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Spatial distribution and habitat preferences of the prairie crocus (Pulsatilla patens) in an urban landscape

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No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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Abstract of the thesis

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for the degree of Master of Science and entitled: Spatial distribution and habitat preferences of the prairie crocus (*Pulsatilla patens*) in an urban landscape.

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The prairie crocus *Pulsatilla patens* (L.) Mill. is a perennial forb whose populations have declined substantially in some parts of the world. In North America it is strongly associated with native prairies, a heavily degraded ecosystem.

Despite its sensitivity, *P. patens* can be found within the city of Saskatoon, Saskatchewan. The aim of this research is to map the distribution of *P. patens* within Saskatoon and its vicinity and to identify the ecological, physical, and demographical forces that shape its spatial configuration.

Nine potential areas were identified and surveyed. The locations of *P. patens* were mapped and their ecological and physical characteristics were recorded. Spatial data regarding historical and future development of the city was also gathered from several sources. All the collected data was integrated with other sources and analysed statistically in order to reveal trends in the distribution of *P. patens*. The analysis was divided in four parts: habitat preference, spatial relationship, disturbance and urban growth.

Differences with European studies regarding topographical preferences were revealed. Spatial considerations seem to explain the distribution of *P. patens* better than the type and degree of disturbances. Human population density and proportion of urbanized land were negatively correlated with *P. patens* population size and density. Exotic species seem to have a detrimental effect on *P. patens*, although this effect is species dependant and needs further research. Urban development is a key factor in shaping the distribution of this species, especially by the designation of conservation areas.

Keywords: Prairie crocus, species distribution, habitat preferences, urban ecology, Saskatoon

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Introduction

Pulsatilla patens (L.) Mill., commonly known as the prairie crocus or eastern pasqueflower, is a long-lived perennial herb from the family Ranunculaceae. As it will be detailed in the following chapters, this species is widely distributed in Eurasia and North America (Hultén and Fries 1986). It is an important species not only from an ecological perspective but also from a cultural point of view, being present in traditional medicine, folklore and symbols both in Europe and North America. *P. patens* is considered to be resistant to disturbances and can tolerate human influence to some extent. However, its conservation is of growing concern in some parts of the world, especially in Europe where the general population is declining (Bilz 2011). In Fennoscandia, *P. patens* is associated with dry heath forests dominated by pine (Uotila 1969, Pilt and Kukk 2002). Changes in forest management including the end of grazing and especially an improvement in the efficiency of fire prevention techniques, has resulted in a decrease of light availability and a lack of patches of open soil for the establishment of seedlings of *P. patens*. In Central Europe, loss of habitat has resulted in a drastic decrease in the number of populations. In Germany, for example, only one population is left (Röder and Kiehl 2006). This has led to the inclusion of this species in the Red List of practically every country in Europe where it occurs. It is therefore protected by national and European legislation including the Berne Convention and the EU Habitats Directive.

In North America, *P. patens* is relatively well represented in the United States and Canada and has limited legal protection in some of the states and provinces of these countries. Nevertheless, this plant is strongly associated with burned and grazed native prairies (Wildeman and Steeves 1982), which is one of the most endangered ecosystems of North America. For the whole continent, native mixed and short-grass prairies have declined to 20-30% of their original extension (Gauthier et al. 2003). The case of tall-grass prairie is perhaps the most dramatic example, reduced now to just 1% of its historic land cover (Samson and Knopf 1994). In Saskatchewan, Canada, where this research takes place, only between 17-21% of the prairie ecozone remains as native grassland, much of it fragmented into small patches (Hammermeister 2001). This is due to loss of habitat from urban development, agriculture and resource extraction; but also to the reduction in the frequency of fires and the absence of the huge herds of bison that once grazed on the prairies. Paradoxically, an excessive disturbance and the lack of it are critical threats for the survival of *P. patens*.

Urban areas have potential in the conservation of *P. patens*. While the proportion of urban land cover is still small in Canada, more than 80% of Canadians live in cities and this percentage is expected to continue growing (Statistics Canada 2012). Urban development has been acknowledged as a threat for *P. patens* (Uotila 1969). However, little is known about the mechanisms by which this happens. No study has ever considered how disturbances affect *P. patens*, either positively or negatively, in an urban setting. This knowledge will be crucial in order to consider any future plan to reintroduce *P. patens* in cities where it has disappeared or to integrate urban development with the conservation of this plant.

This thesis is structured in four chapters: literature review, methodology, results and discussion, and conclusions. Literature regarding *P. patens* is dispersed and sometimes not easily found. The taxonomic confusion regarding this species and the distribution of the plant across many countries, cultures and scientific traditions contributes to this. In addition, no review has ever been published for this species. In the following chapter, available literature regarding *P. patens* is thoroughly examined and reviewed covering taxonomy, ethnobotany, morphology, distribution, biology, management and conservation of this species.

The methodology section provides details of the methods used to assess the spatial distribution of *P. patens* within the City of Saskatoon, Saskatchewan, its habitat preferences and relation with disturbances. The results of fieldwork and analysis are detailed in the results and discussion section. The conclusion section provides a summary of the findings and main recommendations of this research.

Literature Review

A taxonomic nightmare

Scientific name

This species was first described by Linnaeus (Linnaeus 1753) as *Anemone patens L.* (Ranunculaceae) from a specimen collected in Tobolsk, Siberia, in the former Russian Empire (Figure 1). Later Miller (1768) classified the species under the genus *Pulsatilla* expressly distinguishing it from the genus *Anemone*. European botanical literature is relatively consistent in the use of the name *P. patens*. Exceptions would be the use of such names as *wolfgangiana*, *latifolia* and *intermedia*.

Figure 1. Specimen of *Anemone patens* L. from Linnaeus herbarium (www.linnaean-online.org).

Besser (1826) classified and illustrated a specimen of this plant from Lithuania under the name *A. wofgangiana* Besser. In the same work Besser also considered *P. wolfgangiana* as a potential synonym of *A. patens*. Later, Ruprecht (1854) supported Miller's treatment of this plant under the genus *Pulsatilla* and reported populations of *P. wolfgangiana* from the area of Narva, Estonia. In the same work, this author mentioned the presence of *P. latifolia* Rupr. applied to specimens of *P. halleri* (All.) Willd. subsp. *rhodopaea*, as it is currently known. Notwithstanding the original use, later authors have referred to *P. paten*s using the name *P. latifolia*, as reported by Tutin and Akeroyd (1993). For this reason, *P. latifolia* is included in this taxonomic review as an illegitimate synonym. Although the name *latifolia* did not become widespread, *wolfgangiana* was for many years a common synonym to designate*P. paten*s , especially as a variety rather than as a species itself. This was due to the job of Trautvetter and Meyer (1856) who, almost contemporarily to Ruprecht (1854), classified the Siberian populations as *P. patens* var. *wolfgangiana*. This denomination is still considered as a valid synonym (Dutton *et al.* 1997).

Other denominations for European populations, which were rarely mentioned in later studies, include *P. longipetala* Schleich. ex Steud. and *P. intermedia* G. Don. Don (1831) already noticed that *P. intermedia* could be just a variety of *P. patens*. The names *P. ovczinnikovii* Maximova and especially *P. kiovensis* Wissjul. are not infrequent in the Slavic botanic tradition but rarely used in Western publications. The name *teklae* have been used both at species level, as *P. teklae* Zämels (1925), and subspecies level *P. patens* subsp. *teklae* (Zämels) Zämels (Tutin *et al.* 1964). Both *P. teklae* and *P. patens* subsp. *teklae* are currently considered to be synonyms of *P. patens* subsp. *patens* (Tutin and Akeroyd 1993). On the Far East, *A. taroi* Takeda was used as a synonym for *A. patens* (Takeda 1910).

The efforts to prepare treatment of these taxa for the North American flora resulted in numerous denominations and synonyms including new species and varieties. Table 1 summarizes all the historical nomenclature applied to *P. patens* both in American as well as European and Asian literature. The first description of this plant in the New World was surprisingly attested to the genus *Clematis* (Pursh 1814). Later, Nutall (1818) transferred it to the genus *Anemone* as *A. ludoviciana*. During the XIX century this species was classified under several denominations, mostly as a new taxon within *Anemone* or *Pulsatilla* genera (Table 1). During the second half of the century, some botanists noticed the similarity of the taxa described in North America with the Old World *P. patens* and classified them as its varieties; e.g. *Anemone patens* (L.) var. *nuttalliana* (DC) (Gray 1867) or *Anemone patens* L. var. *hirsutissima (*Pursh) (Hitchcock 1891). This treatment took more weight during the XX century, and after the works of Hultén (1944) there was little doubt about the Old World and New World taxa being the same species. Some of the nomenclature developed during the 1800s is now considered illegitimate or superfluous such as *P. hirsutissima* (Pursh) Britton and *P. ludoviciana* (Nuttall) A. Heller (Dutton *et al.* 1997).

Table 1. Published nomenclature of Pulsatilla patens.

Taxa	Author	Link to original source
Eurasia		
Anemone patens L.	Linnaeus 1753	Link
Pulsatilla patens (L.) Mill.	Miller 1768	Link
Pulsatilla longipetala Schleich. ex Steud.	Steudel 1821	Link
Anemone wolfgangiana Besser	Besser 1826	Link
Anemone intermedia G.Don	Don 1831	Link
Pulsatilla wolfgangiana (Besser) Ruprecht	Ruprecht 1854	Link
Pulsatilla latifolia Ruprecht	Ruprecht 1854	Link
Pulsatilla patens var. *wolfgangiana* (Besser) Trautv. & C.A. Mey	Trautvetter and Meyer 1856	Link
Anemone taroi Takeda	Takeda 1910	Link
Pulsatilla teklae	Zämels 1925	Link
Pulsatilla kioviensis Wissjul.	Wissjulina 1939	Cited by Czerepanov (1995) Link
Pulsatilla patens (L.) Mill. var. *kioviensis* (Wissjul.) Tzvelev	Tzvelev 2001	International Plant Name Index webpage
Pulsatilla ovczinnikovii Maximova	Maximova 1970	Cited by Czerepanov (1995). Classified as "unresolved" by the WCSP (2012): Link
North America		
Clematis hirsutissima Pursh	Pursh 1814	Link
Anemone nuttalliana DC.	de Candole 1817	Link
Anemone ludoviciana Nuttall	Nuttall 1818	Link
Pulsatilla nuttalliana (DC) Sprengel	Sprengel 1825	Link
Anemone nuttallii (DC) Nuttall ?	Nuttall 1825	Link
Anemone patens L. var. nuttalliana (DC) Gray	Gray 1867	Link
Anemone patens L. var. *rosea* Cockerell	Cockerell 1888	Link
Anemone patens L. var. hirsutissima (Pursh) Hitchcock	Hitchcock 1891	Link
Pulsatilla hirsutissima (Pursh) Britton	Britton 1891	Link
Anemone hirsutissima (Pursh) MacMillan	MacMillan 1892	Link
Pulsatilla ludoviciana (Nuttall) Heller	Heller 1900	Link
Viorna hirsutissima (Pursh) A. Heller	Heller 1904	Link
Anemone patens var. wolfgangiana (Besser) Koch	Johann F.W. Koch	Cited by Dutton *et al*. 1997
Pulsatilla patens (L.) Miller subsp. *asiatica*	Krylov and	Cited by Dutton *et al*. 1997

Krylov & Serg	Sergievskaja	

In current taxonomic treatments, all major botanical literature and compilations covering the range of *P. patens* [i.e. Flora of Europe (Tutin and Akeroyd 1993), Flora of North America (Dutton *et al*. 1997) and Flora of China (Wencai and Bartholomew 2001)] agree on the classification of the North American populations within the subspecies *multifida*. However, there is a major difference between these botanic traditions. While Flora of Europe, Flora of China and the vast majority of authors include the species under the genus *Pulsatilla*, Flora of North America and many American authors prefer to include it under the genus *Anemone*. The same approach is taken by most of Canadian authors (Table 2). Some of the oldest works refer to it as var. *wolfgangiana* but in recent times most Canadian authors classify this plant as either a variety or subspecies of *multifida* within the taxon *A. patens*. A notable exception is Harms (2006) who preferred to include this plant under the genus *Pulsatilla*.

Table 2. Primary scientific names for P. patens from Canadian authors.

Author	***A. patens* (L.) Mill. var. *multifida* Pritz.**	***P. patens* (L.) P.Mill. subsp. *multifida* (Pritz.) Zamels**	***A. patens* L.**	***A. patens* L. var. *wolfgangiana* (Bess.) Koch**
Currah *et al*. 1983				X
Budd and Best 1969				X
Scoggan 1978			X	
Aiken *et al*. 2007	X			
Harms 2006		X		
Moss 1983			X	
Meades 2004	X			

According to Flora of North America (Dutton et al. 1997), the reason to include this taxon under the genus *Pulsatilla* is purely morphological, based on the presence of long plumose achene beaks. These authors argue that genera *Pulsatilla* and *Hepatica* should be subsumed under *Anemone* according to phylogenetic analyses based on morphology and chloroplast DNA (Hoot et al. 1994). More recent molecular studies also point in this direction (Ehrendorfer and Samuel 2001). On the other hand, other authors consider the mentioned phylogenetic studies to be too limited with an underrepresented number of taxa being considered (Yaprak et al. 2011). They argue that, in contrast, morphological differences are clear, well known and based on a long botanical tradition, justifying this way their choice for the genus *Pulsatilla*. In any case, it should be noted that the discussion turns around the genus level and there is an international consensus about the distinctiveness of both the species and the subspecies.

Given these arguments, it is understood in this thesis that the choice of any of the two genera (*Anemone* or *Pulsatilla*) count as perfectly sound justifications. Therefore, both options are considered as legitimate here. However, the genus *Pulsatilla* is significantly smaller and more restricted in morphological features than *Anemone*. This fact makes the use of the genus *Pulsatilla* simpler and more effective in order to compare different species within the genus or make generalizations. Therefore, in order to maintain simplicity and consistency this thesis considers *P. patens* subsp. *multifida* as the priority name for the study.

Intraspecific structure

According to Tutin and Akeroyd (1993), *A. patens* includes three subspecies: subsp. *patens*, subsp. *multifida* and subsp. *flavescence*. The main morphological differences between these subspecies are outlined in the morphology section. Their spatial range is detailed in the distribution section.

Pritzel (1841) coined the name *multifida* for the first time, using it to designate a variety of *A. patens* in the Siberian populations. At the beginning of the XX century, Zämels (1926) used the name *multifida* as a subspecies of *P. patens*. Juzepczuk (1937) in Flora of the USSR went beyond and considered *multifida* as a separate species. According to this author, *P. multifida* could be distinguished from *P. patens* by the strongly dissected leaf blades, narrower leaf segments and a distinct petiole. However, this view was criticized by other authors that could not see a real difference between the Siberian and the North American populations and should therefore be referred to as the same subspecies (Hultén 1944). It has been suggested that the observed differences were the consequences of differentiating geographic races (subspecies) within a continuous range of *P. patens* across the northern hemisphere (Hultén and Fries 1986; Lindell in Jonsell 2001). This taxon was also classified as *P. patens* (L.) Mill. var. *multifida* (Pritz.*)* S.H. Li & Y.H. Huang in Flora of China (Li and Huang 1975).

Albino individuals have been described for this plant as f. *stevensonis* (Boivin 1968). This form is characterized by white or very pale flowers and has been recorded in Manitoba (Boivin 1968) and Saskatchewan (Kricsfalusy et al. 2012). The holotype of this form is deposited in the AAFC National Collection of Vascular Plants (Cody 2012) and the specimen was collected in 1960 near Brandon, Manitoba by G.A. Stevenson, hence the name.

Common name

The etymology of *Pulsatilla* is closely related to the folklore of the people coexisting with this plant. In ancient Greece, the flowers of *Pulsatilla* were believed to be sent by Anemos, god of the winds, as heralds of his coming at the beginning of the spring, hence the name of *Anemone*. According to Shosteck (1974) the name *Anemone* would refer to the windswept habitat of the plant. The name *Pulsatilla* derives from the Latin word *pulsatus* ("to beat") as the flowers of this plant pulsate with the wind. The Latin term *patens* means open or spreading, in a reference to sepals of the flower which spread backward.

The common name, pasque flower (or pasqueflower), is believed to derive from the Latin name *pascha* meaning Easter, which in turn derives from Hebrew *pesah*, "to pass-over", probably because of the flowers of this plant appearing close Easter time. Parts of this plant were also used to dye Easter eggs green (Walker 2011). The original French name for this plant was *passefleur*, being altered by Gerard to its present name. The name pasque flower is also used to identify *P. vulgaris* (Walker 2001). In order to differentiate these two species, *P. patens* is frequently called "Eastern pasque flower" in reference to its European distribution. The common name of this species in most Slavic languages is *son-trava*, which means "dream herb". When placed under the pillow, it will induce dreams, which are generally supposed to be fulfilled (Thiselton-Dyer 2011).

Another major common name, prairie crocus, was given by the settlers that colonized the American prairies as it reminded them of the real crocuses, which belong to the genus *Crocus* (Iridaceae), back home. In the same way, the common name "crocus anemone" refers to the similarity of the plant to these two genera. *P. patens* is also known as prairie smoke, cutleaf anemone, windflower and gosling plant. The Blackfoot called this flower *Napi* ("old man"), as the grey, silky achene of the seeds of prairie crocus reminded them of the grey hair of an old person (Johnston 1987).

Ethnobotany

Medicinal value

Plants from the genus *Pulsatilla* have been used for millennia for medicinal purposes. Roman physician Dioscorides (40 to 90 A.D.) was known to have used *Pulsatilla* on his preparations for eye treatments (Fetrow and Avila, 2000). The medicinal use of *Pulsatilla* is closely related to its toxicology. Many species from the family Ranunculaceae (including *P. patens*) create a highly irritant oil called protoanemonin, which is the product of a enzymatic breakdown of the glycoside ranunculin. The chemistry and concentration of protoanemonin varies between species and between dry or fresh tissue. This substance can cause skin, eye and gastrointestinal irritation to humans and even be fatal to grazing animals (Turner and von Aderkas 2009).

