving average. The green and blue dots represent the highest and lowest year values, respectively.

Descriptive statistics were calculated for composite stable isotope chronologies from Ili and Manas (Table 6). The average Std.Dev were 0.78 and 0.27, respectively. Among all sites, the GS3 site had the highest AC1 and Std.Dev (0.65 and 0.78), which indicates that the growth of trees at this site was more restricted by climatic parameters and that the tree-ring isotopes may contain more climate information.

| Location | Length of Iso-Series | Mean(‰) | Min(‰) | Max(‰) | Range(‰) | Std.Dev | Variance | AC1 |
|----------|----------------------|---------|--------|--------|----------|--------|---------|-----|
| Manas    | 1962–2012            | –25.54  | –26.45 | –25.20 | 1.25     | 0.27   | 0.07    | 0.56|
| Ili      | 1921–2016            | –23.78  | –26.37 | –21.56 | 4.81     | 0.78   | 0.72    | 0.62|
| GS3      | 1921–2016            | –23.91  | –26.52 | –21.59 | 4.93     | 0.78   | 0.82    | 0.65|
| WS1      | 1925–2016            | –23.71  | –26.26 | –21.53 | 4.73     | 0.66   | 0.74    | 0.52|
| WS2      | 1932–2016            | –23.70  | –26.28 | –21.46 | 4.82     | 0.69   | 0.78    | 0.54|
| AH2      | 1928–2016            | –23.82  | –26.42 | –21.66 | 4.76     | 0.69   | 0.80    | 0.52|

Note: iso-series is the series of δ13C; Std.Dev is the standard deviation; AC1 is the first-order autocorrelation.
4.2. Tree-Growth Response to Meteorological Parameters and Baseflow

4.2.1. Climatic Signal in Tree Rings

In order to identify the most important impact of climate on tree growth, we firstly carried out the annual correlation analysis between tree-ring parameters (TRW chronologies, δ¹³C series) and influencing factors (Table 7). A significant negative relationship between temperature (Temp) and the TRW chronologies was found for both Ili and Manas, whereas a significant positive relationship between the average relative humidity (RH) and the TRW chronologies was found for both Ili and Manas. There was no obvious response of TRW chronologies to precipitation (Prec) and vapor pressure (VP), and when the impact of Temp was controlled, Prec still had no positive impact on the TRW chronologies. When the impact of Prec was controlled, Temp showed no significant impact on the TRW chronologies. A significant negative relationship between temperature and the δ¹³C series was found for Ili and Manas, as well as a significant positive relationship between the RH and the δ¹³C series for Ili. In addition, VP has a significant negative impact on δ¹³C series. There was no obvious response to Prec, and when the impact of Temp/Prec was controlled, the partial correlation between Prec/Temp and the δ¹³C series weakened.

**Table 7.** Correlation analysis between the tree-ring variables (TRW chronologies and δ¹³C series), climatic factors of the Ili and Manas for the time period from the previous July to the September of the same year.

| Tree-Ring Parameters | Climatic Parameters | Cor/Partial–cor | Correlation Coefficients | Manas | Ili |
|----------------------|---------------------|----------------|--------------------------|-------|-----|
| TRW chron             | Cor Temp            | −0.546 *       | −0.485 **                |       |     |
|                      | Cor max Temp        | −0.624 **      | −0.545 **                |       |     |
|                      | Cor min Temp        | −0.555 *       | −0.462 **                |       |     |
|                      | Cor Prec            | −0.085         | 0.341 **                 |       |     |
|                      | Cor RH              | 0.472 **       | 0.341 *                  |       |     |
|                      | Cor VP              | 0.02           | −0.028                   |       |     |
|                      | partial–cor Temp    | −0.547         | −0.024                   |       |     |
|                      | partial–cor Prec    | 0.091          | 0.128                    |       |     |
| δ¹³C series           | Cor Temp            | −0.319 *       | −0.466 ***               |       |     |
|                      | Cor max Temp        | −0.632 **      | −0.518 **                |       |     |
|                      | Cor min Temp        | −0.346 *       | −0.478 *                 |       |     |
|                      | Cor Prec            | −0.020         | −0.109                   |       |     |
|                      | Cor RH              | 0.016          | 0.373 **                 |       |     |
|                      | Cor VP              | −0.426 **      | −0.463 **                |       |     |
|                      | partial–cor Temp    | −0.318         | −0.478                   |       |     |
|                      | partial–cor Prec    | −0.004         | −0.163                   |       |     |

Note: * significance at the level of $p < 0.05$ (2-tailed). ** Significance at the level of $p < 0.01$ (2-tailed). *** Significance at the level of $p < 0.001$ (2-tailed). Cor is the correlation, partial-cor is partial correlation, Temp is temperature, Prec is precipitation, RH is average relative humidity, VP is vapor pressure.

A single month or a seasonal combination may be more representative of temperature conditions than focusing on just a year. Thus, we screened the TRW chronologies and the tree-ring δ¹³C series in the correlation analyses with monthly temperatures and precipitations from the previous January to the current December. The correlation coefficients for the climate response analyses on a monthly scale for the TRW chronologies and δ¹³C series of Ili are shown in Figure 6a,b, and TRW chronologies and δ¹³C series of Manas are shown in Figure 6c,d. The climate response analyses indicate that the TRW chronologies of Ili have significant negative responses to the temperature from the previous April ($r = −0.450, p < 0.01$) to October ($r = −0.292, p < 0.05$), and from the current April ($r = −0.465, p < 0.01$) to October ($r = −0.29, p < 0.05$). Meanwhile, a high positive correlation was found between the δ¹³C series and temperatures for some of the different months. The TRW chronologies of Ili have significant responses to the precipitation of the previous July ($r = 0.429, p < 0.01$) to the previous
September \((r = 0.298, p < 0.05)\), the current May \((r = 0.318, p < 0.05)\), and the current July \((r = 0.358, p < 0.01)\), while the \(\delta^{13}C\) series of Ili have significant negative responses to the precipitation of cold months (February or December). The climate response analyses indicate that the TRW chronologies of Manas have significant negative responses to the temperature of the previous February, April, May, and June \((r = -0.375 \text{ to } -0.555, p < 0.01)\), as well as from the current February to June \((r = -0.389 \text{ to } 0.585, p < 0.01)\). The \(\delta^{13}C\) series of Manas has significant negative responses to temperature of different months \((r = -0.349 \text{ to } 0.427, p < 0.01)\). The TRW chronologies of Manas have significant responses to precipitation of the previous December and the current December, while the \(\delta^{13}C\) series of Manas has significant negative responses to the precipitation of the previous January and the previous July instead of the current year.

