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The dendrochronological potential of some shrub species in Mongolian forest steppe

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Abstract
The impacts of land use changes and climate change on shrub expansion have been extensively documented in the Northern Hemisphere. Studies conducted in the Tibetan Plateau indicate that shrub expansion is more reliant on soil moisture than in the Arctic, where results indicate that changes in temperature and precipitation have a significant correlation with shrub expansion. Studies on the spread of shrubs throughout Central Asia, including the northern part of our country, are, unfortunately, insufficient. We carried out studies on 5 shrub species present in Shatan river area (Batsumber sum, Tuv aimag, Mongolia) to determine the response from climate factors and habitat types. According to the results of our research, there is a weak correlation (R2=0.24) between the morphological characteristics of the shrub. Also, depending on the type of habitat, the growth of annual rings is different for among growth habitats (df=2, F=13.5, P<0.0001). In addition, each species has different annual ring growth (df=4, F=8.63, P<0.0001). In terms of climatic factors, wind had a negative effect (R2=0.47), precipitation had a positive effect (R2=0.57) on the annual ring width of Salix divaricata, a shrub growing in river valley habitats, and it was weakly related to other species (df=2, F=13.5, P<0.0001). This differential pattern indicator may function depending on the habitat. That being the case, dominant shrub species in southwestern Khentii taiga, Mongolia have successfully been proven to have a high dendrochronological potential and it is practicable to apply it for rangeland and ecological assessments.

Keywords: Climate change, habitats, growth rings, climate factors

Introduction

In some areas of Mongolia, the landscape has been changed dramatically in recent years following mining activity and the development of agriculture. Researchers are aiming to observe and document the changes in biodiversity of such areas. Undergraduate students from the Departments of Biology and Geography, Mongolian National University of Education, Ulaanbaatar, Mongolia have been doing summer field studies in the past 10 years, with the basic goal to practice on animal and plant identification and their systematics. Here we represent the results from data gathered by our observations and registration during the past 10 years.

Climate change scenarios predict increasing air temperatures for the coming decades, with most of the warming occurring at high latitudes [1]. Climate change is projected to cause vegetation shifts [2] and northern ecosystems will be affected the most through alterations of the surface energy balance, permafrost thaw, and consequent changes in vegetation growth and reproduction [3]. Vegetation changes, in turn, can alter regional climate system through changes in the surface albedo, soil moisture exchange, and the soil carbon balance [4]. According to the results of some studies across the Arctic, deciduous shrubs are the most responsive to changes in temperature [5-7].

In these ecosystems, soil water is charged by pulses of precipitation and highly diversified in several dimensions because of these characteristics. Shallow layers (0-30 cm) are frequently subjected to evaporation, while deeper layers are slightly affected by the direct evaporation.

Shrubs have the advantages of using deep soil water resources utilizing their roots to penetrate deep layers and distribute vertically in shallow depths, and sizeable energy and water stored in woody tissues [8]. Therefore, shrubs are more drought persistent, keeping their biomass at a nearly constant level throughout growing season than herbaceous species, which synchronously respond to highly variable precipitation events. A space beneath shrub canopies is a mesic microclimate, contributes to soil water and nutrients, and protects other plant species [9]. Shrubs create spatial variations in a uniform habitat of arid grasslands forming different ecological niches available for many other species [10-11]. Positive influences of shrubs for any ecosystem may vary depending on factors such as regional climate, shrub size and temporal scale [12]. In the continuity of soil-plant-atmosphere, wood is involved in a variety of functional processes of woody plants, including the movement of nutrients and carbon as well as water through the xylem [13-14]. The effectiveness of this water transport capacity controls how well plants can fix carbon and thrive. Moreover, the maintenance of this capacity during stress conditions is involved in the resistance to drought, a key issue in the framework of global climatic change. At xylem level, this capacity as described. The loss of water conduction brought on by rising negative pressures in known as xylem cavitation [15]. When the water of xylem is replaced by air, embolism occurs [16]. Dendrochronological studies can help to predict future vegetation responses to environmental change by establishing how populations have responded to environmental variability in the past [17-20]. The use of dendrochronology in many Central Asian ecosystems is limited by absence of trees. Shrubs, however, are common and exhibit annual growth rings similar to tree species. Thus, there is a potential to use shrubs in dendrochronological, ecological, cytological studies. Significant efforts have been made to determine the dendrochronological potential of shrubs, and three major directions have been overviewed in dendrochronological studies of shrub species in the last decade [21-23]. These studies have proven the dendrochronological potential of several shrub species. However, dendrochronological studies related to shrub expansion in Central Asia, including Mongolia, continue to be rare. The aim of our study was to perform dendrochronological analysis on main stems of several shrub species in order to evaluate the growth response to climate factors and disturbances. The specific objectives of this study were: (1) to determine dendrochronological potential of some shrub species based on cross-sectioning of main stem, (2) to define the shrub responses to climate factors, (3) to determine if wide range of habitats affect annual ring of the shrub.