Being a widespread plant across North America, *P. patens* has been used by many native tribes for several illnesses. Table 3 summarizes the use of this plant by native people.

Table 3. Medicinal use of P. patens by Native American tribes.

Tribe	Function	Notes
Cheyenne	Poison / Stimulant	Symbolic use of smashed root by passing over the body to revive a person.
Chippewa	Analgesic	Headache treated by smelling pulverized leaves.
	Pulmonary aid	Root decoction / Smelled once dried and pulverized.
Great Basin Indian	Anti-rheumatic	Poultice of fresh leaves.
Omaha	Anti-rheumatic / anti-neuralgic	External application of leaves
Sources: Moerman (2009), Densmore (1974) and Vogel (1970).		

P. patens is known to be used by the first nations in Saskatchewan, Canada. Blackfoot applied a poultice of crushed leaves typically as a counterirritant. They also use this plant to speed birth delivery by taking a decoction of the plant (Howarth and Keane 1995; Moerman 2009). There is no evidence of other native tribes such as Cree using this plant for medicinal purposes. In a study about wild plant use by the Woods Cree, none of the respondents acknowledge any use of the prairie crocus (Leighton 1985).

Cultural value

The Prairie crocus has an important symbolic and cultural value among Slavic people. As its name “dream-herb” indicates, this plant is deeply connected with the sleepy kingdom in the folklore of Eastern Europe. The prairie crocus was believed to have prophetic powers and could reveal secrets and future predictions through dreams. Tales of the realm of dreams, mainly express the idea of the winter sleep of nature and vernal awakening (Sobolev 1999).

This species is also present in popular music. Songs about the prairie crocus are part of the Soviet music legacy becoming even unofficial anthems for the people. In Canada, there is a musical band from Manitoba called Prairie Crocus that plays traditional Ukrainian music.

The prairie crocus also has an important symbolic value among North American peoples. As in ancient Greece, this plant is also a herald of the arriving spring. In an old Dakota song, recorded and translated by Gilmore (1921), the prairie crocus asks the rest of flowers to wake up from their winter dream:

"I wish to encourage the children of other flower nations

Which are now appearing all over the land;

So while they waken from sleep and rise from the bosom

Of Mother Earth, I stand here old and grey-headed."

This song refers to the early flowering habit of *P. patens* and the aforementioned parallelism between the grey seeds of the plant and the head of an old man. There is also a nice Blackfoot legend about the relation between a boy on his adulthood initiation experience and the prairie crocus. It explains how the boy cared for the plant on the loneliness of the hill and how the plant offered him advice and wisdom in return. The Indian boy prayed for the plant and the Great Spirit and pleased with what happened, rewarded the flower with purple petals, like the distant sky, a bright yellow sun in the middle and a fur coat to be protected during early spring (Brown 1954).

The prairie crocus is also present in more "formal" symbology. It is the official plant of the province of Manitoba, Canada and the state of South Dakota, USA. It also appears on the Coat of Arms of the province of Manitoba and the city of Winnipeg (Figure 2).

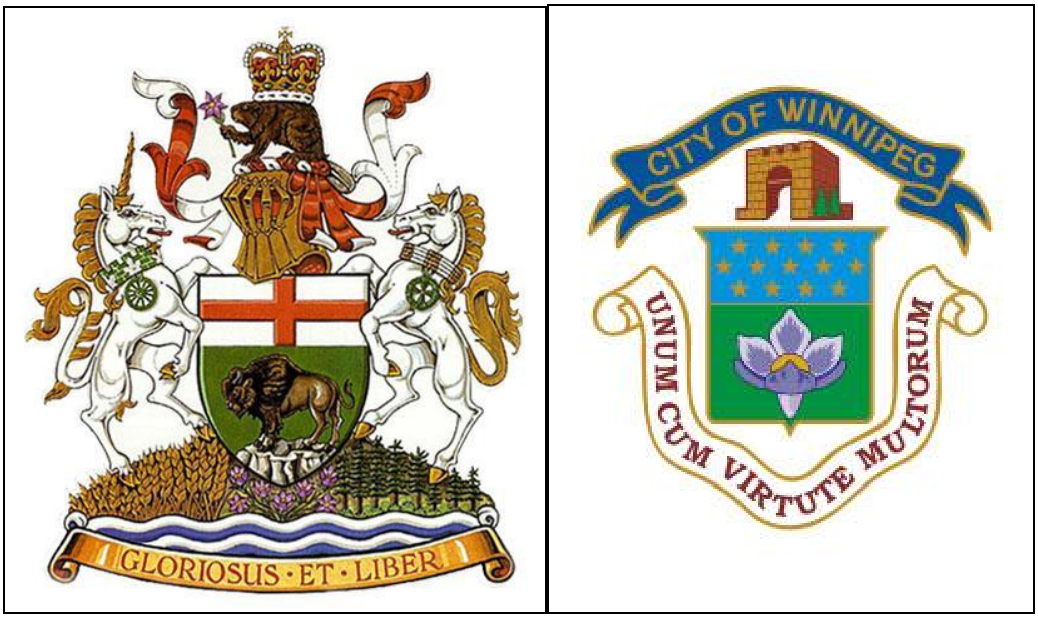

Figure 2. The Coat of Arms of Manitoba (left) and Winnipeg (right). Note a group of purple prairie crocuses right under the seal in Manitoba's emblem (source: www.travelmanitoba.com).

In Manitoba, the prairie crocus was officially adopted as the official flower in 1906. Interest had first been aroused by the Manitoba Horticultural Society. A subsequent vote among schoolchildren put the crocus in first place, the prairie lily second and the wild rose third. As the province emblem, the crocus' name and likeness are common place on government publications and even in the private sector. Also, the Prairie Crocus Award is presented by Nature Manitoba "for outstanding service in preserving a part of Manitoba in its natural state." (Nature Manitoba 2012). The image of the prairie crocus has also been profusely used in collectable items including stamps of many countries and the world's purest gold coin (Royal Canadian Mint 2010).

Morphology

The morphological description of *P. patens* has been elaborated from published literature using Flora of North America (Dutton et al. 1997) as a primary source. Flora Europaea (Tutin and Akeroyd 1993) and Flora of the Canadian Arctic Archipelago (Aiken *et al.* 2007) have also been consulted for this purpose.

Habit: Perennial herb, silky-villose throughout, with erect (or spreading) aerial shoots 5-40(-60) cm tall and 5-10 mm wide, growing from many-headed vertical caudices. Only fibrous roots present.

Basal leaves: Basal or basal in a rosette (3-)5-8(-10), erect , alternate, with three folioles, each leaflet dissected dichotomously. Stipules absent. Petiole present 5-10(-13) cm with hairs longer than the diameter of the petiole. Petiolulate to nearly sessile terminal leaflet, obovate in outline, (2.5-)3-5 cm. Folioles spreading, straight, veins palmate. Margins dichotomously dissected throughout, apex acute to obtuse; lateral leaflets 3-4-parted (±dichotomously); ultimate segments 2-4 mm wide. Base narrowly cuneate. Villous surface, hairs white or translucent, simple or stellate, straight, spreading or erect; moderately dense on the abaxial surface, sparse on the adaxial surface.

Inflorescences: Flowering stems clearly taller than the leaves; with leaves. Solitary flowers with a villous or glabrate peduncle; involucral bracts present 3, 1-tiered, simple, different to basal leaves, (2-)2.5-4 cm, bases clasping, connate, margins deeply laciniate throughout; segments usually 4-6, filiform to linear, unlobed, 1-2(-3) mm wide. Villous surfaces, rarely glabrous.

Flowers: Large flowers, 5.5-8.5 cm in diameter, campanulate. Epycalix absent. Conventional sepals, 5-8, free, oblong to elliptic, coloured in blue, purple or rarely near white. Villous on the abaxial surface, glabrous on the adaxial one. Petals present. Stamens 150-200. Stamen filament glabrous. Anthers yellow; long-cylindrical; (0.8-)1.1-1.3(-1.8) mm long. Nectaries present. Ovary carpels 30-45; apocarpous. Densely hairy ovaries. One stigma per ovary, one ovule per ovary.

Fruits: Heads of achenes spheric to ovoid; pedicel 10-18(-22) cm. Achenes: body ellipsoid to obovoid, 3-4(-6) × ca. 1 mm; dry, brown, not winged, villous; beak curved, 20-40 mm, long-villous, plumose, indehiscent. One seed per achene. Styles modified and persisting in fruit; remaining straight.

Subspecies *multifida* differs primarily from ssp. *flavescens* on the colour of the flowers, yellow to yellow-white on the latter. Subspecies *patens* presents fewer and bigger leave lobes than *multifida*.

Chromosome numbers: The chromosome base-number of the genus *Pulsatilla* is 8 (Walker 2011). Aiken *et al*. (2007) listed a number of studies identifying *P. patens* subsp. *multifida* as diploid (2n (2x) = 16) both in Asia and North America. However, an early study by Löve (1954) identified North American populations of this taxon to be tetraploid (2n (4x) = 32) in contrast to diploid European populations (Agapova et al. 1993). Especially relevant to this study are the chromosome counts made by Taylor and Brockman (1966) with a specimen collected near Bellevue, Alberta; and by Löve and Löve (1982) near Pine Ridge, Manitoba identified as diploid (2n (2x) = 16).

Distribution

Eurasia

P. patens has a wide distribution in high latitudes of Eurasia and North America (Hultén and Fries 1986). It ranges from Eastern Europe to North America, passing through Central Asia and the Far East (Figure 3). Within Western and Central Europe, *P. patens* can be found in Poland, Czech Republic and Romania (EUNIS 2012). Germany counts just one population (Röder and Kiehl 2006). Slovakia has ten populations of *P. patens*, nine of them on higher altitudes (EIONET 2012). In Hungary, most of populations disappeared decades ago, currently existing less than 10 flowering individuals in just one locality (Bilz 2011). *P. patens* also occurs in Northern Europe, particularly in Estonia, Finland, Latvia, Lithuania and Sweden (EIONET 2012).

Within Eastern Europe, *P. patens* occurs frequently in Ukraine, Belarus and the European part of Russia (Juzepczuk 1937). The Asian part of the species range includes Russia, Kazakhstan, Mongolia and China (Juzepczuk 1937; Wencai and Bartholomew 2001). The three subspecies differ in their range. Subsp. *patens* is mainly located in Eastern Europe and Central Asia while subsp. *multifida* occurs in Central Asia, the far East and North America, not being present East of the river Volga. Subsp. *flavescens* occurs in Eastern Russia.

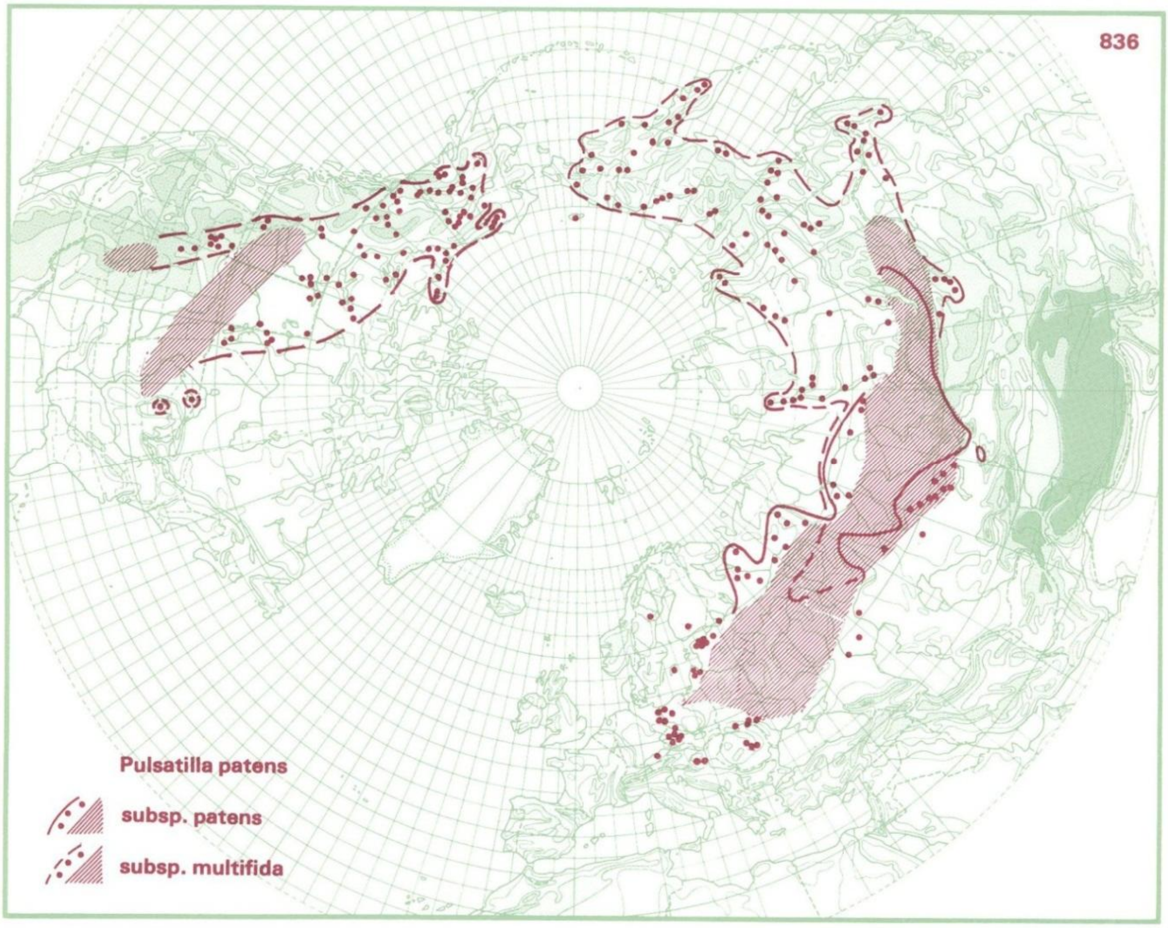

Figure 3. Distribution of *P. patens* across the northern hemisphere (after Hultén and Fries 1986).

North America

Only the subspecies *multifida* can be found on the American continent (Dutton *et al.* 1997; Hultén and Fries 1986; USDA 2012). *P. patens* has a wide distribution in North America, from Alaska to Southern United States, covering a wide range of climatic and habitat conditions (Figure 4). Given the strong association between *P. patens* and native grassland, the distribution of this species on the United States overlaps significantly with the Great Plains, being especially common in the Northern Centre of the country (Montana, Wyoming, North Dakota and South Dakota). Although less common, *P. patens* can also be found in southern locations

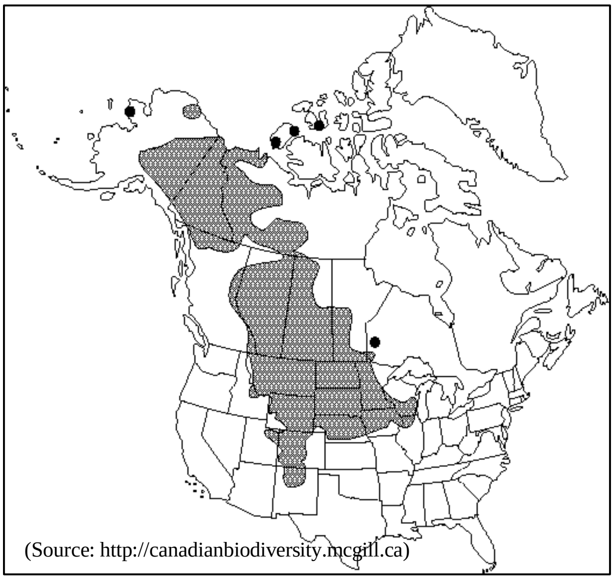

Figure 4. Distribution of *P. patens* in North America. Some isolated populations are known to occur outside this range.

such as the states of Nebraska, Colorado, New Mexico and Texas.

The Rocky Mountains are the western boundary of the distribution of *P. patens* in mainland USA. It is relatively abundant in eastern Idaho and Utah but very rare in western locations. It extends east to Lake Michigan covering the states of Minnesota, Iowa, Wisconsin and Illinois. Given the boreal character of *P. patens,* it is also very common in Alaska. Other states where isolated populations of *P. patens* can be found are Kansas, Michigan and Washington (USDA 2012).

Canada

P. patens is common and widespread across the prairie provinces of Winnipeg (VASCAN 2012), Saskatchewan (Harms 2006) and Alberta (Moss 1983). The Rocky Mountains also act as a barrier in Canada so, within the province of British Columbia, *P. patens* is only widespread in northern and eastern extremes (Klinkenberg 2012). It is also relatively common in Yukon (Cody 1996) and in the Northwest Territories, both continental and islands (Aiken *et al.* 2007). *P. patens* is also present in Nunavut, although it should be noted that there is only one population recorded within the limits of its territory, located specifically to the south east of Victoria Island (Aiken et al. 2007). A similar situation occurs in Ontario, with just one herbarium record of *P. patens* from 1998, collected from a single population near Lake of the Woods, very close to the border with Winnipeg (Meades *et al.* 2004). According to the data from Natural Heritage Information Centre (NHIC 2009) there are two registered element occurrences (locations) of *P. patens* in Ontario.