**Figure 6.** (a) Correlation coefficient of the lagged monthly temperature with the Ili TRW chronologies and isotope series. (b) Correlation coefficient of the lagged monthly precipitation with the Ili TRW chronologies and isotope series. (c) Correlation coefficient of the lagged monthly temperature with the Manas TRW chronologies and isotope series. (d) Correlation coefficient of the delayed monthly precipitation with the Manas TRW chronologies and isotope series.

The previous results clearly show that the TRW chronology of Ili has a significant negative correlation with the July to September temperature, but the response of the TRW chronology is only seen in the September temperature as depicted in Figure 7a. The weather–growth analysis for the control plots showed no correlation with the previous seasonal temperature. However, there was a significant positive correlation between the \(\delta^{13}C\) series of Ili and mean autumn to early winter temperature (Figure 7b). We did not find significant correlations between TRW chronologies of Manas and temperature, but a significant positive correlation could be found from the previous August to the current July between TRW chronologies of Manas seasonalized precipitation (Figure 7c). The \(\delta^{13}C\) series of Manas showed a positive correlation with precipitation of summer. In addition to this, the seasonal correlation shows that the \(\delta^{13}C\) series has a significant positive correlation with the season at a six-month resolution, with the previous October being the ending month (Figure 7d).
Figure 7. Plot of a seascorr analysis relating (a) TRW chronology of Ili; (b) δ¹³C series of Ili; (c) TRW chronology of Manas; (d) δ¹³C series of Manas to temperature and precipitation. Composites with lengths of 1, 3, and 6 months. Simple correlations with monthly temperature (top) and partial correlations with monthly precipitation (bottom). Solid dark bars show significant correlation at \( p < 0.05 \) level.

The moving correlation analyses (Figure 8) show that the majority of correlations tested display temporal fluctuations. For TRW chronology of Ili, the positive correlation with March precipitation
is the most stable one found, and the May temperature had a positive influence on the middle decades (1973–2004). Furthermore, we found negative correlations with July temperatures in recent decades (1981–2016) and April temperatures (1981–1998, 1987–2006) (Figure 8a). The most special correlations found between the δ13C series of Ili and monthly climate are the positive correlations with August precipitations (Figure 8b). This correlation is, however, no longer significant when measured over the middle two decades (1979–2002). Instead, we found a negative correlation between the δ13C series of Ili and the August precipitations in recent decades (1989–2012). The most prominent correlations found between TRW chronology of Manas and monthly climate are the positive correlations with August precipitation (1957–1984) and negative correlations with June temperatures (1959–1988) (Figure 8c). April temperatures were positively associated with the δ13C series of Manas in earlier decades (1963–1990). Other distinct features consist of the positive influence during earlier decades of August precipitation (1975–2002) and October temperatures (1977–2002) (Figure 8d).

**Figure 8.** Plot of moving correlation function relating (a) TRW chronology of Ili (b) δ13C series of Ili (c) TRW chronology of Manas (d) δ13C series of Manas to temperature and precipitation of current March to current October. The moving correlation is carried out in windows of 18 a, offset by 2 a. Asterisks (*) indicate significant correlations (p < 0.05).

Summarizing, TRW chronologies of both Manas and Ili show a similar relationship with temperature (negative) and RH (positive). However, the δ13C series of both Manas and Ili contain more climatic signals, such as VP (negative). Only the relationship between RH and the δ13C series represents different results, as RH has a significant positive influence on the δ13C series of Ili, but not on the δ13C series of Manas. Spring, summer, and autumn temperatures (both previous year and current year) have a significant impact on TRW chronologies of Ili; meanwhile, the δ13C series of Ili can also record the previous February temperature in addition to the spring, summer, and autumn temperatures (both previous year and current year). In addition, TRW chronologies of Ili are sensitive to summer precipitation (both previous year and current year), whereas the δ13C series of Ili are more sensitive to precipitation of the previous year, especially February and December. Unlike Ili, TRW chronologies of
Manas are more responsive to winter temperature (previous and current February) and precipitation (previous and current December), and the $\delta^{13}C$ series are less sensitive to temperatures of the previous year and the precipitation of the current year. We found a continuous positive influence of several months in spring or summer precipitation on the radial growth of spruce as well as a negative effect of several months in spring and summer temperatures. This may be due to the fact that cool and wet conditions during spring or early summer recharge the soil moisture that can benefit the trees by enhancing the cambial activity during the growing season.

### 4.2.2. Baseflow Analysis

The time series cross-correlation analyses revealed that BF for both watersheds exhibited significant and negative correlations with $\delta^{13}C$ series, but no significant correlation was found between BF and TRW chronologies (Table 8). Both watersheds exhibited the same lag of four years between BF and $\delta^{13}C$ series. The BF showed a significantly positive correlation with temperature and precipitation and the same lag of two years between BF and climatic factors. Cross-correlation analyses were also conducted for the BF with the other seasonal climatic factors. However, no significant correlations were found between them.

