PLANTS

USING MULTIPLE DATA SOURCES ON SPECIES DISTRIBUTION FOR BIODIVERSITY ASSESSMENT: THE PRARIE CROCUS (ANEMONE PATENS) AS A CASE STUDY

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INTRODUCTION

Biodiversity assessment requires precise data about species distribution that are lacking for many areas because they are often incomplete or biased[1,2]. Recently, many studies are turning to the vast amount of information associated with the natural history collections, particularly herbaria. Herbarium data are useful for biodiversity exploration[3,4], identification of species of conservation concern[5], development of regional red lists[6], prioritizing of rare species for conservation planning[7,8], documenting effects of urbanization on flora[9] as well as assessment of spread and status of invasive species[10,11]. For a comprehensive analysis of studies on biogeographical patterns and various environmental questions where herbarium collections have been successfully used, refer to Lavoie[12]. In most cases herbarium data provide error-free information[5]. However, because of its existing limitations[2], additional sources of information are required to assist in biodiversity assessment and conservation planning.

Although mostly ignored until now, freely accessible citizen science phenology databases, which have advanced intensely during the last decades, might be another source of information about species distribution. Monitoring programs like NatureWatch in Canada are highly cost effective and provide a wealth of accurate data[13]. A part of NatureWatch is the PlantWatch program which was established by Nature Canada and Environment Canada's Ecological Monitoring and Assessment Network[14]. PlantWatch enables citizen scientists to get involved in research by recording flowering times for selected plant species and reporting these dates to databases or researchers. Based on the evidence of high effectiveness of the PlantWatch program[13], the phenological records from the regional databases like the Saskatchewan PlantWatch[15] might be a good data source about plant species distribution.

Field observations and surveys, recorded in the form of vegetation relevés, also provide valuable data for biodiversity assessment; however they are not often used for distribution analysis. Field surveys can help to establish how representative existing herbarium specimens are of general species range within the study area. In the course of the recent studies on sensitive plant species and vegetation communities in Saskatchewan[8], a few hundred inventories were produced which contain georeferenced distribution data. These data offer particularly valuable information on plant species occurrence within the province's Representative Areas Network (RAN), which is intended to conserve varied and unique landscapes of Saskatchewan[16].

Data on species distribution obtained from different sources, i.e. herbarium collections, phenological database and field surveys, often do not have the same level of accuracy[17]. This is mostly because they were collected using different approaches, i.e. the traditional *ad hoc* method versus systematic survey. Also, distribution data often were recorded before the widespread use of global positioning systems (GPS), particularly the older data in herbarium collections, and therefore in many cases cannot be georeferenced with a high level of accuracy. The combined analysis of data obtained from different sources may minimize the biases associated with each of the data sets which will eventually help to judge the biodiversity conditions to improve the quality of biodiversity assessments.

We initiated study on using multiple data sources for distribution analysis to inform biodiversity assessment by selecting the prairie crocus (*Anemone patens* L.) from the buttercup family

(Ranunculaceae) as a model species (Figure 1). This plant is a common species of native grasslands in Saskatchewan[18], which have experienced a dramatic decline as a result of changes in land use and the lack of a natural dynamic regime (e.g. grazing, fire) during the last centuries[19]. Current estimates indicate that, on average, less than 20% of the original prairie in the Central Plains remains, and only 3.5% has been protected overall within Canada. For some prairie types, the situation is critical; e.g. most of the fescue prairie in Saskatchewan was ploughed and less than 1% of the once vast area remains[19].

A. patens is a typical example of a prairie plant that has declined greatly because most of its habitat were ploughed or cultivated[20,21]. Therefore, studying distribution and range dynamics of *A. patens* can provide conservation planners with important insights into how this and other prairie plants may respond to the increasing anthropogenic impact and how to model the landscape to help assess the effects of different projects development on biodiversity. This approach will also allow expanding the current knowledge on habitat preferences of *A. patens*, as well as important features of the species ecology and biology.

Figure 1. The prairie crocus (*Anemone patens*).

METHODS

For the purposes of this study we access the freely available distribution records of *A. patens* from herbarium collections and phenological database, as well as conducted intensive field surveys. Distribution records of *A. patens* were obtained from herbarium specimens collected in the period from 1920 to 2000. In order to reduce the herbarium data gap which occurred after the year 2000, observation records from the SK PlantWatch (2001–2010) and author's field surveys (2011–2013) have been included in this study.