Saskatchewan

In Saskatchewan, Kricsfalusy et al. (2012) compiled 154 historical records of *P. patens* within the province from F.W. Fraser Herbarium (SASK) in the University of Saskatchewan (Appendix 1). Populations are distributed across the province being more numerous within the southern half. The ecoregions with the higher number of records are Mixed Grassland, Moist Mixed Grassland, and Aspen Parkland. These ecoregions are the main representatives of prairie habitat in Saskatchewan. The first two are classic grassland habitats while aspen parkland works as a transition habitat between the prairies and the boreal plain. The distribution of herbaria records of *P. patens* is not surprising given the preference of this species for prairie native habitat, common in the southern part of the province. It is an interesting fact that no specimens have been recorded in northeast Saskatchewan. There are records in the northwest, indicating that latitude is not a limiting factor. This absence of records may be due to a less intensive botanic survey activity in northern latitudes, rather than to the absence of the species. Herbarium data were complemented with the field survey of *P. patens* populations in Saskatoon and vicinity.

Habitat

In Northern Europe, *P. patens* occur in dry coniferous forests dominated by *Pinus sylvestris*. It also occurs in taiga woodland dominated by *Picea*. and is especially common on the forest fringes and clearances. Bare pavements, steep slopes and sandstone rocks also host populations of this species (Bilz 2011). In central and eastern Europe, *P. patens* is also associated with dry grasslands and steppes (Röder and Kiehl 2006; Bilz 2011). In North America, this species is a clear prairie species, occurring mainly in disturbed prairies (Wildeman and Steeves 1982). Although common in all types of prairies it seems to be especially linked with fescue prairie (Thorpe 2007).

According to Uotila (1969) half of the studied Finnish locations of *P. patens* were located on gentle slopes, mainly facing South, West or Southwest. Although less common, several populations were also found on level ground. Populations on moderate and steep slopes were infrequent. This author justifies the affinity of *P. patens* for sunny slopes based on their characteristic microclimate. Sunny slopes offer a more thermally continental microclimate than level ground, resulting in higher temperature fluctuations between day and night and between seasons, as well as earlier snow melting in the spring compared to northern facing slopes. These conditions resemble the prevailing climate conditions of the main area of distribution of *P. patens* (i.e. Russian steppes or North American prairies). As a result of this, vegetation on sunny slopes tends to show more seasonal characteristics. These climatic conditions reduce the presence of competitors of *P. patens*, increasing the availability of some resources, especially light. On the other hand, it exposes individuals to a difficult living environment with extreme variations in diurnal temperatures and frequent drought. These conditions are particularly challenging for newly emerged seedlings (Kalliovirta et al. 2006). There are no studies regarding aspect preferences in North America but preliminary observations in the field suggest it may differ from the results in Europe.

Regarding soil preferences, *P. patens* covers a wide range although it tends to grow on dry soils without signs of gleization. Pilt and Kukk (2002) analyzed the soils of several Estonian populations and recorded rendzinas, podzols, brown forest soils, sands and gravels. Other authors have also stated the preference of this plant for well drained soils (Porsild and Cody 1980, Cody 1996).

Conservation Status

On a global scale, *P. patens* is considered to be a common, abundant and secure species (NatureServe 2012) and has not been included in the IUCN Red List. However, over recent decades a decline on the abundance of this species has been observed across Europe (Pilt and Kukk 2002). The reasons behind this decline are detailed in the section Threats and Conservation. *P. patens* has been awarded international protection by its inclusion in Annex I of the Convention on the Conservation of European Wildlife and Natural Habitats known as Berne Convention (Council of Europe 1979) and in Annex II of the European Habitats Directive (European Communities 1992). It is included in the European Red List of vascular plants as “Data deficient” (Bilz 2011). Although the authors of the European Red List recognize that populations of *P. patens* are declining across the whole continent, this species was classified under the category of “Data deficient” given the lack of information about the population size and trend in some of the countries. *P. patens* is also included in most of national Red Lists where this plant is present. Table 4 summarizes the national conservation status for *P. patens*.

Although a signatory of the Berne Convention, Romania is the only European country within the distribution range of *P. patens* that has not included it in any of its Red Lists, as it is not considered threatened there (Witkowski *et al.* 2003). Also, *P. patens* is not included in the Red Data Book of the Russian Federation (Iliashenko and Iliashenko 2000), however species is listed in the Red Lists of Kaliningrad and St.Petersburg region/oblast located in the European part of the country (Pilt and Kukk 2002).

Table 4. Conservation status of *P. patens* in European countries

Country/Region	Status	Source
Estonia	Care demanding	Lilleleht 1998
Finland	Care demanding	Pilt and Kukk 2002
Germany	Critically endangered	Ludwig and Schnittler 1996
Hungary	Critically endangered	Király et al. 2007
Latvia	Data deficient	Priede and Klavina 2011
Lithuania	Vulnerable	Pilt and Kukk 2002
Poland	Critically endangered	Juśkiewicz-Swaczyna 2010
Slovakia	Endangered	Witkowski et al. 2003
Sweden	Near Threatened	Aronsson et al. 2010
Ukraine	Data deficient	Kagalo et al. 2009

According to national self-evaluations compiled as part of the Habitats Directive - Article 17 reporting process, for the period 2001-2006, most participant countries (CZ, DE, EE, FI, HU, LT, LV, PL, SE, SK) reported conservation efforts for *P. patens* to be “inadequate” (category U1) or “inadequate and deteriorating” (U1-). Exceptions were Hungary, with an overall assessment of “bad” (U2) and Germany, which is the only positive remark (Good - FV). Slovakia scored “good” for its only Pannonian (lowland) population but “inadequate” for the alpine ones. Although conservation measures were considered as inadequate in Latvia and Estonia, future prospects are good for the populations of *P. patens* in these countries and Germany. Poland, The Czech Republic, and Sweden reported poor prospects, while Hungary is even more pessimistic stating bad future prospects for this species. Slovakia, Latvia and Finland either did not report publicly or offered contradictory or incomplete assessments (EIONET 2012).

P. patens ssp. *multifida* is considered to be apparently secure (N4) at a national level for the whole United States and is not included under the US Endangered Species Act (NatureServe 2012). However, its conservation status has been reviewed and ranked in the following states: Wyoming (apparently secure – S4), Montana (apparently secure – S4), Utah (critically imperilled – S1), Illinois (critically imperilled – S1), Iowa (apparently secure – S4) and Kansas (possibly extirpated – SH) (NatureServe 2012).

In Canada *P. patens* is classified as apparently secure (N4) at a national level (NatureServe 2012). It is not protected under the Species at Risk Act (SARA 2002) and is not included on the Canadian Wildlife Species at Risk list (COSEWIC 2011). Conservation status of *P. patens* varies between provinces (Table 5) but in general this species is considered to be secure, except in Nunavut and Ontario (CESCC 2006; NatureServe 2012) due to its very limited presence.

Table 5. Conservation status of *P. patens* in the Canadian provinces and territories.

Province/Territory	Status by CESCC 2006	Status by NatureServe 2012
Yukon	Secure	Not ranked/Under review
Northwest Territories	Secure	Not ranked/Under review
Nunavut	May be at risk	Not ranked/Under review
British Columbia	Secure	Secure (S5)
Alberta	Secure	Secure (S5)
Saskatchewan	Secure	Secure (S5)
Manitoba	Secure	Not ranked/Under review
Ontario*	May be at risk	Critically imperilled (S1)
Quebec	Not present	Not ranked/Under review
New Brunswick	Not present	Not ranked/Under review
Nova Scotia	Not present	Not ranked/Under review
Prince Edward	Not present	Not ranked/Under review
Newfoundland and Labrador	Not present	Not ranked/Under review

* *P. patens* is included on the Rare Vascular Plants of Ontario (Oldham and Brinker 2009).

There was a time when *P. patens* was present everywhere in the prairies. In Manitoba, the official emblem carries with it no protection status. The only plants having official protection in Manitoba are those listed under the Endangered Species Act. Ironically, this means that in order to be protected, the *P. patens*, or any other plant, must be near extinction (Caryopsis 2011). A similar situation happens in Saskatchewan. Due to cultivation of native prairies, *P. patens* is now relatively uncommon in the Regina area (Royal Saskatchewan Museum 2012) as well as in the Saskatoon area (Kricsfalusy et al. in press).

Management implications

As aforementioned, *P. patens* is a long-lived perennial herb with limited dispersive capacity (Pilt and Kukk 2002). Its long-term strategy is based on individual survival rather than long range dispersion and colonization of new areas. This makes *P. patens* a poor competitor unable to thrive in ungrazed, overgrown areas. A high density of tall grasses, forbs or shrubs and large amounts of litter will inhibit regeneration of *P. patens* due to a heavy competition for light. On the other hand, the detailed adaptations for variable and harsh conditions (protective structures, development of dormant buds, regeneration capacity, etc.) provide this plant with a series of mechanisms for coping with mild disturbances that would potentially enable *P. patens* to outcompete other species. Therefore, management practices able to reduce litter, control coarse grasses and open small patches of bare soil for seed germination will favour populations of *P. patens*.

Grazing is one of the management practices that have traditionally encouraged the development of *P. patens*. In Fennoscandia, cattle grazing of forests was a common management practice. This kept vegetation open and prevented litter to build up, creating gaps in the soil for seeds to germinate (Kalliovirta et al. 2006). In North American prairies, *P. patens* has been reported to flourish in overgrazed areas as it is not being heavily relished by livestock (Wildeman and Steeves 1982). It seems however that some animals actually feed on this plant. Yagovkina (2010) described how a high proportion of flowers of *P. patens* showed evidences of grazing, probably by moose. Other parts of the plant showed no animal damage as they are too unpalatable and toxic given the high concentration of the glycoside ranunculin and associated alkaloids. Similar observations were made by the author of this thesis. During fieldwork numerous grazed flower stalks were found in areas with signs of grazing damage and herbivore presence (Appenix D). Deer were spotted in one of these areas. Given that *P. patens* is one of the first plants to flower after the winter and considering the low food availability in early spring, it seems logical that this plant will be targeted by herbivores in spite of its poor palatability.

Direct human mechanical intervention may also reduce competition and avoid litter accumulation. In Estonia, where *P. patens* is largely associated with forests, forestry techniques such as selective logging, forest clearance and scrub removal may facilitate regeneration from seeds (Pilt and Kukk 2002). In areas of the world where *P. patens* occurs mainly in grassland vegetation, moderate mowing has been reported as an important beneficial factor (Röder and Kiehl 2006; Wildeman and Steeves 1982). Mowing has been used in Germany in order to maintain the last population in the country with some success. However grazing is preferred, as this practice is more effective at creating patches of bare soil through trampling and enhances zoochory (Röder and Kiehl 2006). Light trampling is not considered to be a threat to this plant (Uotila 1969).

Fire as a management practice affecting *P. patens* is frequently mentioned in literature (citas aqui). Although there is no evidence supporting that *P. patens* is strictly fire-dependant, it is known for this species to survive extensive fires of different nature (Uotila 1969, Rowe 1969). In Fennoscandia and the Baltic region, forest fires play a key role in the survival of the species, especially in the germination and recruitment of new seedlings. The reasons for that are several. As already described, *P. patens* have a preference for areas with a disturbed moss and litter layer due probably to their difficulty to germinate in densely covered areas (Uotila 1969, Juśkiewicz-Swaczyna 2010, Kalliovirta et al. 2006). Fire has the potential to destroy the moss layer and reduce litter but without destroying the deep-penetrating roots and the vegetative buds, allowing for the regeneration of the plant (Wildeman and Steeves 1982). Fire also increases the penetration of light to the forest ground. Kalamees et al. (2005) provided experimental evidence of improvement in seed germination and early survival for *P. patens* after a forest fire. These results were acknowledged to the disturbance of the moss and litter layer. Changes in light conditions were not considered to be a relevant factor. The authors also discuss the possibility of changes in soil chemistry due to the addition of charcoal after fire. Charcoal can mitigate the effect of phenolic acids, abundant in forest soil, and detrimental to some herbaceous species. In order to test this hypothesis, Kalamees et al. (2012) conducted a pot experiment including the addition of polyphenol rich ericoid litter and charcoal. Contrary to the hypothesis, growth was more vigorous than control with the addition of ericoid soil. This suggested that allelopathic effects of ericoid species on *P. patens* are minimal. However, when forest litter and charcoal were both added to the soil, plant growth was most intense. The study also revealed an adaptive anticipating behaviour in shoot/root allocation by *P. patens* according to the intensity of the fire. These results indicated a strong adaptation by this plant to forest fires.

In North America, grassland fires are considered to be an essential part of the natural cycle of the prairies and the used of prescribed burning for conservation of the prairie habitat and their biodiversity is gaining more supporters (Romo 2003; 2007). Regarding *P. patens*, fire is a mild disturbance that prevents the built up of litter, remove competitors and allows access to light and other resources (Wildeman and Steeves 1982). In Saskatchewan grasslands, *P. patens* was reported to be one of the first species to flower in spring after a late summer fire without showing signs of stress (Rowe 1969). Henderson (1990) conducted a burning experiment in grassland containing populations of *P. patens* at different flowering stages. He concluded that the earlier the burn, the greater the flower bud survival. In any case, the area burned consistently at the flowering peak still had 15-20% flower bud survival rate. This is probably due to the regeneration from dormant buds, evidencing a high adaptation to regular fire conditions.

Although in the case of grasslands phenolic acids are not very relevant, other changes in soil chemistry occur as a result of fire. Fire is known to increase the concentration of P in soil for grasslands. Picone et al. (2003) observed that plant available P increased in 10 ppm immediately after burning due to ash deposition. Mineral N also increased while organic C and N decreased due to volatilization. Jariel et al. (2004) recorded a similar increase in P (8 ppm) but noticed that the effect was highly reduced after a few months from the burning time. This last author also recorded higher level on Ca, Mg and Na in burned prairies against unburned ones.

Threats and conservation

Paradoxically it seems that the worst threats to the conservation of *P. patens* are both the excess and the total lack of disturbance. The prairies have been subject to disturbance by grazing from large herds of ungulates and wild fires for millennia. Native Americans have traditionally used fire on the prairies to satisfy their needs. It was after the European colonization when major changes in land use and management occurred on the prairies. Grasslands were cleared for cropland and rangelands were opened for cattle breeding while fires became a progressively rarer phenomenon (Guyette et al. 2002). The lack of regular disturbance is leading to the encroachment of prairies by woody species with its associated change in communities and ecosystem services (Briggs et al. 2002).

P. patens and prairies share the same fate. In North America, this plant is considered to be a prairie species and those impacts able to severely alter the prairie are likely to destroy populations of *P. patens*. Excessive fire and overgrazing may hinder the long term persistence of this plant. However, land use change, particularly for agriculture and resource extraction, is considered the most threatening disturbance for the prairies (Archibold and Wilson 1980). In

North America, native mixed and short-grass prairies have declined to 20-30% of their original extension (Gauthier et al. 2003). The case of tall-grass prairie is perhaps the most dramatic example, reduced now to just 1% of its historic land cover (Samson and Knopf 1994). The remnant areas are highly fragmented and threatened by woody species encroachment, loss of biodiversity and invasive species (McLachlan and Knispel 2005). In Saskatchewan, only between 17-21% of the prairie ecozone remains as native grassland, much of it fragmented into small patches (Hammermeister 2001). Fescue prairie, which has declined to less than 1% of its original range, is a critical grassland type for *P. patens*. This plant is a frequent species of this community with more than 70% occurrences (estimated from Thorpe 2007). Eutrophication from agriculture also seems to be detrimental for this species (Bilz 2011).

In Europe, *P. patens* has declined rapidly in all the countries where it occurs. This is also related to changes in management and land use although agricultural expansion does not seem to be the main cause anymore. Instead, the termination of cattle grazing in forests and the increasingly effective wildfire prevention systems are resulting in a growth of moss and a more competitive grass community, preventing the regeneration of the species (Uotila 1969).

Another major threat to the survival of populations of *P. patens* in Canada is the proliferation of invasive grasses. Some of them can grow in high densities, competing for nutrients and especially light. Williams and Crone (2006) modeled the evolution of populations of *P. patens* growing in a matrix of native grasses against growing in patches characterized by the invasive species *Poa pratensis* (Kentucky bluegrass), and *Bromus inermis* (smooth brome). The result was that *P. patens* tends to prosper in native grass patches and decline in invasive ones, especially *B. inermis*. The presence of *B. inermis* also increased substantially the modelled probability of extinction *for P. patens*. No invasive species are known to pose a threat to European populations.

Pulsatilla patens and urban areas

Urban impact is also considered an important factor for the conservation of *P. patens*. In Europe, this plant has disappeared from the vicinity of many big cities (Pilt and Kukk 2002). Uotila (1969) specifically pointed out urban development as one of the main causes of decline for this species. He specifies a number of examples where occurrences of *P. patens* have been covered by human settlements and associated infrastructure. This author also points out that, despite the legal protection, the plant was eagerly picked by the general public as it is visually appealing and one of the first flowers to occur in the spring. However, *P. patens* is known to occur in many locations within the city of Saskatoon, Saskatchewan (Lineman 2000). The spatial distribution of the plant within Saskatoon and vicinity has not been studied. Similarly, the forces driving spatial distribution of this species in urban areas remain unknown.

According to Statistics Canada (2006), urban land corresponds just to 0.25% of Canadian total land. This proportion drops to 0.14% in the case of Saskatchewan. Given this small proportion of land, why should we conduct a research about *P. patens* on urban areas instead of focusing in the remnants of natural prairie? As aforementioned, little is known about how urban conditions affect the ecology and distribution of this species. Covering this knowledge gap would help restoring populations of *P. patens* within cities but also contribute to the general understanding of the ecology and habitat preferences of the species, being this knowledge applied in other type of land use (pasture land, natural grassland, etc.). Similarly, this knowledge may be applied in other areas of the world where *P. patens* occurs; especially in Europe, where this species is protected and the proportion of urban land is much higher than in Canada (Reginster and Rounsevell 2006).

Conservation of *P. patens* in urban settings would be beneficial, not only for this species, but also for urban dwellers. Studies have suggested that personal exposure to wild species in everyday life is a major determinant of sensitivity to environmental issues (Sebba 1991). Exposure to biodiversity in urban areas has also been linked with improvements in mental health and wellbeing (Dean et al. 2011).

