

# Evaluating the suitability of nine shelterbelt species for dendrochronological purposes in the Canadian Prairies

Emma L. Davis · Colin P. Laroque ·  
Ken Van Rees

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**Abstract** Shelterbelts have played an important role in prairie agriculture since the late 1800s; however, little is known about how these shelterbelts may be affected by climate change. The objective of this study was to determine if shelterbelt species, which are heavily influenced by human activity, express a common radial-growth signal within and between trees. The study focused on the annual tree-ring growth of the nine most common shelterbelt species of the Canadian Prairies: *Salix acutifolia* (Acute willow), *Caragana arborescens* (caragana, or Siberian pea shrub), *Picea pungens* (Colorado spruce), *Fraxinus pennsylvanica* (green ash), *Populus* sp. (hybrid poplar), *Acer negundo* (Manitoba maple), *Pinus sylvestris* (Scots pine), *Ulmus pumila* (Siberian elm) and *Picea glauca* (white spruce). Tree core samples were collected near Saskatoon, Saskatchewan using traditional dendrochronological

methods. The standardized growth of each species was compared with historical homogenized climate data in order to determine the key monthly climate variables impacting each species. Prior to this analysis, little was known about the suitability of six of these nine species for dendrochronological purposes. It was found that all species crossdate at a significant level, and that the three most significantly correlated climate factors are able to account for up to 37 % of the annual variation in tree-ring growth. The findings of this study suggest that all nine species are suitable, to varying degrees, for future dendrochronological research in the Canadian Prairies as well as having implications for shelterbelt systems elsewhere in the world. The top four species based on four ranking criteria (interseries correlation, mean sensitivity, climate explanatory power, and commonality) were white spruce, acute willow, caragana, and Manitoba maple, and initial results suggest that all species have the potential to be investigated in greater depth.

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E. L. Davis (✉) · C. P. Laroque  
Mount Allison Dendrochronology Laboratory,  
Department of Geography and Environment,  
Mount Allison University, Sackville,  
New Brunswick E4L 1A7, Canada  
e-mail: eldavis@mta.ca

C. P. Laroque  
e-mail: claroque@mta.ca

K. Van Rees  
Centre for Northern Agroforestry and Afforestation,  
College of Agriculture and Bioresources, University  
of Saskatchewan, Saskatoon,  
Saskatchewan S7N 5A8, Canada  
e-mail: ken.vanrees@usask.ca

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## Introduction

Shelterbelts consist of trees and shrubs planted in long rows around a farmstead or agricultural field. This agroforestry system has played an important role in the

Canadian Prairie landscape since the beginning of the 20th century (Kulshreshtha et al. 2010). In 1901, a Tree Nursery under the Department of the Interior was created at Indian Head, Saskatchewan. Currently known as the Agriculture and Agri-Food Canada Prairie Shelterbelt Program (PSP), complimentary trees have been sent to farmers for planting on their properties upon request for over 100 years. Shelterbelt systems provide protection from wind (Wang and Takle 1995; Torita and Satou 2007) and aid to minimize the deleterious impacts of soil erosion and snow loss (Brandle et al. 2004; Kulshreshtha et al. 2010). Shelterbelts also play a significant role in mitigating carbon dioxide emissions (Montagnini and Nair 2004; Dixon et al. 1993): throughout the history of the Canadian shelterbelt program, approximately 218 megatons of CO<sub>2</sub> have been sequestered from the atmosphere (Agriculture and Agri-Food Canada 2008). This speaks to the potential of shelterbelts to act as carbon credits for farmers as a method of offsetting the greenhouse gas emissions associated with land use change and agricultural pursuits. Other benefits of shelterbelts include their ability to reduce the odor from farm animal barns (Lin et al. 2006; Tyndall and Colletti 2007; Tyndall and Grala 2008), decreasing building heating costs by up to 18 % (Liu and Harris 2008), and providing habitat for local wildlife (Kulshreshtha et al. 2010).

Trees and their annual-growth rings have long been used as paleo-climate proxies, allowing researchers to create chronological records describing past climate conditions (Fritts 1976; Schweingruber 1988; Schweingruber 1996). The science of tree-ring analysis is referred to as dendrochronology, a powerful tool that enables us to glean information about past environments. Alternations in patterns of wide and narrow growth allude to favorable and unfavorable growing conditions, which when averaged over a given area can provide insight into the historical environments of the region. Dendrochronology is more traditionally applied to forest systems that are self-established, rather than those planted by humans.

Shelterbelt tree growth is related to human activity, in ways more direct than typical forest systems, both because of the benefits derived from them by landowners and because they are hand-planted according to the specifications and designs provided for each species. Particularly in the seedling stage of tree development, shelterbelt trees are greatly assisted in

their establishment by landowners who often provide additional watering, weeding, and who may also apply fertilizer. This differs significantly from a natural forest system where planted seedlings generally receive no management to enhance their growth and survival against a suite of natural ecological processes (Rooney and Waller 1998). To date, no known dendrochronological analyses have been completed to determine if shelterbelt trees express a common annual-growth signal within and between trees. It is unclear whether the intense influence that humans have on these trees might mask any existing environmental and specifically climate signal held within their rings. Determining this baseline information is the first step required to answer larger questions such as how shelterbelt trees sequester carbon over time and space, or how climate conditions may have changed in locations where established meteorological stations do not exist. In an ideal situation, it would be possible to compare the growth patterns of shelterbelt trees with those of the same species in nearby forest systems in order to determine the extent of signal distortion caused by human activity. This is not possible in the Canadian prairies, however, due to the lack of remaining forested land in the area, as well as the prolific use of non-native species in shelterbelt systems that would not be found in nearby natural forests.

Despite the relatively young age of most shelterbelts (<100 years), the trees planted in the Canadian Prairies have the potential to provide valuable insight into past climatic conditions. Historical climate data has both temporal and spatial components; long-term meteorological stations are particularly suitable for providing temporal data, but provide only discrete spatial information. Applying dendroclimatological techniques to shelterbelt systems would significantly improve the spatial resolution of proxy climatic data, allowing us to view changes in climate in areas between meteorological stations over time, as well as across spatial transects where no coverage of meteorological stations currently exist.

Of the over 20 tree and shrub species distributed by the PSP, we chose the nine most commonly planted for our study. The species sampled and analyzed include *Picea glauca* (white spruce), *Picea pungens* (Colorado spruce), *Pinus sylvestris* (Scots pine), *Populus* sp. (hybrid poplar), *Fraxinus pennsylvanica* (green ash), *Salix acutifolia* (acute willow), *Caragana arborescens* (caragana, or Siberian pea shrub), *Acer negundo*

(Manitoba maple), and *Ulmus pumila* (Siberian elm). Having a wide range of species types, we set out to determine if and which of the most prolific deciduous and conifer species share a common growth signal within and between trees. Caragana, a drought tolerant shrub that is frequently planted in prairie shelterbelts systems, was also selected for analysis due to its importance as an abundant shelterbelt species.