Herbarium data

Specimens of *A. patens* from the collections in the W.P. Fraser Herbarium of the University of Saskatchewan in Saskatoon (SASK)[22] and the G.F. Ledingham Herbarium of the University of Regina (USAS)[23] were the primary sources of herbarium data for this study. Distribution data from the National Collection of Vascular

Table 1. Records of *Anemone patens* occurrences in Saskatchewan (derived from the W.P. Fraser Herbarium of the University of Saskatchewan – SASK)

Period	No of collectors	No of specimens in SASK deposited	No of specimens in SASK analyzed*	Percentage of total
1920–1930	4	4	0	2.6
1931–1940	7	10	5	6.6
1941–1950	2	4	3	2.6
1951–1960	13	13	13	8.6
1961–1970	10	36	35	23.8
1971–1980	13	27	27	17.9
1981–1990	18	30	29	19.9
1991–2000	18	27	27	17.9
Total		154	137	100.0

Note: *Specimens were removed from analysis if they could not be georeferenced.

Plants in Agriculture and Agri-Food Canada (DAO)[24], the National Herbarium of Canada (CAN)[25] in Ottawa, and the Vascular Plant Herbarium of the University of Alberta in Edmonton (ALTA)[26] were also used in our study.

In total, 179 specimens of *A. patens* from the SASK were investigated (Table 1). Of these, 24 specimens outside of Saskatchewan and one specimen lacking location data were excluded from the analysis. Therefore, 154 records have been further analyzed. In cases where latitude and longitude were not indicated, the coordinates were estimated based on the legal survey information given in terms of quarter, section, township and meridian data or the best possible location point was estimated using the Google Earth and the Atlas of Canada reference maps[27]. Coordinates that were estimated may have inaccuracies of 5–10 km. All recorded points were mapped using Google Earth. From the preliminary selected 154 records, 17 locations could not be correctly estimated due to inadequate data on the voucher specimens and hence 137 locations of *A. patens* from SASK were identified for the distribution analysis.

The same procedure was used with respect to specimens from all herbarium collections listed above. In addition to the data gathered from the herbaria, a total of 3 records of *A. patens* specimens collected in Saskatchewan were obtained using on-line access from the Vascular Plant Herbarium of the University of Alberta[26]. Thus, finally selected 177 voucher specimens, asserted from 1920 to 2000, formed database of records from herbarium collections (137 – SASK; 31 – USAS; 6 – DAO and CAN; 3 – ALTA) for the *A. patens* distribution analysis.

Phenological data

The SK PlantWatch[15] database contains 83 georeferenced phenological observations of *A. patens* recorded by volunteers in Saskatchewan between 2001 and 2010. All recorded points were checked for accuracy and mapped using Google Earth. All recurrent points were excluded to eliminate multiple year collections at the same location (58 points). Two locations were excluded, as the plants were not growing in the wild. In this way 23 observation records from the database were selected and included in further distribution analysis.

Survey data

Field surveys to search for *A. patens* were conducted by researchers and student volunteers from the University of Saskatchewan in the six province's ecoregions (Table 2). These field surveys were carried out at the sites with federal (2 national parks), provincial (3 provincial parks), and private (7 rangelands) land ownership. We also surveyed preserved remnants of natural grasslands within the city of Saskatoon and its vicinity, which are under municipal administration (9), managed by the Meewasin Valley Authority (8), Wanuskewin Heritage Park (1) or the University of Saskatchewan (1). Visits were made from the end of April to early June in 2011–2013. Student volunteers from the School of Environment and Sustainability at the University of Saskatchewan contributed above 150 hours to this survey effort.

Field surveys were conducted by walking. A total 288 point occurrences of *A. patens* were georeferenced in these locations using a handheld GPS unit. As a general rule, two occurrences of *A. patens* were considered to be distinct if their centers were separated by at least 100 m. In some cases the recorded large locations were an artificial representation of a population continuum. To minimize sampling bias, we identified occurrences as separate points only when they were more than 1 km apart. In this way, 74 occurrences out of 288 were selected for distribution analysis.