Aim and objectives

In the previous chapters, knowledge gaps regarding habitat preferences of *P. patens* have been identified. It has been argued the necessity of identifying spatial trends in the distribution of this species within urban areas and the mechanisms underlying them. Different types and degrees of disturbances have been considered to be potential determinants of the mentioned spatial trends. Finally, urban expansion has been considered as a potential impact for existing populations of *P. patens* within the study area.

On the grounds of the exposed the aim of this research is to know the ecological, physical and demographic factors influencing the spatial distribution of *P. patens* within Saskatoon and its vicinity.

For this aim, the current study has adopted the following objectives:

- Identifying and mapping sites with potential to host populations of *P. patens* in order to know the distribution of this plant within Saskatoon and vicinity.
- Collecting and integrating data regarding habitat preferences of *P. patens*.
- Identifying trends and correlations underlying the distribution of *P. patens* within the study area, with emphasis on spatial relationships, disturbances and historical urban development.
- Assess the potential impact of projected urban expansion on current populations of *P. patens* in Saskatoon and its vicinity

Methodology

Study area

The study area is the City of Saskatoon and its vicinity, in the province of Saskatchewan, Canada. Specifically, the spatial boundary of this research corresponds to the "Corman Park - Saskatoon Planning District" as delimited in the Corman Park - Saskatoon Planning District Zoning Bylaw (City of Saskatoon – R.M. of Corman Park 2010). The District is an area belonging to the Rural Municipality of Corman Park that extends approximately one to three miles from the boundaries of Saskatoon. Both the City and the Rural Municipality have joint interest in this land, so development and land use are being managed jointly by these institutions. The planning district has also a practical meaning as a boundary for this thesis. First, it acts as a buffer zone between urban and rural habitats. Second, all the medium-term urban development is expected to happen within this area (City of Saskatoon 2012) with its associated impact on wildlife. And third, it is stable, identifiable and easy to map. This area is illustrated on Appendix B and is referred during the rest of the thesis as planning district or study area.

Existing data

Comprehensive field surveys were carried out on spring-summer 2011 covering some areas on the eastern riverside of Saskatoon by Vladimir Kricsfalusy and Yakiv Ponomarenko from the School of Environment and Sustainability, University of Saskatchewan. The resulting dataset contained records of several ecological and physical parameters from locations hosting *P. patens*, including all the variables considered in this research with the exception of population area which has been recorded only during this field season. These data were raw, unprocessed and had never been used in any published study or academic thesis. The results of a soil analysis made by an external laboratory (Exova located in Calgary, Alberta) were also available prior to the beginning of fieldwork.

Identification of survey sites

For this research, the main objective of field surveys was to collect a comprehensive set of data regarding habitat and ecological conditions of *P. patens* within the study area. Therefore, it was intended to cover all the possible sites hosting populations of *P. patens* within this area. The whole planning district covers an area of 44633 ha of which near a tenth is considered to be natural grassland according to the best available land cover dataset (NRC 2009). Given the large extension of the study area, time constrains and logistic limitations, the identification of priority areas for fieldwork became a vital step prior to data collection. Areas surveyed during the field season 2011 were discarded as data from those sites was considered to be complete and accurate enough for this research.

A number of sources were consulted in order to identify potential areas containing populations of *P. patens*. These were:

- **Records from herbaria**: Records of *P. patens* from several herbaria, especially W.P. Fraser herbarium at the University of Saskatchewan, had been previously assessed by Kricsfalusy et al. (2012b) for the whole province of Saskatchewan. A total of 23 records where collected in Saskatoon from 1920. Most of them lacked coordinates or detailed description of their location. Others were located in already surveyed areas. At the end, three points were selected as indicative of potential current locations.
- **Publications**: A report covering natural areas remaining in Saskatoon and vicinity identified a number of patches of good quality habitat that, according to the author, were worthy of protection (Weichel 1992). A vegetation inventory of Saskatoon and area (Bizecki-Robson and Nelson 1998) offered valuable information from vegetation in local natural areas at community level. These reports helped to identify potential areas of natural grassland remains within the study area. Finally, a master thesis from the University of Saskatchewan (Lineman 2000) offered a good account of flora composition, both quantitative and qualitative, along the South Saskatchewan River. This thesis identified seven locations of *P. patens* within the planning district, of which three were in areas not previously surveyed.
- **Consultation with experts and local NGO**: Luc Delanoy from Meewasin Valley Authority (the conservation authority responsible for protected areas in Saskatoon) and Gary Pedersen, Naturalized Areas Supervisor of the City of Saskatoon, were contacted regarding their knowledge of populations of *P. patens* within Saskatoon. They identified a number of areas hosting *P. patens,* some of them completely absent in other sources. Chet Neufeld, Executive Director of the Native Plant Society of Saskatchewan was also inquired, providing valuable information.
- **Land cover data**: It consisted on a circa-2000 land cover vector dataset developed by the Centre for Topographic Information (NRC 2009) from remotely sensed imagery (Landsat 5 and 7). Although Saskatoon has changed considerably since 2000, this

dataset allowed the identification of areas of natural grassland in the within the study area, separating them from adjacent cropland.

- **Imagery**: Recent high resolution aerial imagery of the study area (SGIC 2010) and common remote sensing commercial products (such as Google earth or Google Streetview) helped evaluate the chances of P. patens to grow in a specific area.
- **Communication with local people**: Informal chats with gardeners, dog walkers, bird watchers or acquaintances born and raised in Saskatoon helped on the selection of survey sites. Simple comments of the kind of "when I was a teenager I used to pick them on that area for my girlfriend" turned out to be very useful.
- **Other**: Name of places (e.g. the Crocus Park), own observations during daily activities, accessibility of the site, etc.

Although no formal quantitative method of prioritization was developed, these sources were considered and ranked subjectively according to their importance. Nine areas were eventually considered to have high potential for *P. patens* and be suitable for survey. They can be found in Appendix C.

Data collection

Instable weather conditions during early spring delayed the flowering of *P. patens* this year in comparison to its normal phenology. Field surveys were carried out between the 26th of April and the 11th of May, 2012. This was considered the best survey time for *P. patens* as the majority of individuals were blooming, making their identification easier.

Field surveys were conducted by walking using a rapid assessment approach. In some cases, areas were preliminary screened by visual assessment from a bike or car at low speed in order to identify suitable habitat for the species. The walking route was intended to maximise the area of potential habitat observed without venturing for too long into obviously unsuitable habitat. Every time a population of *P. patens* was found, its location and elevation was recorded at the centre of the population using a hand-held autonomous GPS receiver (Garmin eTrex Vista). Three types of data were recorded for each of the locations: topographical conditions, disturbance and population size. Topographical conditions included a visual estimation of the slope (in degrees), aspect and slope position (level, crest, upper slope, mid slope, lower slope and toe).

Six disturbance types, common in the prairies and suspected to affect *P. patens* were recorded for each location. Their impact was assessed and classified into a scale of four ranks being: 0 = disturbance absent, 1 = light disturbance, 2 = moderate disturbance and 3 = strong/severe disturbance. The recorded disturbance types were:

- **Browsing/grazing**: It considers the impact of herbivores (wild or domestic) by feeding on the area. It was estimated by the presence of grazed stalks or leaves (not only in *P. patens* but also in other surrounding plants), and other signs of herbivore use of the area such as droppings and tracks.
- **Burrowing**: Reflects the density of burrows from mammals (e.g. gophers, badgers, etc).
- **Trampling/trails**: This disturbance was estimated from the presence of trails from human use of natural areas, but also from the presence of disturbed patches attributable to animal trampling.
- **Burning**: The score of this disturbance reflects the extension and freshness of fire within and around the location. Recent (within season) fire covering the whole population would get a high score while a site burned in past seasons and affecting the population marginally would be recorded as light.
- **Litter**: This score considers the amount of dry organic litter covering the soil in terms of mass and, especially, cover. It can be argued that this factor is not a disturbance itself but the result of a lack of disturbance (e.g. lack of fire or grazing) or an excess of disturbance (e.g. overgrowth by exotic weeds). However, litter is known to have a direct pervasive effect on the establishment of seedlings of *P. patens* (Kalliovirta et al. 2006, Juśkiewicz-Swaczyna 2010) and is therefore included here.
- **Exotics**: This disturbance was scored according to the dominance, cover and diversity of exotic species within the site. The invasive capacity or negative influence on *P. patens* was not considered.

Population areas were estimated visually or by walking the perimeter of the site and counting steps. Population size was calculated by counting only those individuals with obvious flowers or fruiting bodies. Seedlings, juveniles and vegetative individuals were not counted. It is assumed here that the frequency of flowering individuals is proportional to the whole population size. Individual counting was done for populations of fewer than 50. The size of larger populations was estimated visually and by extrapolation from a smaller sample plot.

Population size was recorded using nine ranges: 1–10, 11–25, 26–50, 51–100, 101–500, 501–1000, 1001–5000, 5001–10,000 and >10,000.

As a general rule, two locations were considered to be distinct if their centres were separated by at least 100 m. If two locations were closer than 100 m but showed very distinct features in their habitat or community, they were considered as different populations. Large scattered populations (like the upland prairie in Wanuskewin Heritage Park) were treated as follows: the centre of the first location was defined at approximately 50 m from its edge. Then, all individuals within an approximate 50 m radius were treated as belonging to this population. The centre of the second location is dropped at 100 m from the previous point and it again covers another 50 m radius. This means that in some cases the recorded locations are an artificial representation of a continuum. They still keep the geographical and statistical relevance for the analysis but they do not correspond to distinct populations from a genetic and ecological point of view. Because of this, the term location is preferred to population in the discussion when referring to each of the recorded points.

Data analysis

Field data was subject to a quality control process to ensure its completeness and its accordance with GPS data. Location points were transferred to a computer with the software ArcGIS 10 (ESRI 2010) and incorporated into a GIS system. Four secondary parameters were calculated from primary field data for each location:

- **Distance from the city centre**: Using ArcGIS the distance of each individual point with the centre of the city was calculated. The geographical centre of the study area lacked any demographic or ecological meaning so an arbitrary point was chosen. Because of its location, Bessborough Hotel was chosen as the centre of the city. It is located in the eastern section of downtown, the busiest and most urbanized area of the city, but is also close to Nutana on the east shore, the oldest part of the city where the first pioneers settled. Bessborough Hotel is also an emblematic building and an important and easily recognizable landmark associated by Saskatonians with downtown and the centre.
- **Distance between points**: Linear distance from each point to the nearest one was calculated for every location. This parameter was intended to be an indicator of isolation between populations.

- **Population density of *P. patens***: This parameter was calculated dividing population size by the area covered by each population. The middle point of the population size interval was considered. This parameter was only calculated for newly collected data.
- **Disturbance from exotics (excluding *Poa pratensis*)**: Field observations and preliminary data analysis suggested that different exotic species could have disparate impacts on the size distribution of *P. patens*. *Poa pratensis*, given its ubiquity but lower impact on *P. patens* compared to other exotics, was considered for a separate analysis. In order to test this, the influence of *Poa pratensis* was subtracted from the records. The original dataset was reviewed and adapted using the following criteria. Comments on field notes and pictures were also taken into account.
    - If *Poa pratensis* was the only mentioned exotic species the score was turned to 0.
    - If just one more exotic species other than *Poa pratensis* was mentioned the score was lowered one point (keeping a minimum score of 1).
    - If two or more species were mentioned besides *Poa pratensis*, the scored was not altered.
    - If besides the score there was no detailed information about exotic species present, the record was not changed.

Data were subject to preliminary descriptive analysis including frequency and, if parametric, mean, mode and median. In order to determine the relationships between the size of the recorded populations and the studied variables (degree of each type of disturbance, elevation, distance from the centre and distance between points), all the 171 points were considered. The correlation between *P. patens* population density and the different variables only comprised the 73 locations recorded during this field season.

The statistical correlation method was chosen in accordance to the scale of measurement. The Pearson product-moment correlation coefficient (*r*) measures the strength of a linear association between two parametric variables (StatSoft Inc. 2005). This correlation test was used whenever all the involved variables were in a ratio scale. This was the case of the correlation between elevation, distance from the centre and distance between points. The rest of collected variables were in an ordinal scale (disturbances, population size and population density), as they were collected using rankings or calculated after them. In order to estimate the influence of each disturbance type on the survival of *P. patens,* Spearman correlation coefficients between disturbance type, population size and population density were calculated

(StatSoft Inc. 2005). In addition, each disturbance type was correlated against each of the other types in an attempt to reveal synergies and causalities between them. Correlations between disturbances and distance were also carried out in order to identify spatial patterns. For all these correlations Spearman's correlation coefficient (r_s) was calculated. This test is a non-parametric version of Pearson correlation and allows the use of data in an ordinal scale. In all the cases, using both Pearson and Spearman, two significance levels were considered α= 0.01 and α= 0.05.

Apart from the data collected on the field, two more variables were calculated from spatial datasets. The first one was human population density by administrative area within the study area. This variable was calculated from a GIS shapefile developed from the 2011 census (City of Saskatoon undated). The second one was the proportion of built-up land, calculated from a land-cover dataset (NRC 2009). These two spatial variables, together with the frequency of locations of *P. patens*, were grouped into 11 concentric rings and correlated using Spearman correlation.

For the analysis of urban development, six different maps covering the whole history of the city were combined (Lake and Blake 1883; Saskatoon Board of Trade 1910; 1955; 1966; Department of Energy, Mines and Resources 1988; City of Saskatoon 2006). Some of the maps were manually digitized from hard-copy maps. The digital copies were incorporated into a GIS system with data retrieved from the University of Saskatchewan database. The locations of the points were compared to the maps in order to assess the influence of the historical development of the city.

Results and discussion

A total of nine previously identified sites were surveyed for *P. patens*, with this species being present on six of them. Seventy-three (73) locations of *P. patens* were mapped during the field surveys. Together with the 93 locations recorded in 2011, this thesis considers a total of 171 locations and their individual ecological description. Appendix C illustrates the distribution of the locations and the survey areas.

Habitat preferences

In order to gain insights about the habitat preferences of *P. patens*, three parameters have been analysed: slope, aspect and soil type. The first two were directly recorded on site for each location. The third one was inferred from the spatial distribution of the species and soil maps.

Slope

During fieldwork it was observed that, in open prairie land, the preferred location for individuals of *P. patens* was the crest or higher sections of mounds in gently rolling moraine. Alternatively, this species was also widely found in the higher slope of riverbanks and ravines. In order to confirm these observations, slope position and incline in degrees was recorded for each of the locations hosting *P. patens*. Figure 5 illustrates their distribution grouped in intervals of steepness.

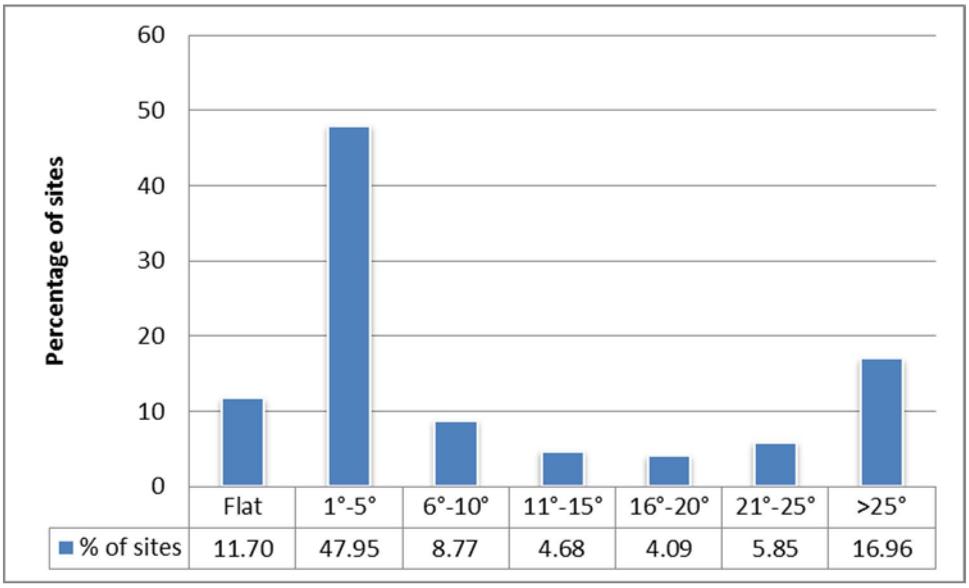

Figure 5. Distribution of sites hosting *P. patens* according to slope steepness within the study area.

Figure 5 reveals that most of recorded populations in Saskatoon are located on slopes with less than five degrees of slope. Uotila (1969) offers a numerical assessment of the slope preferences of *P. patens* in Finland. Although he did not use degrees on his study, he described the majority of localities (84%) on gently sloping or level ground. Even if there is no complete certainty regarding the steepness of “gently sloping”, it is usually considered in some field guides to be between 2° and 5°. In any case, these results do not differ much from the results found in Saskatoon and vicinity, where almost 60% of recorded sites were estimated to have a slope lower than 5°.

The position of the studied populations within the slope also seems to match field observations. In figure 6 it can be seen that *P. patens* has a higher affinity for upper slopes, being more infrequent on middle and lower slopes and rare on the toe.

