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Distribution and natural history of carnivorous plants of Saskatchewan, Canada

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ABSTRACT: We provide distribution maps of carnivorous plants as well as an assessment of rarity status and potential threats to diversity of carnivorous taxa in Saskatchewan using a biodiversity informatics approach. Saskatchewan is home to ten carnivorous species ranging from the Mixed Grassland ecoregion in the southwest to the Selwyn Lake Upland ecoregion in the northeast. Several areas exhibiting high carnivorous plant diversity including rare and endangered species are: the Nesbitt Provincial Forest, the Prince Albert National Park, and the Athabasca Sand Dunes. We propose these areas as deserving conservation priority.

Carnivorous plants, those that draw a portion of their nutrients from animal prey rather than the soil, have long intrigued and confounded biologists. In 1796, American naturalist John Ellis described the insect trapping habit of *Dionaea muscipula* J. Ellis (Venus Fly Trap) to Carl Linnaeus, who responded with disbelief, arguing that a plant preying upon animals was "against the order of nature as willed by God" (Barthlott *et al.* 2007). Nearly a century later, Charles Darwin offered the first formal scientific treatment of carnivorous plants. With a series of characteristically elegant experiments, Darwin showed that *D. rotundifolia* along with other species of *Drosera* L. (Sundew), *Utricularia* L. (Bladderwort), and *Pinguicula* L. (Butterwort) were indeed capable of capturing, dissolving, and absorbing insect prey (Darwin 1875). Despite the novelty implied by their unusual habit, carnivorous plants do not constitute a single branch of the evolutionary tree. Carnivory is a convergent lifestyle and has independently evolved at least five times in the plant kingdom (Barthlott *et al.* 2007).

Carnivorous plants are found on every continent except Antarctica (Albert *et al.* 1992; Barthlott *et al.* 2007) and exhibit a degree of morpho-physiological specialization unrivalled by most species in the plant kingdom. While the majority of carnivore plant diversity is found in the tropics, various species of *Utricularia*, *Pinguicula* and *Drosera* possess adaptations that allow their ranges to extend into higher latitudes of the Canadian arctic, Scandinavia, and Greenland (Barthlott *et al.* 2007). The Malaysian, Australian and Brazilian floristic regions are the most significant centers of carnivore diversity globally, with 133, 86, and 65 species, respectively (Barthlott *et al.* 2007). Within North America, the southeastern region of the United States, especially the swamps and wetlands of Florida, is home to a high diversity of carnivorous taxa, including various endemics (Barthlott *et al.* 2007). Canada has 19 species of carnivorous plants (10 of which occur in Saskatchewan) (Harms 1978; Canadensys 2012). These plants are widespread throughout Canada, mostly occurring in small, well defined habitat patches due to their unusual ecological requirements.

Saskatchewan is home to four genera belonging to different lineages of carnivorous plants: *Drosera* (Droseraceae), *Sarracenia* L. (Sarraceniaceae), *Pinguicula,* and *Utricularia* (Lentibulariaceae) (Harms 1978, 2003). These three families are placed in three distinct phylogenetic orders: Caryophyllales, Ericales, and Lamiales (Albert *et al.* 1992). The general distribution of carnivorous plants in Canada and North America is known based on distributional data in provincial and/or regional floras, *e.g.*, Porsild and Cody (1980), Mellichamp (2009). In Saskatchewan, the broad geographic range of these species has been presented (Harms 1978), but little is known regarding the extent of their distribution and the specific ecological areas these plants occupy. This investigation is a case study based on digital information from herbarium specimens stored in the database of the W.P. Fraser Herbarium (SASK) and is pioneer in involving aspects of biodiversity informatics in the province. It provides the first approach in understanding the distribution patterns of carnivorous plants in Saskatchewan. Its relevance at the regional and national levels stands for various reasons. Foremost, it will enhance the utility of herbarium voucher specimens and contribute to the understanding of endangered and rare species by georeferencing and mapping updated occurrences of threatened taxa. Also, it will facilitate targeting areas with high demographic indices and biodiversity of carnivorous plants in Saskatchewan, which can be proposed as areas deserving conservation priority. Maps integrating specimen locality can help identify areas requiring further study, sampling, protection and monitoring and ultimately assist in predicting the future of ecosystems and the shifts of common and rare species in view of human activities and climate change.

We used digitized label information from voucher specimens at the W.P. Fraser Herbarium (SASK) of the University of Saskatchewan and several other Canadian herbaria with the following objectives: 1) to generate a general provincial distribution map for carnivorous

genera as well as create a searchable database of these plants, 2) to re-assess the species' rarity status on a provincial and national scale, and 3) to identify areas of diversity in carnivorous plants. The limited understanding of distributional patterns of carnivorous plants, the lack of a complete Saskatchewan flora, and the accelerated loss of natural habitats justifies this biodiversity-based research. Furthermore, SASK herbarium is the primary institution devoted to the documentation and study of Saskatchewan's flora and is home to a systematic collection of 180,000+ specimens, covering over 125 years of botanical exploration with the most comprehensive chronological, historical, taxonomic, and geographic coverage of provincial plants (Cota-Sánchez and Harms 2009), thereby offering an ideal data mining opportunity for this study. Additionally, SASK Herbarium contains the main collections of almost all significant Saskatchewan-based collectors, spanning the time period of ca. 1910 to the present. Coverage of species at risk is equally strong at SASK Herbarium. No other research institution, with the possible exception of the Saskatchewan Conservation Data Centre (SK-CDC), has such comprehensive information on geography, taxonomy, and rarity status of Saskatchewan flora. Finally, SASK is part of the Canadensys group, a multidisciplinary network aiming to preserve biodiversity while maximizing the use of systematic collections across Canada. Within this scope, the present study is in line with the ongoing biodiversity informatics program and digitization of systematic collections to mobilize the wealth of information stored in labels of herbarium specimens and endow policy makers and scientists with tools relevant to conservation management, modelling systems, and environmental programs dealing with the flora of Saskatchewan, in particular, and Canadian biodiversity in general.