**Table 8.** Cross-correlation between baseflow (BF) and tree-ring variables (TRW chronologies and $\delta^{13}C$ series), climatic factors (temperature and precipitation) of the Ili and Manas, and lags between the baseflow and tree-ring variables or climatic factors.

| Watershed | TRW Chronologies | $\delta^{13}C$ Series | Snowmelt Season Temp | Winter Prec |
|-----------|------------------|-----------------------|----------------------|-------------|
|           | $C-C$ Coef | Lag/Years | $C-C$ Coef | Lag/Years | $C-C$ Coef | Lag/Years | $C-C$ Coef | Lag/Years |
| Ili BF    | $-0.340$ | $-2$ | $-0.336$ * | $-4$ | $0.650$ ** | $2$ | $0.145$ * | $2$ |
| Manas BF  | $-0.262$ | $-2$ | $-0.468$ ** | $-4$ | $0.572$ ** | $2$ | $0.369$ ** | $2$ |

Note: * significance at the level of $p < 0.05$ (2-tailed). ** Significance at the level of $p < 0.01$ (2-tailed). $C-C$ Coef is the cross-correlation coefficient, and BF is baseflow. The autoregressive integrated moving average (ARIMA) models pre-whitened time series data of flows.

For BF, the results of the $\delta^{13}C$ series and TRW chronologies response analysis indicate different results; only Ili BF has a noticeable negative impact on the $\delta^{13}C$ series (Table 8). There are significant decadal periodicities in the cross-wavelet transform (XWT) and the wavelet coherence (WTC) of the BF and $\delta^{13}C$ series in different time scales over the two study regions. Here, we note that the common features we found by eye from the individual wavelet transforms stand out as being significant at the 5% level.

The XWT shows that BF and the $\delta^{13}C$ series in the Ili River Basin are in antiphase in all the sectors with significant common power (two significant resonance periods), and WTC shows that BF and the $\delta^{13}C$ series are in antiphase in all the sectors with significant common power (one significant resonance period) (Figure 9a,b). There was a significant negative correlation between the two, and the correlation factor is approximately 0.9. We also note that there is a significant common power in the 1–2 a and 7–9 a band from 1988 to 1993 and from 1978 to 1990, respectively, and significant common power in the 8–10 a band from 1976 to 1992.

The XWT shows that BF and the $\delta^{13}C$ series in the Manas River Basin are in antiphase in all the sectors with significant common power (one significant resonance period), and WTC shows that BF and the $\delta^{13}C$ series are in antiphase in all the sectors with significant common power (one significant resonance period) (Figure 9a,b). Some significant common oscillations of 4–7 years between the BF and the $\delta^{13}C$ series are revealed by wavelet analysis in the Manas River Basin (Figure 9c,d). There was a significant negative correlation between the two, and the correlation factor is approximately 0.7.

In addition, there is a significant common power in the 4–7 a band from 1988 to 1997 and a significant common power in the 4–7 a band from 1991 to 1998. This shows that the resonance cycle changes around 1981 and 1997. It further indicates that the Manas River Basin experienced a transformation of periods from “dry season to wet season” and from “wet season to dry season” before and after these two time nodes.
The effect of temperature on tree-ring growth constitutes at least three-quarters of the factors related to the summer and autumn temperatures of the current and previous years. The temperature of the current growing season can affect the growth of tree-ring in the next year, and in some regions can even affect the growth of the tree-ring many years thereafter. The effect of precipitation on TRW chronologies and δ13C series has an obvious lag effect, and the lag effect of precipitation on the tree-ring is generally greater than that of temperature. Generally, the number of months with large absolute correlation coefficient values that can pass the $\alpha = 0.05$ significance level test is taken as the best time (months) to measure the time delay tree-ring parameters and meteorological factors. Therefore, identification of the optimal number of delay months has an important reference value for understanding the lag mechanism and can provide theoretical support for climate and BF prediction.

![Figure 9](image_url)

**Figure 9.** (a) Cross-wavelet transform of the Ili baseflow and tree-ring isotopes. (b) The wavelet coherence between the Ili baseflow and the tree-ring isotopes. (c) Cross-wavelet transform of the Manas baseflow and tree-ring isotopes. (d) The wavelet coherence between the Manas baseflow and tree-ring isotopes. The 5% significance level against the red noise is shown as a thick contour. The relative phase relationship is shown as arrows (with in-phase pointing right and antiphase pointing left). Arrows indicate the phase of the coherence, where the right is in-phase and the left is antiphase; note that significant regions all show an in-phase relationship, which supports the idea that there may be a simple cause and effect relationship between the two phenomena.

5. Discussions

Numerous studies in the Tianshan Mountains on TRW chronologies, tree growth climate responses, and historical climate reconstruction have been based on the widely distributed primordial coniferous forests growing in the mountainous area [13,21,23–26,29,53,74–80]. The results of our research indicate that Schrenk's spruce in different regions of the Tianshan Mountains have different responses to changes in climatic factors.

5.1. Inconsistent Response of Tree-Ring Parameters of Two Study Region

Although both the Manas River and Ili River regions are located in the North Tianshan Mountains area, their tree-rings record different results (Figures 6–8), and the underlying reason is their unique regional climatic and BF characteristics (which are also related to unique regional climatic influences). The southeast monsoon vapor from the Pacific Ocean is blocked by the Tianshan Mountains, and the
southwest monsoon vapor from the Indian Ocean is blocked by the Qinghai–Tibet Plateau; therefore, little water vapor is left by the time it arrives. Whereas, water vapor carried by the cold air in the south of the Arctic Ocean drives directly from the northern part of the Tianshan Mountains, and the vapor from the Atlantic Ocean, carried by the westerlies, enters and produces precipitation across the western mountains and the Pamir Plateau [53,81,82]. However, the northern and southern branch ranges of the Tianshan Mountains partition the two study areas of our research, which generates different responses of tree-rings to regional climate change. In recent decades, we observed anomalous positive impact of July to October temperatures on tree-ring parameters of Ili, but of March to June on tree-ring parameters of Manas (Figure 8). Due to the unique geographical environment of Ili, the southern area of the Tianshan Mountains is a natural barrier with high mountains, blocking the invasion of the dry and hot flow in the southern Taklamakan Desert. The northern Tianshan branch restrains the attack of the northern Arctic Ocean cold flow; only the west side is open, accepting the warm and humid Atlantic air flow brought by the westerlies, forming a humid temperate continental semi-arid climate, with abundant precipitation and a mild climate, which is completely different from Manas. Our data confirm that the growth of spruce in the Ili is sensitive to moisture availability, as evidenced by negative correlations with growing season temperature and positive correlations with summer precipitation (Figures 7 and 8).

