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The Saskatchewan Shelterbelt Inventory

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Abstract

Shelterbelts represent a significant carbon reserve on the agricultural Prairie landscape and knowledge of their extent can be of importance to atmospheric carbon mitigation strategies. We describe the creation of a detailed inventory of the shelterbelts across the agricultural region of Saskatchewan. A total of 262,000 shelterbelts covering over 51,000 km were identified by species composition, row width, stand condition, and type. This inventory is an important baseline for monitoring changes in prairie agroforestry systems arising from climate change and land use conversion.

Keywords: FlySask aerial photographs, farm and field shelterbelts, on-screen digitizing, GIS shapefile

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Introduction

A shelterbelt is a row of trees or shrubs that grows along field boundaries, adjacent to roads and waterways, and around farmyards and livestock facilities (Agriculture and Agri-Food Canada, 2015). While most shelterbelts are planted from seedlings, a small proportion are left as remnants from the clearing of woodlots. Shelterbelts have been used to mitigate the effects of soil erosion due to wind, protect homes, crops and livestock, control snow blowing over roads, and provide wildlife habitat (Wiseman *et al.*, 2009).

Shelterbelt agroforestry systems have been planted in Saskatchewan for more than a century, becoming an integral part of the Prairie landscape. From 1888 to 2014, the Agriculture and Agri-Food Canada Agroforestry Development Centre (ADC) at Indian Head, Saskatchewan distributed over 600 million trees to farmers across the Prairie Provinces.

Recent attention to the impacts of greenhouse gases (GHG) on the global climate system has focused attention on the carbon sequestration potential of shelterbelts. Shelterbelts represent a significant carbon reserve on the agricultural Prairie landscape and Kort and Turnock (1999) estimated that if a shelterbelt enhancement program planted six million trees a year, almost 0.4 million tonnes of atmospheric carbon would be sequestered. Over the past eighty years, Amichev *et al.* (2016) calculated that more than 130,000 tonnes of carbon have been sequestered in tree biomass and the soils of white spruce shelterbelts in Saskatchewan alone. Furthermore, the recognized value of shelterbelts as a GHG mitigation practice could also provide an additional incentive for not removing, but retaining, existing shelterbelts and for planting new ones. In a survey of producers and land owners throughout Saskatchewan, Rempel *et al.* (2016) found that the perceived benefits of shelterbelts were non-economic and difficult to value within the producers' operations.

While there are records of the numbers of shelterbelt trees shipped from the ADC and their destinations, until now there has not been an accurate inventory of where these trees were planted and how many are still growing. In recognition of the importance of shelterbelts on the Prairies, the objectives of this study were to (i) create an inventory of all planted and remnant shelterbelts across the 260,000 km² agricultural region of Saskatchewan; and (ii) investigate ways in which this inventory could be completed as accurately and efficiently as possible.

Methods

We investigated new semi-automated technologies for efficiently identifying shelterbelt species using remote sensing data analysis. Previous research by Wiseman *et al.* (2009) suggested that object-oriented image analyses of the spectral reflectance, variance, and shape parameters of shelterbelts visible in digital aerial imagery had the potential to identify field shelterbelts with greater than 95% accuracy. Additionally, Liknes *et al.* (2010) successfully used object-oriented image analysis to generate predictive estimates of agricultural forest cover, although they did not inventory individual shelterbelts. It is noted that both Wiseman *et al.* (2009) and Liknes *et al.* (2010) focused on areas smaller than 250 km² where the location and composition of the shelterbelts was well known.

Based on the findings of Wiseman *et al.* (2009) and Liknes *et al.* (2010), we evaluated the ability of object-oriented image analysis for the identification of linear features on air photo imagery and came to a similar positive conclusion (Olowokudejo & Piwowar, 2013). Our study, however, was conducted to find linear clearings in forested regions; i.e., the vegetative opposite of finding tree rows on an open landscape. When we tried to apply our findings to the problem of identifying shelterbelts in agricultural regions, our results were not as conclusive. We discovered that the additional complexities of an agricultural landscape confounded the object-oriented classifier and although we could obtain reasonable results from a single air photo, they were not transferrable between scenes. That is, in order

to identify shelterbelts with an accuracy of greater than 50%, the object-oriented procedure required manual fine-tuning for each air photo sequence examined (Liknes *et al.*, 2010; Pankiw and Piwowar, 2010).