We surveyed herbarium voucher specimens representing the range of taxonomic diversity and geographic distribution of carnivorous plants in the province. We compiled and digitized label information from 759 voucher specimens available from herbaria of the following institutions: 13 from the University of Alberta (ALTA), 25 from the Canadian Museum of Nature (CAN), 91 from the Agriculture and Agri-Food Canada (DAO), and 630 from the W.P. Fraser Herbarium of the University of Saskatchewan (SASK). The number of vouchers per species varied depending on rarity, distributional range, and representation within the botanical collections surveyed. The specimens labels contain information useful to understand the taxonomic diversity, phenology, geographic distribution, ecological range, and other attributes of carnivorous taxa. With these data, we created a catalogue of provincial carnivorous plants in the Specify database of SASK Herbarium. Specify software is an open source database program which facilitates the digitization of museum and herbarium collection data (Specify Software 2012) and provides a data-computing interoperable platform that is responsive to evolving community needs and to new research opportunities enabled by the Internet. An electronic database (Baalim *et al.* published online) was developed for the specimens of carnivorous plants investigated and maps created depicting the distribution of each carnivorous genus (included in this paper) and species (not included in this paper but can be produced at the above link) in Saskatchewan. The digitized data includes the geographic coordinates provided by the original collector in the herbarium labels. When no coordinates were specified, the latitude and longitude were estimated based on the given locality information using the Natural Resources Canada on-line Atlas of Canada – toporama (Natural Resources of Canada (2013) reference maps. Our mapping protocol follows that of Choi and Cota-Sánchez (2010), implemented in *Allium* L. of the Canadian Prairie Provinces. First, locality data for each species were imported into a customized map development tool based on an open-source Google™ Maps API on-line development tool. Once generated, the Google™ map was imported into Adobe Photoshop as a JPEG image, and the boundaries were eliminated, leaving only the province of Saskatchewan. We created provincial maps depicting the overall distribution of all records of carnivorous plants in the collections obtained from all the above herbaria in three different layers, namely general topographic and hydrological information, ecoregions, and soil types. In addition, we generated distributional provincial maps for each carnivorous genus with the ecoregions layer. This study also includes a literature review to provide general information dealing with taxonomic diversity, morphological adaptations and specializations as well as ecological requirements of each of the Saskatchewan species. The rarity status of the species was determined based on previously published data such as the Canadian Endangered Species Conservation Council (CESCC 2011), Maher *et al.* (1979), Harms (2003), the SK-CDC, and the Nature Conservancy Ranking of rare species (Table 1).

The taxonomic range of Saskatchewan carnivorous plants lies in three plant families: Droseraceae, Lentibulariaceae, and Sarraceniaceae (Harms 1978, 2003). These three phylogenetically distant carnivorous families exhibit a perplexing array of morphological traits that characterize their traps. The trap design in Saskatchewan carnivorous species is of three types: sticky traps, pitfall traps, and suction traps (Table 1). A total of four genera and ten species of carnivorous plants occur in Saskatchewan (Table 1), and though they are relatively common in the province, these taxa are restricted to boggy areas, which are characterized by acidic, nutrient-poor soils, sphagnum moss, and standing water (Schnell 2002). Globally, the province of Saskatchewan falls within a latitudinal band (50°N to 70°N) which contains most of the world's peatlands (Moore 2002). Hence, islands of boggy habitats, the preferred environments of carnivorous species, are widespread throughout the province.

Saskatchewan houses three species from the Droseraceae: *Drosera anglica, D. linearis* (Figure 1A-C), and *D. rotundifolia* (Harms 1978, 2003). The genus *Drosera* takes its common name, "Sundew", from the appearance of the brightly coloured mucilage secreted by glands on the tips of tentacles covering the adaxial surface of the leaves (Figure 1B), forming the characteristic sticky trap. In general, *Drosera* species are small perennial herbs, weakly rooted, with a rosette of modified trap leaves borne on a short, unbranched shoot (Harms 1978). The small, perfect, actinomorphic flowers (Figure 1C) are ephemeral, self-pollinated, and presented above the sticky trap leaves on a

determinate raceme (Judd *et al.* 2008; Schnell 2002). Late in the fall, *Drosera* form hardy winter buds (hibernacula), which allow the plant to survive through the winter and reproduce both asexually and sexually during spring and summer (Schnell 2002).

The family Sarraceniaceae is represented by a single species in Saskatchewan, *Sarracenia purpurea* (Harms 1978, 2003), a perennial, rhizomatous herb with leaves highly modified to form the pitcher or pitfall traps (Figure 1D-F). Insects are drawn to the lip (peristome) of a pitcher trap by nectar secreting glands and red pigment, while a slippery, waxy cuticle and downward pointing hairs on the inside of the pitcher walls (Figure 1E) prevent the prey from escaping the pitfall trap (Barthlott *et al.* 2007). A long scape (up to 35 cm) bears a single, actinomorphic, downward-pointing flower with a five-lobed, umbrella-shaped style nearly enclosing the stamens (Figure 1F) (Judd *et al.* 2008). The unique flower shape limits pollinator visits to large, strong insects (usually queen bees) while imposing specific entry and exit points, maximizing the odds of successful cross pollination (Schnell 2002). This species reproduces sexually by seed and asexually through fragmentation of the rhizomes (Barthlott *et al.* 2007).

The third carnivorous Saskatchewan plant family, the Lentibulariaceae, includes the genera *Pinguicula* and *Utricularia* ("Bladderwort"). *Pinguicula,* commonly called "Butterwort" due to their fleshy, greasy looking leaves, includes two species in the province, *P. vulgaris* (Figure 1G-I) and *P. villosa* (Harms 1978, 2003). These are small, perennial herbs with compressed rosette leaves measuring 1-4 cm long and a highly reduced root system (Harms 1978; Barthlott *et al.* 2007). The small, zygomorphic, purple flowers (one in *P. villosa* and up to six in *P. vulgaris*) bloom on an erect scape (Figure 1I). Nectar is produced in elongated, rearward-pointing spurs (Barthlott *et al*. 2007). As with *Drosera*, the trap leaves of temperate *Pinguicula* species die back in the winter, leaving bulb-like, perennial hibernacula, which have the potential to re-emerge the next growing season to restore the population mainly by asexual reproduction (Schnell 2002).

The second carnivorous genus of the Lentibulariaceae, *Utricularia*, is cosmopolitan and includes four terrestrial, sub-aquatic and aquatic herbs species in Saskatchewan (Harms 1978, 2003). The genus has zygomorphic, bilabiate flowers (Figure 1L) and includes four species in the province, namely *U. cornuta, U. intermedia*, *U. macrorhiza* (Figure 1J-L), and *U. minor* (Harms 1978, 2003). The plants form stolon-like structures bearing filiform photosynthetic leaves and modified trap leaves (Figure 1J, K). Compared to the relatively simple adhesive or sticky traps of its sister taxon, *Pinguicula*, the sophisticated suction traps of *Utricularia* are very specialized in form and function. The small, hollow bladders (0.2-1.2 cm), each with a single, inward-opening door, are borne on stalks underwater or below the soil surface (Figure 1K).

Despite the widespread geographic distribution and the relative abundance of numerous species, over-collection and other human pressures, such as agricultural expansion, continue to threaten plant and animal life. Changes in landscape, including habitat fragmentation and the removal of entire plants, are major factors that deplete wild populations and lead to the loss of genetic diversity. Carnivorous plants have long been considered precious specimens by collectors, and it appears that the rarer the plant, the more desirable the specimen. As a result of over-exploitation and habitat loss, several carnivorous plants are listed as rare species. In Saskatchewan ca. 35% of native species are listed in five categories as provincially rare (Harms 2003). Following, we summarize the information available regarding the current rarity status of carnivorous plants in Saskatchewan.