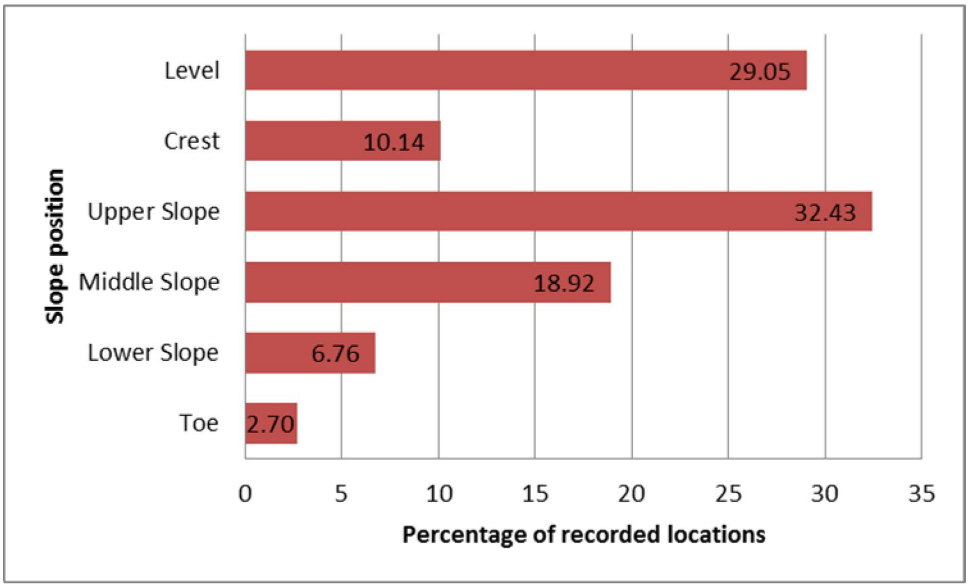

Figure 6. Distribution of sites hosting *P. patens* according to slope position within the study area.

Baines (1973) recorded the slope position, water retention capacity and soil humidity of several prairie plant locations within Kernen Prairie, in Saskatoon. This natural grassland area has been subject to little anthropogenic disturbance in the past and is considered to be a representative example of local natural prairies. Actually, Kernen Prairie was one of the areas surveyed in 2011 and 21 of the locations considered in this thesis were recorded there. In this prairie, Baines (1973) found *P. patens* to be much more common in upper and mid slopes (51 and 31.2% of the surveyed quadrats respectively) being almost absent in lower slopes and completely absent at depressions. These results are similar to those found in this thesis for the whole area of Saskatoon.

It is considered here that the preference of *P. patens* for upper slope positions may be related to soil moisture. As water filters by gravity from the top of hills to the bottom, upper areas tend to be better drained. Some authors have also stated the preference of P. patens for well drained sites (Porsild and Cody 1980; Cody 1996), hence the affinity. This idea is supported by the findings of Baines (1973) regarding soil moisture and water retention capacity. This author found the majority of locations containing *P. patens* to be on the driest considered range (10 - 15%), being the species completely absent in zones with more than 25% humidity. Similarly, the study revealed that low water retention capacity was preferred by *P .patens*.

This preference for drier soils explains the absence of *P. patens* on the surroundings of Lakewood (Appendix C), where the water table was high, the soil has high humidity, and a large proportion of the grassland area are subject to seasonal flooding.

Elevation

Elevation on each site was recorded using a GPS device. The mean elevation was 494.93m (σ_X = 8.99) and the records follow a symmetrical normal distribution (median = 494.72, mode = 494) as illustrated in figure 7.

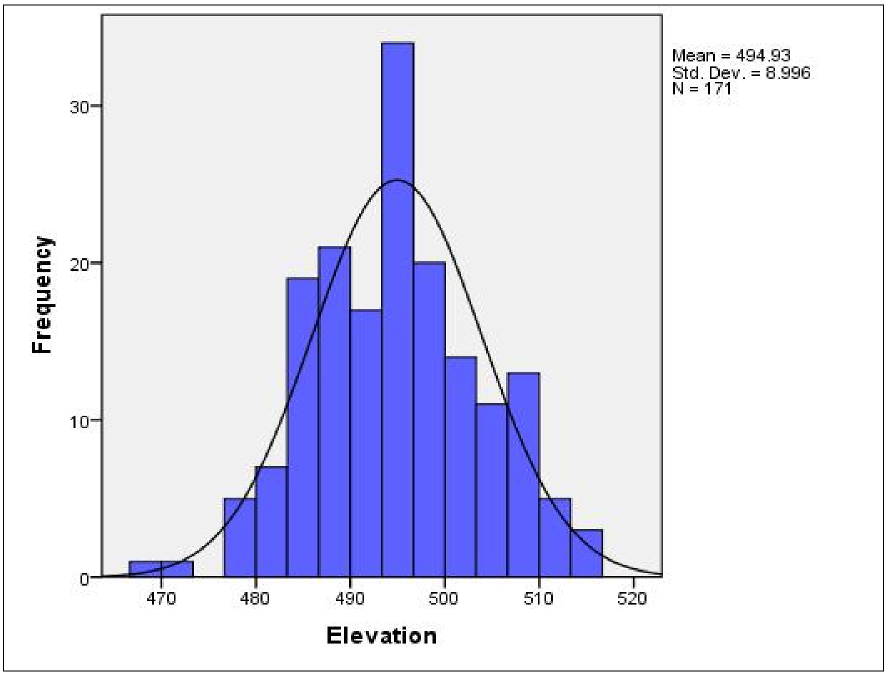

Figure 7. Histogram plotting elevation of recorded localities hosting *P. patens* against their frequency within the study area.

In order to find trends linked to elevation, Pearson Product Moment Correlation Coefficients were calculated between elevation and both distance from the city centre and distance from the closest location. Population size and population density were correlated to elevation through the Spearman Rank Order Correlation Coefficient. No statistically significant correlations were found between elevation and any of these parameters, suggesting that both spatial distribution of locations and number of individuals were independent from elevation.

Spearman correlation was also calculated between elevation and each of the recorded disturbances. Surprisingly there was a positive correlation between elevation and both litter accumulation (r_s= 0.350) and browsing/grazing (r_s= 0.321). A negative correlation between elevation and invasive species was also found (r_s= -0.237). In the three cases, the level of significance was 0.01.

The negative correlation between invasive species score and elevation is probably related with the habitat preferences of a widespread prairie invasive grass, *B. inermis*. This plant usually thrives in relatively moist soil (Blankespoor and May 1996), being this condition more common in lowland areas than in the crest of knolls and upper slopes where *P. patens* tend to grow. During fieldwork, it was observed that *B. inermis* could largely dominate and get very dense on this type of lowland moist areas (e.g. Surrounding of Lakewood in Appendix C) displacing other species and reducing plant diversity. However, other authors have found drier soil conditions beneath *B. inermis*, possibly due to the long-term water uptake capacity of this plant (Fink and Wilson 2001). No apparent explanation was found for the positive correlation between elevation and browsing or litter accumulation.

In any case, it should be noted that Saskatoon area, and the prairies in general, are characterized by a very flat topography. In fact, the range of our data is just 46 m. Such a narrow range precludes any conclusion based on absolute changes in elevation. Even within the study area, elevation varies depending on what zones we are considering. For example, the average elevation of the points located on the east side of South Saskatchewan River is 8.3 m higher than the west side. Such a small difference may seem insignificant but, in this case, it means a difference of 18% of the total range. Therefore, it is considered here that a fully effective field study of the influence of elevation on *P. patens*, or any other species, within Saskatoon and vicinity must be approached from a very small scale, e.g. recording absence/presence of the species along an elevation gradient within a specific survey site. Another option, with high potential in spatial analysis, is the use of high resolution digital elevation models (DEM) developed from remote sensing technology (e.g. LIDAR). These models allow analysing the results in relation to local micro-topography, revealing trends and correlations at a very fine elevation scale. Unfortunately, unlike other Canadian provinces, this technology has not been extensively applied in Saskatchewan and no high resolution DEMs have been found for the study area, either public or commercial.

Aspect

The aspect of each of the locations where *P. patens* was present was recorded, as long as there was a discernible slope. From all the recorded locations 12% were completely flat and therefore lacked any aspect. The rest where distributed as represented on figure 8.

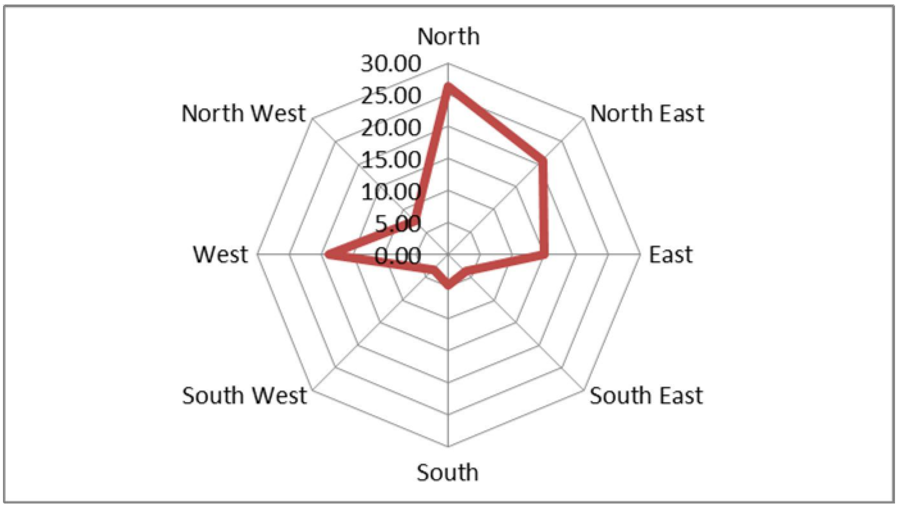

Figure 8. Compass rose of sites hosting *P. patens* according to slope aspect within the study area. Sites facing more than one direction have been counted multiple times, one for each of the faced directions.

Most of populations covered in this study face North, Northeast or West, being South facing populations very poorly represented. These results seem to be almost opposed to those found in Finland (Uotila 1969). As mentioned on the habitat section, this author found that *P. patens* occurs more often in south and west facing slopes, being very rare on northern ones. Figure9 compares the proportion of localities facing each of the cardinal directions for both Finland and Saskatoon. As Uotila (1969) only considered four cardinal points, records from intermediate directions (NE, NW, SE and SW) were allocated in equal proportions to the two closest cardinal directions.

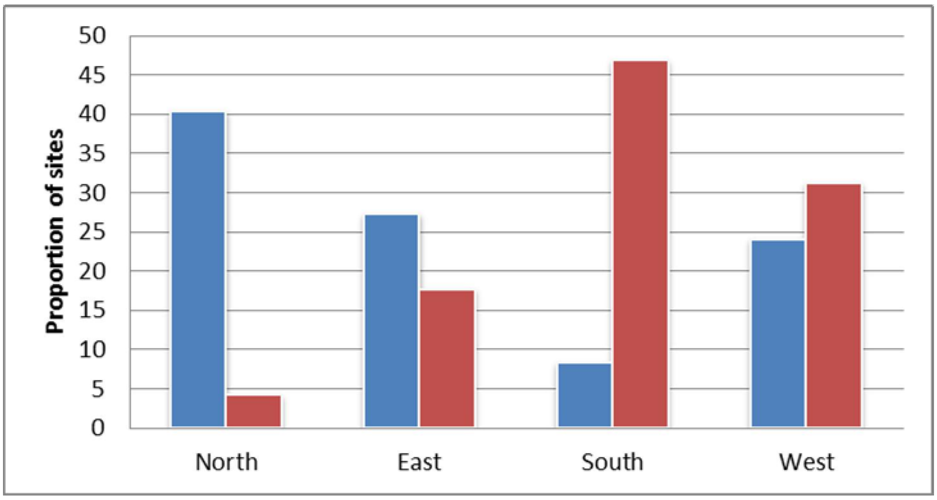

Figure 9. Distribution of localities hosting *P. patens* according to slope aspect in Saskatoon (blue) and Finland (red).

A quick look to figure 9 is enough to assert that there is a clear difference between aspect preferences of *P. patens* in Scandinavia and Saskatoon. A potential explanation for this distribution can be found in the continental climatic character of sunny slopes. General climate in the Canadian prairies already has a high continental character. South facing slopes may enhance this character making it too harsh for *P. patens*. For example, warmer and sunnier conditions on a south facing slope may be beneficial in Finland as they encourage the bloom of the plant on the early spring while keeping competition low. In the Canadian prairies, these conditions may result on a premature flowering and eventual damage by early spring harsh weather conditions. This was actually observed during fieldwork. Individuals on south facing slopes were usually on a later development stage, many of them showing signs of damage by frost. Moisture conditions may also be too dry on south facing slopes, precluding the germination of the seeds on late summer and forcing the plant to germinate only at the beginning of the next season.

Light availability also seems to play an important role. Most of populations studied by Uotila (1969) were growing in open boreal forests located on dry moraine hills and eskers. In these habitats, individuals of *P. patens* have less available light than the Saskatoon ones, which are growing on grassland or open parkland with none or little above canopy. Therefore, growing on South facing slopes with high light availability offers an important advantage in the boreal forest, especially during early spring when there is still no shading leaves or herbs. This advantage is minimized or inexistent on a prairie context, where shading is low and light is available during the whole growing period. Actually, Uotila (1969) already indicates that ground vegetation growing in habitats with better light conditions throughout the year shows a less distinguished seasonal character.

Soil

The recorded locations were with a soil survey developed by Acton and Ellis (1978). Six of the studied locations fall within the urban soil that was not surveyed by Acton and Ellis (1978). The rest of locations fall within one of these four soil associations: Runway, Hillwash, Sutherland and Elstow, with the exception of the two most southwestern populations.

Regarding soil types, four main areas hosting populations of *P. patens* can be identified. The first of them is the central area considered as urban soil. Six locations next to the east margin of the river fall within this area. The second area is the Kernen Prairie, corresponding to the most eastern population. According to Acton and Ellis (1978) this zone is dominated by orthic dark brown soils with significant influence of rego, calcareous and eluviated dark brown soils. The third identifiable area is the one to the northeast, between the river and Kernen Prairie. Locations of *P. patens* in this area seem to match the runway complex soil with a surprising accuracy. The runway complex is a potpourri of deposits from glacial melt water channels. The forth most noticeable soil group is the hillwash association, which comprises the northern locations on the west bank of the river, including Wanuskewin Heritage Park. This soil association is described by Acton and Ellis (1978) as a complex of Regosolic, Chernozemic and Podzolic soils developed on variable fluvial deposits. The two isolated populations, present to the southwest of the city, are placed on different soils. The one enclosed within the urban area (11th street) is located in a soil from the Bradwell association, strongly dominated by orthic dark brown series. The one close to the southwest boundary (Chief Whitecup Park) is in a transition area between orthic dark brown and sand dunes.

A soil chemical analysis for some of the locations was carried out by an external laboratory. The results were analysed and are summarized on table 6.

Table 6. Result of soil analysis for selected locations within the study area.

Site name	Site ID	N (ppm)	P (ppm)	K (ppm)	S (ppm)	pH	EC (dS/m)	OM (%)
Crocus Prairie CA	CP 3	12	9	260	6	7.9	0.47	5.3
Northeast Swale CA	NS 33	7	10	256	9	7.5	0.46	10
Northeast Swale CA	NS 34	6	7	268	8	6.8	0.32	9.3
Peturrson's Ravine CA	PR 4	48	<5	268	6	7.9	0.69	3
Saskatoon Grasslands CA	SNG 18	19	10	327	6	6.9	0.5	6.5
Saskatoon Grasslands CA	SNG 19	>80	6	229	10	6.7	1.62	10.4
Saskatoon riverbank	ST 14	45	<5	199	6	7.6	0.62	4.3
Kernen Prairie	KP 21	>80	<5	383	10	6.2	1.17	9.7
Mean *		37.13	7.13	273.75	7.63	7.19	0.73	7.31
Standard deviation (σX)		30.92	2.23	57.24	1.85	0.62	0.44	2.90

* For the calculation of the mean, >80 has been considered as 80 and <5 as 5.
All the samples belong to the top 6 inches of soil.
Results categorized as deficient by the analyst have been coloured in light blue, while excessive results are in red. Marginal and optimal results are not coloured.

These results are very variable. The only parameter which remains more or less constant is pH which tends to be neutral with an average of 7.19 (ranging 6.2 - 7.9). These results are just slightly higher than those found by Baines (1973). On his study on Kernen Prairie, the huge majority of recorded locations were found in soils with a pH ranging from 6.1 to 7.0. Actually, our soil sample coming from that site is the most acidic one of all the collected samples (pH 6.2). Organic matter ranges from 3 to 10.4% (normal to high). High values are related in many cases with an observed high amount of litter on the field. Conductivity is also quite variable (0.4 - 1.6 dS/m) although in no cases salt content is considered to be an issue for plant growth.

Nitrogen (N) and phosphorous (P) are the more variable nutrients. P remains significantly low in all the cases (<5 – 10 ppm). N offers a higher variability (6 - >80 ppm); sometimes even between samples collected on the same site suggesting strong intra-site differences in management practice or the influence of external sources of N. The differences between the two samples from Saskatoon Grasslands CA (SNG 18 and SNG 19) are especially illustrative of the impact of different management practices on soil chemistry. Both sample points are close to each other (387 m) but SNG 18 has been subject to burning while SNG 19 has not (Meewasin 2009). Considering that 40 – 60% losses of N can occur in grassland fires

(Redmann 1991) we should expect a lower concentration in SNG 18 in relation to SNG 19. Data from table 1 confirms this point (19 to >80 ppm respectively). Other expected consequences of fire are also observed such as a smaller proportion of organic matter and a lower concentration of sulphur, which is also a volatile element.

Potassium ranges from 199 to 383 ppm while sulphur does from 6 to 10 ppm. When these ranges are compared with the results obtained by Pilt and Kukk (2002) on sites where *P. patens* was present, it can be observed that K values in Saskatoon samples are higher than in the mentioned study (31 – 274 ppm) while P values are on the lowest extreme of their range (6 - 101 ppm). All the pH and OM results for the recorded sites fall within the ranges observed by these authors (pH 5.1 – 8.1, OM 2.14 – 31.14%).

