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FLORA OF NORTH DAKOTA PROJECT

ALEXEY SHIPUNOV*[1], LIUDMILA ABRAMOVA[2], JOSHUA BEAUDOIN[1], JIN HEE CHOI[1], DALLAS FRY[1], RYAN PERRY[1], VERA SHIPUNOVA[3], JARED SCHUMAIER[1], JASON THEODORE[1]

[1] Department of Biology, Minot State University, Minot, North Dakota 58707
[2] Moscow South-West High School (No. 1543), Moscow, Russia
[3] Falmouth High School, Massachusetts 02540

*correspondence: Alexey Shipunov, dactylorhiza@gmail.com

ABSTRACT

In 2011, we started the systematic investigation of the North Dakota flora with a priority of filling "botanical white spots." Most of the state is now covered with sampling of approximately 30 by 30 miles density. More than 3,500 herbarium samples were deposited into Minot State University herbarium collection (MISU). Databasing and digitization started at the time of collection: almost every sample has an associated geo-referenced photograph and permanent herbarium labels have been made from the database. The checklist of North Dakota plants is published both as a Web service and as downloadable PDF book; it is a result of automated conversion of more than 40 species lists, processed with multiple "filters" that add information to species names. Nomenclature problems were solved via programmatic normalization. To date, the known flora of North Dakota consists of 1751 species, 667 genera and 124 families of vascular plants. While proportions of plants common between this state and neighboring territories are equal, species composition reveal that the flora of North Dakota is most similar to the flora of South Dakota.

Almost every state in the USA has created multiple inventories of its plant and animal life. These reviews help to manage natural resources, monitor invasive and dangerous species, identify new useful plants and animals, educate local communities, supply natural gardening, and save rare and endangered species from extinction. North Dakota has never been researched in full for plant diversity: only one book has been published (Stevens 1950); floristic research begun in the 1970s at NDSU was not finished, and by 2010 more than 45% of North Dakota's territory was still awaiting botanical investigation (Fig. 1). From several North Dakota counties, less than 10 herbarium samples had been collected.

Although North Dakota was not under intensive natural history investigation, the state has several unique features. Being treeless and the most flat and wetland-rich part of the Northern Great Plains, it includes a Continental Divide, a region of numerous prairie potholes that are result of delayed glacial melting (Bluemle 2000). The western part of the state was not under glaciation and is therefore more similar to the neighboring territories of Montana (Royer 2003). One of the most remarkable spots is the Devils Lake region, the second self-drainage basin in North America. The wide Red River Valley is the remnant of Great Lake Agassiz (Bluemle 2000). One of the few forested regions is the "glacier garbage" Turtle "Mountains, which contain the only known peatmoss bog in the state (Stevens 1950).

Material and Methods

In 2011, we started the systematic investigation of the state flora with a top priority of filling "botanical white spots" (Fig. 1) and normalizing the sampling level for counties underrepresented in herbarium collections. To date, most of the territory is covered with sampling of approximately 30 by 30 miles density. In 2013-2014, attention was paid to the "hot spots," regions with the richest flora such as Forest River (Grand Forks County) with 504 species of vascular plants. We have collected more than 3500 herbarium samples, which are deposited in Minot State University herbarium