Assessing the general status of Canadian and world species is a challenging, but essential process. To date, 25 vascular plant species have been extirpated from Canada (CESCC 2011). Even though most Canada's carnivorous plants are ranked in the Secure category, two species (California Butterwort, *Pinguicula macroceras* Pall. ex Link, and Yellowish-white Bladderwort, *Utricularia ochroleuca* R.W. Hartm.) have a Canada rank of Sensitive, and one species (Thread-leaved Sundew, *Drosera filiformis* Raf.), has the At Risk rank in Canada (CESCC 2011). Several schemes have been proposed to assign rarity status to Canada's vascular plant species. The Wild Species 2010 report (as per the CESCC 2011) recognizes the following general categories: Extinct, Extirpated, At Risk, May Be At Risk, Sensitive, Secure, Undetermined, Not Assessed, Exotic, and Accidental (the reader is referred to CESSC 2011 for detailed description of each type). Here we focus on the categories applied for the carnivorous plant species in province of Saskatchewan. At the national level, *Pinguicula villosa, P. vulgaris, Utricularia cornuta*, and *U. minor* are included in the May Be At Risk category (may be at risk of extirpation and are candidates for additional detailed risk assessments), followed by *D. anglica* and *D. linearis* placed in the Sensitive category (Species that are not believed to be at risk of immediate extirpation or extinction but may require special attention or protection to prevent them from becoming at risk), with the remaining provincial species considered Secure (CESCC 2011) (Table 1). In turn, Harms' (2003) framework divides Saskatchewan's plant species into seven provincial categories: Common (C), Fairly Common (FC), Uncommon (UC), Vulnerable (V), Threatened (T), Endangered (END) and Extirpated (EXT). According to this ranking scheme, one carnivorous species, *Utricularia cornuta*, is threatened in Saskatchewan (Table 1), *i.e.*, it is likely to become endangered in the province as it occurs in only six to 15 localities. Three other species, *Drosera linearis, Pinguicula villosa* and *P. vulgaris*, are listed in the vulnerable category (Table 1), warranting special concern because of their low or declining numbers with plants locally sparse in 16-25 sites in the province but free from obvious, immediate endangerment (Harms 1978, 2003).

The Nature Conservancy Element Rankings (NCER) evaluates the rarity of species at the global and subnational (provincial) scale (reviewed in Harms 2003). According to the Saskatchewan Conservation Data Centre (2011), which uses the NCER system, two of Saskatchewan's carnivorous plants, *Drosera linearis* and *Pinguicula villosa*, are given a global rank of G4, (apparently secure, uncommon but not rare, typically less than 100 occurrences and less than 10,000 individuals), while the others are considered "Demonstrably Secure-Common" (G5) (Table 1). On the provincial scale, *D. linearis* is given a rating of S1, defined

as "Critically Imperilled", having five or fewer occurrences, or less than 1,000 individuals in Saskatchewan. *Utricularia cornuta* has a provincial status of S2, defined as "Imperilled" and "very vulnerable to extinction", typically with six to 20 occurrences or 1,000 to 3,000 individuals. *Pinguicula villosa, P. vulgaris,* and *Utricularia minor* are each given the provincial rating S2S3 (Table 1), indicating that their status lies somewhere between "Imperilled" and "Vulnerable" (21 to 100 occurrences, or between 3,000 to 10,000 individuals).

In the cases of *D. linearis* and *U. cornuta*, Harms' (2003) and the Nature Conservancy's systems disagree in their relative rankings. The Nature Conservancy (NC) gives *D. linearis* a higher conservation priority than *U. cornuta* (G4 S1 and G5 S2 respectively), while Harms (2003) lists *U. cornuta* as requiring higher conservation priority than *D. linearis* (threatened *vs.* vulnerable) (Table 1). Although both organizations, the NC and the SK-CDC, are devoted to the preservation of ecological diversity, the conflicting designation between these authorities and those of Harms (2003), which were based on personal and field observations (V. Harms, pers. comm., University of Saskatchewan), highlights the need for further inquiry to re-evaluate the categories assigned.

Our carnivorous plants database contains plants collected since the late 1800s, but we established 1950 as a cutoff to consider vouchers in the historical category. We gathered 83 historical records dating prior to 1950 for the carnivorous plant group in Saskatchewan (see Appendix 1). A common issue among historical specimens in our list is the amount and accuracy of the information provided by the collector. While recent voucher specimens have complete and detailed label information, earlier collections often lack accurate locality and collector number. In spite of this limited label information, data from the past were useful to locate the oldest collection(s), main collectors and localities of carnivorous species. Our database survey indicates that the oldest collection of Saskatchewan carnivorous plants dates back to 1911. This specimen of *Sarracenia purpurea* (SASK 12946) was collected by Walter P. Thompson in the area of Prince Albert (Appendix 1). It is worth noting that W.P. Thompson was the University of Saskatchewan's third president and founder of the Department of Biology, which he led from 1913-1949, which adds further significance to this specimen. Six specimens are from the 1920s. Five of these records are for *Utricularia macrorhiza*, of which two were collected by William P. Fraser in 1922 (SASK 86773 and 86774) around the city of Saskatoon (Appendix 1). These historical specimens have added value because W.P. Fraser was responsible for the creation of SASK Herbarium in 1925 (Cota-Sánchez and Harms 2009), hence the naming of this facility after him. The remaining three specimens of *U. macrorhiza* date from 1923, 1924, and 1927 collected by W.C. McCalla, ALTA 65412 (Buttress area), R.C. Russell, SASK 86772 (Duncairn area), and W.H. Cameron SASK 21178 (Saskatoon area) (Appendix 1). The sixth record from the 1920s is for *Drosera rotundifolia* collected by R.C. Russell, SASK 91998, in 1926 in the area of Speddington (Appendix 1). The remaining specimens in the list of historical accessions are from the 1930s and 1940s, when further botanical exploration took place in Saskatchewan. These pre-1950 collections are mostly concentrated in the vicinities of the cities of Saskatoon and Prince Albert (Appendix 1).

The mapping protocols used here were useful in elucidating distribution patterns of the species investigated. Carnivorous plants are distributed throughout Saskatchewan from the southern to northern borders (Figure 2A-C). The southernmost occurrences are represented by *Utricularia* found in the Mixed Grassland ecoregion in the southwest corner of the province, at 49.1°N and 108.1°W (Figures. 2A-C and 3D). Conversely, the northernmost occurrences are represented by *Drosera* and *Utricularia* found in the northeast corner of the province, within the Selwyn Lake Upland ecoregion at ca. 59.9°N and 102.1°W (Figure 3A, D). Also, *Drosera, Pinguicula,* and *Utricularia* occur north of Lake Athabasca in the Tazin Lake Upland ecoregion at ca. 59.5°N and 108°W (Figure 3A, C, D). Ongoing digitization of Canadian voucher specimens at SASK Herbarium indicates that the occurrence of carnivorous plants goes well beyond the northern provincial boundaries to areas beyond the Arctic Circle in the Northwest Territories, approximately 69.4°N

Table 1. Families and species of carnivorous plants reported in Saskatchewan, their rarity status as assigned by CESCC (2011), Harms (2003), and the Nature Conservancy (as per the Saskatchewan Conservation Data Centre), and their trap types. *Mellichamp (2009) in Flora of North America now merges subsp. gibbosa under subsp. purpurea.