Only three of the nine species selected for this study have been previously used for dendrochronological pursuits in forest systems: The International Tree Ring Database of species used in tree-ring research describes white spruce, Colorado spruce, and Scots pine as being known to crossdate (a group of trees expressing a common annual growth signal) across a region (Grissino-Mayer 1993, 2007), while Siberian elm and green ash are classified as having no known crossdating information or as unable to crossdate, and the remaining four species are not included in the database (Grissino-Mayer 1993, 2007). The objectives of this research were to determine (1) if shelterbelt trees, which are heavily influenced by humans, still share a common growth signal; and (2) whether they are suitable for further dendrochronological research by understanding the degree to which their variation in radial-growth can be explained by local climate factors. With enough trees planted in the Canadian Prairies to circle the globe roughly 27 times, it becomes apparent that these trees must, and will continue to have, an increasingly significant impact on the overall ecology as well as contributing to biomass accumulation in the environment. By investigating the way in which individual tree species have grown and responded to climate in the past, it will be possible to make more informed decisions about which shelterbelt species to plant today in order to maximize their carbon storage capacity in the future as regional climates continue to alter.

### Study sites

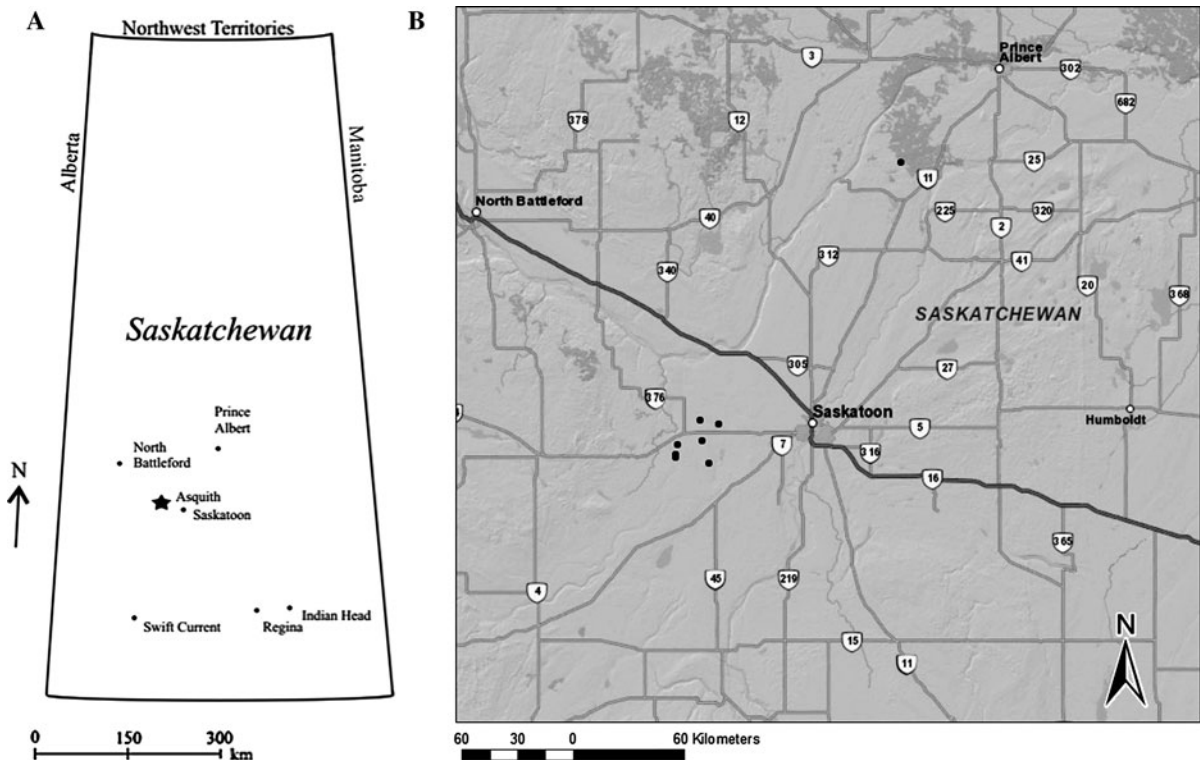
Sampling for this study took place in south-central Saskatchewan, near the city of Saskatoon, where long-term (1895 to present) homogenized climate data is available for climate analyses (Environment Canada 2010; Fig. 1a, b). Site selection was based on accessibility, although certain selection criteria had to be met in order for sampling to advance. The species of interest had to be present in greater numbers than what

was required for our analysis, allowing for random sampling within the site. Additionally, consultation with the landowner provided preliminary information (i.e. shelterbelt age) that helped us determine whether sampling would proceed. The eight sample sites were located between 500 and 550 m above sea level. Seven sites were clustered between the town of Asquith, and Saskatoon, and the eighth was located at Dorval, Saskatchewan, approximately 110 km north of Saskatoon. Having one species, Colorado spruce, located at distance from the others is relatively inconsequential for this study, as the aim of this study is to determine the relative usefulness of each species for dendrochronological purposes, rather than providing an analysis about a single location. Any detailed analysis about a single location's shelterbelt trees over time should be compounded by a huge number of factors that are constantly under some degree of human influence, and so if basic climatological relationships can be established first, then future experiments can be attempted to see how changes to other external variables alters radial growth.

The study sites and the surrounding areas are classified as tall grass prairie with Chernozemic soils, and parent material of fluvial and glaciofluvial origin (Dale and Lewry 2007). The climate of the Saskatoon region is highly variable and is considered to have a warm summer with a continental climate (Dfb) (Environment Canada 2010). The mean monthly temperature for Saskatoon varies between  $-17.5^{\circ}\text{C}$  in January and  $18.5^{\circ}\text{C}$  in July (Environment Canada 2010; Fig. 2). For our purposes, we considered the growing season of the shelterbelt species to span from April to September, as outside of this window, temperatures drop too low to reasonably expect any substantial above- or below-ground growth. Mean monthly precipitation varies throughout the year, with the summer months experiencing significantly more precipitation than in the winter. Average precipitation is highest in June (70 mm) and lowest in February (20 mm) (Environment Canada 2010; Fig. 2).