GIS analysis

A map depicting the distribution range of *A. patens* in Saskatchewan was prepared for the final 274 records from different data sources: herbarium collections (177), phenological database (23) and field surveys (74). Distribution of *A. patens* is shown in 325 UTM grid cells 50 x

Table 2. Geographical locations of field surveys of *Anemone patens* in Saskatchewan (n = 74 occurrences)

Survey site	Ecozone	Ecoregion
Greenwater Lake Provincial Park	Boreal Plain	Mid-Boreal Upland
Prince Albert National Park	Boreal Plain	Mid-Boreal Upland
Redberry Lake Biosphere Reserve	Prairie	Aspen Parkland
The Battlefords Provincial Park	Prairie	Aspen Parkland
City of Prince Albert	Prairie	Boreal Transition
Cypress Hills Interprovincial Park	Prairie	Cypress Upland
Grasslands National Park	Prairie	Mixed Grassland
City of Saskatoon	Prairie	Moist Mixed Grassland
Meewasin Valley Authority	Prairie	Moist Mixed Grassland
University of Saskatchewan	Prairie	Moist Mixed Grassland
Wanuskewin Heritage Park	Prairie	Moist Mixed Grassland

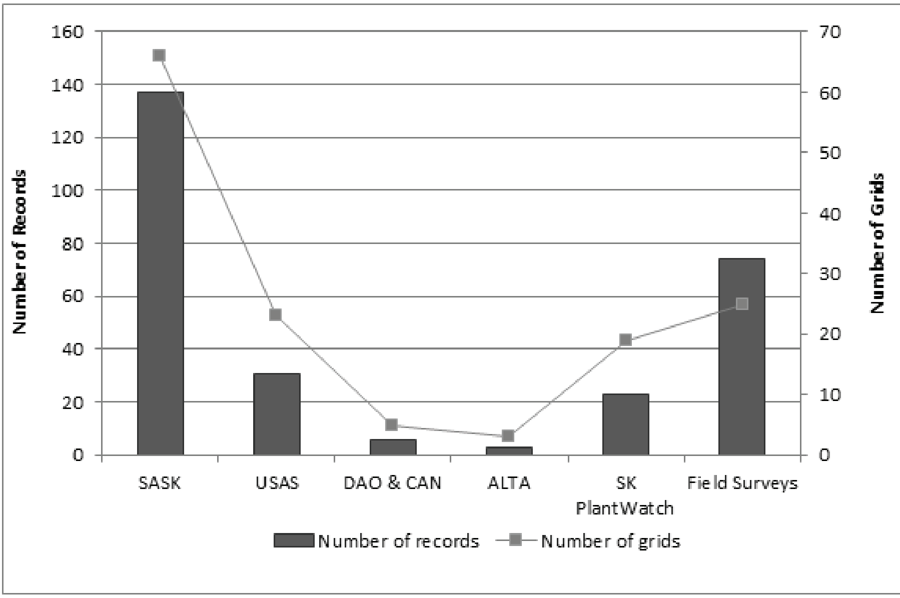

Figure 2. Collecting intensity of *Anemone patens* in Saskatchewan (location records and mapping grids): SASK – W.P. Fraser Herbarium of the University of Saskatchewan; USAS – G.F. Ledingham Herbarium of the University of Regina; DAO – National Collection of Vascular Plants in Agriculture and Agri-Food Canada; CAN – National Herbarium of Canada; ALTA – Vascular Plant Herbarium of the University of Alberta; SK PlantWatch – Saskatchewan PlantWatch phenological database; Field surveys – author's vegetation relevés.

50 km (Table 3). This approach is in accordance with plant distribution maps for other parts of the world.

We developed ArcGIS layers using data from different sources and plotted *A. patens* occurrences. To analyze the *A. patens* habitat associations across the range, the following GIS layers were considered: topography, ecological systems (ecozone, ecoregion and ecodistrict), climate (precipitation, temperature and climate moisture index), soils, land cover, and protected area. The ecological systems layer is a subset of the National Ecological Framework for Canada, which is designed in a nested hierarchy of ecozones, ecoregions, and ecodistrict, all these 3 layers were acquired from AAFC website[28], and analyzed in this paper.

Table 3. Records of *Anemone patens* occurrences in mapping grids 50 x 50 km in Saskatchewan (derived from different data sources)

Data source	# records	% total	# grids	% total	# new grids	% total	accumulated # new grids	% total
SASK	137	50.0	66	46.8	66	67.3	66	67.3
USAS	31	11.3	23	16.3	10	10.2	76	77.6
DAO & CAN	6	2.2	5	3.5	5	5.1	81	82.7
ALTA	3	1.1	3	2.1	0	0.0	81	82.7
SK PlantWatch	23	8.4	19	13.5	6	6.1	87	88.8
Field surveys	74	27.0	25	17.7	11	11.2	98	100.0
Total	274	100.0	141	100.0	98	100.0	98	100.0

Note: SASK – W.P. Fraser Herbarium of the University of Saskatchewan; USAS – G.F. Ledingham Herbarium of the University of Regina; DAO – National Collection of Vascular Plants in Agriculture and Agri-Food Canada; CAN – National Herbarium of Canada; ALTA – Vascular Plant Herbarium of the University of Alberta; SK PlantWatch – Saskatchewan PlantWatch phenological database; Field surveys – author's vegetation relevés.