Besides physical and chemical properties of the soil, biological activity also plays an important role. Moora et al. 2004 observed a better growth of *P. patens*, higher establishment of seedlings and changes in nutrient composition in soil with inoculate from grasslands compared to just soil. Similarly, inoculate from forest soil would enhance growth conditions but to a more limited extent that grassland inoculate. This indicates the existence of mycorrhizal relations between *P. patens* and the soil of the prairies.

In conclusion, it is considered here that soil type may be an important factor determining the survival of individuals of *P. patens*, especially regarding biotic relationships, soil drainage and water retention capacities. However, given the wide range of soil types and chemical parameters recorded here and in literature, it seems that *P. patens* has a high tolerance regarding soil conditions and is far from being an edaphic specialist. Other factors, such as degree of disturbance or vegetation community seem to be more important in shaping the spatial distribution of the plant.

Spatial relationships and distribution

The whole study area falls within the Moist Mixed Grassland Ecoregion, although near to its northern edge. The Aspen Parkland Ecoregion starts around 5 km north of the planning district boundary. The study area comprises sections of four different ecodistricts, namely Saskatoon Plain, Elstow Plain, Mixed Wood Sand Hills and Minichinas Upland. The one with the highest extension is Elstow Plain, covering 56% of the study area. However, only 32 points fall within this ecodistrict. The majority of them (137) are located on the Saskatoon Plain, which only covers 27% of the study area. Only the two most southern locations are found on the Mixed

Wood Sand Hills, covering 16% of the land. The cover of Minichinas Upland is testimonial (1.3%) and includes no locations.

The spatial distribution of recorded locations was analysed according to their distance from the city centre. Frequency of locations happens to be positively correlated to distance from the centre (r_s= 0.486 p<0.05). The histogram plotted in figure 10 illustrates this gradient.

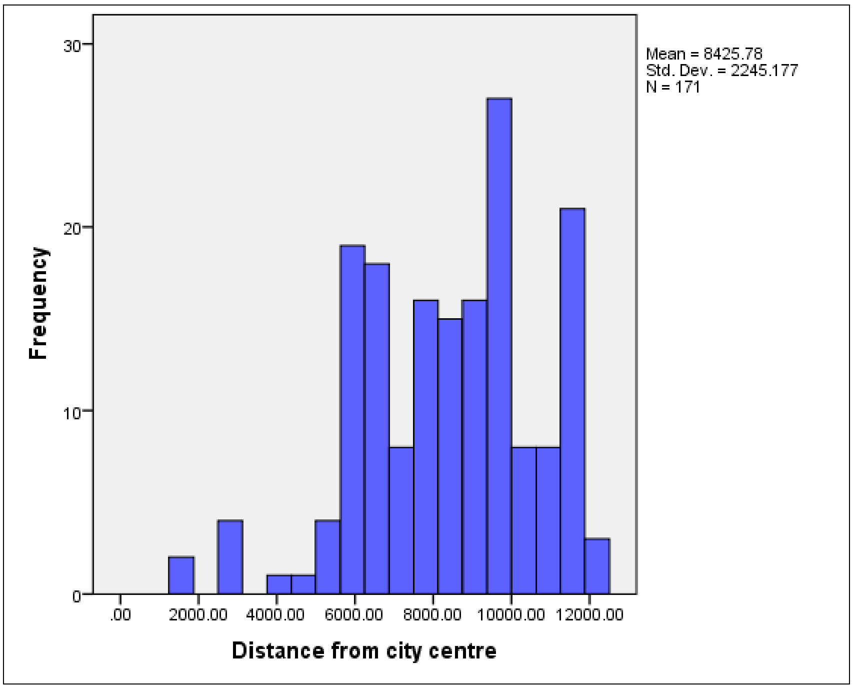

Figure 10. Histogram plotting the frequency of recorded localities hosting P. patens against distance from the centre of Saskatoon.

The statistical analysis also revealed a significant positive correlation between population size and distance from the city centre (r_s= 0.225, p<0.01). For those locations where population density was recorded, this parameter also seems to be related with distance from the centre (r_s= 0.244, p<0.05). This means that *P. patens* tends to occur in more locations, in higher numbers and higher densities as we move from the centre of Saskatoon to the suburbs and semi-rural areas of the outskirts.

This phenomenon of gradual change in species abundance and composition from urban centre to rural areas is well known and has been widely studied since the 1980s (McDonnell and Hahs 2008). Maurer et al. (2000) described a concentric zonation of human impacts on plant species in urban areas. According to these authors this spatial pattern was due to the decreasing human population density and its associated pressure to nature from the centre to the suburbs. Similarly, Godefroid and Koedam (2007) found density of built-up areas to be a determinant factor in species composition. A look at the demographic and land use map of

Saskatoon (Figure 11) suggested that there could be a relation between this two factors and the occurrence of *P. patens*. A geographical analysis was carried out in order to confirm this hypothesis. As detailed in the Methodology, the study area was divided in 11 concentric rings of 1 km width around the central point. Three parameters were calculated for each ring: average human population density, percentage of built-up land over the total area and number of locations of *P. patens*. The results can be found in Table 7.

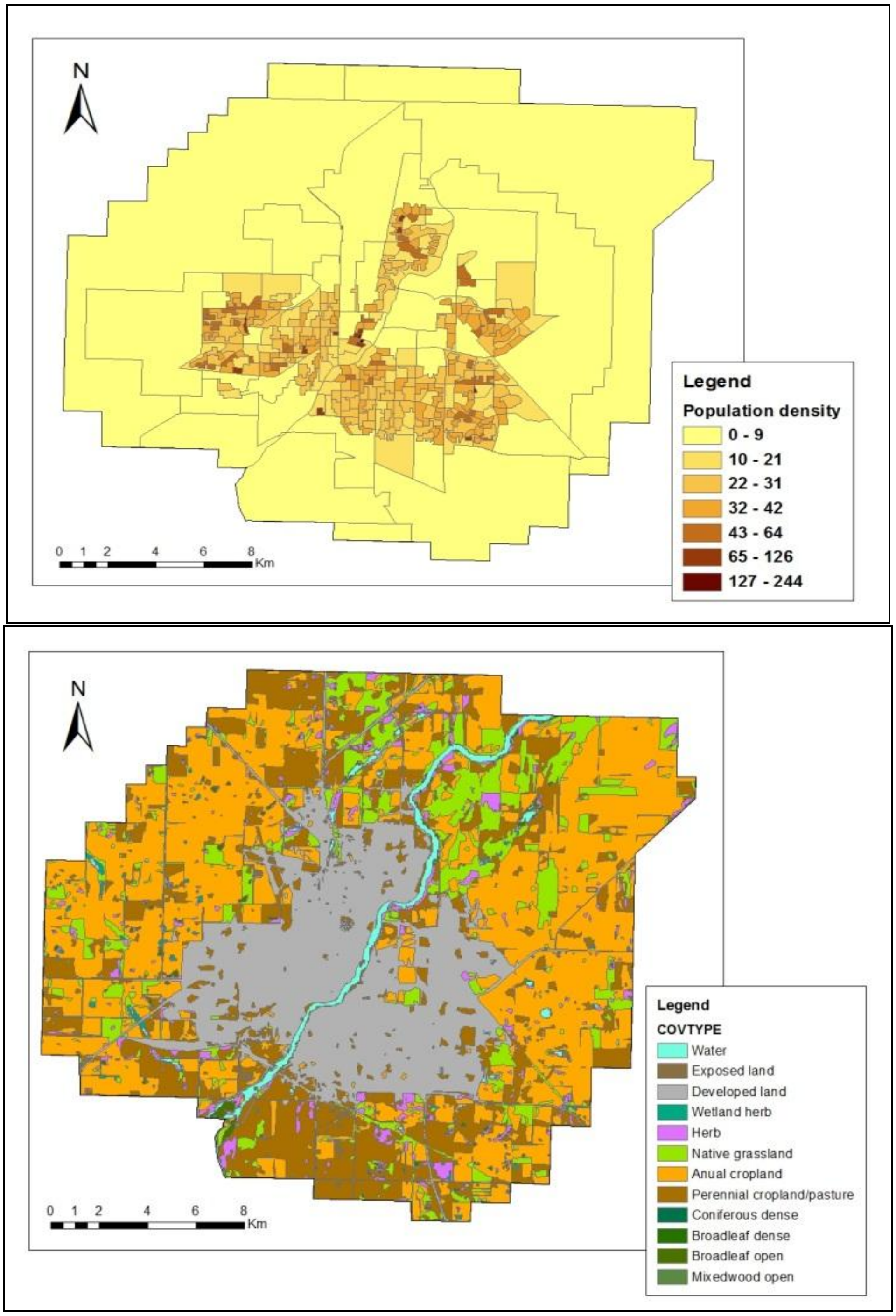

Figure 11. Map of human population density in persons per hectare (up) and map of land use (down) within the study area.

Table 7. Population density, relative cover of developed land and locations of *P. patens* for each distance interval within the study area.

Distance from the city centre (m)	Population density (people/ha)	% of developed land	No of locations of *P. patens*
0 - 1000	25.63	83.31	0
1000 - 2000	21.63	92.33	2
2000 - 3000	18.29	88.50	4
3000 - 4000	13.78	76.16	0
4000 - 5000	13.74	67.85	2
5000 - 6000	14.45	51.87	9
6000 - 7000	8.30	31.27	35
7000 - 8000	2.22	10.49	18
8000 - 9000	0.57	4.19	23
9000 - 10000	0.13	1.90	38
>10000	0.14	1.38	40

The Spearman Rank Order Correlation Coefficient was calculated for every pair of variables. An almost linear positive correlation was found between distance from city centre and both human population density (r=0.964) and proportion of developed land (r=0.973). As expected, there was also a very strong negative correlation between these two factors and the number of locations of *P. patens*. Specifically, r=-0.831 for population density and r=-0.854 for the proportion of developed land. All these correlations were significant at the 0.01 level. Therefore, it seems clear that there is a positive relationship between closeness from city centre, degree of urbanization and population, and that these three factors have a negative relationship with occurrence of *P. patens*. These findings match with the aforementioned studies by Godefroid and Koedam (2007) and Maurer et al. (2000) and seem to explain reasonably well the main distribution patterns for the studied species.

It can be argued that biological responses, especially regarding population ecology, are complex and sometimes subtle, and that a spatial correlation does not necessarily mean a causal relationship. Establishing causality between the proportion of built-up land and the survival of *P. patens* seems easy, given the widely recorded incapacity of this plant to cope with the strong degree of disturbance associated with densely built-up areas (Uotila 1969; Pilt and Kukk 2002). The case of population density does not seem so obvious. Other than flower picking (Uotilla 1969), literature does not offer arguments about conflicts between exposure to dense human population and conservation of *P. patens*. The negative spatial correlation may be ascribed to the lack of suitable habitat for *P. patens* near the city centre rather than a direct influence of this parameter on the survival of the species. In addition, it should be noted that *P. patens* is resistant to a moderate degree of disturbance. Some authors even consider the lack of disturbance as a very serious threat for the survival of the species (Kalliovirta et al. 2006). Therefore, asserting a causal relationship between population density and occurrence of *P. patens* would depend on whether we are able to quantify and assess the direct disturbance attributable to human urban population on this species. Some of these disturbances are considered in the next section.

Another spatial parameter calculated for each location of *P. patens* was their distance from the closest recorded location. This parameter is expected to provide an estimation of the degree of isolation of each locality. Spearman's rank correlation was calculated between this parameter and *P. patens* population size resulting in a low negative correlation (r_s= -0.158 $p<0.05$). That is, the further locations are distributed between each other, the smaller they are. This could be interpreted as an evidence of the detrimental effect of habitat fragmentation on plant populations. It is known that habitat fragmentation is a leading factor in the demographic decline of plant populations due to several mechanisms such as increase of edge effect, reduced gene flow, loss of elasticity, etc. (Bruna et al. 2009). Therefore, the correlation between population size and distance between locations may look sound from an ecological point of view.

However, it is argued here that the ecological relevance of this correlation value may be very limited. First, it is assumed that distance between locations is a good indicator of isolation or fragmentation. This research only considers linear distance regardless of the type of land use and the infrastructural features between recorded locations. It seem logical to think that pollinators will be more likely to reach populations of *P. patens* that offer land connectivity rather than locations completely surrounded by inhospitable land. It has also been proved that pollinators are influenced by landscape features, such as linear infrastructures, and the distribution of these features may have a direct impact on the reproductive success of the plant population (Cranmer et al. 2012).

Second, there may be a methodological bias on this reasoning. As explained in the methodology section, those populations that spread over a continuum of land, usually on open prairies, were recorded with one point every 100m approximately, recording the conditions within a 50 m radius. Although this methods is useful in representing local conditions (disturbances, density of population or number of individuals) and keeps the proportions regarding absolute distance from a reference point (the city centre); it distorts relative distance between points by the addition of a disproportionately high number of occurrences separated by 100 m. Finally, the spatial scope of the research also introduces a bias as only those populations within the vicinity of Saskatoon are considered, neglecting the influence of populations of *P. patens* located outside the study area.

Due to all these reasons, the calculated correlation is not considered to be significant and, therefore, it must be taken as an indication for future research rather than evidence. It is suggested that future researches could incorporate land use and spatial features into a spatial model, able to offer a more accurate and ecologically relevant estimation of isolation. Similarly, locations can be grouped into bigger units that reflect real functional populations and the impact of external populations can be integrated into the model. This approach will probably be able to offer more reliable and ecologically relevant results.

Disturbances

General distribution

Six different types of disturbance common in grasslands were recorded for each of the locations hosting *P. patens*. The degree of disturbance was classified in an ordinal scale of four ranks from zero (no disturbance) to three (strong disturbance). The proportion of locations showing evidences for each type and degree of disturbance is illustrated on figure 12.

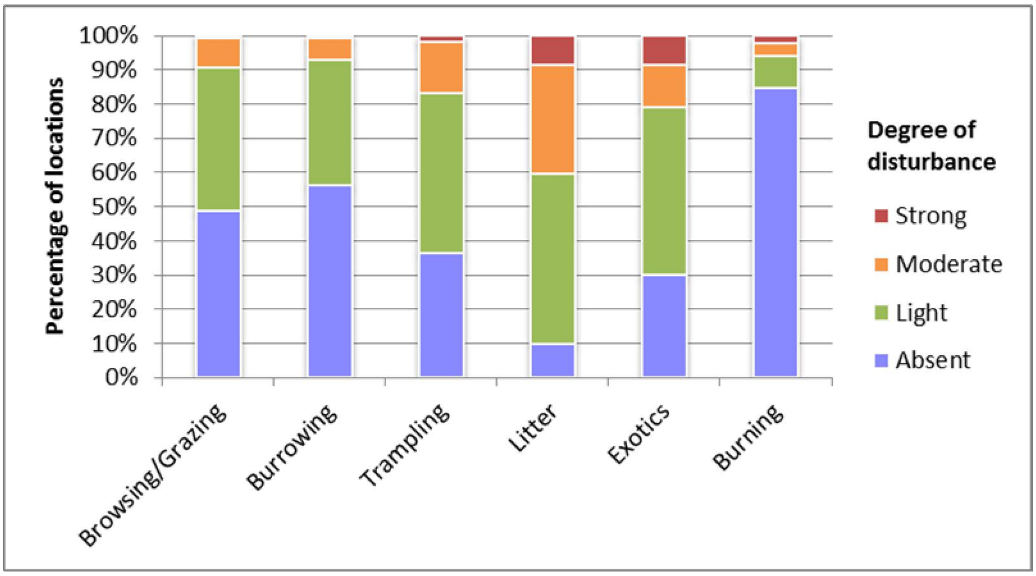

Figure 12. Proportion of sites being affected by different degrees of disturbance.

In the above figure it can be seen that there are relevant differences between disturbance types in their prevalence and degree. Browsing/grazing and burrowing show a similar pattern. Near half of the surveyed sites were free of these disturbances. In those locations where they were recorded it was mostly as a light disturbance. Only 8.8% of recorded sites hosting *P. patens* showed a moderate degree of disturbance by browsing/grazing. This proportion is even lower (6.4%) for burrowing. For both types of disturbance only one location was considered to be strongly affected.

Trampling (including the presence of trails) was a more common disturbance, being recorded in almost two thirds of the locations. Near a half of the surveyed sites (46.8%) were subject to light trampling either by humans, dogs or wildlife. Moderate trampling accounts for 15.2% of the records. Off-leash areas were observed to be particularly prone to show trails and evidences of light to moderate trampling. Once again, extreme cases trampling were rare, accounting only for three locations (1.7%) where strong trampling disturbance was recorded.

Accumulation of organic litter was the most ubiquitous type of disturbance, being found in 90% of locations. Almost half of total locations (49.7%) were subject to light litter built up. No other light disturbance was more frequently recorded than this one. Similarly, litter accumulation was also the most common type of moderate disturbance, affecting almost a third of sites (31.6%). Strong litter accumulation was found in 8.7% of sites, most of them on Kernen Prairie.

Although not as widespread as litter, disturbance by exotic species was very common. Exotic plant species were recorded as part of the community in 70.2% of locations. Light disturbance by exotic plants affected 49.2% of sites, being almost as common as litter accumulation. Moderate disturbance was rarer, being recorded for 12.2% of locations. A smaller proportion of sites (8.7%) were heavily invaded in exotic species, being subject to a strong disturbance.

Finally, burning was the most infrequent disturbance type affecting only 15.2% of recorded locations. Less than a tenth of sites (9.4%) affected by light trampling. Moderate or strong burning was found in just 3.5 and 2.3% of sites respectively.

All the exposed percentages are useful to provide an idea of the extension and the proportion of disturbances that are affecting the recorded populations of *P. patens* in Saskatoon and its vicinity. However, descriptive statistics has a limited capacity to reveal trends and synergies. In order to estimate the influence of each disturbance type on the survival of *P. patens*, Spearman correlation coefficients between disturbance type, population size and population density were calculated. In addition, each disturbance type was correlated with the other ones in an attempt to reveal synergies and causalities between them. Spatial patterns regarding concentric zonation were also analysed. The results are analysed below for each of the considered disturbances.