When a 10 year moving average was applied to the four series, the inter-decadal variability was conspicuous (Figure 5). The periods of enrichment of $\delta^{13}$C in Ili (above the mean value of the $\delta^{13}$C series) were 1939–1958 and 1961–1976. The periods of depletion of $\delta^{13}$C in Ili (below the mean value of the $\delta^{13}$C series) were 1929–1935, 1979–1983, 1988–1997, and 2010–2016 (Figures 3 and 5a). The period of enrichment of $\delta^{13}$C in Manas (above the mean value of the $\delta^{13}$C series) was 1966–1978, and the periods of depletion of $\delta^{13}$C in Manas (below the mean value of the $\delta^{13}$C series) were 1986–1992 and 2007–2011 (Figures 4 and 5b). The drought events of the Tianshan Mountains, which link with the Asian monsoon, are the most severe drought events, as evidenced by many dendroclimatological studies [83–87]. The extreme drought years in the inner Tianshan Mountains were 1778, 1830, 1864, 1917, 1945, 1970, 1985 and 1995 when the TRW chronologies of Ili were lower than the mean – $\sigma$ (standard deviation) and $\delta^{13}$C series of Ili was higher than the mean + $\sigma$ (standard deviation). These dry events have had profound effects on the inhabitants of Western China and Central Asia over the past several centuries [19,53].

5.2. Different Potential of TRW and Isotope in Characterization

The growth records suggest these spruces have experienced similar growing conditions (e.g., light, temperature, humidity, and soil moisture) and that they have not influenced the trees disproportionately. As such, we may expect the TRW to have similar characteristics with the carbon isotope. In the Ili River Basin, the TRW chronology and $\delta^{13}$C series both comprehensively characterize temperature changes. Spruce growing at lower elevations are sensitive to temperature in snowmelt seasons, which has increased in intensity during the studied period [29]. Thus, it is no surprise that the radial growth of the spruce in the low elevation area of Ili responds to maximum temperature variation very well (Table 7). In the Manas River Basin, the TRW records the temperature information of the previous year and the current winter and the snowmelting season, while the $\delta^{13}$C series record the temperature better from the current growth season to the winter. In the low-altitude area, the summer temperature is extremely high, which inhibits plant growth [88]. Meanwhile, too high a temperature leads to high evaporation, along with limited precipitation [89,90]. In summer, the transpiration of trees is also strengthened, resulting in the loss of water in the soil and trunk, leading to the formation of narrow tree-rings that affect the isotopes [91]. At the same time, the tree-ring $\delta^{13}$C series of the Ili River Basin, as well as those of the Manas River Basin, are more obviously characteristic of the precipitation information of the previous winter and summer, while the effect of width shows the opposite effect. By comparing the relationship between the $\delta^{13}$C series of the TRW and the precipitation in the study area, we found that the $\delta^{13}$C series have a significant negative correlation with monthly precipitation, which indicates
that the carbon isotopes’ composition within the tree-ring can record changes in precipitation to a certain extent (Figures 7 and 8). For single-month or seasonal precipitation changes, isotopes can record information pertaining to TRW in different periods. Combined with regional climate change background analysis, multi-parameter proxy data have more potential to characterize climate change.

In the Ili River Basin, April–October is one of the most active periods of spruce growth throughout the year, and is the key period for tree-ring formation, at which time the cell division and elongation are more vigorous, completing more than half of the annual tree-ring growth [92]. The temperatures of April to October (both previous and current year) are important to the growth of trees in Ili (Figures 6a, 7a,b and 8a,b). Average monthly temperatures in Ili usually reach above 0 °C in late March of the year. Temperature rises rapidly from April and June, and the soil snowmelt recharge is basically consumed in late June. The average temperature reaches the highest value of the year in mid-August. Warm and dry late summers can reduce the accumulation of carbohydrate reserves by limiting photosynthesis through drought stress, by increasing respiration rate, and by diverting energy reserves to current year growth. Therefore, the consumption of plenty of water is necessary for such a rapid growth of spruce. On the contrary, this period is the water shortage period in Xinjiang, and the effect of low humidity and high temperature on tree growth is much greater than that of high humidity and low temperature. In addition, due to the vigorous growth of spruce in May–August, trees can store more nutrients to meet the needs of rooting and germination in the coming year. Therefore, the high temperature in May–August leads to a decrease in nutrient accumulation, which is not only unfavorable to the growth of tree-ring in that year, but also affects the growth of tree-ring in the next year. The negative correlation between the growth of tree-ring and the average temperature in June and July is significant in tree physiology.

5.3. Linkages between the Tree-Ring Parameters and Baseflow under Climate Change

According to a comparison between the watersheds in the northwest arid area, The Gongnais River of Ili is of a snow meltwater recharge type; its glacier area accounts for 1.3% of the whole basin, the rate of contribution of meltwater is 2.9%, and the BFI is 79% [67]. Meanwhile, relative to Ili, Manas has less precipitation and more extreme temperatures. The advance of the snowmelting season causes more sensitive source water environments for the forest. The Manas River is of a rain/snow/glacier meltwater recharge type; the rate of contribution of meltwater is 34.6%, and the BFI is 60% [67]. Rising temperatures and anthropogenic influence have significantly changed the hydrologic conditions in the river basin area. A warming climate results in less precipitation falling as snow and an earlier onset of snowmelt, and these changes in turn influence the timing of the intra-annual streamflow distribution.

The δ13C of plant matter is controlled fundamentally by the isotopic composition of atmospheric CO2 and modified by isotopic discrimination occurring during CO2 uptake and photosynthesis. Carbon assimilation and leaf boundary layer and stomatal pore conductance are influenced by environmental variables [93], which provide a realistic link between δ13C and climate. The increases in baseflow are likely related to enhanced groundwater storage and winter groundwater discharge caused by permafrost thaw and are potentially also due to an increase in the wet season rainfall. Baseflows exhibited statistically significant positive correlations with melt season temperature (Table 6).