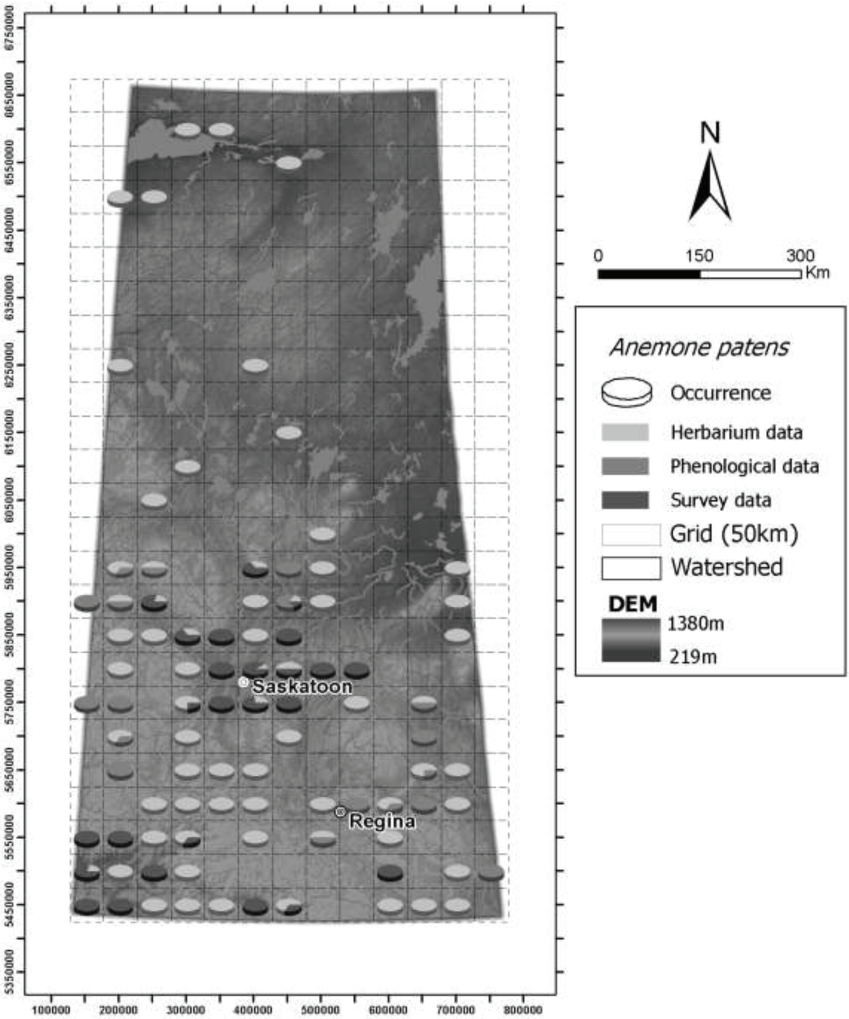

Figure 3. Distribution of *Anemone patens* in Saskatchewan.

The digital elevation model (DEM) layer at the scale of 1:250,000 was derived from GeoBase website in ASCII format and is part of the Canadian Digital Elevation Data[29]. To cover the whole territory of the province, 54 sliced tiles of the DEM layer were downloaded, mosaicked and clipped in this study. The land cover layer was acquired from the Geogratis website in vector format, at the scale of approximately 1:2,000,000 from