We concluded that the level of effort required to accurately digitize shelterbelts on the 100,000 available aerial images of Saskatchewan by semi-automated methods exceeded the time that it would take to achieve the same results by manual on-screen techniques, so research on the semi-automated methods was set aside.

Thus, an inventory of all shelterbelts in the agricultural region of Saskatchewan was created through heads-up (on-screen) digitizing of aerial images obtained from the Saskatchewan Geospatial Imagery Collaborative (SGIC, FlySask.ca). The digital air photos were acquired between 2007 and 2012 at a nominal ground resolution of 60 cm. We found the FlySask image resolution to be sufficient to observe shelterbelts as narrow as 2 metres (Pankiw and Piwowar, 2010).

Colour Infrared (CIR) images were selected as the primary data source over standard true-colour imagery because of the enhanced distinction of vegetated versus non-vegetated ground in the near-infrared spectral region. This was especially important when working with the FlySask air photos because they were acquired during leaf-off conditions (i.e. in the spring and fall seasons). We found that, even for leafless vegetation, the near-infrared reflectance from shelterbelts was in greater contrast to the surrounding landscape than for images acquired mid-season. True-colour scenes from FlySask were examined when the CIR images were unclear and when supplemental detail was needed to validate shelterbelt identification.

After sorting the air photos into collections based on National Topographic System 1:250,000 map sheets, they were visually examined for shelterbelts at a scale of 1:5,000. At this scale, grid roads and field boundaries were used as guides to track the visual scan of the map sheet since they have a consistent cardinal orientation and a spacing of 1 mile (1.6 km). Rows of vegetation observed on the air

photos were considered to be shelterbelts if they were nominally longer than 100 m and thinner than 20 m. Shorter lengths were included when it was clear that the vegetated object was a segment of a larger shelterbelt, for example if it was a disconnected leg of a farmyard shelterbelt or an interrupted segment of a field shelterbelt. Both planted and remnant shelterbelts were included. As each shelterbelt was traced on the screen, it was assigned a set of attributes, as specified in Table 1.

Both farmyard and field shelterbelts were digitized as linear features. A field shelterbelt was one that was observed to be located in an agricultural field, away from any farm buildings. Field shelterbelts included the subtypes of: dugout shelterbelts, livestock shelterbelts, roadside shelterbelts, and riparian buffers (Agriculture and Agri-Food Canada, 2015). A farmyard shelterbelt was one that was observed to surround farm buildings on at least 2 sides, within a nominal distance of 50 m. If a shelterbelt was observed to be protecting both a farmyard and a field, it was assigned to the farmyard category.

Results and Discussion

Over 262,000 individual shelterbelts were digitized (Figure 1, Table 2) in approximately 4,000 person-hours. We found 51,653 km of shelterbelts of various designs and age across the agricultural region of Saskatchewan. Narrow, single-row shelterbelts account for 85% of the plantings. Farmyard shelterbelts (total length of 29,754 km) were more prevalent than field shelterbelts (total length of 21,899 km). The majority of farmyard shelterbelts were planted with deciduous species, 74% of the farmyard shelterbelt total, followed by conifers > shrubs > mixed species. The majority of field shelterbelts were planted with shrub species, 71% of the field shelterbelt total (e.g., caragana), followed by deciduous > mixed > conifer species. Approximately 95% of the shelterbelts examined were in "good" condition, meaning that they were highly intact, with minimal gaps.

The inventory was validated by comparing the shelterbelt data produced by different individuals digitizing the same area. The digitized location accuracy exceeded 90%. Further validation against *in situ* data, particularly for the shelterbelt width, composition, and condition attributes is ongoing and will be updated as more field data becomes available.

In order to demonstrate the potential utility of the shelterbelt inventory, we joined it with soils data (Table 2, Figure 2). We found that deciduous species were consistently the preferred choice for farmyard shelterbelt planting across all soil zones. Shrub species were the preferred choice for field shelterbelts in the Brown, Dark Brown and Black soil zones, while conifer and deciduous species were the preferred choice in the Dark Gray and Gray soil zones. The total length of planted shelterbelts within a soil zone ranged from 23,274 km to 21 km in (descending order) the Dark Brown (23,274) > Brown (16,347) > Black (10,940) > Dark Gray (1,071) > Gray (21) soil zones (Figure 2). The ratio of farmyard:field shelterbelts ranged from 88:12 to 52:48 in (descending order) the Gray (88:12) > Black (74:26) > Dark Gray (73:27) > Dark Brown (53:47) > Brown (52:48) soil zones.