Browsing/grazing

As mentioned in the management section, grazing favours the establishment of *P. patens* as it prevents the built up of litter and decreases competition, while *P. patens* is not heavily grazed due to its toxic properties (Wildeman and Steeves 1982; Kalliovirta et al. 2006). Then, a positive correlation between grazing intensity and density/size of populations of *P. patens* could be expected. Regarding spatial considerations, grazing could be expected to increase as we move from the centre to rural outskirts. However, the results differ substantially from the expectations.

No significant correlation was found between browsing/grazing and either population size or population density. Instead, minor relationships with exotics (r_s= -0.210 p<0.01) and litter (r_s= 0.158, p<0.05) were revealed. No spatial correlation was found. The negative relationship between grazing and exotics seems interesting. Grazing is considered to be a very important factor in enhancing and keeping biodiversity in grasslands and has been widely used as a management technique for this purpose (Rook and Tallowin 2003). This is due to the differences in dietary choices and grazing pressure, resulting in an increased structural heterogeneity and, consequently, higher plant diversity. Notwithstanding, studies revealed that grazing can enhance species richness among both native and exotic species (Smith and Knapp 1999). Actually, these authors found that two of the most common exotics in Saskatoon, *B. inermis* and *Poa pratensis,* increased notably their frequency from ungrazed to grazed plots. Herbivores are known to facilitate the dispersion and invasion of many plant species through direct influence, such as importation of propagules or provision of disturbed microsite, from trampling or digging, for their establishment (Hobbs and Huenneke 1992). Grazing animals may also alter community structure and biotic interactions favouring indirectly the appearance of invasive species (Richardson and Bond 1991).

A possible explanation for this relationship strives on the argument that the effects of grazing are species-specific (Hobbs and Huenneke 1992). In our case, three of the most common exotics found during the surveys (*B. inermis, Poa pratensis* and *Agropyron cristatum*) were introduced in North America as foraging plants. Therefore, it seems logical to think that grazing will have a detrimental effect in their abundance and distribution. On the other hand, this consideration is contradictory with the positive correlation found between grazing/browsing and litter accumulation. If we assume that a higher number of herbivores and more intensive grazing are able to reduce the presence of exotics, where is the litter coming from? Do herbivores graze only on exotics letting native grasses to accumulate as litter? That does not seem biologically wise or coherent.

The obtained contradictory results may be related to the surveying methodology. In the field, grazing/browsing was estimated by visual proof of grazed plants, but also by other evidences that indicated the presence of herbivores such as droppings or tracks. Presence of herbivores, however, does not necessarily mean that the area is being used for foraging as it may be used just for transit, introducing a bias in the collected data. For all these reasons, it is considered here that the relationship between these variables needs further research prior to any assertion.

Burrowing

Burrows by gophers and other animals can provide small open areas of land, free of competitors, which can serve as substrates for seedling establishment of both native and exotic species (Hobbs and Huenneke 1992). Given the affinity of *P. patens* for open disturbed microsites (Uotila 1969; Kalliovirta et al. 2006) this disturbance type has potential to affect the distribution or abundance of *P. patens*. Nonetheless, the statistical correlation revealed no significant relationship between burrowing intensity and *P. patens* population size/density. Similarly, it was not correlated with any other disturbance type.

Trampling

No significant correlation between trampling and population size/density was revealed. A significant negative correlation with distance from the centre was found (r_s= -0.205 p<0.01). It is common sense that the further we move from the densely populated city centre, the smaller the presence of trails and the lower the impact from dog and human trampling will be. A positive correlation with litter accumulation was found (r_s= 0.265 p<0.01). No ecological meaning or explanation has been found for this relationship.

Although the plant can stand light trampling, excessive trampling can have an adverse effect on the species (Uotila 1969). This fact has been recorded in the field, where individuals located on the margin of trails tend to be smaller and have fewer flowers than those individuals located in less trampled areas. However, some sites such as the upland prairie at Wanuskewin Heritage Park, showed a surprisingly high density of *P. patens* within the trail, in comparison to the surrounding area. This is probably due to the fact that trampling there was strong enough to open areas and reduce competition but no so intense to preclude the plant to develop. It also seemed that the trail is regularly mowed, fact that can also help *P. patens*.

Litter

No significant correlations between litter accumulation and any other parameter were found other than the already mentioned browsing/grazing and trampling. This is surprising, given that the detrimental effect of litter in seedling establishment of *P. patens* has been widely recorded in European populations (Kalliovirta et al. 2003; 2006; Röder and Kiehl 2006; Juśkiewicz-Swaczyna 2010). It can be argued that European locations of *P. patens* are usually related to boreal forest habitat with different light regimes than in North America, where *P. patens* is a clear prairie species. However, the study by Röder and Kiehl (2006) develops on the only German population which happens in open grassland. Probably the scale of this thesis is too big and the methodology too coarse (simple visual scoring). A more detailed study using small quadrats and a numerical quantification rather than a score may help to clarify the influence of this parameter in the performance of *P. patens*.

Burning

Fire is a common management technique for biodiversity conservations in the Canadian prairies (Romo 2003; 2007). Occasional fire is also considered to be a positive disturbance for *P. patens* as it can survive them easily and grow in a competitor free environment (Wildeman and Steeves 1982). However, the statistical analysis showed no correlation with any of the other disturbance types or with the size or density of population of *P. patens*. This suggests that fires in urban settings may have a lower impact than in open extensive prairies, being other disturbances more relevant. In any case, it should be noted that very few sites were recorded to be affected by burning so the sample size may be too small to establish significant correlations. A larger dataset may offer more detailed insights.

Exotics

During the XX century, efforts to provide erosion control and improve forage quality involved the introduction of several exotic pasture grasses such as the already mentioned *B. inermis*, *P. pratensis* and *A. cristatum* (crested wheat grass). Together with *Melilotus* spp. they were the most frequent invasive plants found during field surveys. None of them are included in any schedule of the Saskatchewan Weed Control Act (Government of Saskatchewan 2010) and only *M. officinalis* is included on the invasive species list elaborated by the Saskatchewan Conservation Data Centre (2012). Among the observed exotics, *B. inermis* was the most common, being found almost everywhere, particularly on disturbed areas. In some of the surveyed areas, especially those with a high water table, *B. inermis* reached very high densities, seriously hindering the development of any other herbaceous species. In rolling moraines, it was common to record populations of *P. patens* grouped on the drier top of the mounds while *B. inermis* was crawling up from the bottom enclosing them. *P. pratensis* was also quite common although not as dense as *B. inermis*.

A study at Grasslands National Park, Saskatchewan, concluded that the invasion of natural grassland by *B. inermis* results in lower diversity and decreased resource availability. This was especially true for light availability, which is a key factor for the development and recruitment of new individuals of *P. patens* (Pilt and Kukk 2002; Kalliovirta et al. 2006; Röder and Kiehl 2006). In a modelling study, William and Crone (2006) found that *P. patens* tends to prosper in native grass patches and decline in invasive ones. The presence of *B. inermis* also increased substantially the modelled probability of extinction *for P. patens*. They also found that *B.*

inermis has a significantly more pervasive effect than *P. pratensis* on the survival of populations of *P. patens.*

The scores for exotics species were correlated with the rest of disturbances as well as with population size/density. No significant correlation was found other than the aforementioned one with browsing/grazing. These results were striking given the mentioned observations and studies.

The equal consideration given to all exotics during the surveys could have had an influence on the statistical analysis. During the data collection phase, all the invasive species were considered equally regardless of their effects on the prairie habitat and *P. patens* in particular. Also, both density and diversity of exotics were regarded when awarding a score. This means that a location with a moderately dense cover *of P. pratensis* and three or four other exotic species present would probably get the maximum score, the same than a monoculture of *B. inermis*. The difference strives in that the first example is probably able to support populations of local plant species, like *P. patens*, while the second is very low in diversity and completely dysfunctional from an ecological point of view.

As aforementioned, *B. inermis* is more threatening to *P. patens* than *P. pratensis*. In addition, the biogeographic status of *P. pratensis* is controversial. Although this species is generally considered as an invasive exotic in Canada (IUCN-ISSG 2010), some authors consider this species to comprise a set of varieties and subspecies, some of which are native to Canada and some of which are introduced (Sutherland 1986; Gleason and Cronquist 1991; Cody 1996). It has even been suggested that *P. pratensis* has always been part of the natural flora of Saskatchewan and the observed invasive expansion is the response to relatively recent climatic events (Delcan Western 1994). In any case, it seems clear this plant is naturalized and has been part of the flora of Saskatoon for at least near a century (Delcan Western 1994). These considerations suggest that *P. pratensis* could be treated differently to the rest of recorded exotics and, if we accept that this species may be native, it should be removed from the exotics score in the field surveys.

As described in the methodology section, original data were reviewed case by case and the effect of *P. pratensis* on the dataset was minimized. New Spearman correlation coefficients were calculated, offering very different results. First, and apart from the mentioned relationship with grazing, exotic species happened to be positively correlated with trampling (r_s= 0.233, p<0.01). As aforementioned, trampling from animals or humans can result in disturbed microsite bare land that favours the establishment and germination of exotics (Hobbs and Huenneke 1992). Humans are also known to be a very important vector for the dispersal of exotics therefore, assuming trampled areas are more frequented by humans, it seems logical to find a positive relation between trampling and exotics.

Statistics also revealed a negative correlation between invasive species and burning (r_s= -0.176, p<0.05). This correlation makes ecological sense as burning eliminates individuals of exotic species but allows native species, adapted to cyclical fires, to survive. In fact, burning is one of the most common techniques in the prairies to fight against invasive species in general (DiTomaso 2000) and against *B. inermis* in particular (Willson and Stubbendieck 2000; Salesman and Thomsen 2011). Finally, it should be noted that this is the only disturbance type that has a significant correlation with population size of *P. patens* (r_s= -0.158, p<0.05). The potential impacts of invasive species, particularly *B. inermis, on P. patens* have already been detailed before.

No correlation between exotics and distance from the centre or *P. patens* population density was found. Cities are known to be hotspots for exotic species. In some North America cities, the proportion of aliens was estimated between 19 and 46%, with an average percentage of 35% (Clemants and Moore 2003). A decreasing urban-to-rural gradient regarding number of exotics has been recorded by some authors, suggesting the functioning of human settlements as invasion foci (Kowarik 2011). This is also the case of Saskatoon, where Lineman (2000), on his study about the flora of the valley, found exotics to be more abundant in the centre of the city than in the outskirts. Because of this, the absence of a correlation seems surprising. It is argued here that this urban-to-rural gradient may exist in Saskatoon but the field methodology precludes it to be revealed. As aforementioned, density of alien individuals was considered on the score together with species diversity. This means that a location strongly dominated by one exotic species may be awarded the same score than another location with two or more less dominating ones. Therefore the score recorded here is not representative of the number of exotic species. More detailed species-specific research is needed in order to accurately estimate the impact of exotics on *P. patens*.

Regarding *P. patens* population density, no disturbance type has been correlated with it, only distance from the city centre seem to match. Similarly, population size only was valid for this last case of exotic species. This lack of correlation suggests that either *P. patens* is not influenced in a relevant way by any of the studied disturbances or, what is more likely, that population size and density may not be good indicators of local disturbance. It should be noted that population size and density offer a picture of the population at the moment of the research, but offer no information about population dynamics. Recent disturbances may be affecting a population but this may not be obvious until a few seasons or even some generations. Also, population size and distance may change from one year to the other simply because of weather conditions (e.g. late spring frost). Therefore, long term studies have probably more potential to identify trends than a one season study like this research. Consideration of the age structure of the population may also be very useful as it can show the response of the whole population against disturbances and indicate the direction of the population (increasing, stagnant, shrinking). Future research considering *P. patens* should take these approaches into account.

Urban Development

Historical development

In order to estimate the impact of urban development on the populations of *P. patens*, existing locations were plotted over a map illustrating the historical expansion of the city (Appendix D). It should be noted that the areas showed on the figure correspond to that land being annexed to the City of Saskatoon on its expansion, but does not necessarily mean that land to be developed or urbanized on that time. Table 8 summarizes the results.

Table 8. Number of locations hosting *P. patens* according to the period when that land was purchased by the City of Saskatoon.

Pre 1883	1883 - 1910	1910 - 1919	1950 – 1959	1960 - 1969	1970 - 1979	1980 - 1989	1990 - 1999	2000 - 2005	2005 - 2012	Outside city limits
0	0	4	50	1	7	0	0	34	27	48

It is assumed that, before the arrival of the first European settlers, a big proportion of the city had potential for *P. patens*. Given the limited dispersal capacity of the species, it is also assumed that none of the current populations of *P. patens* are new and that they were present before the expansion of the city. As we can see in the above figure and table, no *P. patens* were located on the oldest part of the city and only four records are located on lands annexed before 1950. It was in the expansion of the 50s, with the annexation of the land corresponding now to the University of Saskatchewan North Management Area and surroundings, when the land containing a significant proportion of current locations was included into the city limits.

Most of locations on the northwest part of the river were incorporated to the city during the 70s. However, during the last twelve years the city has expanded covering as many locations of *P. patens* as in the rest of its history.

The lack of locations in the oldest part of the city is probably due to the strong and continued human influence on the area. This part of the city is heavily urbanized and most of available green areas dominated by heavily managed parks with manicured lawns and little potential for biodiversity. The only noticeable exception is the riverbanks. During fieldwork the margins of the river were surveyed and some small parts, especially some slopes on the east side, were considered to have good “landscape features” to host *P. patens* (e.g. slope, aspect, soil). However, these areas were generally heavily overgrown in exotics, particularly *B. inermis,* being too inhospitable for *P. patens*. The dense presence of exotics was a common factor in many surveyed area that had been surveyed in the past. Probably during the conditioning of green areas (e.g. trails along the river) these areas of grassland were heavily disturbed, being rapidly colonized by exotics. *P. patens* and other native grasses and forbs would not be able to survive such grade of disturbance and would not be able to establish on the area. Other factors such as fertilization with N from human influence is likely to be happening and this would also favour the appearance of invasive exotics.

It can also be seen that many of the current locations have been part of the city for more than 50 years. Why are there so many locations hosting *P. patens* there and not in other older or newer areas of the city? The answer seems easy: conservation. The populations of *P. patens* in areas annexed during the 50s are mainly located within Saskatoon Natural Grassland and Regional Psychiatric Centre Prairie conservation areas. These conservation areas are managed by Meewasin Valley Authority with the intention of preserving them as natural prairies. Notwithstanding the status of conservation areas, most of their extension is open to the public and are used as off-leash and recreational areas. Some impacts from public use has been observed of these areas (e.g. vandalism, off-trail trampling) but in general they provide a good example of prairie habitat within an urban matrix, including many individuals of *P. patens*. Therefore, it seems that time of exposure to human influence is not as important as preservation and management of the area. Actually, from all the 171 locations considered on this study, 143 fall within managed and protected areas. Of them, 121 are included in Meewasin Valley Authority conservation land, 1 in their buffer area and 21 in Kernen Prairie, a University owned land preserved managed as a prairie for research purposes. This confirms the importance of the designation of conservation areas within the urban fabric and the importance of balancing public access, management and conservation goals.

From the locations hosting *P. patens* which are not in conservation areas, there are two which deserve special interest. These are the one next to the 11th St grain elevator and, especially, the one in Ravine Drive. Their position is identified in the map of Appendix C. The small population on 11th St is roughly 50 m from the residential neighbourhood of Montgomery Place. This neighbourhood was already in place in 1953. It was included into the city shortly after and now, although near the urban perimeter, the location is surrounded by residential suburbs.

The population of *P. patens* present there have survived more than half a century of proximity to a relatively dense human settlement. However, during the survey just a few individuals were found, being the place severely impacted by the very recent construction of a road right across the grassland area. The disturbance from road construction works extended largely, reaching more than 50 m to each side of the road. This is not the only example of a population of *P. patens* being severely affected by road development. One of the herbarium records was collected in the road cross of Clarence Ave. with Idylwyld Dr. (Appendix C). That population has disappeared, probably due to road works to upgrade the mentioned road cross.

Another interesting urban population is the one found on Ravine Drive (Appendix C). This population was limited to a pocket, small in size, but containing near 100 individuals. It was located on a slope, out of sight from the sidewalk, but just 10 m the road and an adjacent house. This location was outside the urbanized areas in 1953, with some nearby development being carried out by 1966. Nineteen years later it was completely urbanized. Although still counting with several dozens of generative individuals, this population has been noted to be slowly declining for the last two decades (Delanoy, L. Personal communication). Once again, lack of management and invasion of exotics were evident in the field.

The exposed cases are examples of populations surviving in an urban dominated area for a long period of time. However, there are other populations which can be now affected by just the proximity to humans. A spatial analysis revealed that 33 of the 171 locations are within 100 m distance from existing roads. This distance may seem arbitrary and exaggerated. However, it should be noted that the points are recorded at the centre of the population and this can cover up to 50 m radius from the centre. In any case, this number suggests that people and *P. patens* are not as distant as one may think and their coexistence is not as improbable as Uotila (1969) described.

The future of *Pulsatilla patens* in Saskatoon

The future expansion area of Saskatoon is shown in Appendix D. Considering a buffer zone of 100 m from the projected roads and residential development, 24 locations could be potentially affected. It is assumed that Kernen Prairie will not be affected by development as this land belongs to the University of Saskatchewan. It seems that only a few of the recorded populations will be affected by new residential development. This includes the areas in the North West side of the river. Only four locations were found there, however that area needs to be developed and was not fully surveyed due to access constrains to private property and it is suspected to be richly populated with *P. patens*. Also, after more than 50 years surviving in close relation to people, the population on 11th street, the only one at the south west of the city, will be turned into a residential complex. Roads are also deemed to have a significant potential to impact current populations. The planned perimeter highway, which will involve a new bridge at the north of the city, will have an impact on populations at both margins of the river. However the most threatening road is the one running in parallel to the Northeast Swale. This road is projected to run directly over recorded populations of *P. patens*. As this plant is not legally protected, no legal claims can be done. However, this area was considered of ecological importance. Not only because of *P. patens,* but also because it was a natural grassland of relatively good quality, with a good representation of native species and it was very close to a residential area. This area is also located between three conservation areas, Saskatoon Natural Grassland, Regional Psychiatric Centre Prairie and Northest Swale, having an important role as an ecological corridor. During the survey, some neighbours also showed their concern about this projected road.