Family & Species	Canadian Carnivorous Plants (CESCC 2011)	Saskatchewan Rarity status (Harms 2003)	Saskatchewan Rarity status (Nature Conservancy)	Trap type
Droseraceae				
Drosera anglica Huds.	Sensitive	Uncommon	Not threatened	Sticky
D. linearis Goldie	Sensitive	Vulnerable	G4, S1	Sticky
D. rotundifolia L. var. *rotundifolia*	Secure	Common	Not threatened	Sticky
Lentibulariaceae				
Pinguicula villosa L.	May Be At Risk	Vulnerable	G4, S2S3	Sticky
P. vulgaris L.	May Be At Risk	Vulnerable	G5, S2	Sticky
Utricularia cornuta Michx.	May Be At Risk	Threatened	G5, S2	Suction
U. intermedia Hayne	Secure	Common	Not threatened	Suction
U. macrorhiza Le Conte	Secure	Common	Not threatened	Suction
U. minor L.	May Be At Risk	Uncommon	Not threatened	Suction
Sarraceniaceae				
Sarracenia purpurea L. subsp. *gibbosa* (Raf.) Wherry*	Secure	Uncommon/Fairly common	Not threatened	Pitfall

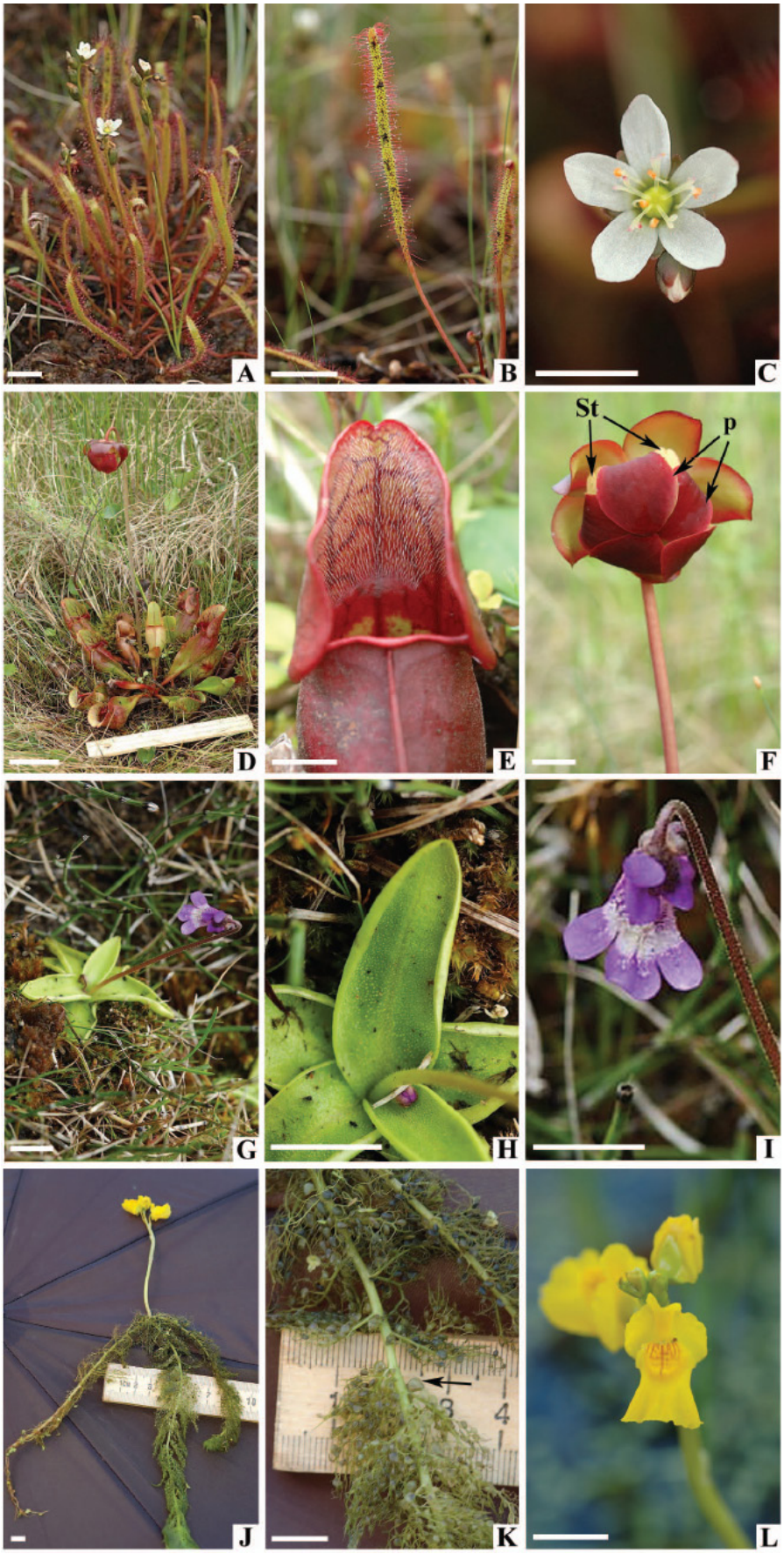

Figure 1. Representative native species of carnivorous plants in Saskatchewan. A-C: *Drosera linearis*, a vulnerable species in Saskatchewan with nationally rare status. A. Plant in natural habitat (scale = 1.0 cm). B. Close up of the leaf sticky trap with insects (scale = 1.0 cm). C. Flower detail (scale = 0.5 cm). D-F: *Sarracenia purpurea*. D. Plant in natural habitat (scale = 5.0 cm). E. Close up of the leaf pitcher trap showing the operculum and downward-pointing hairs inside the pitcher wall (scale = 1.0 cm). F. Flower detail showing the umbrella-shape style (St) and petals (p) as indicated by the arrows (scale = 1.0 cm). G-I: *Pinguicula vulgaris*, a vulnerable species in Saskatchewan with nationally rare status. G. Plant in natural habitat (scale = 1.0 cm). H. Close up of the rosette leaves (sticky traps) with insects (scale = 1.0 cm). I. Flower detail (scale = 1.0 cm). J-L. *Utricularia macrorhiza*. J. Plant removed from its aquatic habitat (scale = 1.0 cm). K. Close up of stem showing linear leaves and suction traps (arrow) (scale = 1.0). L. Flower detail (scale = 1.0 cm).

and 133.2°W, where records of *P. villosa* exist. Porsild and Cody (1980) mapped *Pinquicula vulgaris, P. villosa,* and most *Utricularia* species northward and northwestward to the Arctic Ocean. The wide geographic coverage of these species within the province and beyond is evidence of the degree of specialization and adaptability of carnivorous plants to a wide diversity of climatic conditions.

It is noteworthy that the distributions of *Drosera, Sarracenia* and *Pinguicula* in Saskatchewan share a common pattern. Most occurrences were recorded in the Boreal Transition ecoregion (Figure 2B), which is dominated by *Populus tremuloides* Michx., *Picea glauca* (Moench) Voss, and *Pinus banksiana* Lamb. (Fung 1999), among other species. These three genera are totally excluded from the Mixed and Moist Mixed Grasslands, and only two records each of *Drosera* and *Pinguicula* have been collected in the Aspen Parkland, an ecoregion characterized by *P. tremuloides*, *Symphoricarpos* Duhamel, and *Rosa* L. (Fung 1999), though these collections were made in boggy or calcareous fen microhabitats. Interestingly, the two *Drosera* records from the Aspen Parkland correspond with small patches of gray soil within a large band of black soil (Figure 2C). These two occurrences suggest that *Drosera*'s niche is better defined by soil chemistry than by temperature and precipitation as its distribution is restricted to areas of grey soil or Canadian Shield (Figure 2C). *Utricularia*, in turn, is the genus with broadest distribution in Saskatchewan. It is a truly aquatic plant found in lakes, ponds, and sluggish streams and shares a sympatric distribution with its congeneric terrestrial carnivorous species in the northern two thirds of the province. Species of *Utricularia* are also found in aquatic environments throughout the Aspen Parkland, Mixed, and Moist Mixed Grasslands and are the only carnivorous species with occurrences in the Cypress Upland region (Figure 3D).