### Methods

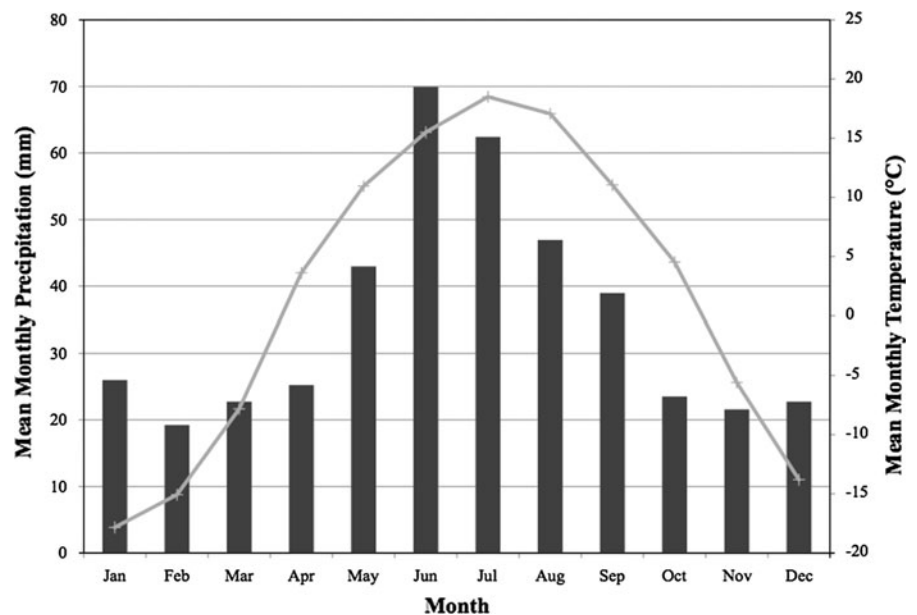
At each site, the appropriate tree or shrub species were identified and 20 individuals were randomly selected for sampling. Because of the inherent nature of shelterbelts being planted after 1903 and in far greater



**Fig. 1** **a** Map of the province of Saskatchewan. Most samples for this study were collected near Saskatoon, in the town of Asquith with Colorado spruce samples collected 110 km to the

northeast towards Prince Albert. **b** Sample sites (*black dots*) in relation to the city of Saskatoon and surrounding areas (ESRI 2012)

**Fig. 2** Mean monthly temperature and precipitation data for Saskatoon, SK (1900–2008) (Environment Canada 2010). The *line* represents the change in annual mean-monthly temperature, and the *bars* provide an indication of mean-monthly precipitation. The data presented here is derived from the climate data used for later analyses



numbers more recently, the landowner was questioned when possible, as to the approximate age of the trees before sampling began. A minimum tree age of

30 years and preferably older than 50 years was necessary to complete statistically significant analyses (Grissino-Mayer 2001; Biondi and Waikul 2004). For

all species except caragana, two core samples were taken from each tree at right angles from one another. The samples were collected at breast height using a 5.1 mm increment borer and stored in straws from transportation.

Caragana was sampled differently than the tree species because it often has as many as 25 stems or branches growing outwards from one central root mass, and because the girth of an individual stem is too small to sample using traditional methods. Instead of using increment borers, a healthy branch from the shrub was identified and removed using a reciprocating saw. For each sampled branch, a section approximately 15 cm in length was collected near the base of the stem for analysis. Individual shrubs were sampled about every three metres down a row of caragana in order to minimize the impact on the function of the overall shelterbelt. Twenty caragana stems were sampled at each site.

In the lab, the tree core samples were prepared for analysis by first gluing the samples into slotted mounting boards, and then by sanding them with progressively finer sand paper (80–600 grit). Because the best possible surface was sought, each sample was then further buffed to eliminate any fine dust particles that were trapped within the wood pores. Caragana samples were prepared by cutting each 15 cm sample in half with a band saw to create two discs. One disc was saved and the other was sanded and buffed in a similar manner to the tree core samples above.

The samples were initially visually crossdated (pattern matched) for common marker years of suppressed or increased radial growth (Stokes and Smiley 1968). The annual-ring widths of the cores and discs were then measured to 0.001 mm precision on a Velmex measuring stage and viewed through a 63× microscope. Measurements were computerized and recorded using the program Measure J2X (VoorTech 2011) and statistical crossdating was then conducted utilizing the computer program COFECHA (Holmes 1983). COFECHA functions by establishing a master chronology from the raw ring-width measurements, and then by comparing each individual core to the overall master chronology. A degree of correlation with the master chronology is provided for each individual core in addition to each segment within the core. This aids to identify missing or false rings, or to determine if a section was incorrectly measured. The data were analyzed in 30-year segments with a 15-year

lag due to the limited age of most samples. While crossdating, care was taken to maximize sample depth, and so on only a few occasions did a sample need to be eliminated due to irresolvable errors in dating the tree rings which may have occurred due to any number of reasons.

COFECHA produces a statistical output that provides insight into the growth characteristics of each series of tree-ring measurements. The autocorrelation value produced by the analysis is the degree to which the previous year's growth influences the current year's growth. A high autocorrelation value would suggest that if a tree experiences a year of favorable growing conditions, which is made visible by the presence of a wide ring, the tree rings would also be enlarged in the following year in part because of the success of the previous growing season. The mean sensitivity is a statistical descriptor of how responsive the growth of a particular species is to its surrounding environment (Fritts 1976; Grissino-Mayer 2001). A high degree of sensitivity indicates that the radial tree growth is being more heavily influenced by a single overriding environmental parameter. This can be determined visually by the alternation of wide and narrow rings on a tree core or disc, while a core whose rings appear to be all of a similar width is less sensitive (Stokes and Smiley 1968). The last key statistic used in this study is the interseries correlation value, a measure of the strength of the common growth signal that is being expressed within and between trees at a given site. An interseries correlation value of 0.423 was required to exceed the 99 % confidence interval and to be considered significant in our study.

Once a final master chronology was established for each of the nine species, the computer program ARSTAN (Cook 1985) was used to standardize the measurements by treating the data with a single detrending. This is a statistical method of eliminating the pattern of increased growth that is typically expressed in the early years of a tree's life. Standardizing the measurements allows individual trees, trees of different ages, and different species of trees to be directly compared (Cook 1985).

The standardized-growth measurements were compared using a Pearson's Product Moment correlation matrix to identify the presence of interspecies relationships. This analysis allowed us to determine if different species are responding to external factors in the same way. If this were the case, in future studies it

may not be necessary to sample many different shelterbelt species in order to acquire a complete picture of all the species' responses to climate in a given region.