Material and methot

Study area and climate

The study area is located in Batsumber Soum, Tov province (N48.52117, E107.83190), Mongolia, some 120 km north of Ulaanbaatar. Geomorphologically it belongs to the Tuul River basin and Orkhon-Selenge basin. The maximum altitude is 1300 - 1700 m a.s.l; mean altitude is between 1063 m and 1187 m. Surface soil is composed of imperial granite and mafic rock minerals of the Paleozoic era. The highest point is Tsogt Khairkhan mountain (1628 m), located west of our camp site, and the lowest point is in the meeting point of Shatan and Kharaa river (1200 m; Figure 1). Common habitats of birds are mixed forest (trees are larch and birch) on the shady side of the Mountain, and water meadows of Kharaa, Ulgii, and Shatan rivers [24]. Our study area also included Khan Kentii Natural Park, where various mammal and bird species are found [27]. Moreover, the study area is located on the Khentii mountain taiga region.

At the meteorological station in Batsumber Soum (N48’21’56, E106’44’20, 1.133 m; Figure 2), the long-term mean of annual precipitation is above of 350 mm, especially, in high mountain region it reaches 400-500 mm and the annual mean temperature is below +15ºC, with July (mean temperature of 16.8ºC) and January (below -25ºC) the warmest and the coldest month, respectively. Around 51% of annual precipitation falls between June and September.

Shrub sampling and growth-ring dating

Field method: In August of 2019, 17 plots were chosen for field sampling. The root collar of the ends of rhizomes are the most important parts for age determination [26]. Therefore, at each plot, one to three shrub individuals were randomly selected and cut at the root collar, to ensure that samples contain the oldest, first formed parts of the shrubs (Table 1). Each collected individual was cut with pruning shears and preserved in 40% ethanol [21-22], prior to transporting them for further analysis.

Lab method: The collected samples were sectioned with a GSL-1 core microtome at the Dendrochronological laboratory, Department of Agroecology, Mongolian University of Life Science in accordance with the micro-core processing protocol which was described in detail in previous research [26]. The thin sections were 5-10 µm (micrometer) and were stained with a safranin solution to enhance contrast between wood tissues, which greatly improves the detection and ability to accurately measure annual rings. After staining, samples were dehydrated by rinsing them subsequently with 96% alcohol. Dehydrated samples were adhered to a microscope slide with Canada balsam, dissolved in xylol, and covered with a cover glass in order to prepare the samples for further analysis [21]. Samples with larger diameter (more than 2.5 cm) were sanded using progressively finer grades of sandpaper (180, 400 and 600 grit) until the cellular structure was visible under a microscope.

Dendrochronological analysis: Microscopes with objective magnifications of x10, x20, x40 were used for observations and photography. The samples were photographed using MotiCam 10+ and the annual ring widths were measured in mm using ImageJ software [28]. All samples were visually cross-dated using skeleton plots, as outlined by [28], and pointer years were recorded as well. Climate-growth relationships were investigated using linear regression between ring widths and a) the mean annual temperature, and b) total annual precipitation of the current and previous year, using data from the meteorological station. During cross-sectioning, it was possible to see the diverse pore arrangements of various shrub species (Figure 3). Annual growth-ring patterns can differ dramatically as demonstrated in Figure 3. This growth variation could reflect the ecology of the plant and will influence the interpretation of growth-climate analysis.

Statistical analysis

Climate response analysis was investigated using linear regression between ring widths and including, the mean temperature from March to June, total precipitation from 2020 year and the previous year, using data from the meteorological station for Batsumber soum, Tuv province. One-way analysis of variance (ANOVA), in which different habitat type is considered as the main factor, was run to determine effect of habitat on annual ring width of shrubs. An a posteriori Tukey-Kramer HDS test for all comparisons was conducted on the parameter means and on ring width. Linear regression models were tested to examine relationships between weather factors (precipitation and temperature) and a yearly performance (ring-width) of some shrub species.

Result

We collected samples from 10 shrub species present in Shatan river sites. However, due to the morphological diversity of shrubs, we were able to cross-section only 5 species, including, Amygdalus pedunculata, Crataegus sanguinea, Cotoneaster melanocarpus, Dasiphora fruticose and Salix divaricate, (Table 1). Moreover, habitat type was four different section, such as north slope, south slope, river valley and forest area. In total, 59 samples were included in the chronology and the remaining samples were removed due to the impossibility of cross-sectioning, and presence of scars. The oldest individual used in the chronology construction was a 14-years old wild almond individual (Amygdalus pedunculata), while half of the population consisted of 1-5 years old shrubs. The constructed chronology covered 2007-2020. The average growth of the shrub is 40.1 cm, and the intensity of growth is 210.9. Moreover, considering the anomaly conditions, it was observed as normal.