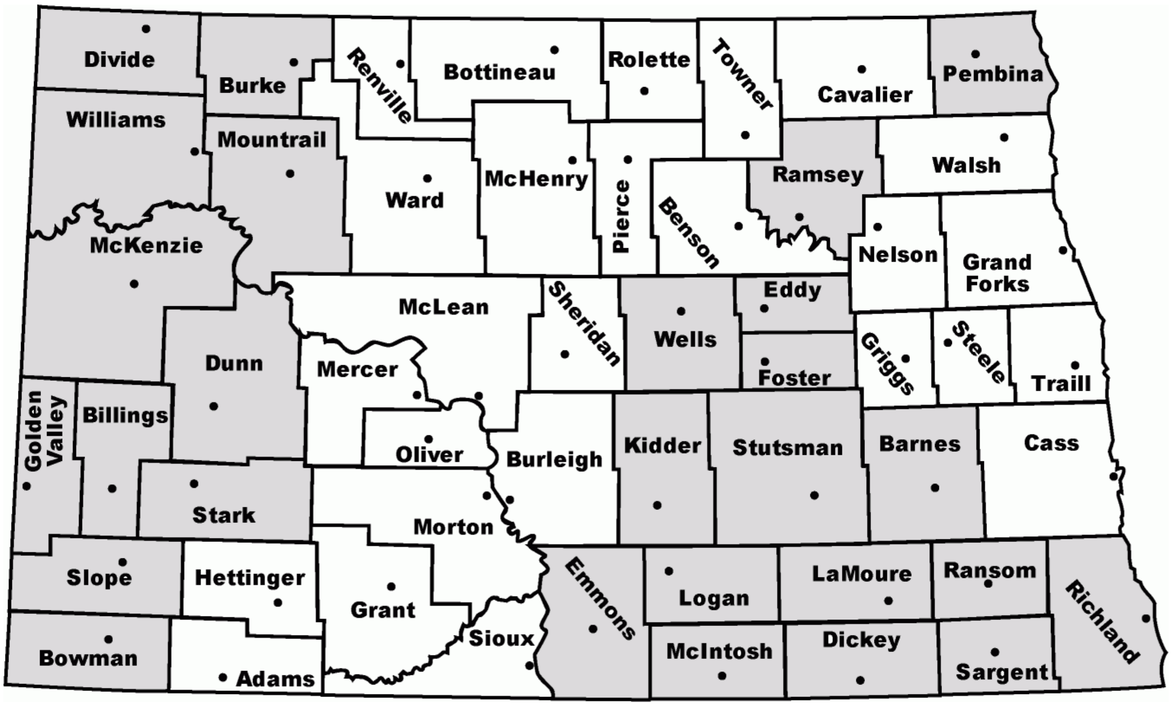

Figure 1. North Dakota counties. Counties not investigated botanically by 2010 (botanical “white spots”) are not shaded.

(MISU). As a result, the total size of the collection was doubled (from 3300 samples in 2010 to 7100 in 2015). In addition, the DNA barcoding project for North Dakota flora was started in collaboration with the Barcoding of Life Consortium and now includes sequences from almost 400 species.

Our collection workflow (Fig. 2) has consisted of several steps. First, Google Earth maps, along with North Dakota Fish and Wildlife “PLOT” maps, were used to select the candidate locations, usually non-private land with potentially undisturbed or little disturbed plant communities. Every year, our season started in the end of May and ended in October. Neighboring locations were usually accessed in different months. Since our driving distances were typically large (200–300 miles round trip in average), we frequently spent only 2–4 hours per locality. To optimize the collection process, we photographed every plant before collection (with GPS location recorded in EXIF data of photograph), pre-pressed it, and labeled with temporary labels containing only three numbers: locality, collection and image, and habitat notes. In most locations, we collected all plant species with flowers and/or fruits.

To make the permanent labels and herbarium database, we used the location table and the primary table, which contained the data from temporary labels plus the plant identification. Merging these two tables programmatically updated the MISU herbarium database, which in turn was the source of permanent herbarium labels. Consequently, since labels were created from database entries, the databasing of herbarium was not needed as a separate working task. In addition, as every plant was photographed in the field, herbarium digitization was done on its own.