The standardized measurements of each series, along with historical homogenized climate data from Saskatoon, were input into the program DendroClim2002 to determine the main climate factors influencing annual-radial growth (Biondi and Waikul 2004). The months of April of the previous-growth year, to September of the current-growth year, for both monthly temperature and precipitation variables, were selected for the analysis (a total of 36 predictors). This window was selected as it is considered to include the months most likely to influence the radial-growth of the nine shelterbelt species tested. DendroClim conducts both correlation and response function analyses, and provides an output that indicates which climatic variables are significantly related to growth (Biondi and Waikul 2004). The degree of significance of the correlation and response function tests are provided and are useful in demonstrating which climate factors are likely to be the strongest predictors of radial growth in terms of months in the current, and/or previous year, as well as in terms of a temperature and/or precipitation variable (Biondi and Waikul 2004).

From each of the nine DendroClim2002 outputs, the three climate factors that explained the highest degree of variation in radial growth were identified and selected for use in a multiple regression analysis. The resulting  $R^2$  value describes the degree to which these leading monthly climate factors are able to account for the annual variation in the ring width of each species. Trees with more variability explained by the three climate variables will be considered more valuable for any further dendrochronological studies. Only the top three variables per species were selected to eliminate the possibility of over-fitting the regression.

Because of the limited age of the collected samples, the climate analysis for caragana had to be completed in a slightly differently manner. For each parameter (e.g. monthly climate variable) that was analyzed with DendroClim 2002, the chronology had to be 1.5 times longer than the number of climate predictors due to the lagged variables and the loss of a year by the degrees of freedom. The length of the caragana chronology was just below this threshold. Instead of creating dummy variables to extend the length of our chronology to be

able to run the lagged component of the analysis (which would perhaps create errors of bias in the output), we chose to complete the analysis for only the current year's climate variables, excluding those of the previous years. We knew that this would produce slightly different results than if the previous and current years were analyzed simultaneously, but also that it would be more accurate than constructing dummy-year values to extend this shortened chronology.

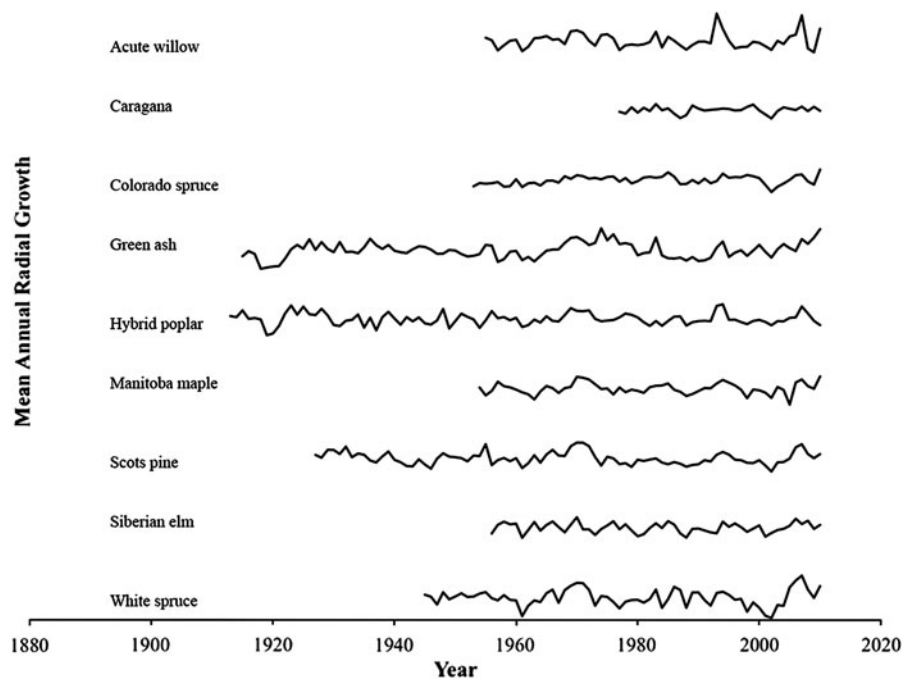
Finally, each of the nine species was ranked in order of their relative usefulness for dendrochronological purposes compared to the other species based on four characteristics: (A) mean sensitivity values, (B) inter-series correlation values, (C) variation explained by climate, and (D) perceived commonality (an assigned variable based on the overall number of each tree species planted, reflecting the total numbers of trees per species distributed by the PSP in 1960 or before). This was done in an effort to quantify the suitability of each of the nine species for further dendrochronological research in similar shelterbelts elsewhere, and provides insight into where to focus future spatial research efforts (Fig. 3).

## Results

Of the total 320 cores and 20 cookies from 180 individual trees and shrubs that were collected, 284 cores and 17 cookies were included in the final analysis, which account for an inclusion of 89 % of the collected samples (Table 1). All of the species' chronologies were over 50 years in length (ranging between 56 and 98 years), except the chronology of the shrub caragana, which was 34 years in length. This may be attributable to the short lifespan of individual caragana stems. A minimum interseries correlation value ( $r$ ) of 0.423 was required to reach the 99 % confidence level, based on a 30-year window that overlapped every 15 years. All nine crossdated species chronologies surpassed this confidence level and were found to correlate well within and between trees, with  $r$ -values ranging between 0.53 and 0.73 (Table 1). Autocorrelation values for the nine species ranged between 0.43 and 0.72. These values are deemed to be relatively high, based on accepted levels of the statistic for tree-ring chronologies (Grissino-Mayer 2001). The mean-sensitivity values for the nine



**Fig. 3** Master chronologies of the nine species, demonstrating standardized ring-width growth over time



**Table 1** Individual chronology statistics summarizing the growth characteristics of each species that describe the length of the chronology, interseries correlation value, autocorrelation

value, mean sensitivity, and the degree of influence the three most significant climate variables have on each species

Species (common)	Time	Cores	Corr.	Auto.	Sens.	Length (years)	Climatic influence (R <sup>2</sup> )
<i>Salix acutifolia</i> (acute willow)	1955–2010	34	0.72	0.53	0.37	56	0.35
<i>Caragana Aborescens</i> (caragana)	1977–2010	17	0.61	0.43	0.26	34	0.37
<i>Picea pungens</i> (Colorado spruce)	1953–2010	38	0.58	0.62	0.27	58	0.34
<i>Fraxinus pennsylvanica</i> (green ash)	1915–2010	37	0.63	0.63	0.34	96	0.15
<i>Populus</i> sp. (hybrid poplar)	1913–2010	37	0.70	0.72	0.31	98	0.21
<i>Acer negundo</i> (Manitoba maple)	1954–2010	33	0.59	0.52	0.45	57	0.22
<i>Pinus sylvestris</i> (Scots pine)	1927–2010	33	0.53	0.63	0.38	84	0.24
<i>Ulmus pumila</i> (Siberian elm)	1956–2010	32	0.58	0.55	0.33	55	0.25
<i>Picea glauca</i> (white spruce)	1945–2010	40	0.73	0.53	0.46	66	0.28