In the Manas River Basin, the rising temperature in spring causes early snowmelt at high altitudes. Tree growth starts in the middle of May, and the rapid growth period is in early June [93]. The monthly minimum temperature reached the condition of tree growth beginning in late April. Even if the growth of trees is limited by a lack of precipitation, it can be recharged by BF from snowmelt during the previous winter [94,95], so that the formation of trees in the year can make full use of nutrient accumulation and BF recorded in the previous year. Therefore, the moving correlation results show that the effect of BF is more significant, but the effect of temperature in the previous year on the tree-ring δ13C series is not significant. Similarly, the temperature increases rapidly from April to June, the soil snowmelt recharge was basically consumed in August, and the daily mean temperature reached the
highest value in the year in mid-August. The early snowmelt in high mountainous areas results in water loss in key periods of growth. Additionally, the positive correlation between winter temperatures and TRW chronologies can explain the fact that low temperatures in winter lead to a deepening of the frozen soil layer or to a delay in the melting time of said frozen soil layer and the glaciers and snow, which leads to a shortened tree growth season. These findings confirm that water supply during the spring season is crucial for tree growth at low elevations.

6. Conclusions

In previous hydrological studies in the Tianshan Mountains, it has been shown that regional climate changes have a strong impact on river BF, and tree-rings offer a great advantage in the research of paleoclimatic information archives, with the advantages of accurate annual resolution. By analyzing the long-term growth response of spruce forests to climate variability and changes in river BF, we conclude that the climate signal of spruce in Ili is slightly more stable, without the dramatic changes exhibited by spruce in Manas. Temperature, particularly the mean late summer to early winter temperature, is a pronounced limiting factor for the TRW chronologies and the $\delta^{13}$C series in the Manas River Basin, located in the middle of the North Tianshan Mountains. Meanwhile, mean early spring to early autumn temperature is a limiting factor for that of the Ili River Basin, located on the southern slope of the North Tianshan Mountains. The influence of climate on trees located at different slopes of the Tianshan Mountains is not the same due to different regional climatic backgrounds. In addition, we found significant fluctuations in temperature–growth correlations during the recent period for both TRW chronologies and $\delta^{13}$C series. TRW chronologies and tree-ring $\delta^{13}$C differ in their sensitivity to climate and hydrological parameters to which tree-ring $\delta^{13}$C is more sensitive. By seasonally analyzing the $\delta^{13}$C series of four sites in the Ili River Basin and one site in the Manas River Basin, spanning the 1921–2016 period, we conclude that the stable $\delta^{13}$C series in spruce tree-ring proved to be more sensitive to snowmelt season temperature and winter precipitation than TRW chronologies, which relate to stable BF. This study further advances the dendroclimatology in the Tianshan Mountains and is helpful for disaster prevention and water resource management in arid Central Asia.

Author Contributions: Conceived and designed the experiments: Y.F. Performed the experiments: Q.L. and Y.F. Analyzed the data: Y.W. Contributed reagents/materials/analysis tools: Q.L. and H.S. Contributed to the writing of the manuscript: Q.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Natural Science Foundation of Xinjiang (no. 2018D01B07).

Acknowledgments: We thank the anonymous reviewers for useful comments to improve the manuscript.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Ljungqvist, F.C.; Krusic, P.J.; Sundqvist, H.S.; Zorita, E.; Brattström, G.; Frank, D. Northern Hemisphere hydroclimate variability over the past twelve centuries. *Nature* 2016, 532, 94–98. [CrossRef]

2. Chase, T.N.; Pielke, R.A.; Knaff, J.A.; Kittel, T.G.f.; Eastman, J.L. A comparison of regional trends in 1979–1997 depth–averaged tropospheric temperatures. *Int. J. Clim.* 2000, 20, 503–518. [CrossRef]

3. Cook, B.I.; Smerdon, J.E.; Seager, R.; Coats, S. Global warming and 21st century drying. *Clim. Dyn.* 2014, 43, 2607. [CrossRef]

4. Sorg, A.; Mosello, B.; Shalpykova, G.; Allan, A.; Clarvis, M.H.; Stoffel, M. Coping with changing water resources: The case of the Syr Darya river basin in Central Asia. *Environ. Sci. Policy* 2014, 43, 68–77. [CrossRef]

5. Kezer, K.; Matsuyama, H. Decrease of river runoff in the Lake Balkhash basin in Central Asia. *Hydrol. Process.* 2006, 20, 1407–1423. [CrossRef]

6. Vogel, R.M.; Kroll, C.N. Regional geohydrologic–geomorphic relationships for the estimation of low–flow statistics. *Water Resour. Res.* 1992, 28, 2451–2458. [CrossRef]
7. Nathan, R.J.; Austin, K.; Crawford, D.; Jayasuriya, N. The estimation of monthly yield in ungauged catchments using a lumped conceptual model. Aust. J. Water Resour. 1996, 1, 65–75.

8. Lacey, C.G.; Grayson, R.B. Relating baseflow to catchment properties in south–eastern Australia. J. Hydrol. 1998, 204, 231–250. [CrossRef]

9. Haberlandt, U.; Klocke, B.; Krysanova, V. Regionalisation of the base flow index from dynamically simulated flow components—A case study in the Elbe River Basin. J. Hydrol. 2001, 248, 35–53. [CrossRef]

10. Mwakaila, S.; Feyen, J.; Wyseure, G. The influence of physical catchment properties on baseflow in semi–arid environments. J. Arid Environ. 2002, 52, 245–258. [CrossRef]

11. Longobardi, A.; Villani, P. Baseflow index regionalization analysis in a Mediterranean area and data scarcity context: Role of the catchment permeability index. J. Hydrol. 2008, 355, 63–75. [CrossRef]

12. Gan, R.; Luo, Y.; Zuo, Q.; Sun, L. Effects of projected climate change on the glacier and runoff generation in the Naryn River Basin, Central Asia. J. Hydrol. 2015, 523, 240–251. [CrossRef]

13. Niederer, P.; Bilenko, V.; Ershova, N.; Hurni, H.; Yerokhin, S.; Maselli, D. Tracing glacier wastage in the Northern Tien Shan (Kyrgyzstan/Central Asia) over the last 40 years. Clim. Chang. 2008, 86, 227–234. [CrossRef]