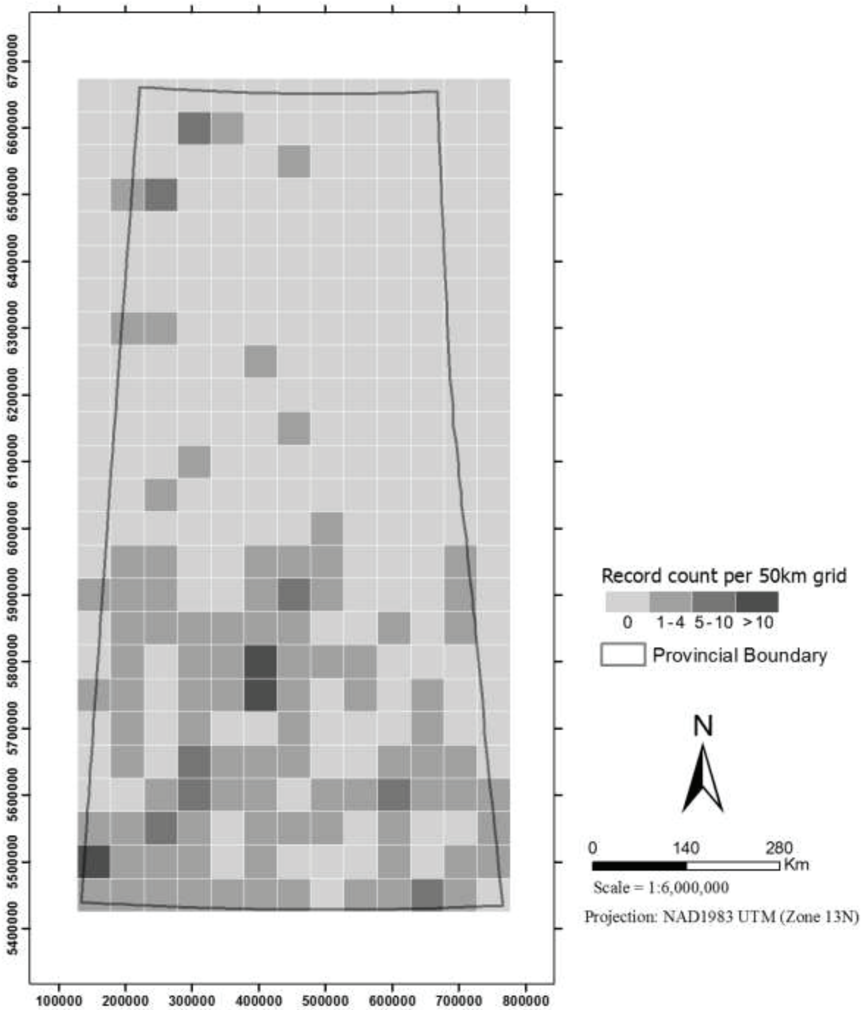

Figure 4. Density of *Anemone patens* in Saskatchewan (number of locations per 50 x 50 km mapping grid).

AVHRR Land Cover Data[30]. We also evaluated other land cover data products with much higher spatial resolutions. For example, the Land Cover Data vector layer (circa 2000) generated from Landsat TM5/7 images is available at the scale of 1:250,000[31]. However, the purpose of this study was to investigate the distribution of *A. patens* in the provincial scale, which covers

652,000 km^2 makes the coarser resolution more effective than the finer dataset (33 vector layers with around 1G filesize) in the analysis.

For the climate layers, annual precipitation and annual mean temperature were acquired from the WorldClim website (version 1.4, release 3) in Geotiff format at the spatial resolution of 30 arc–seconds[32]. Original data were published in the DBase format, which was linked to the ecodistrict layer. Climate Moisture Index (CMI) data were calculated following Hogg's method[33] by subtracting annual potential evapotranspiration (PET) from annual precipitation (P). Both P and PET (prepared using Thornthwaite Method) were acquired from the Agriculture and Agri–Food Canada website[34]. CMI was linked to the ecodistrict layer.

The soil order layer was derived from Soil Landscapes of Canada (SLC) version 3.1 for agricultural areas and SLC version 2.2 and 1.0 for non–agricultural areas[35]. There were in total 9 soil orders identified within the province. The protected area layers were derived (500 m buffer is used as the threshold for this assessment to factor in errors in data quality) from the Atlas of Canada 1,000,000 National Frameworks Data, Hydrology version 6[36].

RESULTS

Distribution

A. patens is registered in 98 UTM grid cells established for Saskatchewan which accounts for more than one-quarter (30.2%) of all mapping units (325 UTM grid cells) for the province. Herbarium collections (SASK, USAS, DAO, CAN, and ALTA) are a primary source of data (177 points or 64.6%), while observations from phenological database (23 points or 8.4%) and vegetation relevés from field surveys (74 points or 27.0%) together account for one-third of all records (97 points or 35.4%) (Figure 2). In terms of new (actual) mapping grids, this difference is more substantial: herbarium data accounts for most of the units (81 grids or 82.7%), while phenology database (6 grids or 6.1%) and field surveys (11 grids or 11.2%) together contributes only 17 grids or 17.3% of new mapping units.