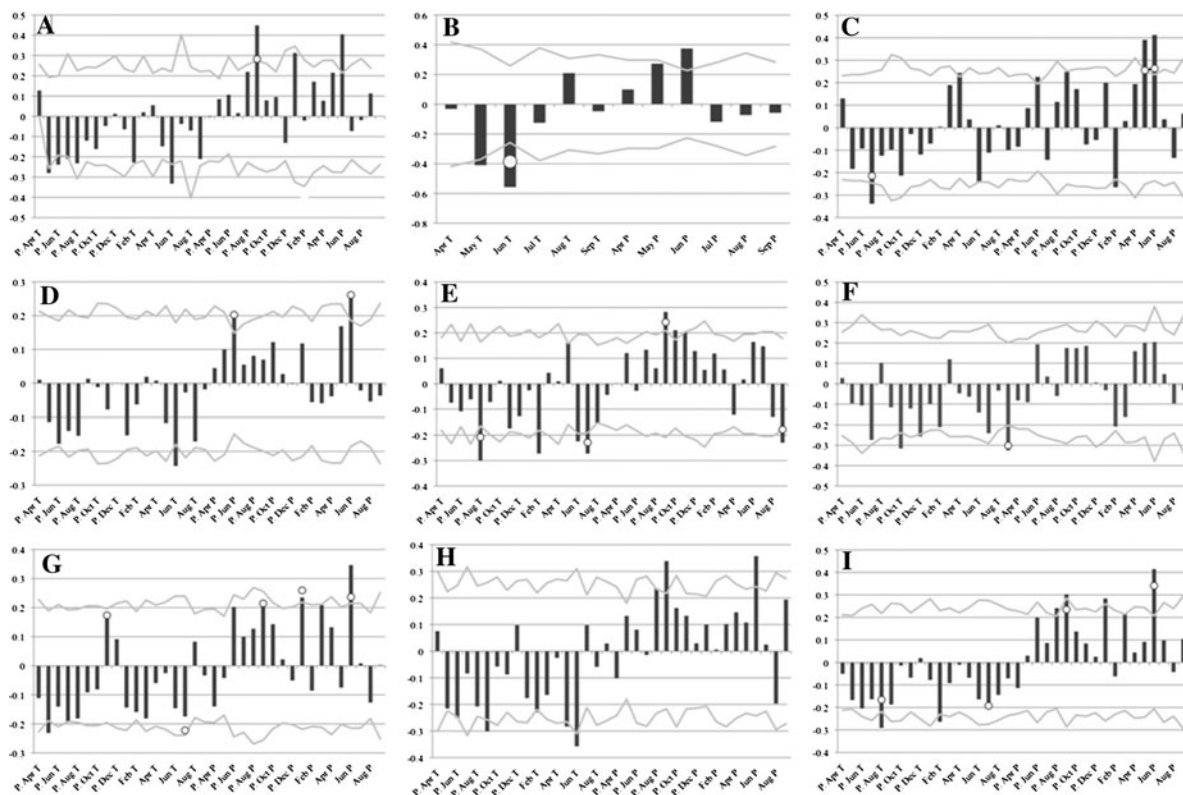
*Time* time-span of master chronology, *Cores* tree cores used in final chronology, *Corr.* Interseries correlation value (r value), *Auto.* Autocorrelation value, *Sens.* Mean sensitivity value, *Length* length of chronology in years, *Climate* influence of climate (R<sup>2</sup> value)

species were consistent within a window of 0.26 and 0.46. This indicates that all trees in this study exhibit intermediate to high environmental sensitivity compared to previously established thresholds (Low: 0.10–0.19, Intermediate: 0.20–0.29, High: >0.30 respectively, Grissino-Mayer 2001).

The variation in relative age and mean sensitivity of each chronology become particularly apparent when compared graphically (Fig. 4). Mean sensitivity is visually expressed by deviations above or below the

mean ring growth for a particular year. Caragana, for example, was found to have a low mean sensitivity and exhibits complacency in its variation when plotted over time. When compared to a more sensitive species (e.g., acute willow), the low deviation from the mean ring growth from year-to-year for caragana was noticeable.

The results of the climate analysis using DendroClim 2002 are depicted in Fig. 4. The analysis demonstrates the variation in the influence of the climate



**Fig. 4** The nine Dendroclim2002 analyses for **a** acute willow, **b** caragana, **c** Colorado spruce **d** green ash, **e** hybrid poplar, **f** Manitoba maple, **g** Scots pine, **h** Siberian elm, **i** white spruce. The independent axis is the correlation index created by the output, indicating the degree of correlation between ring growth and the particular climate variable. The *upper* and *lower boundary lines* indicate the degree of correlation required

factors on a monthly basis where each species responded to monthly climate parameters in different ways, although some over-arching trends did exist. The majority of the species tended to be negatively correlated to temperature and positively correlated to precipitation, suggesting that moisture was a limiting factor, and can be exacerbated under the presence of high temperatures (temperature and precipitation are two closely linked climate variables). Conducting a multiple regression analysis that compared annual-radial growth to the top three climate variables (the three most significantly correlated as determined by the DendroClim analyses) provided an indication of the strength of the relationship between climate and annual-radial growth. The  $R^2$  value resulting from each analysis expresses the percentage of the variation

between the monthly climate variable and the corresponding standardized ring-width growth to be considered significant at the 95 % confidence interval. Any bar that crosses this linear threshold, therefore, is considered to be a significant factor in the individual species' growth. The circular function marker implies the attainment of a significant response variable for the corresponding monthly climate variable

in growth that is accounted for by the top three chosen climate variables (Table 1).

When the standardized ring-width measurements were compared between species using a Pearson's Product Moment correlation matrix, the strength of interspecies correlations ranged from a low of 0.101 between caragana and hybrid poplar ( $p = 0.571$ ), to a high of 0.702 between Scots pine and white spruce ( $p = 0.000$ ) (Table 2). Most of the interspecies relationships are significant at either the 95 or 99 % confidence interval except the relationships with the shrub species caragana. This indicates that while the species are responding differently to climate on a monthly level (see DendroClim analyses, Fig. 4), the overriding annual-growth signal is shared by most of the species.