In addition to location, the other shelterbelt attributes collected during the digitizing process have considerable research value. For example, shelterbelt condition can be related to the ADC tree distribution records to estimate the age and longevity of the stands, and to ultimately estimate the success rate of the ADC prairie shelterbelt program. Further, since it has already been established that shelterbelts mitigate soil erosion, supplement soil moisture, and provide wildlife habitat, studies that examine how shelterbelt width affects these parameters can provide valuable information for new shelterbelt planting. Some other applications include identifying areas where shelterbelts appear to be most vulnerable for removal or die-out and mapping land-owner shelterbelt tree species preferences.

Amichev *et al.* (2015) described the importance of enumeration of shelterbelt establishment, maintenance, and diversity for policy makers. An inventory of shelterbelt designs (i.e., spacing, width,

number of rows) is especially needed to determine the most effective designs to maximize GHG mitigation. It is expected that the effectiveness of shelterbelt designs to maximize GHG mitigation will vary by location, such as soil zone, and by the choice of planted shelterbelt species because of the differences in the tree growth conditions across the province and species growing properties. All this can be accomplished by the means of extensive field data collection aided by the shelterbelt inventory created in this study.

Shelterbelts have the potential to play a major role in climate change mitigation by sequestering significant amounts of atmospheric carbon dioxide (CO₂) into the soil and as biomass carbon in aboveground and belowground parts of planted shelterbelt trees or shrubs (Kort and Turnock, 1999; Amichev *et al.*, 2016). This inventory can be used to help determine if the prairie agroforestry systems are disappearing because of climate change (Sauchyn *et al.*, 2010) or through direct removal by producers (Rempel *et al.*, 2016).

This research benefitted from the intuitive power of human discriminatory powers during the heads-up digitizing of the shelterbelts. However, the manual procedure was laborious, time-consuming and costly. Research into semi-automated image analysis methods that can consistently separate shelterbelts from other ground clutter in remotely sensed imagery is continuing. While it is very likely that a method to locate shelterbelts will be available within a couple of years, it may require several more years of development to provide the additional width, type, composition, and condition attributes that we obtained through manual digitizing.

Conclusions

An inventory of the shelterbelts in the agricultural regions of Saskatchewan was created by on-screen digitizing of CIR air photos. The location accuracy of the inventory was found to exceed 90%;

further validation against *in situ* data, particularly for the shelterbelt width, composition, and condition attributes is ongoing.

When we investigated new semi-automated technologies for efficiently identifying shelterbelt species using remote sensing object-oriented image analysis, we found them to be difficult to implement over a wide area. Continued research to address these shortcomings is needed.

The shelterbelt inventory of Saskatchewan described here can be combined with other data (e.g. soils and tree species) to make important contributions to our understanding of carbon cycling in agricultural environments. The inventory is an important baseline upon which future studies can be built. It would be very useful to repeat this inventory on decadal time scales, both where historical air photos are available and when new imagery is collected.

GIS shapefiles of the shelterbelt inventory of Saskatchewan can be obtained by contacting the first author of this paper.

Acknowledgments

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Tables and Figures

Table 1: Digitized shelterbelt attributes.

Attribute	Values	Description
Type		
	Field	Shelterbelts growing in fields, typically along field boundaries.
	Farmyard	Shelterbelts planted around farm buildings.
Width		
	Narrow	A shelterbelt composed of a single row of vegetation.
	Medium	A shelterbelt composed of 2-3 rows of vegetation.
	Wide	A shelterbelt composed of more than 3 rows of vegetation.
Composition		
	Grass	Shelterbelts composed primarily of grasses.
	Shrubs	Shelterbelts composed primarily of shrubs.
	Coniferous	Shelterbelts composed primarily of coniferous trees.
	Deciduous	Shelterbelts composed primarily of deciduous trees.
	Mixed	Shelterbelts composed a mixture of shrubs and coniferous and deciduous trees.
	Undetermined	Shelterbelts whose vegetation type could not be determined.
Condition		
	Good	Shelterbelts that are highly intact with minimal gaps; between 80-100% of the shelterbelt remains.
	Fair	Shelterbelts that are mainly intact with few gaps; between 50-80% of the shelterbelt remains.
	Poor	Shelterbelts that have considerable gaps and missing sections; less than 50% of the shelterbelt remains.