Our work has expanded previous geographic ranges of vulnerable and threatened species with more recent collections and records from Canadian herbaria. For instance, Harms (1978) reported only five occurrences of the vulnerable species *D. linearis* in the province: two near Prince Albert (53.6° N, 106.2°W, [12/07/1933, SASK 12947 and 05/08/1933, SASK 12952]), two near McKague (52.6° N, 103.9° W [10/08/1933, SASK 12950 and SASK 12951]), and one near Garthland (53.0° N, 106.3° W [07/07/1971, SASK 54271], with updated information by Schwab-Moe (1999) indicating its occurrence in Greenbush on the Red Deer River east of McKague. *D. linearis* was again reported in the Garthland area in 2008 (12/07/2008, SASK 179631); however, no further collections have been made near Prince Albert or McKague. Despite the recent absence of *D. linearis* in these regions, subsequent collections have revealed that this species' range extends north of Prince Albert into the boreal forest (*e.g.*, 08/09/1984, SASK79389 and 21/08/1996, SASK 139967), including the Athabasca Sand Dunes (59.0° N, 109.0° W [08/05/1975, SASK 68579 and 07/08/1979, SASK 145934]).

According to Harms (1978), *P. vulgaris*, listed in the vulnerable category, occurs in sporadic patches throughout the Boreal, Aspen Parkland, and Athabasca Plain ecoregions. Recent collections confirm that this distribution pattern persists (*e.g.*, 16/06/1983, SASK 134706; 20/06/1992, SASK 136189; 08/04/1993, SASK 163973; 01/07/2004, SASK 170442). Similarly, *P. villosa* has been and continues to be found predominantly along the Wollaston Lake road in the northeast portion of the province (*e.g.*, 26/07/1973, SASK 52755; 07/09/1973, SASK 52756; 13/07/1998, SASK 147567; 07/08/1998, SASK 147687; 27/06/2006, SASK 171128; 17/07/2008, SASK 179297), though a historical record exists from the north shore of Lake Athabasca (59.6°N, 109.2°W, by H.M. Raup, 24/07/1935, CAN 99311 (Appendix 1) and a single specimen has been collected in the Wildcat Hill Provincial Park (53.3°N, 102.5°W [07/10/1992, SASK 107572]).

U. cornuta, currently in the threatened category, has been reported only along the Wollaston Lake road (21/07/1973, SASK 53180; 28/07/1973, SASK 52748), where it continues to be collected (19/07/1983, SASK 94565; 09/07/1998, SASK 147682; 12/07/2005, SASK 170918), on the south shore of Lake Athabasca (59.0°N, 109.0°W [07/08/1975, ALTA 83184; 11/08/1975, SASK 145991; 07/07/1979, SASK 70096; 11/08/1979, SASK 70090), and on the site of the since decommissioned Cluff Lake uranium mine (58.4°N, 109.6°W [26/08/1978, SASK 174243]). No occurrences of *U. cornuta* have been reported at Lake Athabasca or Cluff Lake since 1978-79.

The wide distribution of carnivorous plants depicted in our maps demonstrates the ample degree of adaptability of these plants to altitudinal gradients while remaining restricted to specific ecological conditions, *e.g.*, soils with low pH and low nitrogen content. The ecological and habitat restrictions of the carnivorous habit have resulted in a remarkable set of homoplasious characters in morphology and physiology among disparate angiosperm lineages. The shared preference for open, moist, low nutrient habitats means that unrelated carnivores often co-exist in bogs, fens and similar ecosystems (Barthlott *et al.* 2007). In fact, more than 13 carnivorous plant species exist in a single bog (Folkerts 1982). Our study indicates that carnivorous diversity converges in the fen and boggy areas of three provincial areas, namely the Athabasca Sand Dunes, the Nesbitt Provincial Forest, and Prince Albert National Park region. As indicated next, we suggest these areas as candidates for conservation priority not only for the abundance of carnivorous species but also because these areas host a number of endemic and narrowly distributed species that are provincially rare and/or threatened (Maher *et al.* 1979; Harms 2003). Further, early vegetation studies emphasized the unique floristic elements of the northern prairie province regions and Athabasca Sand Dunes. Our findings indicating the presence of seven carnivorous species (including *U. cornuta* in the threatened category) emphasize the uniqueness of the Athabasca Sand Dunes regions in terms of the diversity, endemism and rarity of plant species. All Saskatchewan carnivorous genera, except *Sarracenia*, range well north of SK, most to the Arctic Ocean (V. Harms, pers. comm.).

Our maps have identified several areas of high carnivorous plant biodiversity deserving special attention in terms of conservation. Among these areas, the Nesbitt Provincial Forest (52.9°N and 106.0°W) contains six carnivorous species, two of which (*D. linearis* and *P. vulgaris*) are in the vulnerable category and are restricted to calcareous fens. The Prince Albert National Park region

(53.9°N and 106.2°W) is another area of high incidence of carnivorous plants, featuring records of eight species, including two vulnerable taxa: *D. linearis* and *P. vulgaris*. The Athabasca Sand Dunes (59.1°N and 109.1°W) are home to seven carnivorous species including the vulnerable *D. linearis* and the threatened species *U. cornuta*. Slightly southwest of the Athabasca Sand dunes is another distinct area (58.4°N and 109.7°W) with a relatively high abundance of carnivorous plants, including records of six species, among them the vulnerable *P. vulgaris*. Because of the relatively rich levels of taxonomic diversity, including the presence of rare plants, we propose these areas as priority sites for conservation.

The distributional patterns of carnivorous plants presented in this paper provide useful clues and potential guides to establish conservation priorities. However, we would like to note the intrinsic biases imposed by the sole use of herbarium specimens in the generation of maps. Foremost, the geographic range of collection sites (and hence distribution) is non-random; typically more specimens are collected close to major population centres, especially cities with universities or herbaria (Crawford and Hoagland 2009), main roads, and accessible areas. For instance, the area of high incidence we identified at 58.4°N and 109.7°W corresponds with the decommissioned Cluff Lake uranium mine, the site of which has been sampled heavily compared to the surrounding areas due to environmental impact assessments of mining activities. Similarly, the band of high *Utricularia* density extending northeast from La Ronge (55.1°N, 105.3°W) is likely a spurious pattern caused by heavy collection efforts along the Wollaston Lake road. While *U. cornuta* and *U. minor* are rare compared to their sister species, the paucity of records may be exaggerated by the fact that, when not in bloom, these plants are easily overlooked or mistaken for other, more common *Utricularia* species (Harms 1978). Since much of Saskatchewan's landscape is uninhabited and difficult to access, botanical collections are lacking for large portions of the province. However, we hypothesize that the diversity found in local "hotspots" indicated above and in our maps is also representative of the diversity present in other provincial regions with similar ecological conditions, even though the vast majority of the landscape remains botanically unexplored.