**Table 2** A Pearson’s product moment correlation matrix demonstrating the relationship between species master chronologies

Species	A. willow	Caragana	C. spruce	G. ash	H. poplar	M. maple	S. pine	S. elm	W. spruce
A. willow									
Caragana	0.319 (0.066)								
C. spruce	0.435 (0.001)	0.431 (0.011)							
G. ash	0.45 (0.000)	0.326 (0.060)	0.413 (0.001)						
H. poplar	0.568 (0.000)	0.101 (0.571)	0.250 (0.059)	0.343 (0.001)					
M. maple	0.422 (0.001)	0.227 (0.197)	0.471 (0.000)	0.356 (0.007)	0.436 (0.001)				
S. pine	0.590 (0.000)	0.342 (0.048)	0.406 (0.002)	0.342 (0.001)	0.448 (0.000)	0.537 (0.000)			
S. elm	0.348 (0.009)	0.339 (0.050)	0.426 (0.001)	0.267 (0.049)	0.278 (0.040)	0.349 (0.009)	0.521 (0.000)		
W. spruce	0.638 (0.000)	0.291 (0.095)	0.456 (0.000)	0.363 (0.003)	0.548 (0.000)	0.489 (0.000)	0.701 (0.000)	0.54 (0.000)	

Interspecies correlations values are listed, with *p* values in brackets below. Dark grey blocks represent significant relationships above the 99 % confidence interval, and light grey represents significant relationships above the 95 % confidence interval

Determining which species are the most suitable for dendrochronological studies is an important way of informing future shelterbelt studies. Establishing a ranking system that reflects the potential relative usefulness of each species for dendrochronology will benefit future investigations in the region as an important starting point. To establish usefulness ranks, several key statistics resulting from the aforementioned analyses were noted for each species, which resulted in the ability to create a relative usefulness rank between all nine species (Table 3). Each species was ranked by the strength of its interseries correlation, mean sensitivity, the strength of the expressed climate signal, and the species’ commonality. The scores from the four variables were totaled to establish values of relative usefulness (Table 3). For example, the species with the highest total score was white spruce (rank = 1, rank score = 26, based on it being ranked highest in terms of interseries correlation and mean sensitivity, and moderately well in terms of climate explanatory power (percentage of variation explained by three strongest climate variables). With a

total score of 26 (out of a possible 36), it is considered the most useful species (tied with acute willow).

While all plants have an essential need for light, water, nutrients and carbon dioxide, the way that these environmental inputs are expressed in annual-radial growth varies between species and through time. The results of each species are discussed individually below in their ranked order to explain their variation and degree of usefulness. It is worth noting that even the species that rank among the lowest of those studied still crossdated successfully, and therefore can provide valuable insight into past environmental conditions in the locations where they grow.

*Picea glauca* (white spruce)—usefulness rank: 1

Of the nine species studied, the 66-year master chronology of white spruce demonstrated the strongest interseries correlation ( $r = 0.73$ ,  $n = 40$  cores). This suggests that in our study, white spruce was demonstrating the strongest common growth signal within and between trees. White spruce also had the highest

**Table 3** Usefulness ranks for each species, based on interseries correlation, mean sensitivity, explanatory power in terms of climate, and commonality

Species	Inter. Corr.	Sensitivity	Climate	Commonality	Total	Rank
White spruce	9	9	6	2	26	1
Acute willow	8	6	8	4	26	1
Caragana	5	1	9	9	24	3
Manitoba maple	4	8	3	8	23	4
Green ash	6	5	1	7	19	5
Hybrid poplar	7	3	2	6	18	6
Colorado spruce	3	2	7	5	17	7
Siberian elm	3	4	5	3	15	8
Scots pine	1	7	4	1	13	9

Each species was ranked on a relative basis with 9 as the highest and 1 as the lowest. The resulting totals were then converted directly to ranks. Species are listed in order of most to least useful for dendrochronological analyses in this area

mean sensitivity value (0.46), indicating that the surrounding environment has a strong impact on the variation in yearly growth for this species. The strongest interseries correlation and mean sensitivity values, in addition to a high ranking in the explained variance by climate variable (fourth highest), make white spruce a very suitable species for climate modeling. In our study, it was ranked as the most useful for future dendrochronological purposes (tied with acute willow), and is a preferred species for its ease in the crossdating process (Table 3).

Statistical analysis between historical climate data and annual growth provided insight into the driving climate factors accounting for year-to-year variability in ring-width growth. White spruce tree-ring growth appeared to be heavily influenced by the previous year's August temperature (negative correlation), the current years July temperature (negative), previous September precipitation (positive), and current June precipitation (positive). This is indicative of a species that is limited by low soil moisture and high temperatures (which may also decrease the amount of moisture available). It was found that the three most significant climate factors accounted for 28 % of the variation in annual growth.

The standardized growth of white spruce compared well to that of other species, in particular it closely resembled hybrid poplar, acute willow, Colorado spruce, Siberian elm, Manitoba maple, and Scots pine. Each of these species were found to correlate significantly with white spruce ( $p < 0.01$ ). The annual growth of white spruce and Scots pine was particularly similar, with a correlation value over 0.70. This could

be useful in future studies, as Scots pine was determined to be the least abundant species in the field. As Scots pine and white spruce express similar climate signals, it may be that sampling only white spruce would be sufficient.

*Salix acutifolia* (acute willow)—usefulness rank: 1

Acute willow possessed the second highest interseries correlation value of the nine species studied ( $r = 0.72$ ) with a master chronology spanning 56 years ( $n = 34$  cores). The three climate factors that had the largest impact on the annual ring width variation of acute willow were previous September precipitation (positive correlation), June precipitation (positive), and June temperature (negative). These three factors have the combined explanatory power of 35 % of the variance in radial growth.

The combined impact of the high interseries correlation value, and the high explanatory power of the main climate factors (Table 3), suggests that acute willow has the potential to be a useful species for various sub-disciplines of dendrochronology. Currently not listed in Grissino-Mayer's (1993, 2007) database, acute willow should be considered for addition, as it was able to be successfully crossdated within and between trees.

*Caragana aborescens* (caragana)—usefulness rank: 3

Prior to this study, the annual growth characteristics of caragana were largely a mystery. It was unknown

whether the species produced annual-growth rings, or if its life span was long enough to produce a viable chronology. After a visual inspection of the species, it was apparent that it did produce rings. The procedure of crossdating demonstrated that these rings are in all likelihood produced on an annual basis.