But Cotoneaster melanocarpus and Dasiphora fruticosa are different from other species (Figure 4). The width of the annual rings was uniform. A linear regression analysis between the diameter of the crown of the shrub and the height parameter shows that R2=0.25 that is, there is a weak correlation between the diameter of the basal of the shrub and the height, R2=0.25 or a weak correlation (Figure 5). Linear regression analysis checked the effects of mean air temperature, total precipitation, and wind on annual ring width during plant growth, which differed among species. For instance, there was no relationship between average air temperature (R2=0.02) and precipitation (R2=0.05) on Dasipora fruticosa species. On the other hand, in Salix divaricata species, precipitation had a strong positive correlation with R2=0.59, wind had a negative correlation with R2=0.47, and average air temperature R2=0.02, and no correlation was observed with the annual ring width (Figure 6). In the Khentii mountain taiga region, the effects of natural and climatic factors have different effects on each species and show that it depends on many different habitat patterns.

Relationship between rings width and habitats

One-way ANOVA and Tukey-Kramer test were used to check whether the dendrochronological ability of shrubs varies depending on habitat differences. According to this, the growth of the annual rings of individuals along the river and on the slopes of the mountains was good, but the dendrochronological potential of the trees growing in the forest was weak (Figure 7). Also, annual ring growth was statistically different when examining how it differed between species (Figure 8).

Discussion

This study suggests a high dendrochronological potential for some shrub species with markedly different ecology, which was explored and studies for the first time of Khentii taiga. Moreover, there is a clear climatic signal in the annual rings. Our study results corresponded well with other studies. In particular, it was reported that there is significant positive correlation shown between the ring-width of Salix and mean summer temperature in Siberian tundra [3], whereas a negative correlation resulted from winter precipitation in Greenland [7], possibly due to the fact that winter with heavy snowfall and cold spring may result to reduce growth. Additionally, the ring-width chronology is consistently correlated with mean summer temperature of current year in Arctic Circle [20-23], which suggests that the growth season temperature is important for shrub growth. These patterns were demonstrated in our study as well. We witnessed some species responding positively to climate factors, which is annual precipitation in the Salix divaricate. While mean windy speed has shown negative effect. However, mean temperature effect was not significant. Negative associations are far more significant in ecological and dendroclimatological analyses [27], since they signify adverse environmental circumstances. Thus, by identifying exceptional years in samples having a long-term shrub chronology, historical climatic patterns can be reconstructed. The findings show that a number of dominant species were viable and may serve as good representatives of the environmental circumstances seen in their native habitats. Consequently, we were able to acquire information about past events (in this case, wildfire, grazing impact, climate change etc) using the cross-dating method. Furthermore, the conclusion reached was that the morphological traits of dominating shrubs growing in various ecosystems can be used to assess the intensity of growth. We conclude that there is a high potential to evaluate the impacts of natural disturbances and climate events in the past through shrubs. The insect outbreak on shrubs have been studied previously [29], Hence, it is highly possible to create shrub identification database with samples from northern part of Mongolia. In summary, our work indicates the potential for dendrochronological analysis of several Mongolian shrub species to be used in explaining and predicting vegetation change. The Arctic is anticipated to undergo a shift in the next few decades toward an environment that is more dominated by shrubs [26-29]. Such data from Mongolia will be beneficial not just to its natural habitats, but also to understanding the effects of anticipated climate change on the northern boreal forests and the Arctic.

Conflict of interest

The authors declare that there is no conflict of interest. Authors' Contribution M.B., E.D., B.V., E.Ts. designed and performed the study; E.Ts. supervised the experiment; E.D., B.V., A.D. analyzed data; all authors discussed the results and contributed to the final manuscript.