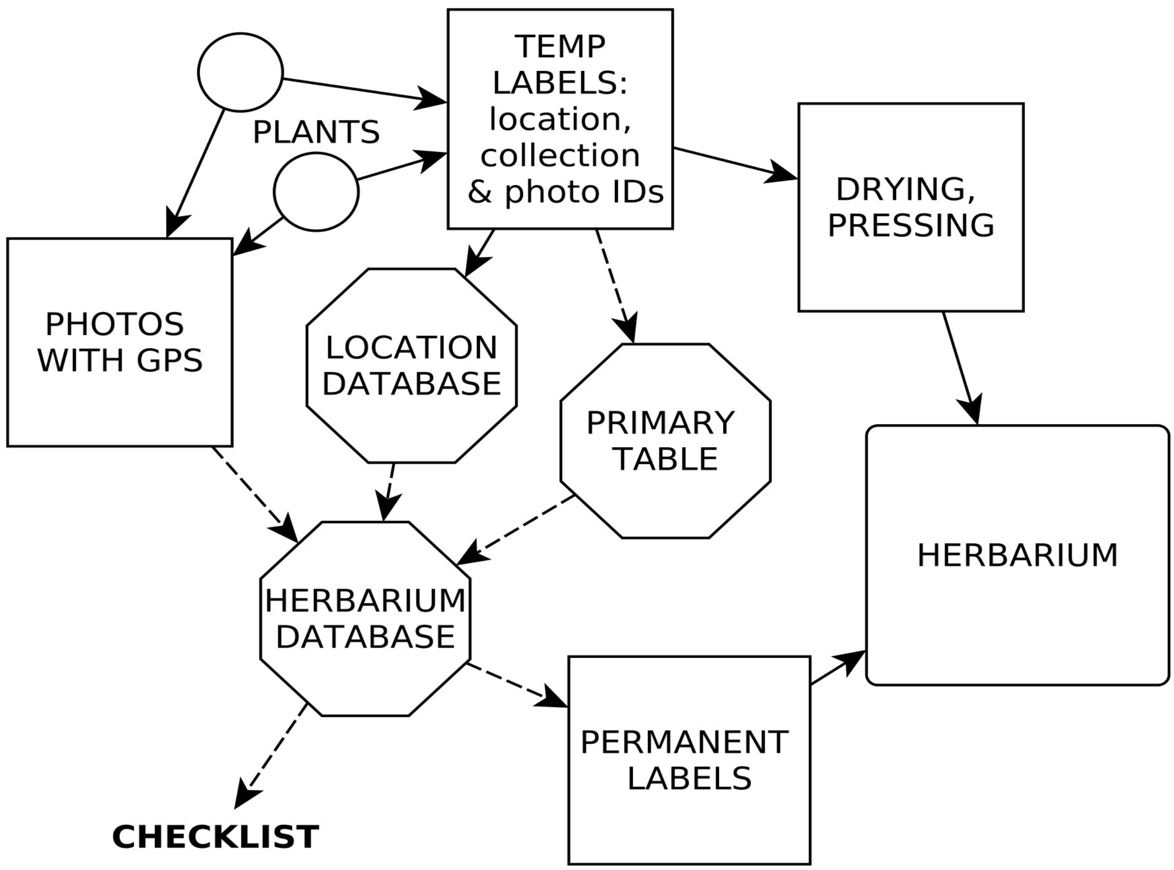

Figure 2. The scheme of our collection workflow. Dashed arrows represent "automatic" steps, performed programmatically.

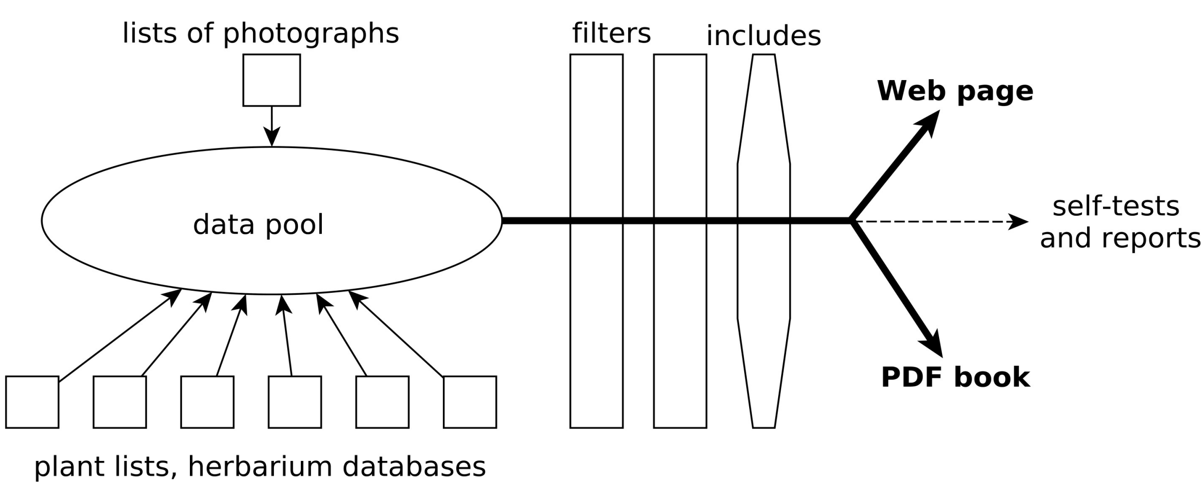

Figure 3. The scheme explaining the creation of the North Dakota checklist. Bold arrows emphasize two main representations of the checklist; the dashed arrow indicates self-testing.