Table 2. Saskatchewan shelterbelt inventory metrics by shelterbelt type and composition across the five soil zones in Saskatchewan.

Shelterbelt Type	Composition	Metrics	Soil Zone					Farm or Field Shelterbelt Total	Grand Total
			Dark Brown	Black	Brown	Dark Gray	Gray		
farmyard	conifers	Cumulative length (km)	1,599	1,762	676	263	8	4,309	
		Percent (%) from total	3.1	3.4	1.3	0.51	0.016	8.3	
farmyard	deciduous	(km)	9,313	5,717	6,362	472	10	21,876	
		(%)	18	11	12	0.91	0.020	42	
farmyard	mixed	(km)	103	47	25	10		186	
		(%)	0.20	0.092	0.049	0.020		0.36	
farmyard	shrubs	(km)	1,406	521	1,424	32	0.4	3,384	
		(%)	2.7	1.0	2.8	0.062	0.001	6.6	
Farm Shelterbelt Total									
(km)			12,422	8,048	8,488	778	19		29,754
(%)			24	16	16	1.5	0.037		58
field	conifers	(km)	74	91	17	103	2	286	
		(%)	0.14	0.18	0.033	0.20	0.004	0.55	
field	deciduous	(km)	3,001	886	1,720	133	0.4	5,741	
		(%)	5.8	1.7	3.3	0.26	0.001	11	
field	mixed	(km)	249	38	101	12		400	
		(%)	0.48	0.073	0.20	0.023		0.77	

field	shrubs	(km)	7,528	1,877	6,022	45		15,472
		(%)	15	3.6	12	0.088		30
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Field Shelterbelt Total								
		(km)	10,852	2,892	7,859	293	3	21,899
		(%)	21	5.6	15	0.57	0.005	42
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Grand Total (farm and field)								
		(km)	23,274	10,940	16,347	1,071	21	51,653
		(%)	45	21	32	2.1	0.042	100

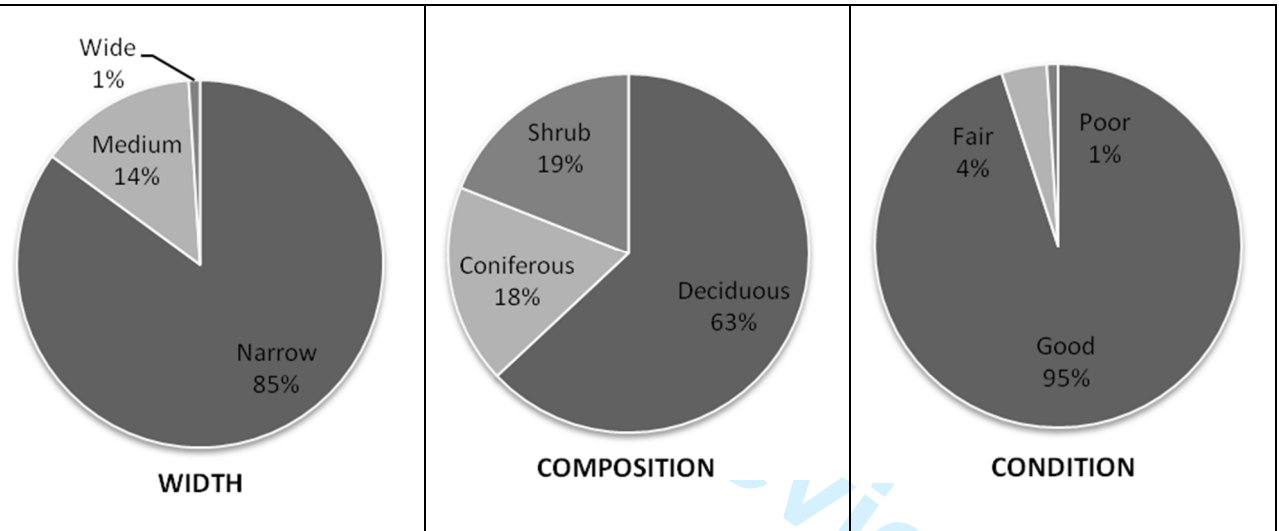


Figure 1. Digitized shelterbelt characteristics.