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Appendix

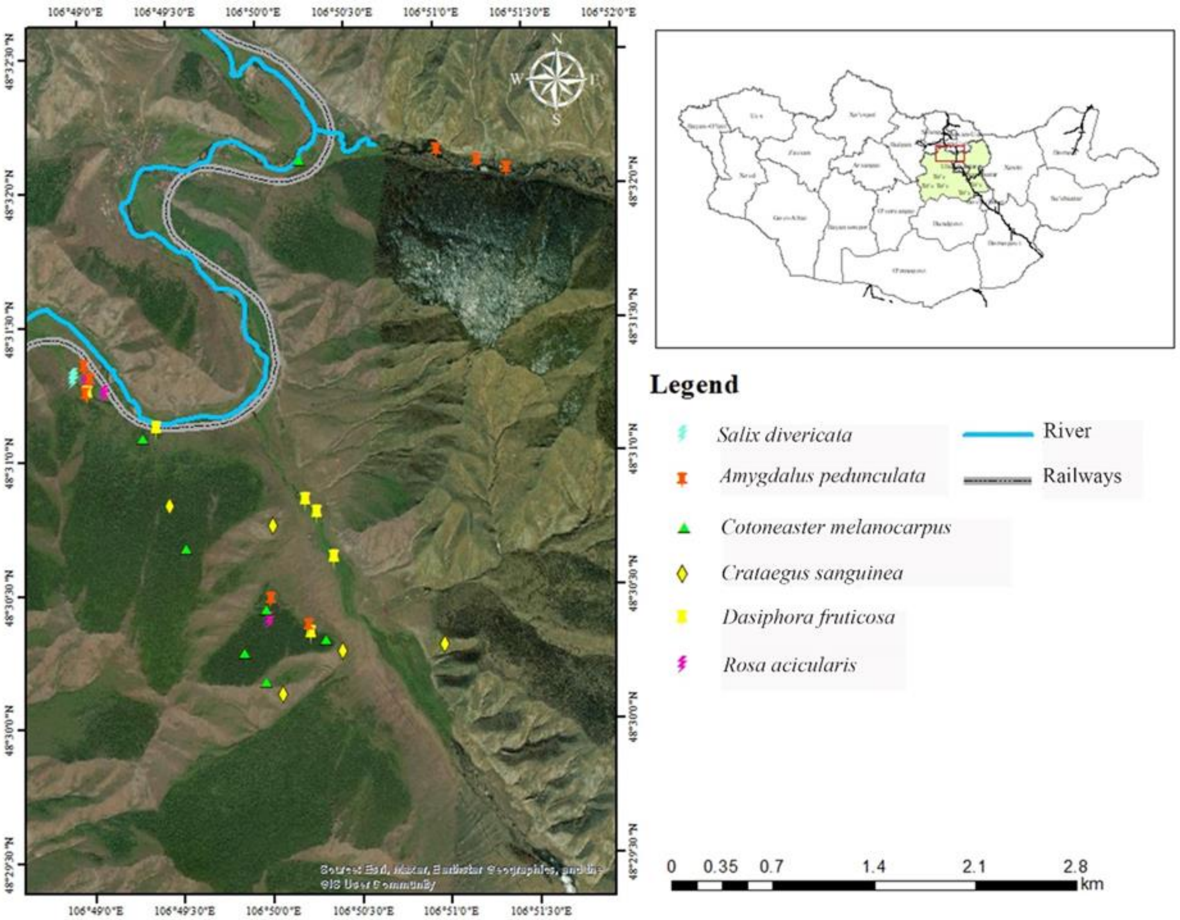

Figure 1. Study plots of shrub species in Shatan River Sites

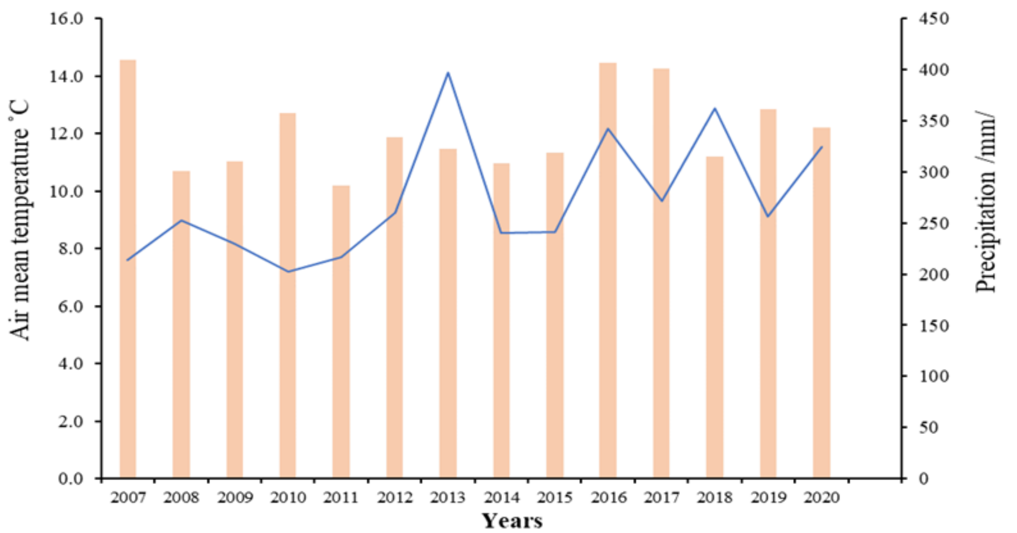