Notwithstanding the potential biases indicated above, carnivorous plants have specific habitats and exhibit intrinsic and interdependent relationships with the environment and other organisms. Due to complex interactions of these plants with other community members, their conservation may have unintended positive effects on ecosystems. Along with pollinator and prey interactions, carnivorous plants may support endemic communities of commensal arthropods within their traps (Istock *et al*. 1983). The traps of some pitcher plants provide refuge for amphibians (Jennings and Rohr 2011), and a species of *Drosera* has been shown to compete with spiders for prey (Jennings *et al.* 2010). Carnivorous plants are particularly sensitive to changes in environmental conditions, and many species are conspicuous and easy to identify. These features make carnivorous plants good candidates as "indicator species" for assessing the health and integrity of the ecosystems they inhabit (Jennings and Rohr 2011), which, in conjunction with the role of *Sphagnum* as a keystone species in restoration (Rochefort

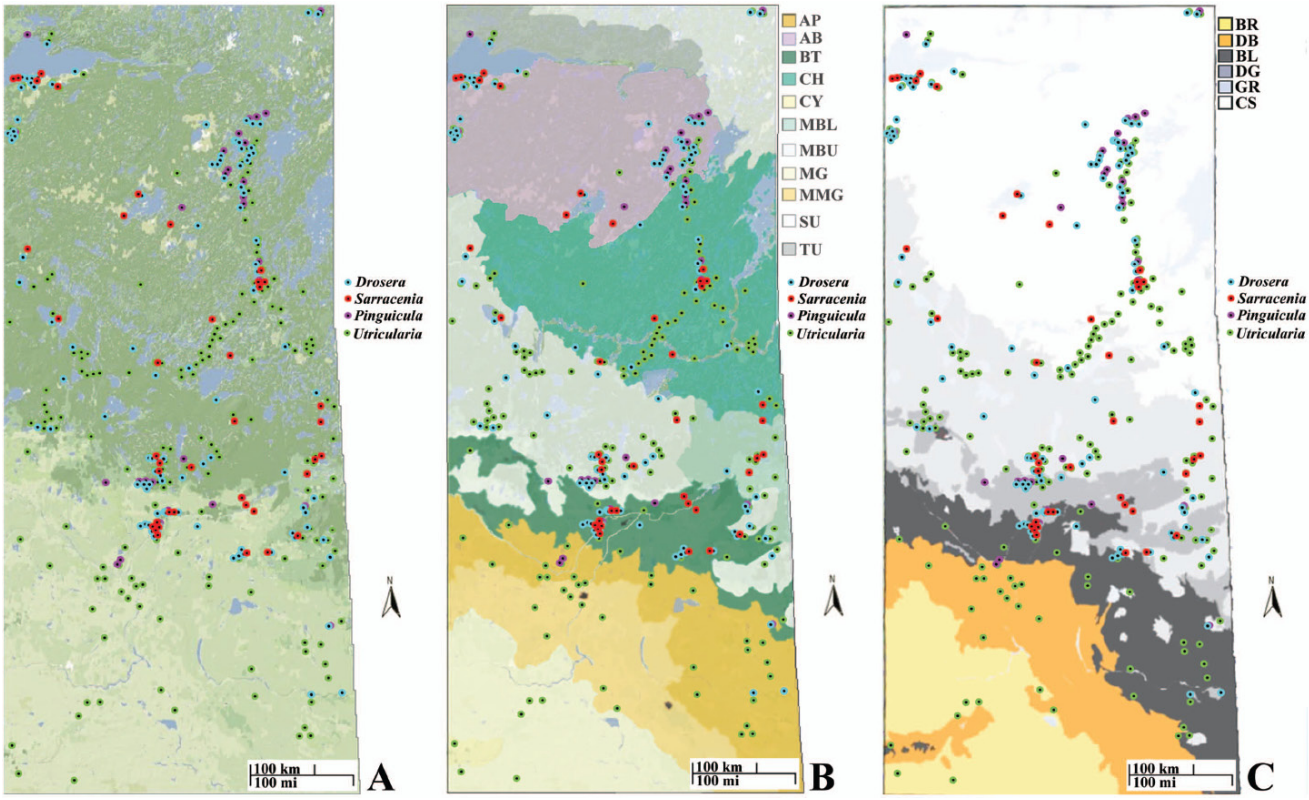

Figure 2. Distribution maps of carnivorous plants in Saskatchewan. A-C: Combined distribution map of the four carnivorous genera (*Drosera*, *Sarracenia*, *Pinguicula*, and *Utricularia*) in Saskatchewan. A. Map with topographic layer. B. Map with ecoregions layer. AP=Aspen Parkland, AB=Athabasca Plain, BT=Boreal Transition, CH=Churchill River Upland, CY=Cypress Upland, MBL=Mid-Boreal Lowland, MBU=Mid-Boreal Upland, MG=Mixed Grassland, MMG=Moist Mixed Grassland, SU=Selwyn Lake Upland, TU=Tazin Lake Upland. C. Map with soil types layer. BR=Brown, DB=Dark Brown, BL=Black, DG=Dark Grey, GR=Grey, CS=Canadian Shield.