Our analysis produced a master chronology that was 34 years in length ( $n = 17$  discs), with an interseries correlation value of 0.61. The mean sensitivity of caragana was 0.26, the lowest of the nine species sampled. This indicates that while the shrubs in one area are responding to a similar annual growth signal, the year-to-year variability in the response as expressed by the width of annual rings is very low. In essence, caragana seems to grow well under a series of varying climatological inputs, and is not overly sensitive to one limiting factor. This result is not unexpected, as caragana is known to be a drought tolerant species.

The annual growth of caragana did not correlate well with the other species. A significant relationship was identified only with Colorado spruce, Scots pine, and Siberian elm ( $p < 0.05$ ) (Table 2). This relationship suggested that the environmental factors that caragana was responding to differs from the other species studied. The three main climate factors (May temperature (negative correlation), June temperature (negative), and June precipitation (positive)), for caragana, accounted for 37 % of the annual variability in its ring-width growth, the most of any of the nine species studied. This indicates that the climatic conditions in late spring and early summer are the main drivers of the plants' success throughout the year.

The strength of the interseries correlation value, the high accountability of the three dominant climate factors to explain much of the year-to-year variability in growth, in addition to its rank as the third most useful species suggests that caragana is a suitable species for further dendrochronology. Additionally, caragana was the most prolific species of the nine sampled, therefore contributing significantly to the overall shelterbelt biomass of the prairies. Caution should be taken while sampling, however, as despite its abundant nature, the stems of this shrub do not appear to live long past the 30 years necessary for a statistically significant analysis. Increasing the number of samples collected in the field would increase the likelihood of collecting viable older samples (as it is common for caragana stems to have rot in their centres).

*Acer negundo* (Manitoba maple)—usefulness rank: 4

The interseries correlation value for Manitoba maple was 0.59 ( $n = 33$  cores) with a master chronology 57 years in length. The annual rings for this species were difficult to discern under a microscope, but became more visible with additional sanding and buffing (up to 1,000 grit). Current September temperature (negative correlation) appeared to be the dominant climate factor, in addition to previous October temperature (negative) and previous December temperature (negative). This may indicate that the conditions on the fringe of the growing season play an important role in the success of this species. The temperature of December of the previous growing season may be of import as higher December temperatures result in less of a snow pack to melt in the spring freshet. These three variables combined to account for 21 % of the annual variability of ring-width growth.

The annual growth of Manitoba maple corresponded well to that of several of the other species studied: acute willow, hybrid poplar, Colorado spruce, Siberian elm, white spruce, and Scots pine in particular ( $p < 0.01$ ) (Table 2). Due to its high mean sensitivity (rank score = 8) and intermediate rankings of interseries correlation (rank score = 4) and explained climate (rank score = 3), Manitoba maple is considered to be the fourth most useful species in our study (Table 3). For these reasons, in addition to Manitoba maple's relative abundance in the prairies (rank score = 8), this species should be added to the species considered useful for dendrochronology.

*Fraxinus pennsylvanica* (green ash)—usefulness rank: 5

Although difficult to core in the field, green ash crossdated with ease, providing the second longest chronology (96 years), and a relatively high interseries correlation value of 0.63 from 37 cores (Table 1). The main climate variable controlling the growth of green ash is previous June precipitation (positive correlation), current June precipitation (positive), and June temperature (negative). These main three climate factors contributed to 15 % of the annual variability in radial growth, and suggest that green ash is responding predominantly to the climatic conditions of the month of June.

When compared to the other eight species sampled, the green ash signal correlated with acute willow, Siberian elm, hybrid poplar, Scots pine, and white spruce at the 99 % confidence interval (Table 2).

This species is listed as ‘not being able to crossdate, or as having no information available’ on Grissino-Mayer’s (2007) tree ring database. While the high degree of interseries correlation suggests that green ash is likely suitable for dendrochronological purposes, the low explanatory power (rank score = 1) of the top three climate factors suggests that perhaps green ash is not as appropriate for studies pertaining to the sub-discipline of dendroclimatology, despite its intermediate ranking of commonality (Table 3).

*Populus* sp. (hybrid poplar)—usefulness rank: 6

The master chronology for hybrid poplar proved to be the longest of all nine species (98 years,  $n = 37$  cores). Hybrid poplar expressed an annual growth pattern that correlated at a significant level with acute willow, white spruce, Manitoba maple, and Scots pine (Table 2). The set of samples expressed a high interseries correlation value (0.70), however, hybrid poplar was ranked as a relatively less useful species for dendrochronology in the Canadian Prairies because of its relatively low mean sensitivity ranking (rank score = 3), its low climate explanatory power ranking (rank score = 2), and its intermediate abundance in the field (rank score = 6).

The main climate factors controlling the majority of the year-to-year ring-width variability were previous August temperature (negative correlation), current July temperature (negative), and previous September precipitation (positive). This suggests once again a limitation in growth due to moisture and high heat.

Prior to this study, little was known about the ability of hybrid poplar to crossdate, or how it responds to climate variables. The large vessels in the growth rings of hybrid poplar make identifying the annual ring boundaries challenging. Based on the details outlined above, hybrid poplar can be considered to successfully crossdate within and between trees, but if time or resources were limited, our assessment would recommend that other species would be more useful to be sampled for dendrochronological pursuits.

*Picea pungens* (Colorado spruce)—usefulness rank: 7

The master chronology for Colorado spruce was 58 years in length ( $n = 38$  cores). The interseries correlation for this species was among the lowest ( $r = 0.58$ ), but was still well above the 0.423 cut off value required for a significant correlation above the 99 % level (Table 1). The mean sensitivity was low for Colorado spruce (0.27) when compared to white spruce (0.46), indicating that while white spruce and Colorado spruce share some morphological similarities in the field, they are responding differently to environmental conditions. Notably, Colorado spruce was one of only three of our species that were included in Grissino-Mayer’s (2007) database, and had it the second lowest interseries correlation value.

Colorado spruce ranks seventh among the other species in terms of usefulness for dendrochronological purposes (Table 3). This was due to a low mean sensitivity ranking and low interseries correlation value. Colorado spruce, however, had one of the highest climate explanatory powers (rank score = 7) and an intermediate level of commonality (rank score = 5).

When analyzed with historical climate data in DendroClim2002, Colorado spruce appeared to be responding largely to three main climate factors. Previous July temperature (negative correlation), current April precipitation (positive) and current July precipitation (positive) accounted for most of the explained year-to-year variability in ring-width growth. These three monthly climate factors were found to account for 34 % of the annual variation in radial-ring growth.

The annual ring-width growth of Colorado spruce produced significant relationships with acute willow, green ash, Manitoba maple, Scots pine, Siberian elm, and white spruce at the 99 % confidence interval, and caragana 95 % confidence interval.