Figure 2. Summary of climate at the meteorological station in Batsumber soum

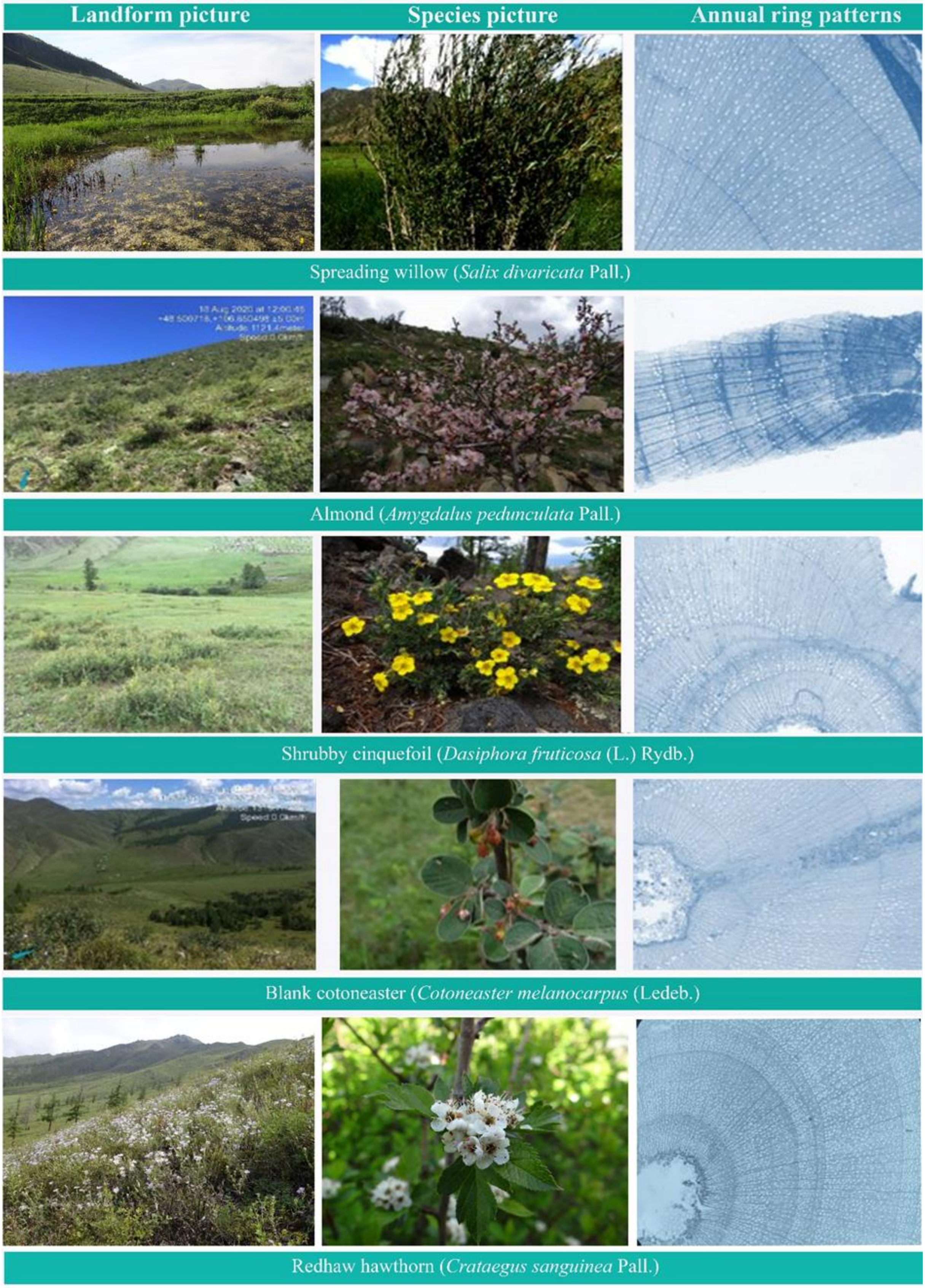

Figure 3. Annual ring patterns of shrub species

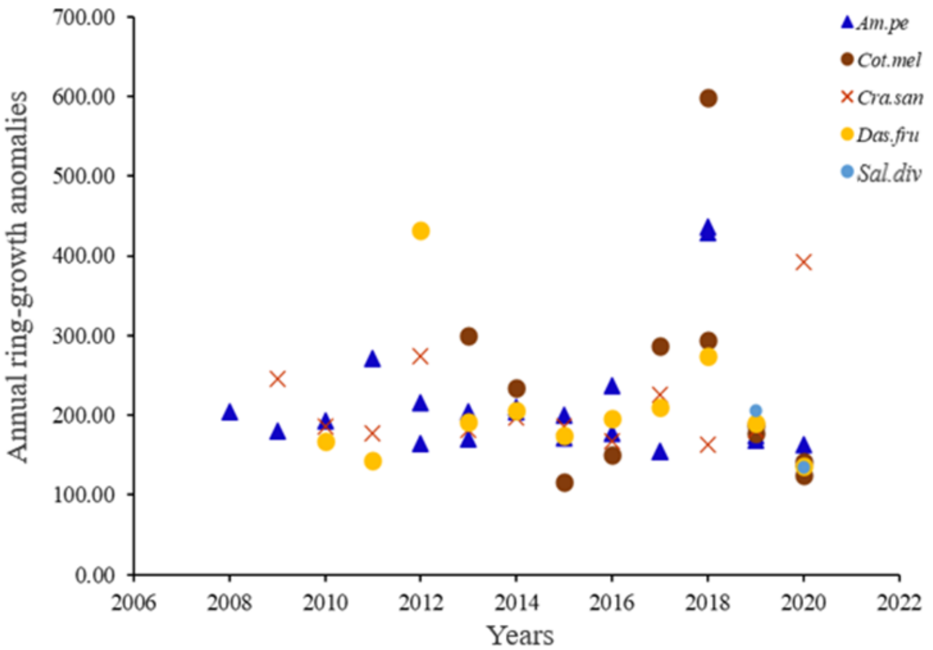

Figure 4. Annual ring-growth anomalies

The species full scientific name is shown*: Am.pe-Amygdalus pedunculata, Cot.mel-Cotoneaster melanocarpus, Cra.san-Crataegus sanguinea, Das.fru-Dasiphora fruticosa, Sal.div-Salix divaricata*