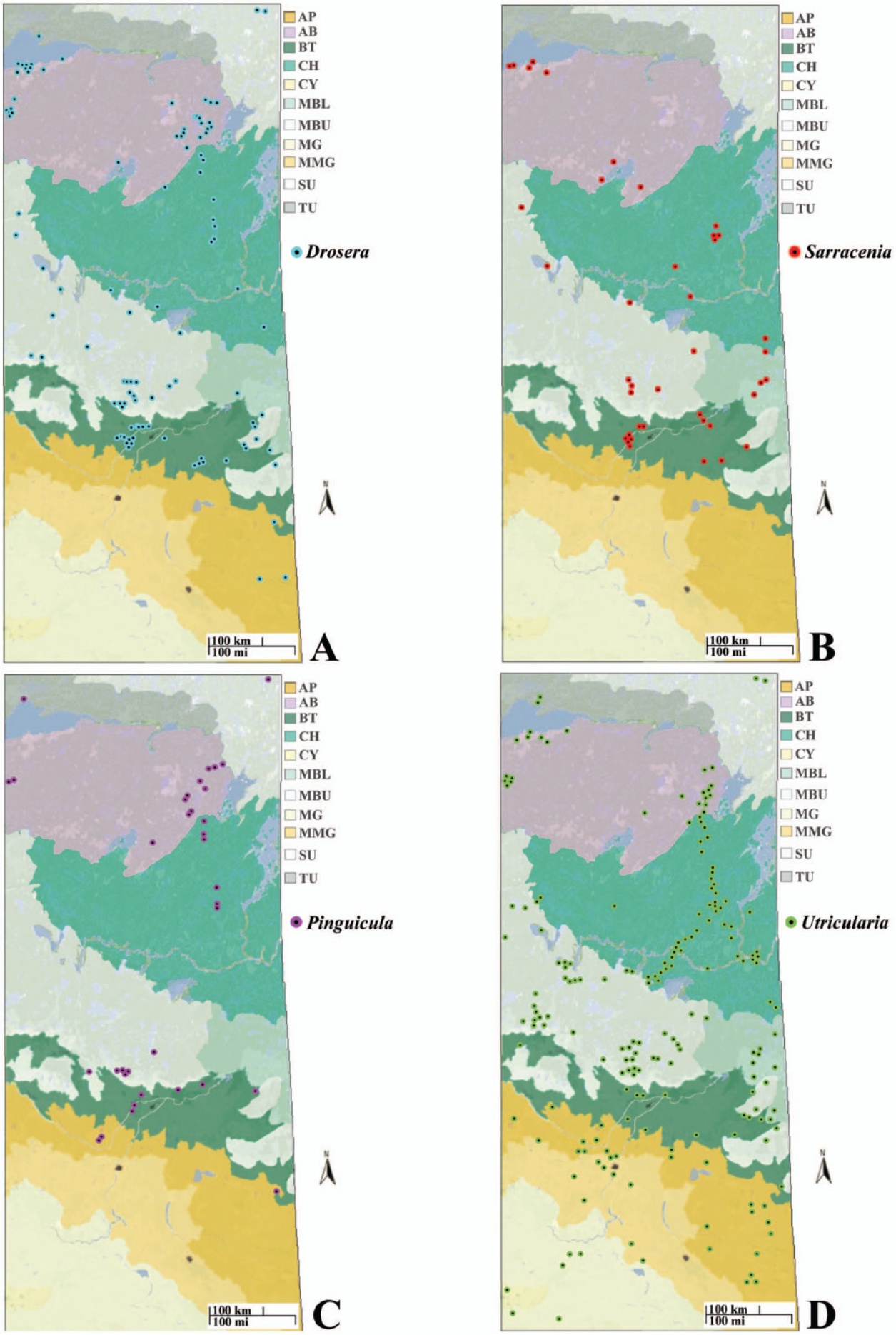

Figure 3. Distribution maps of each carnivorous genus. A. Distribution map of *Drosera* species. B. Distribution map of *Sarracenia purpurea*. C. Distribution map of *Pinguicula* species. D. Distribution map of *Utricularia* species. AP=Aspen Parkland, AB=Athabasca Plain, BT=Boreal Transition, CH=Churchill River Upland, CY=Cypress Upland, MBL=Mid-Boreal Lowland, MBU=Mid-Boreal Upland, MG=Mixed Grassland, MMG=Moist Mixed Grassland, SU=Selwyn Lake Upland, TU=Tazin Lake Upland.

2000), supports the importance of protecting these areas. In fact, there is evidence that boreal peatlands have a higher proportion of characteristic species, both plant and animal, than adjacent upland habitats, such as Aspen Parkland (Locky 2010). The Canadian boreal forests are under intense pressure, but despite the dramatic changes to the Saskatchewan boreal transition zone and the importance of this area to a wide diversity of wildlife, limited efforts or programs have been prepared to stop deforestation and the vanishing of native species (Hobson *et al.* 2002). We propose that data generated from the wealth of information stored in herbarium voucher specimens be used proactively in biodiversity conservation efforts to target specific areas for preservation and mitigate the accelerated destruction of natural habitats and practice more sustainable methods of natural resources. Our method is suitable for generating distributional data at the regional, provincial and national scale, and its accuracy can be refined with more powerful georeferencing methods and geographic information system technology.

In conclusion, specimens in biological collections contain valuable but often hidden information, which aids the investigation of a wide array of biological and environmental processes. Herbarium holdings help determine distributional patterns, major collector(s), and centers of diversity of a particular flora or plant group. Additionally, they aid in preserving records of past distribution of extinct/rare species, tracking the spread and/or naturalization of invasive species (Chauvel *et al.* 2006; Crawford and Hoagland 2009), and determining changes in community composition and phenology in response to environmental change (Primack *et al*. 2004). In addition to document type specimens (Cota-Sánchez *et al*. 2004), they are useful as an archival source of DNA (Cota-Sánchez *et al.* 2006), in genetic studies for conservation biology (Maunder *et al.* 1999), barcoding (Kress *et al.* 2005), and for other scientific and social studies, *e.g.*, Suarez and Tsutsui 2004; Rossman and Farr 2006; Lehtonen and Christenhusz 2010. Databases of herbarium label information are powerful in identifying regions deserving conservation priority based on high diversity and high concentrations of rare or narrowly distributed species. This botanical information facilitates the development of management strategies for the protection of unusual species assemblages, such as carnivorous plant populations, that fluctuate in response to natural and anthropogenic factors. Future studies using information stored in natural history collections will be instrumental contributions to the understanding of past and present species distribution as well as predicting future patterns in relation to environmental changes.

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Appendix 1. Chronological list of historical accessions of carnivorous plants by genus and species collected in Saskatchewan prior to 1950.

TAXON	LOCALITY	COLLECTOR	COLL. NO.	DATE	LATITUDE (°N)	LONGITUDE (°W)	ACCESSION NO.
Drosera anglica	Prince Albert	Fraser, W.P.		23/06/1933	53.2	-105.7	SASK 12955
D. anglica	Prince Albert	Fraser, W.P.		23/06/1933	53.2	-105.5	SASK 91996
D. anglica	Prince Albert	Fraser, W.P.		12/07/1933	53	-105	SASK 12954
D. anglica	Prince Albert	Fraser, W.P.		25/08/1933	53.2	-105.7	SASK12957
D. anglica	Prince Albert	Fraser, W.P.		31/08/1933	53.2	-105.8	SASK12592
D. anglica	McKague	Breitung, A.J.		10/08/1934	52.6	-103.917	SASK 12956
D. anglica	Lake Athabasca	Raup, H.M.	6854	13/08/1935	59.125	-109.317	DAO 568305
D. anglica	McKague	Breitung, A.J.	28	12/07/1936	52.61667	-103.933	CAN 504618
D. anglica	Prince Albert	Furniss, O.C.		19/07/1941	2.216667	-4.40694	SASK 144018
D. anglica	Prince Albert	Furniss, O.C.	860	29/06/1941	53.2	-105.7	SASK 77299
D. anglica	Prince Albert	Fraser, W.P.		23/07/1936	53.2	-105.767	ALTA 58102
D. linearis	Prince Albert	Fraser, W.P.		23/06/1933	53.2	-105.8	SASK 91997
D. linearis	Prince Albert	Fraser, W.P.		12/07/1933	53.2	-105.8	SASK 12947
D. linearis	McKague	Breitung, A.J.		10/08/1934	52.6	-103.9	SASK 12950
D. linearis	McKague	Breitung, A.J.		10/08/1934	52.6	-103.9	SASK 12951
D. linearis	McKague	Breitung, A.J.	29	12/07/1936	52.61667	-103.933	CAN 504400
D. linearis	Prince Albert	Furniss, O.C.		19/07/1941	53.2	-105.767	SASK 144019
D. linearis	Prince Albert	Furniss, O.C.	858	19/07/1941	53.2	-105.8	SASK 77298
D. linearis	Wallwort	Breitung, A.J.		22/07/1941	52.55	-104.05	ALTA 58103
D. rotundufolia	Speddington	Russell, R.C.		14/07/1926	52.8	-103.7	SASK 91998
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		00/00/1930	54	-106.2	SASK 12971
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		00/00/1930	53.9	-106.1	SASK 92000
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		00/00/1930	53.9	-106.1	SASK 12966
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		08/07/1930	54	-106.2	SASK 12967
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		07/08/1930	53.0	-106.1	SASK 149965
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		21/07/1932	53.9	-106.1	SASK 91999
D. rotundifolia	Waskesiu Lake	Fraser, W.P.		26/07/1932	54	-106.2	SASK 12969
D. rotundifolia	Prince Albert	Fraser, W.P.		12/07/1933	53.2	-105.7	SASK 12963
D. rotundifolia	McKague	Breitung, A.J.		10/08/1934	52.6	-103.9	SASK 12964
D. rotundifolia	Prince Albert	Fraser, W.P.		23/07/1936	53.2	-105.767	ALTA 58104
D. rotundifolia	Prince Albert	Fraser, W.P.		23/07/1936	53.2	-106	SASK 106447
D. rotundifolia	Waskesiu Lake	Ledingham, G.F.		07/03/1937	54	-106.1	SASK 106448
D. rotundifolia	Prince Albert	Furniss, O.C.	855	19/07/1941	53.2	-106	SASK 77297
D. rotundifolia	Prince Albert	Furniss, O.C.		19/07/1941	53.2	-105.8	SASK 144078
D. rotundifolia		Breitung, A.J.		22/07/1941	54.00005	-106	ALTA 123407
Pinguicola villosa	Lake Athabasca	Raup, H.M.	6307	24/07/1935	59.6	-109.217	CAN 99311
P. vulgaris	MacDowall	Fraser, W.P.		07/10/1932	53	-106	SASK 67551
P. vulgaris	Prince Albert	Fraser, W.P.		01/07/1935	53.2	-105.8	SASK 21146
P. vulgaris	Prince Albert	Fraser, W.P.		01/07/1935	53.2	-105.8	SASK 21147
P. vulgaris	Prince Albert	Fraser, W.P.		27/07/1937	53.2	-105.8	SASK 116259
P. vulgaris	Prince Albert	Furniss, O.C.		14/06/1940	53.2	-105.767	SASK 144120
Sarracenia purpurea	Prince Albert	Thompson, W.P.		10/06/1911	53.2	-105.7	SASK 12946