14. Bai, J.; Chen, X.; Li, J.; Yang, L.; Fang, H. Changes in the area of inland lakes in arid regions of central Asia during the past 30 years. Environ. Monit. Assess. 2011, 178, 247–256. [CrossRef]

15. Duethmann, D.; Bolch, T.; Farinotti, D.; Kriegel, D.; Vorogushyn, S.; Merz, B.; Pieczonka, T.; Jiang, T.; Su, B.D.; Güntner, A. Attribution of streamflow trends in snow and glacier melt–dominated catchments of the Tarim River, Central Asia. Water Resour. Res. 2015, 51, 4727–4750. [CrossRef]

16. Liu, J.B.; Chen, S.Q.; Chen, J.H.; Zhang, Z.P.; Chen, F.H. Chinese cave δ18O records do not represent northern East Asian summer monsoon rainfall. Proc. Natl. Acad. Sci. USA 2017, 114, E2987–E2988. [CrossRef]

17. Chen, Y.N.; Li, Z.; Fang, G.H.; Deng, H.J. Impact of climate change on water resources in the Tianshan Mountains, Central Asia. Acta Geogr. Sin. 2017, 72, 18–26.

18. Chen, F.; Zhang, T.; Seim, A.; Yu, S.; Kodirov, A. Juniper tree–ring data from the kuramin range (northern tajikistan) reveals changing summer drought signals in western central asia. Forests 2019, 10, 505. [CrossRef]

19. Esper, J.; Treydte, K.; Gärthner, H.; Neuwirth, B. A tree ring reconstruction of climatic extreme years since 1427 AD for Western Central Asia. Palaeobotanist 2001, 50, 141–152.

20. Davi, N.; Jacoby, G.; Curtis, A.; Baatarbileg, N. Extension of drought records for Central Asia using tree rings: West–Central Mongolia. J. Clim. 2006, 19, 288–299. [CrossRef]

21. Yuan, Y.J.; Shao, X.M.; Wei, W.S.; Yu, S.L.; Gong, Y.; Trouet, V. The potential to reconstruct Manas River streamflow in the northern Tien Shan Mountains (NW China). Tree–Ring Res. 2007, 63, 81–93. [CrossRef]

22. Fang, K.; Davi, N.; Gou, X.; Chen, F.; Cook, E.; Li, J.; D’Arrigo, R. Spatial drought reconstructions for central High Asia based on tree rings. Clim. Dyn. 2010, 35, 941–951. [CrossRef]

23. Zhang, T.W.; Yuan, Y.J.; Liu, Y.; Wei, W.S.; Yu, S.L.; Chen, F.; Fan, Z.A.; Shang, H.M.; Zhang, R.B.; Qin, L. A tree–ring based precipitation reconstruction for the Baluntai region on the southern slope of the central Tien Shan Mountains, China, since AD 1464. Quat. Int. 2013, 283, 55–62. [CrossRef]

24. Chen, F.; Yuan, Y.J.; Wei, W.S.; Yu, S.L.; Zhang, T.W.; Shang, H.M.; Zhang, R.B.; Qin, L.; Fan, Z.A. Tree–ring recorded hydroclimatic change in Tienshan mountains during the past 500 years. Quat. Int. 2015, 358, 35–41. [CrossRef]

25. Chen, F.; Yuan, Y.; Davi, N.; Zhang, T. Upper Irtysh River flow since AD 1500 as reconstructed by tree rings, reveals the hydroclimatic signal of inner Asia. Clim. Chang. 2016, 139, 651–665. [CrossRef]

26. Zhang, R.; Yuan, Y.; Gou, X.; Yang, Q.; Wei, W.; Yu, S.; Zhang, T.W.; Shang, H.M.; Chen, F.; Fan, Z.A.; et al. Streamflow variability for the Aksu River on the southern slopes of the Tien Shan inferred from tree ring records. Quat. Res. 2016, 85, 371–379. [CrossRef]

27. Opala, M.; Niedźwiedź, T.; Rahmanov, O.; Owczarek, P.; Malarzewski, L. Towards improving the Central Asian dendrochronological network—New data from Tajikistan, Pamir–Alay. Dendrochronologia 2017, 41, 10–23. [CrossRef]

28. Zhang, R.B.; Ermenbaev, B.; Zhang, T.W.; Ali, M. Records the Hydroclimatic Changes in the Chu River Basin over the Past 175 Years. Forests 2019, 10, 223. [CrossRef]

29. Yuan, Y.J.; Ye, W.; Dong, G.R. Reconstruction and Discussion of 314 a Precipitation in Yili Prefecture, Western Tianshan Mountains. J. Glaciol. Geocryol. 2000, 2, 121–127.
30. Yuan, Y.J.; Li, J.F. The Relationships between Tree–Ring Climate Growth of Spruce Forest and Climate in the West Part of Tianshan Mountain. J. Xinjiang Univ. 1994, 4, 94–98.

31. Wang, C.Y.; Hu, Y.B. Analysis on the Characteristics of Cold–Warm Climatic Variations Since Recent 250 Year in Yili Region, Xinjiang, China. Geogr. Arid Area. 1996, 3, 37–44.

32. Zhang, F.H. The Succession and the Sustainable Development of Oases Ago–Ecosystem in the Valley of Manas River. Ph.D. Thesis, China Agriculture University, Beijing, China, 2004.