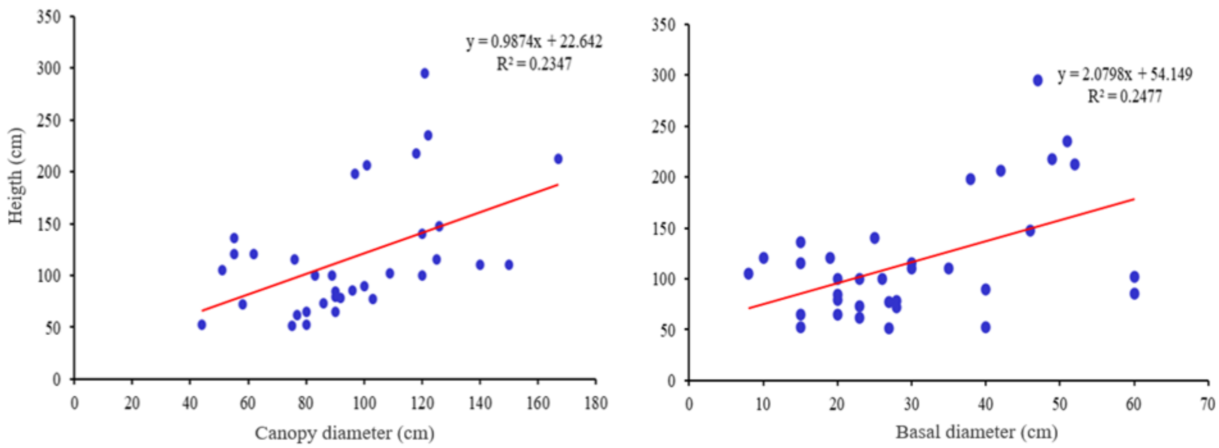

Figure 5. Relationship among morphological trait of shrubs

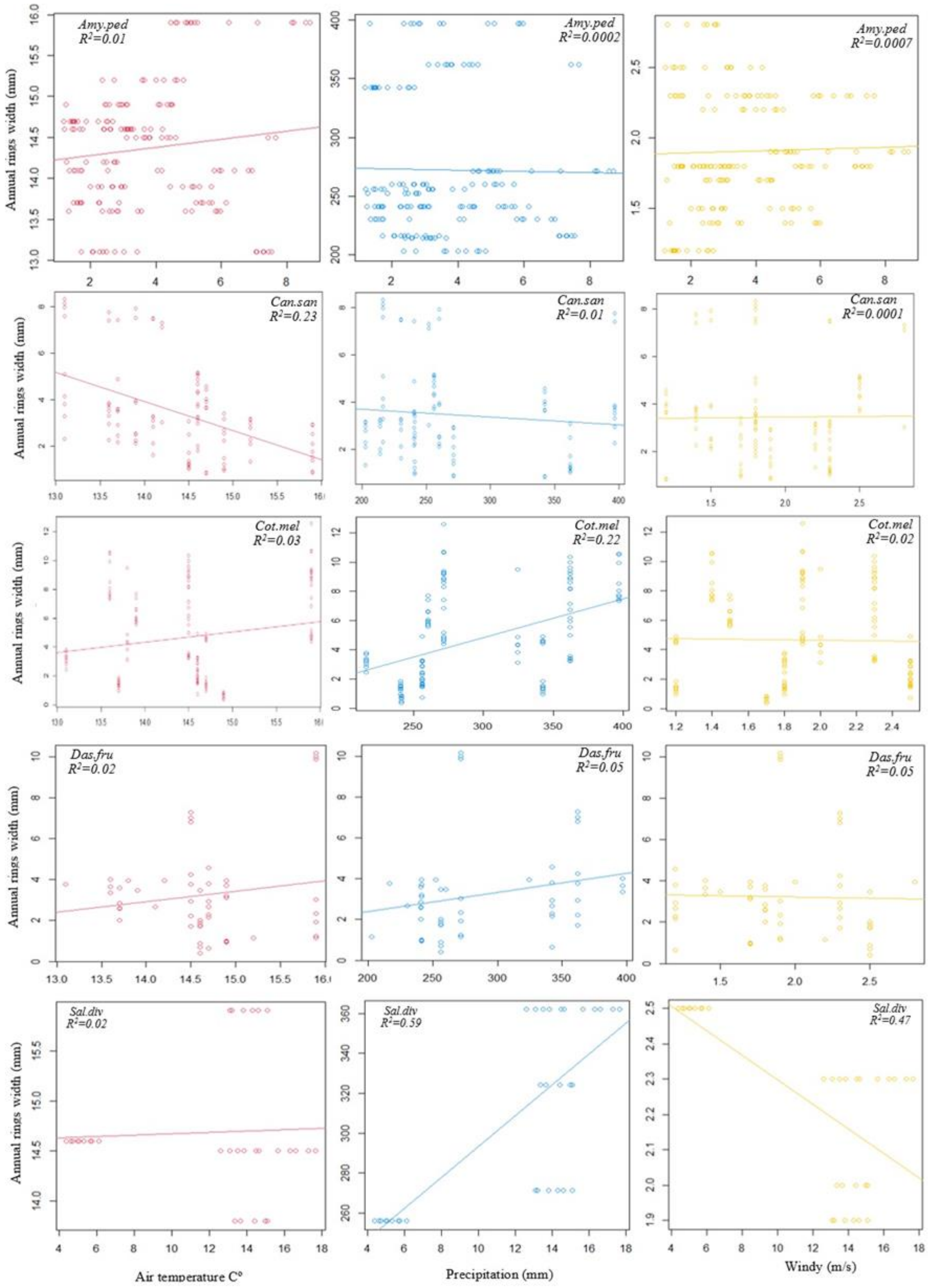

Figure 6. Relationship between annual rings width of shrub species and climate variables
The species full scientific name is shown: *Amy.ped-Amygdalus pedunculata, Cra.san-Crataegus sanguinea, Cot.mel-Cotoneaster melanocarpus, Das.fru-Dasiphora fruticosa, Sal.div-Salix divaricata*