Appendix 1. ***Continued.***

TAXON	LOCALITY	COLLECTOR	COLL. NO.	DATE	LATITUDE (°N)	LONGITUDE (°W)	ACCESSION NO.
S. purpurea	Prince Albert	Fraser, W.P. & Russell, R.C.		10/06/1932	53.2	-105.7	SASK 91991
S. purpurea	Prince Albert	Fraser, W.P. & Russell, R.C.		06/12/1932	53.2	-103.7	SASK 91992
S. purpurea	Prince Albert	Fraser, W.P. & Russell, R.C.		12/07/1932	53.2	-105.7	SASK 12936
S. purpurea	Prince Albert	Russell, R. C.		12/07/1932	53.2	-105.767	ALTA 58100
S. purpurea	McKague	Breitung, A.J.		06/09/1934	52.6	-103.9	SASK 12943
S. purpurea	Lake Athabasca	Raup, H.M.		24/08/1935	59.05	-109.567	ALTA 9968
S. purpurea	Prince Albert	Fraser, W.P.		07/05/1939	53.2	-105.7	SASK 12940
S. purpurea	Prince Albert	Fraser, W.P.		07/05/1939	53.2	-105.7	SASK 12945
S. purpurea	Prince Albert	Furniss, O.C.	870	21/06/1940	53.2	-105.7	SASK 77258
S. purpurea	Prince Albert	Furniss, O.C.		22/06/1940	53.2	-105.7	SASK 145051
S. purpurea	Prince Albert	Furniss, O.C.		17/08/1941	53.2	-105.7	SASK 145049
S. purpurea	Chelan	Robinson, D.R.		15/06/1944	52.6	-103.4	SASK 91993
Utricularia intermedia	Prince Albert	Fraser, W.P.		23/06/1933	53.2	-105.8	SASK 21168
U. intermedia	Prince Albert	Fraser, W.P.		23/06/1933	53.2	-105.8	SASK 86764
U. intermedia	Dahlton	Breitung, A.J.		07/05/1936	52.5	-104.1	SASK 21166
U. intermedia	Pike Lake	Russell, R.C.		07/07/1936	51.9	-106.8	SASK 116266
U. intermedia	Pike Lake	Mead, H.W.		28/08/1936	51.9	-106.8	SASK 86765
U. intermedia	Prince Albert	Fraser, W.P.		24/06/1940	53.2	-105.8	SASK 21169
U. intermedia	Prince Albert	Furniss, O.C.	1659	29/06/1941	53.2	-105.8	SASK 144769
U. macrorhiza	Saskatoon	Fraser, W.P.		00/08/1922	52.1	-106.6	SASK 86773
U. macrorhiza	Saskatoon	Fraser, W.P.		00/08/1922	52.1	-106.6	SASK 86774
U. macrorhiza	Buttress	McCalla, W.C.		18/07/1923	50.20003	-105.634	ALTA 65412
U. macrorhiza	Duncairn	Russell, R.C.		02/08/1924	51.8	-106.5	SASK 86772
U. macrorhiza	Saskatoon	Cameron, W.H.		27/07/1927	52.1	-106.6	SASK 21178
U. macrorhiza	Sutherland	Arnason, T.J.		17/07/1930	52.1	-106.6	SASK 21195
U. macrorhiza	Saskatoon	Fraser, W.P.		17/07/1930	52.1	-106.6	SASK 21196
U. macrorhiza	Waskesiu Lake	Fraser, W.P.		00/08/1930	53.9	-106.2	SASK 21180
U. macrorhiza	Wakaw	Fraser, W.P.		30/06/1933	52.6	-105.6	SASK 21179
U. macrorhiza	Somme	Russell, R.C.		10/07/1934	52.1	-104.8	SASK 21197
U. macrorhiza	St. Gregor	Russell, R.C.		10/07/1934	52.2	-104.8	SASK 86771
U. macrorhiza	Cypress Hills	Bolton, J.L.	109	15/08/1936	49.6	-109.8	SASK 21198
U. macrorhiza	Cypress Hills	Bolton, J.L.		15/08/1936	49.6	-109.8	SASK 116280
U. macrorhiza	Montreal Lake	Fraser, W.P.		15/07/1938	54.1	-105.8	SASK 21182
U. macrorhiza	Emma Lake	Russell, R.C.		18/07/1940	53.6	-106	SASK 86770
U. macrorhiza	Emma Lake	Russell, R.C.		26/07/1940	53.6	-105.9	SASK 21193
U. macrorhiza	Besnard Lake	Campbell, J.A.		20/08/1941	49.1	-108.1	SASK 116278
U. macrorhiza	Heart Lakes	Russell, R.C.		17/06/1944	54.0	-106.2	SASK 86769
U. macrorhiza	Whitewood	Russell, R.C.		08/03/1945	50.3	-102.3	SASK 86768
U. minor	Dahlton	Breitung, A.J.		07/05/1936	52.5	-104.1	SASK 21174
U. minor	Dahlton	Breitung, A.J.		07/05/1936	52.5	-104.1	SASK 21176
U. minor	Dahlton	Breitung, A.J.		00/08/1936	52.5	-104.1	SASK 21175