Given the presence of existing roads running through the projected residential development that the new road is intended to serve, the real necessity of this road is questioned here. Instead of a road, this area could be integrated into the conservation areas network, establishing an ecological corridor between them. Proper management, signposting and development of trails may provide recreational areas of good quality at the doorstep of the surrounding community. In any case, every effort should be done to minimize the impacts around any future development.

Regarding protection measures, areas under development to the southwest of the city were surveyed (Lakewood and surroundings Appendix C). A relevant wetland area, Hyde Wetlands, was located in the centre of the development. There is a plan for these wetlands to be preserved and integrated into the neighbourhood as an educational and ecological site (Ducks Unlimited 2007). During the survey it was observed that the wetlands were fenced and protected from the surrounding development but grassland surrounding it was completely torn up using heavy machinery and turned into bare land. Asked about that, Gary Pedersen, Naturalized Areas Supervisor of the City of Saskatoon, clarified that it was decided after considering that the grassland surrounding the ponds was too heavily invaded in invasive weeds to be kept. After the development a program of restoration with native grassland species will be put in place. The Parks Policy adopted by the local administration is encouraging the maintenance of native flora as much as possible during the construction of new parks. Actually, there is a Naturalized Parks Project in Saskatoon (Pedersen 2011). Under this project, local NGOs, volunteers and the local administration are collaborating for planting native species in local parks. So far it has been focused in berry shrubs to attract birds and a pilot grass seeding study. However, the project is growing and new areas are expected to be seeded. Staff in charge of city parks is also receiving training for management of natural grasslands (e.g. fire). *P. patens* has not been considered yet but this project may result in potential habitat for its reintroduction.

Finally, education of the public is also a key factor. Many people cannot differentiate between natural grassland and an overgrown patch of weeds. This is especially relevant in parks, where some would expect just lawn. Communicating with the communities the benefits of having natural grassland on their area and involving them into their development and management may be a good idea. The erection of informative posts may also help on this duty. In short, the Naturalized Parks Project and the newly adopted policies and practices offer some hope for the establishment of healthy grasslands within the city, combining restoration of natural habitat, reintroduction of native species like *P. patens*, enjoyment of public and education.

Conclusion

The research was focused on four aspects of *P. patens* in urban areas: habitat preferences, spatial trends, effect of disturbances and impact of urban development. Regarding habitat preferences it was observed that *P. patens* has a preference for gentle slopes of less than 5°. It is also more frequent in the upper part or the crest of the slope. These results agree with the observations made in Europe (Uotila 1969). However, aspect preferences within the study area differ totally with those recorded by that author. While in Europe, *P. patens* is much more frequent in southern slopes, in Saskatoon this species clearly prefers north facing slope. This is due to the more continental climate on the prairies compared to Scandinavia. Individuals on south facing slopes in the prairies risk flowering too early, being damaged by early spring frost. Similarly, southern slopes can be too dry during the summer preventing germination of seeds. Regarding elevation, significant correlations were found with browsing/grazing, litter accumulation and impact from exotics. However, differences in elevation within sites are too small to consider these correlations indicative. Soil type and characteristics were inferred from chemical analysis and the location of the occurrences.

Spatial distribution of occurrences of *P. patens* follows a clearly identified trend of concentric zonation. This trend was made evident with the significant positive correlation of distance from the city centre and size, density and frequency of occurrences of *P. patens*. In other words, as we move from the city centre to the outskirts, occurrences of *P. patens* become more common, with more total individuals and more individuals per hectare. Frequency of occurrence of *P. patens* was negatively correlated with human population density and proportion of urbanized land. Therefore, the further from the centre, the more frequent the locations of *P. patens*, the lower the human population and the lower the proportion of built up land. The strength and significance of these correlations suggest that spatial distribution, especially regarding concentric relationships, is an important force driving the distribution of this plant in urban areas. Distance between locations, as a measure of isolation between occurrences, was negatively correlated with population size. However, given the methodological and conceptual limitations of the variable "distance between points", this result should be taken very cautiously.

Disturbances are affecting locations hosting *P. patens* with variable frequencies and intensities, being litter accumulation and presence of exotics the most common ones. A significant negative correlation was established between burrowing/grazing and the impact from exotic species in general. If we ignore the influence of *Poa pratensis* in the analysis, exotic species disturbance is negatively correlated with size of the population of *P. patens* and burning, while it is positively correlated with trampling. This suggests three findings supported by literature. First, *P. patens* is negatively affected by exotic species. Second, there are interactions between disturbances; while burning seems to control the presence of exotics, mechanic disturbances like trampling open new areas for their establishment. Third, the impact from exotics is complex and depends on each exotic species, highlighting the need for more detailed research. Regarding spatial considerations, trampling is the only disturbance type that decreases significantly from the centre to the periphery. It should also be noted that variables expected to show a clear relation with *P. patens* population size, such as litter accumulation, seemed to be less relevant on our case compared to literature.

Regarding historical urban development, field observations and historical development suggest that the presence of *P. patens* is Saskatoon is determined by the degree of disturbance, especially urban expansion and exotics, and the establishment of conservation areas rather than time exposed to human influence. Many populations have been lost due to urban expansion, and a few more are expected to be lost in the following years. However, there is a good pool of individuals within the city, especially in protected sites, and examples show that *P. patens* can live for many years in dense urban areas. Lack of management can come after the mentioned decline of some of the populations but recent policies have included the preservation of natural vegetation and its reestablishment in already developed parks. These initiatives are still young but offer some optimism about the future of natural grasslands within the city. However, these efforts may not be enough for *P. patens*. The creation of suitable habitat within the city is the first step but given the limited dispersive capacity of this plant, direct seeding or seedling transplant should be considered.

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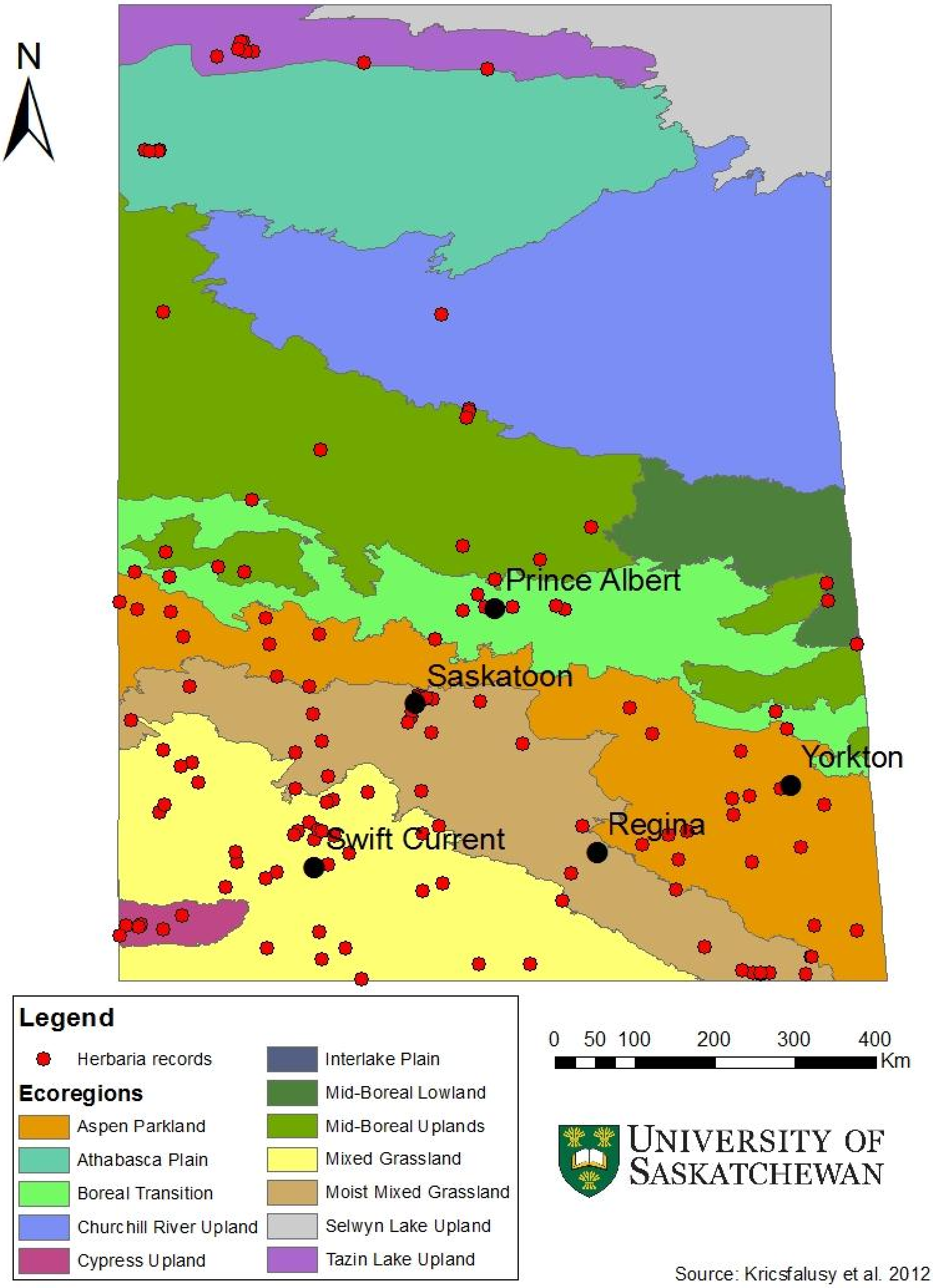
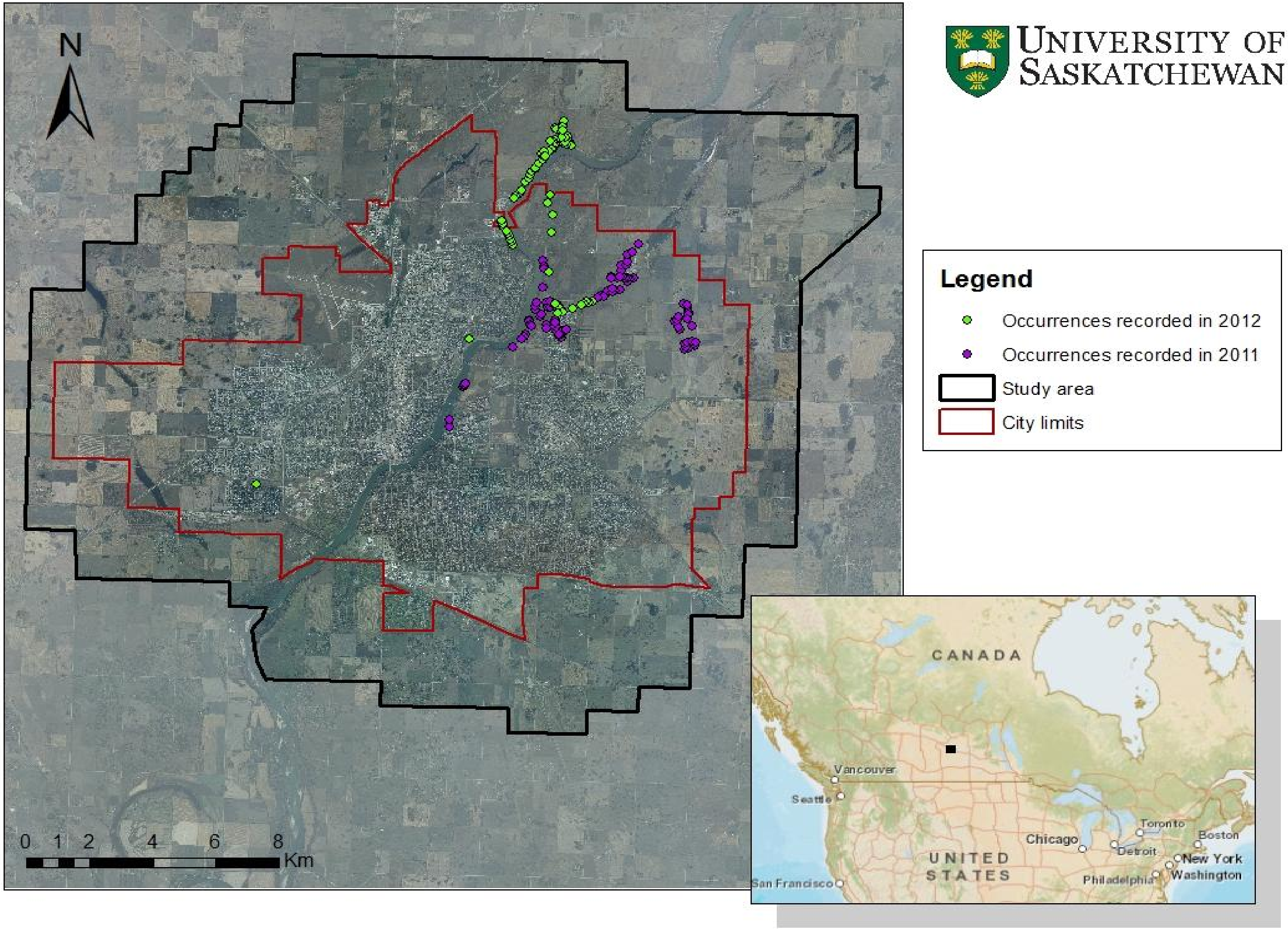
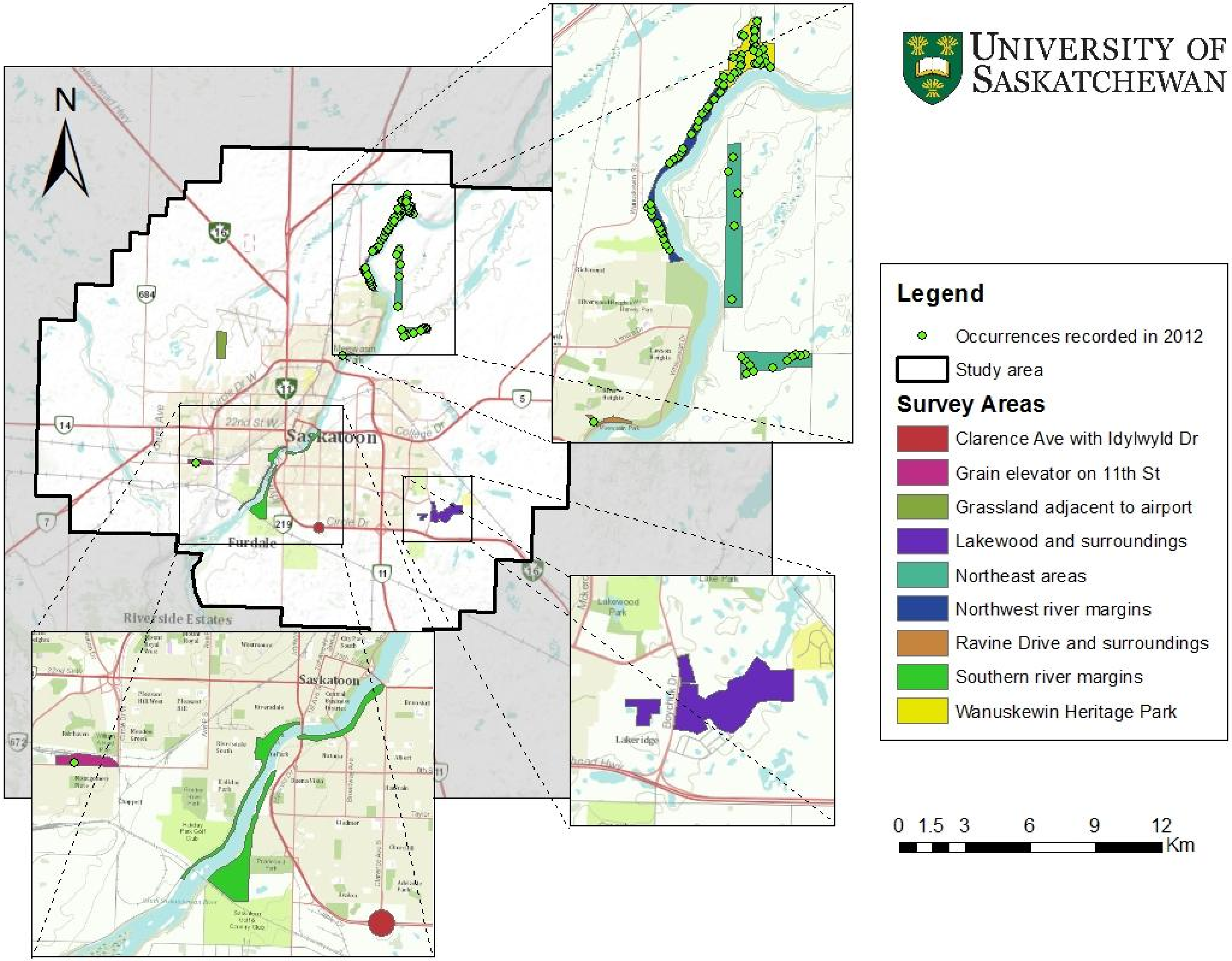
Appendix A - Map of the distribution of herbaria records of P. patens in Saskatchewan



Appendix B – Map of the study area around Saskatoon.



Appendix C – Map of areas surveyed during the fieldwork



Appendix D. Historical land annexation by the City of Saskatoon.