*Ulmus pumila* (Siberian elm)—usefulness rank: 8

Siberian elm proved challenging to crossdate, but it resulted in a master chronology of 55 years with an interseries correlation value of 0.58 ( $n = 32$  cores). The monthly climate variables accounting for the majority of the variability in growth were previous September precipitation (positive correlation), current

June temperature (negative), and current June precipitation (positive). As with green ash, this suggests that the species' annual growth is heavily linked to the environmental conditions in the month of June. These three variables accounted for 26 % of the annual variability. The annual growth of Siberian elm correlated significantly with acute willow, Colorado spruce, Manitoba maple, white spruce, and Scots pine at the 99 % confidence interval (Table 2).

Siberian elm ranked low in relative interseries correlation (rank score = 3), commonality (rank score = 3), only moderately well in mean sensitivity (rank score = 4), and climate explanatory power (rank score = 5) relative to the other species. For this reason, it is among the group of low ranking species in terms of usefulness (Table 3). Although not among the best shelterbelt species for dendrochronological analyses, it is notable that it did crossdate successfully within and between trees.

*Pinus sylvestris* (Scots pine)—usefulness rank: 9

Scots pine samples produced a 57-year chronology ( $n = 33$  cores) with an interseries correlation value of 0.53 (Table 1). This is the lowest interseries correlation value of all of the species studied, but is still considered to be significant. A variety of climate factors appear to be driving the annual variation in ring-width growth for this species. The response function analysis revealed relationships to previous November temperature (positive relationship), current July temperature (negative), as well as a positive relationship to previous September precipitation, and current January and June precipitation variables (January precipitation may be linked to effects of snow pack). These results indicate that the annual growth of Scots pine is influenced to a greater extent by precipitation than by temperature.

The annual growth of Scots pine correlated significantly with all species at the 99 % confidence interval, except caragana (95 % confidence interval) (Table 2).

Scots pine ranked among the least useful species because of its relatively low interseries correlation value (ranked score = 1) and low abundance (rank score = 1). It did, however, have the third highest mean sensitivity value, (rank score = 7), suggesting that while the influential climate factors are many, this species is sensitive to its climatic environment in the same manner between trees across a site.

Based on the numerous significant interspecies correlations between Scots pine and other species, in addition to its low overall usefulness ranking, it may be suitable to forego sampling Scots pine in shelterbelts and to focus efforts on species with similar growth patterns that have been shown to be more useful for dendrochronology (such as white spruce and acute willow, for example).

## Discussion

This study serves to highlight the value of shelterbelt trees for dendrochronology and is the first of its kind. Determining which species are the best suited for dendrochronology in the Canadian Prairies is the first step in addressing a variety of questions in future research. The results have demonstrated that each of the nine species studied express a common annual-growth signal that is correlated, to varying degrees, to climate, despite the large amount of human-induced disturbance in the surrounding environments. Knowing that each species is responding to climate, in slightly different ways from each other, suggests that the individual species' contain important information in their annual-growth rings that can provide us with insight into past environmental conditions in areas where historical climate stations do not exist. The results of the Pearson's Product Moment relationships demonstrate that the growth of the species are related to one another due to common responses to climate factors. This is evident in the over-arching tendencies revealed in the DendroClim analysis; besides caragana, which possesses both a different climatic signal and whose chronology did not correlate well with most of the other species, the species appear to respond negatively to increased temperature and positively to increased precipitation, supporting the notion that the majority of species are moisture-limited. For future sampling, this indicates efforts should be placed on finding the oldest trees that will produce the longest chronology and the species that are ranked most useful for ease of crossdating, rather than focusing on acquiring samples from as many species as possible. In addition to its value in determining the usefulness of each species, this study has greater implications for the carbon sequestration capacity of shelterbelt trees. Agroforestry systems such as shelterbelts have been recognized as one means of reducing greenhouse gas



emission through sequestering carbon from the atmosphere (Kulshreshtha et al. 2010; Montagnini and Nair 2004; Dixon et al. 1993). In the Canadian Prairies, where over 600 million trees have been delivered by the PSP in Indian Head to landowners for planting in shelterbelts, there is a need to understand the role that shelterbelts play in sequestering carbon from the atmosphere. Now that basic climate/radial growth relationships have been established, future dendrochronological studies will be able to forecast future tree growth of each species under changing climate scenarios based on their past historical growth trends. This information will be of value for determining the potential mitigating effects of shelterbelts on GHG emissions and will help in projecting future greenhouse gas inventories from shelterbelt systems. In addition, landowners would be able to use this information to determine the most suitable tree species to plant in the future based on varying warming and drying climate scenarios in order to maximize carbon sequestration for a carbon offset system.

The results of this study raise numerous questions that can be answered with future research. The scope of this study was limited to one sample set for each species, a suitable sample depth to determine if the species within a location are expressing a common growth signal. Further information, however, could be gained from analyzing a larger pool of trees of the same species in order to determine how their response to climate changes across space. Additionally, a larger sample depth would be beneficial for future growth modeling, ensuring that site-specific responses to climate do not mask the overall growth trend in the region. Similarly, the same larger sample depth would be ideal to gauge carbon sequestration values from a site where intense carbon measurement parameters have been collected. Together this information would allow a landowner to make a more informed decision on not only which tree will grow better in the future under a forecasted climate scenario, but perhaps also which tree species will capture the greatest amount of carbon for mitigating greenhouse gases.

## Conclusion

This study set out to determine if shelterbelt tree species in the Canadian Prairies expressed a common annual-growth signal within and between trees in an

effort to demonstrate their potential use in dendrochronological analyses. There are millions of shelterbelt trees and shrubs planted in the Canadian Prairies, and millions more planted around the world, but as our results indicate, they are not all created equal in terms of their usefulness for dendrochronology.

Based on the criteria of interseries correlation, mean sensitivity, the degree of variation explained by the three most explanatory climate factors and commonality, we have ranked the nine most common species in order of usefulness (Table 3). It has been determined that future efforts in sampling Canadian Prairie shelterbelts tree species should be focused on white spruce, acute willow, caragana, and Manitoba maple, as they were found to be the most useful for dendrochronological purposes. Although caragana stems may not capture as long of a record in their rings, this shortcoming is balanced by its high climate explanatory power and its prolific spatial abundance across the Prairies.

The results of this study suggest that all nine species successfully express a common annual-growth signal within and between trees, but that some are more useful than others. Given limited time or resources, it would therefore be beneficial to focus efforts on the four highest-ranking species for future studies of dendrochronology and dendroclimatology. Future studies should also focus on how external natural factors such as soil fertility and changing spatial climate patterns might have on shelterbelts trees planted across the Prairies.

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