33. McCarroll, D.; Loader, N.J. Stable isotopes in tree rings. Quat. Sci. Rev. 2004, 23, 771–801. [CrossRef]

34. Boakye, E.; Gebrekirstos, A.; Hyppolite, D.; Barnes, V.; Porembski, S.; Bräuning, A. Carbon isotopes of riparian forests trees in the savannas of the volta sub–basin of ghana reveal contrasting responses to climatic and environmental variations. Forests 2019, 10, 251. [CrossRef]

35. Marini, F.; Battipaglia, G.; Manetti, M.C.; Corona, P.; Romagnoli, M. Impact of climate, stand growth parameters, and management on isotopic composition of tree rings in chestnut coppices. Forests 2019, 10, 1148. [CrossRef]

36. Lipp, J.; Trimborn, P.; Fritz, P. Stable isotopes in tree ring cellulose and climatic change. Tellus B 1991, 43, 322–330. [CrossRef]

37. Schleser, G.H.; Helle, G.; Lücke, A.; Vos, H. Isotope signals as climate proxies: The role of transfer functions in the study of terrestrial archives. Quat. Sci. Rev. 1999, 18, 927–943. [CrossRef]

38. Waterhouse, J.S.; Switsur, V.R.; Barker, A.C.; Carter, A.H.C.; Robertson, I. Oxygen and hydrogen isotope ratios in tree rings: How well do models predict observed values. Earth Planet. Sci. Lett. 2002, 201, 421–430. [CrossRef]

39. Loader, N.J.; Santillo, P.M.; Woodman-Ralph, J.P.; Rolfe, J.E.; Hall, M.A.; Gagen, M.; Robertson, I.; Wilson, R.; Froyd, C.A.; McCarroll, D. Multiple stable isotopes from oak trees in southwestern Scotland and the potential for stable isotope dendroclimatology in maritime climatic regions. Chem. Geol. 2008, 252, 62–71. [CrossRef]

40. Loader, N.J.; McCarroll, D.; Gagen, M.; Robertson, I.; Jalkanen, R. Extracting climatic in formation from stable isotopes in tree rings. Terr. Ecol. 2007, 25, 27–48.

41. Liu, Y.; Cai, Q.; Liu, W.; Yang, Y.; Sun, J.; Song, H.; Li, X. Monsoon precipitation variation recorded by tree–ring 18 O in arid Northwest China since AD 1878. Chem. Geol. 2008, 252, 56–61. [CrossRef]

42. Liu, X.; Shao, X.; Liang, E.; Chen, T.; Qin, D.; An, W.; Xu, G.; Sun, W.; Wang, Y. Climatic significance of tree–ring D18 O in the Qilian Mountains, northwestern China and its relationship to atmospheric circulation patterns. Chem. Geol. 2009, 268, 147–154. [CrossRef]

43. Farquhar, G.D.; Ehleringer, J.R.; Hubick, K.T. Carbon isotope discrimination and photosynthesis. Annu. Rev. Plant Biol. 1989, 40, 503–537. [CrossRef]

44. O’Leary, M.H. Carbon isotopes in photo synthesis. BioScience 1988, 38, 328–336. [CrossRef]

45. Bert, D.; Leavitt, S.W.; Dupouey, J.L. Variations of wood 13C and d water efficiency of Abies alba during the last century. Ecology 1997, 78, 1588–1596.

46. Han, X.G.; Yan, C.R.; Chen, L.Z.; Mei, X.R. Stable carbon isotope characteristics of some woody plants in warm temperate zone. Chin. J. App. Ecol. 2000, 4, 497–500.

47. Liu, Y.; Ma, L.M.; Cai, Q.F.; An, Z.S.; Gao, L.Y. Reconstruction of summer temperature (June—August) at Mt. Helan, China, from tree–ring stable carbon isotope values since AD 1890. Sci. China. Ser. D Earth Sci. 2002, 45, 1127–1136. [CrossRef]

48. Liu, X.H.; Qin, D.H.; Shao, X.M.; Ren, J.W.; Wang, Y. Stable Carbon Isotope of Abies spectabilis from Nyingchi County of Tibet Autonomous Region and Its Response to Climate Change. J. Glaciol. Geocryol. 2002, 5, 574–578.

49. Dupouey, J.L.; Leavitt, S.; Choisnel, E.; Jourdain, S. Modelling carbon isotope fractionation in tree rings based on effective evapotranspiration and soil water status. Plant Cell Environ. 1993, 16, 939–947. [CrossRef]

50. Leavitt, S.W.; Long, A. Stable Carbon Isotope Chronologies from Trees in the Southwestern United States. Water Resour. Bull. 1989, 25, 341–347. [CrossRef]

51. Francey, R.J.; Farquhar, G.D. An explanation of 13C/12C variations in tree rings. Nature 1982, 297, 28–31. [CrossRef]

52. Yuan, Y.J.; Li, J.F.; Zhang, J.B. 348–year precipitation reconstruction from tree–rings for the north slope of the middle Tianshan Mountains. Acta Meteorol. Sin. 2001, 15, 95–104.
53. Chen, F.; Yuan, Y.J.; Chen, F.H.; Wei, W.S.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

54. Fritts, H.C. *Tree Ring and Climate*; Academic Press: London, UK, 1976.

55. Holmes, R.L. Computer–assisted quality control in tree–ring dating and measurement. *Tree Ring Bull.* 1983, 43, 69–78.

56. Cook, E.; Kairiukstis, L. *Methods of Dendrochronology: Applications in the Environmental Sciences*; Springer: Dordrecht, The Netherlands, 1990.

57. Leavitt, S.W.; Long, A. Sampling strategy for the stable carbon isotope analysis of tree rings in pine. *Nature* 1984, 311, 45–47. [CrossRef]

58. Liu, X.; Shao, X.; Wang, L.; Liang, E.; Qin, D.; Ren, J. Response and dendroclimatic implications of 13 C in tree rings to increasing drought on the northeastern Tibetan Plateau. *J. Geophys. Res.* 2008, 113, G03015. [CrossRef]

59. Leavitt, S.W. Tree-ring isotopic pooling without regard to mass: No difference from averaging values of each tree. *Chem. Geol.* 2008, 252, 52–55. [CrossRef]

60. Treydte, K.; Schleser, G.H.; Schweingruber, F.H. The climatic significance of 13C in subalpine spruces (L. otschental, Swiss Alps). *Tellus* 2001, 53B, 593–611. [CrossRef]

61. Barbour, M.M.; Andrews, T.J.; Farquhar, G.D. Correlations between oxygen isotope ratios of wood constituents in A–cellulose: Implications for environmental reconstructions. *Int. J. Environ. Anal. Chem.* 2010, 90, 605–619. [CrossRef]