Range extent

The species is commonly found in the southern part of the province, but it extends north to Uranium City and Cluff Lake. The species' range map reveals the distribution patterns of *A. patens* (Figure 3), i.e. the number of *A. patens* locations gradually decreases as we move from south to north and from west to east (Figure 4). The most locations are observed in the area lying between Saskatoon (52.5°N, 106.5°W) and Swift Current (50.2°N, 107.5°W), which represents the center of the *A. patens* latitudinal range in Saskatchewan and roughly overlaps with the northern and southern boundaries of the Prairie ecozone. No species' locations identified in this study were recorded in northeastern Saskatchewan.

Range trend

Almost three-quarters (72.6%) of recorded *A. patens* locations are concentrated in areas dominated by agricultural croplands (49.3%) and rangelands (23.4%), which makes their persistence vulnerable to intensification of agricultural practices. The rest of the locations (18.3%) are scattered across forests (transitional, coniferous, mixed, and deciduous) and also found in built–up areas (9.1%). During our field surveys, we determined that several *A. patens* locations (7 or 2.6% of total occurrences) have gone extinct over the 20th century. Out of all recorded locations of *A. patens*, only 44 (16.1%) are found in protected areas within the Saskatchewan's Representative Area Network (RAN).

Habitat affinities

Ecological communities

Most *A. patens* locations (79.9% of total occurrences) were found in the Prairie ecozone. They are allocated within different ecoregions of this zone in the following way: the Moist Mixed Grassland (44.7%), Mixed Grassland (27.9%), Aspen Parkland (20.1%) and Cypress Upland (7.3%). Generally, the number of *A. patens* locations gradually decreases from the Prairie ecozone to the Taiga Shield ecozone. Within the Boreal Plain ecozone (13.5% of total occurrences) the majority of locations are found in the Boreal Transition ecoregion (51.4%) and the Mid–Boreal Upland ecoregion (45.9%). In the Boreal Shield ecozone (4.0% of total occurrences) the richest ecoregion is the Athabasca Plain (72.7%). All the records in the Taiga Shield ecozone (2.6% of total occurrences) have been collected in the Tazin Lake Upland ecoregion. There are records in the northwest, indicating that latitude is not a limiting factor.

Soils

A. patens occurs on soils that belong to the Chernozemic soil order (69.3% of total occurrences). These soils developed under semi–arid to semi–humid grassland conditions. The pH range for these soils is from about 6.6 to 7.2. However, many locations of *A. patens*