To create the checklist of North Dakota plants, we also used programmatic tools (Fig. 3). All data was initially represented in flat text tables on a local computer and then was programmatically merged into the checklist, simultaneously outputting the HTML Web page and PDF book (located at "Flora of North Dakota: Checklist," Shipunov 2012–onwards; the PDF file is also uploaded to archive.org). This semi-static approach is not based on any existent database system but has employed multiple text tools (Mesibov 2015) and in our case, also an R data processing environment (R Core Team 2014). Authors would be happy to share the code with all interested parties.

The aforementioned “flat text tables” were our sources of information. In all, we used more than 40 different resources, from “classically” published works and Internet databases (Atlas of the flora of Great Plains,1977; Barker et al. 1978; Barlow 1987; Bergman 1918; BISON, 2014; Bry 1986; DeKeyser 1995; Dix & Smeins 1967; EDDMapS 2013; Facey et al. 1986; Godfread 1976; Hansen 2008; Hegstad 1973; Larson 1979; Larson 1993; Lautenschlager 1964; Lunell 1915-1918; Meinke 1991; NatureServe 2013; North Dakota Department of Agriculture 2013; Okerson 2001; Pelvit & Barker 1975; Petrik-Ott 1979; Rohde-Fulton 1985; Seiler 1973; Seiler & Barker 1985; Stevens 1950; Stevens 1966; The Biota of North America Program 2013; USDA noxious weeds 2013; USDA PLANT database 2013; Willenbring 1971; Williams 1979; Zaczkowski 1972) to local off-line electronic resources (the most important were UND and NDSU herbarium databases). An updated list of these resources may be found on the checklist Web site.

Two representations (the Web service and the downloadable PDF book) of the illustrated checklist are constantly updating: when a new name or a new list appears, both the book and Web page are updated simultaneously through scripts written for an R statistical environment and TeX/LaTeX text formatting system. The checklist is the product of interactions between computer scripts and multiple flat text databases. This semi-static Web service could be used for the variety of applications; for example, it was used to check and enhance the second edition of P. Kannowski’s book “Wildflowers and Grasses of North Dakota” (2014).

The Web portion of the checklist is based on the DataTables plug-in for jQuery (2015) and therefore is the client-side application. This may be downloaded and used on a local computer without an Internet connection.

One of the key concepts of the checklist is the “filtration.” For example, to create the checklist, all species lists are “filtered” through the synonyms table. This table was initially made with the Taxonomic Name Resolution Service (Boyle et al. 2013) and in essence contains two columns: string to replace and the replacement. If the name from the species list is a taxonomic synonym, or simply mistyped, the filtering process replaces it with the accepted one, because the synonyms table contains replacement rules for most occasions. If after the update of source, the new name appears, it will be easy to catch since it will also appear in the self-test output table (Fig. 3). If this new name is incorrect, the checklist maintainer will add a new entry to the synonyms table, and from that time it will be automatically replaced with a correct one. A similar approach was used to add information about families, common names, rarity, invasive status and color of flower to the checklist. In addition, the programmatically-made PDF book contains information from “includes.” These arbitrarily-placed pieces of the text could be used to insert keys and morphological descriptions into the main text.

The amount of data collected allowed to make the statistical overview of the flora of North Dakota. This includes total numbers of species, genera, and families, most frequent plant species, top families, and elucidation of geographic affinities of the flora, and comparisons between counties. To compare with neighboring states or provinces, we used USDA PLANT database (2013).

Results

The flora of North Dakota consists of 1751 species, 667 genera, and 124 families of vascular plants (in accordance with Shipunov 1991–onwards). In addition, 240 species are mentioned for the state without location. The flora is dominated by Compositae, Gramineae, Cyperaceae, Leguminosae, and Cruciferae (Fig. 4). A high abundance of Cyperaceae, Amaranthaceae, and Ranunculaceae probably is related to a high coverage of wetlands (Larson 1993). The dominant families are frequent for temperate grass and wetland floras and are typical for Northern Great Plains (Great Plains Flora Association 1977).