62. Barbour, M.M.; Andrews, T.J.; Farquhar, G.D. Correlations between oxygen isotope ratios of wood constituents in A–cellulose: Implications for environmental reconstructions. *Int. J. Environ. Anal. Chem.* 2010, 90, 605–619. [CrossRef]

63. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

64. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

65. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

66. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

67. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

68. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

69. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

70. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

71. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

72. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

73. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

74. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

75. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]

76. Chen, F.; Yuan, Y.J.; Yu, S.L.; Chen, X.J.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M.; et al. A 426-year drought history for Western Tian Shan, Central Asia inferred from tree-rings and its linkages to the North Atlantic and Indo–West Pacific Oceans. *Holocene* 2013, 23, 1095–1104. [CrossRef]
77. Li, J.B.; Gou, X.H.; Cook, E.R.; Chen, F.H. Tree-ring based drought reconstruction for the central Tien Shan area in northwest China. Geophys. Res. Lett. 2006, 33, L07715. [CrossRef]

78. Jiao, L.; Jiang, Y.; Wang, M.; Zhang, W.; Zhang, Y. Age-effect radial growth responses of Picea schrenkiana to climate change in the eastern Tianshan Mountains, Northwest China. Forests 2017, 8, 294. [CrossRef]

79. Xu, G.B.; Liu, X.H.; Trouet, V.; Trouet, V.; Treydte, K.; Wu, G.J.; Chen, T.; Sun, W.Z.; An, W.L.; Wang, W.Z.; et al. Regional drought shifts (1710–2010) in east Central Asia and linkages with atmospheric circulation recorded in tree-ring δ18O. Clim. Dyn. 2018, 52, 1–15. [CrossRef]

80. Zhang, R.B.; Yuan, Y.J.; Gou, X.H. 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]

81. Huang, W.; Chen, J.H.; Zhang, X.J.; Feng, S.; Chen, F.H. Definition of the core zone of the westerlies-dominated climatic regime, and its controlling factors during the instrumental period. Sci. China Earth Sci. 2015, 58, 676–684. [CrossRef]

82. Chen, F.; Yuan, Y.J.; Wei, W.S.; Yu, S.L.; Fan, Z.A.; Zhang, R.B.; Zhang, T.W.; Shang, H.M. Tree-ring-based reconstruction of precipitation for the Changling Mountains, China, since A.D.1691. Int. J. Biometeorol. 2012, 56, 765–774. [CrossRef]

83. Chen, F.; Yuan, Y.J.; Yu, S.L.; Zhang, W.T.; Shang, H.M.; Zhang, R.B.; Qin, L.; Fan, Z.A. A 225-year long drought reconstruction for the central Tien Shan. Quat. Int. 2014, 358, 42–47. [CrossRef]

84. Cook, E.R.; Anchukaitis, K.J.; Buckley, B.M.; D’Arrigo, R.D.; Jacoby, G.C.; Wright, W.E. Asian monsoon failure and megadrought during the last millennium. Science 2010, 328, 486–489. [CrossRef]

85. Davi, N.K.; Pederson, N.; Leland, C.; Nachin, B.; Suran, B.; Jacoby, G.C. Is eastern Mongolia drying? A long-term perspective of a multidecadal trend. Water Resour. Res. 2013, 49, 151–158. [CrossRef]

86. Liang, E.; Shao, X.; Kong, Z.; Lin, J. The extreme drought in the 1920s and its effect on tree growth deduced from tree ring analysis: A case study in North China. Ann. For. Sci. 2003, 60, 145–152. [CrossRef]

87. Fan, Y.T.; Chen, Y.N.; He, Q.; Li, W.H.; Wang, Y. Isotopic Characterization of River Waters and Water Source Identification in an Inland River, Central Asia. Water 2016, 8, 286. [CrossRef]

88. Zhang, R.B.; Yuan, Y.J.; Gou, X.H.; He, Q.; Shang, H.M.; Zhang, T.W.; Chen, F.; Ermenbaev, B.; Yu, S.L.; Qin, L.; et al. Tree-ring-based moisture variability in western Tianshan Mountains since A.D. 1882 and its possible driving mechanism. Agric. For. Meteorol. 2016, 218, 267–276. [CrossRef]

89. Jiang, P.; Liu, H.Y.; Wu, X.C.; Wang, H.Y. Tree-ring-based SPEI reconstruction in central Tianshan Mountains of China since A.D. 1820 and links to westerly circulation. Int. J. Climatol. 2017, 37, 2863–2872. [CrossRef]

90. Zhang, R.B.; Yuan, Y.J.; Wei, W.S. Dendroclimatic reconstruction of autumn-winter mean minimum temperature in the eastern Tibetan Plateau since 1600 AD. Dendrochronologia 2015, 33, 1–7. [CrossRef]

91. Dai, X.G.; Wang, P.; Zhang, K.J. A study on precipitation trend and fluctuation mechanism in northwestern China over the past 60 years. Acta Phys. Sin. 2013, 62, 129–201.

92. Yuan, Y.; Li, J. The response functions of tree ring chronologies in western Tianshan Mountain. J. Glaciol. Geocryol. 1995, 17, 171–177. In Chinese with English abstract.

93. Farquhar, G.D.; O’Leary, M.H.; Berry, J.A. On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. Aust. J. Plant Physiol. 1982, 9, 121–137. [CrossRef]

94. Singer, M.B.; Stella, J.C.; Dufour, S.; Piégay, H.; Wilson, R.J.; Johnstone, L. Contrasting water-uptake and growth responses to drought in co-occurring riparian tree species. Ecolhydrology 2013, 6, 402–412. [CrossRef]

95. Stahl, K.; Hisdal, H.; Hannaford, J.; Tallaksen, L.; Van Lanen, H.; Saquet, E.; Demuth, S.; Fendekova, M.; Jordar, J. Streamflow trends in Europe: Evidence from a dataset of near-natural catchments. Hydrol. Earth Syst. Sci. Discuss. 2010, 7, 5769–5804. [CrossRef]