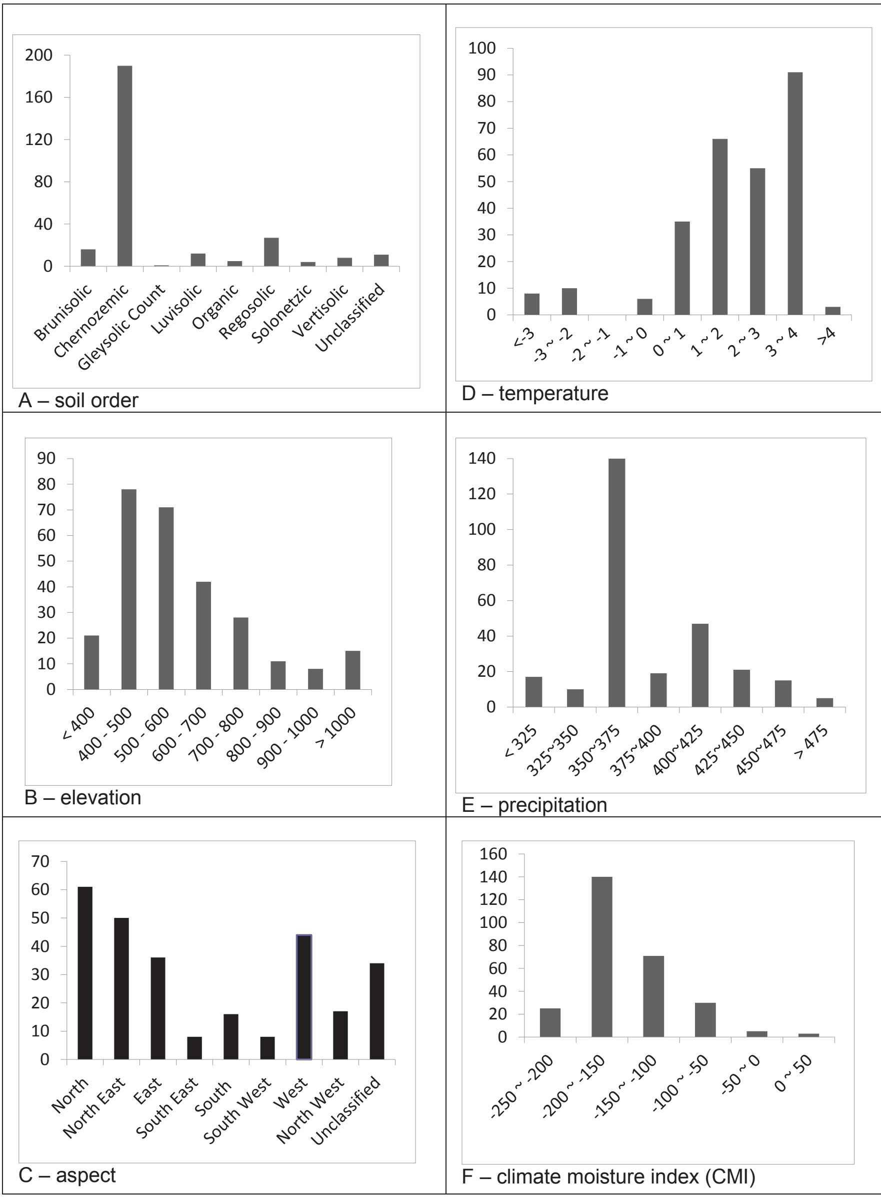

Figure 5. Habitat affinities of *Anemone patens* in Saskatchewan with regards to key ecological factors: in all figures on the vertical axes – number of records, on the horizontal axes – factor's value.

(26.7%) are found on well drained, sometimes sandy soils in the other seven soil orders, namely Brunisolic, Gleysolic, Luvisolic, Organic, Regosolic, Solonetzic, and Vertisolic. The small number of remaining locations (4.0%) is unclassified (Figure 5A).

Topography

Majority of *A. patens* locations (79.2% of total occurrences) are registered within altitudinal zone 400–800 m a.s.l. (Figure 5B). A small part of the range (7.7% of total occurrences) is confined to the lowland conditions in the Boreal Shield ecozone at elevations from 200 to 400 m a.s.l. The lowest occurrence point found is of 233 m a.s.l. which is located near Lake Athabasca in the vicinity of Uranium City. Some locations (12.4% of total occurrences) are found in altitudinal zone from 800 to 1300 m a.s.l. in the occasionally rising upland areas of the Mixed Grassland, Aspen Parkland and Cypress Upland. Only seven locations lie above 1200 m a.s.l. and the highest occurrence point recorded is of 1315 m a.s.l. in the Cypress Upland where a clear shift towards mountain habitats is visible.

Regarding the aspect of the recorded locations, almost half of them faced north and northeast. A proportion of 13.27% faced east, 15.93% eest and 6.19% northwest. South, southeast and southwest facing locations together accounted for less than 12%. These identified patterns are illustrated in Figure 5C, where the sites facing more than one direction have been counted multiple times, one for each of the faced directions. A total of 12.30% of the locations lacked any aspect.

Precipitation

Saskatchewan receives about 250–550 mm of precipitation in the form of rain or snow annually[31]. About three-quarters of *A. patens* locations (75.2% of total occurrences) lie in the region receiving 350–425 mm of precipitation annually (Figure 5D). Slightly above half of locations (51.1%) are found in a region that receives 350–375 mm of precipitation annually. *A. patens* has not been recorded in areas with either very low (< 325 mm) or high (> 475 mm) precipitation.

Temperature

Annual mean temperature in Saskatchewan ranges from -7.5°C to +6.5°C (Hijmans et al., 2005). According to our analysis, overall *A. patens* most commonly grows in the areas with positive annual temperatures ranging from > 0°C to < 4°C (90.1% of total occurrences) (Figure 5E).

Climate moisture index

Our analysis show that the annual climate moisture index (CMI), which was computed by subtracting annual potential evapotranspiration (PET) from annual precipitation (P), in Saskatchewan ranges from -249 to 6. According to our analysis, 97.1% of total occurrences lie in the region having CMI of -250 to -50. The maximum number of locations (51.1%) are found in the region having CMI between -200 to -150, 25.9% fall between -150 to -100 and 10.9% between -100 to -50 (Figure 5F). The species seems to avoid areas with an excess of precipitation over evaporation – 98.9% of total occurrences lie in the regions having negative CMI.