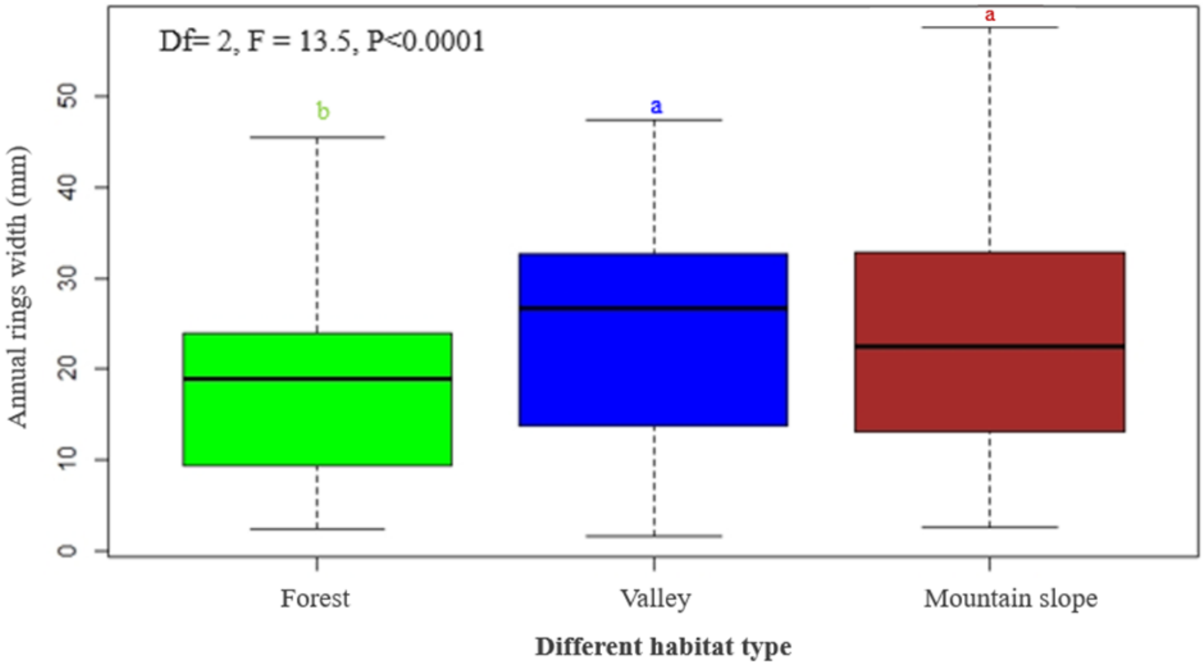

Figure 7. The significant of the analysis of variance among different habitat types

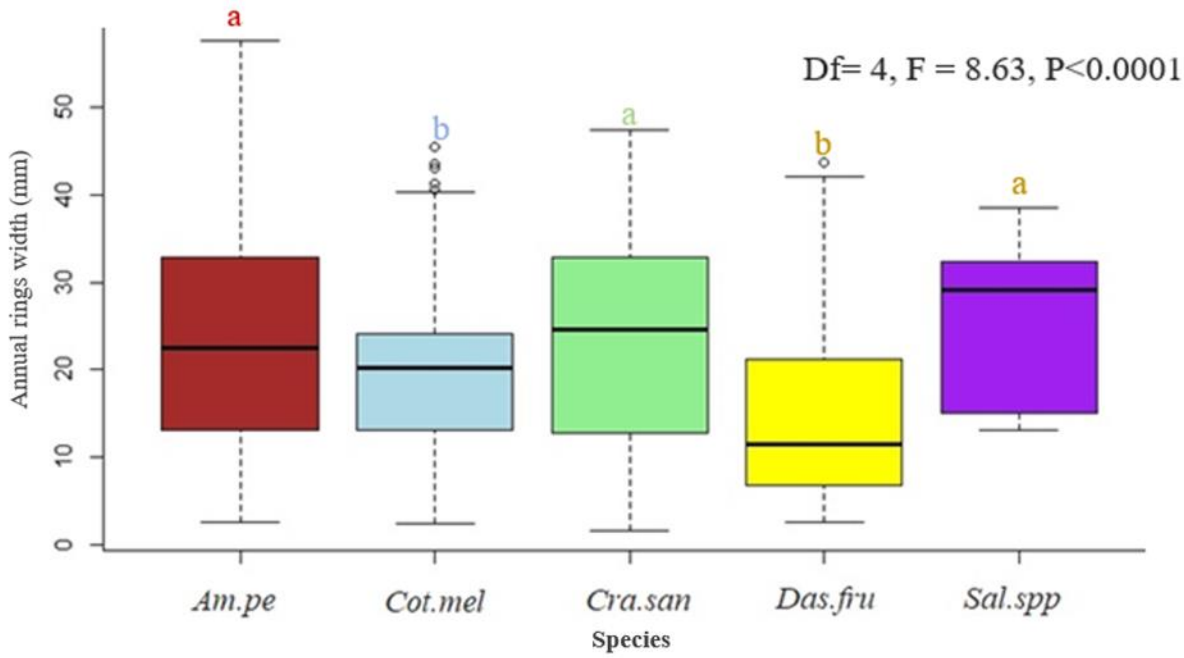

Figure 8. Tukey-Kramer test to detect between-individual differences in annual ring width growth results

Table 1. Species description of the study sites in Shatan River Sites

Family name	Species name	Habitat description	Elevation (m)	Number of samples
Rosaceae	*Crataegus sanguinea* Pall.	River valleys, birch groves, light creek valleys in forest fringes.	1130-1187	11
	Cotoneaster melenocarpus (Ledeb.)	Steppe stony and rocky slopes, shrub thickets on slopes and hollows, birch groves, larch and pine forests, forests fringes	1146-1306	22
	Amygdalus pedunculata Pall.	Stony slopes, sides and bottom of dry riverbeds, alluvial fans, fringes of sands, rocks in steppe and desert zones.	1063-1148	15
	Dasiphora fruticosa (L.) Rydb.	River banks, hollows, canyons and creek valleys, shrub thickets, meadow slopes, larch forests and forest fringes, dwarf birch thickets, stone fields and screes in forest-steppe, forest and alpine belts.	1064-1163	8
Salicaceae	*Salix divaricata* Pall.	Stream banks, moist meadows, sedges and marshed in the highland belt	1063-1058	11