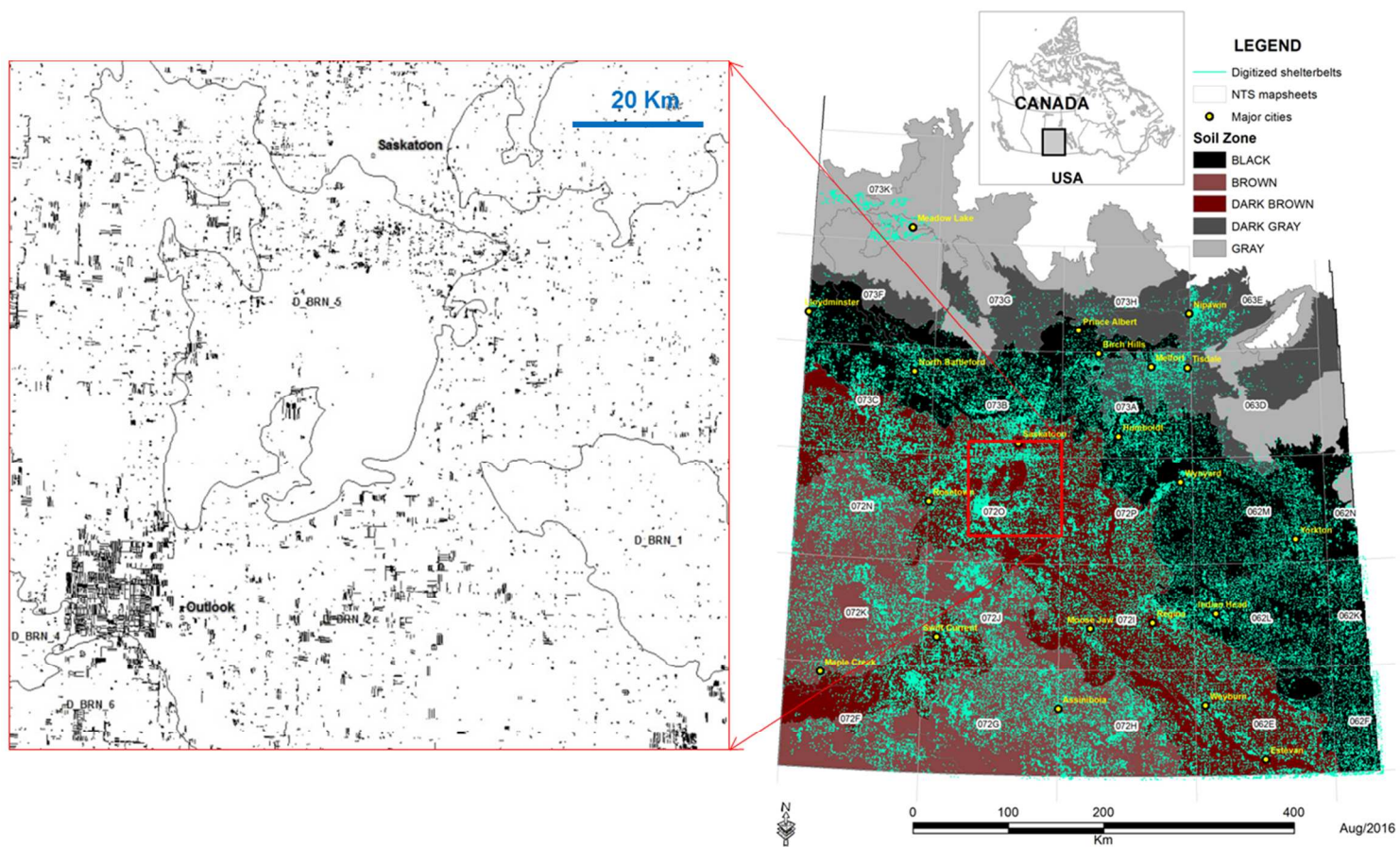


Figure 2. Distribution of digitized shelterbelts across the five soil zones in Saskatchewan.