DISCUSSION

In terms of herbarium data contribution to distribution analysis of *A. patens*, both major regional collections located in Saskatchewan (SASK and USAS) provided a substantially higher number of specimens (94.9%) and accounts for the majority of mapping grids (93.8%) compare to data collected from larger national herbaria (DAO and CAN). Herbarium specimens found in DAO and CAN are almost all duplicates (93.6%) of the specimens deposited at SASK and USAS. The accuracy of information on the species location retrieved from the analyzed herbarium data is rather high, i.e. 89.0% of all deposited specimens in SASK and 90.5% in USAS respectively have been successfully georeferenced and used for further distribution analysis.

In order to reduce the herbarium data gap which occurred after the year 2000, phenological observations from the SK PlantWatch (2001–2010) and vegetation relevés from the author's field surveys (2011–2013) have been included in this study. Employing data obtained from these sources improved the quality of *A. patens* range assessment by adding about one-third of new locations (97 records or 35.4% of total occurrences) to the distribution analysis. In terms of mapped grid cells 50 x 50 km, these records account for 17 new units (17.3% of total) on the species distribution map in Saskatchewan.

The quality of the analyzed information collected from phenological database and field surveys is dramatically different. While all vegetation relevés were properly georeferenced and documented, there were problems with phenological records (multiple year collections at the same location or inaccurate data), hence only about one-quarter of these data (27.7%) was used for distribution analysis. Data entry mistakes and challenges with georeferencing call for rather cautious approach in using computerized databases because it may potentially misinform biodiversity assessment and conservation practices. This is in line with other studies[37] which have revealed that georeferencing errors can cause an overestimation of the area occupied by a species, make impossible to predict a species range dynamics under global warming scenarios or identify geographically invalid locations.

The data obtained from this analysis expanded the current knowledge of biology and ecology of *A. patens*. Applying GIS analysis, the habitat affinities of *A. patens*, including the species relationships to ecological communities, soils, topography, land use, precipitation, temperature, and the climate moisture index were explicitly characterized. This analysis demonstrates that in North America, *A. patens* is a more western species, mainly of the northern Great Plains. It was revealed that *A. patens* is widely distributed in Saskatchewan and that the Prairie ecozone represents the center of the current species range in the province. Although common in all types of prairies it seems to be especially linked with the endangered fescue prairie[38].

Historically *A. patens* was everywhere on the prairies, particularly in Saskatchewan[39]. Currently, a major part the entire Prairie ecozone is converted to croplands and rangelands with remaining lands being used for urban development, roads and highways, rail roads, mining sites, oil and gas production[40]. During last century *A. patens* has been lost due to cultivation, urbanization, industrial areas, and infrastructure and it is now relatively uncommon in and around major cities in Saskatchewan[41]. This range contraction can be mostly attributed to direct habitat loss and fragmentation.

Most recently, a population study of *A. patens* for monitoring its conservation status in Saskatchewan has been initiated[21]. Because range contraction and habitat fragmentation is threatening not only the rarest plants, studying their effects on still abundant species is of scientific and conservation interest[42,43]. There are many documented examples of previously common species that are now listed as threatened with extinction[43], indicating that rapid change of a common species to rare one often occurs. A good illustration of this process might be the fate of *A. patens* in Europe. During the past few decades *A. patens* is dramatically declining across the entire continent and hence the species has recently been legally protected in the majority of European countries where it naturally occurs[21].

Habitat information can also be useful for directing landscape level search for some prairie vegetation communities for which *A. patens* shows a high fidelity. Additionally, the suggested approach may contribute to development of Flora of Saskatchewan and other related projects. Moreover, this approach has potential to enhance such series as Biological Flora of the Canadian Prairie Provinces[44] and Biological Flora of Canada[45], should they be renewed in the future.

This approach can also be transferred to other species in Saskatchewan, particularly focusing on distribution of native plants under the impact of habitat loss and fragmentation, contributing to different biodiversity assessment at different spatial and temporal scales. It may also improve our understanding of species range dynamics in a rapidly changing world. The suggested approach demonstrates how to combine traditional herbarium collections and field surveys with modern technologies (GIS, GPS, and online databases) to map species distribution and analyze their habitats.

We hope that suggested approach will also encourage amateur naturalists and volunteers to collect base inventory data and assist in monitoring activities through mapping species distribution which could be an effective method of documenting land use and conducting different exercises for community planning. While voluntary participation in citizen science is not new, we see our approach as a mean to involve the public in environmental management, which can foster community stewardship and public support for necessary actions. It will be well worth the effort, a new dawn for citizen science.

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