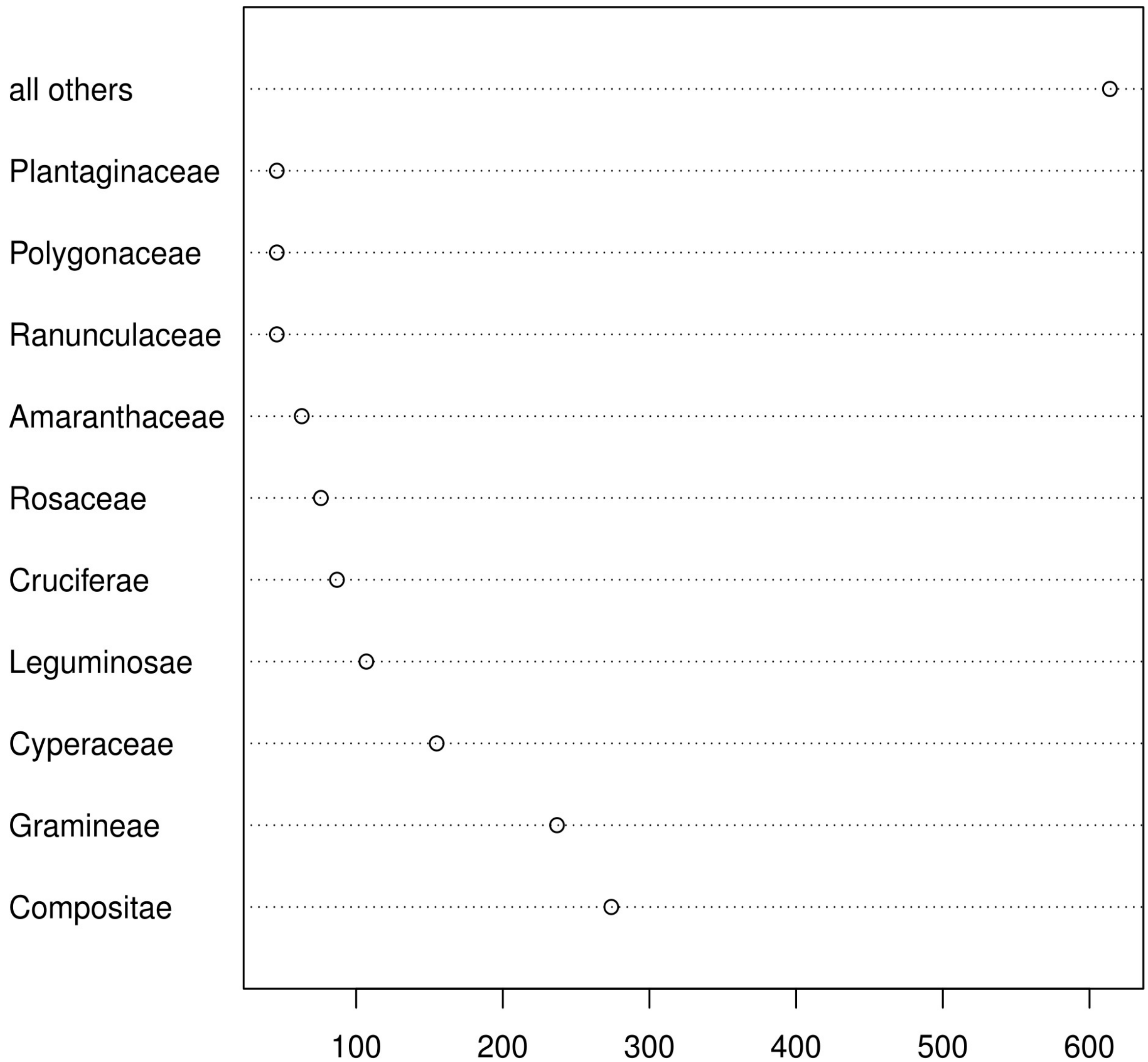

Figure 4. Families of flowering plants dominant in North Dakota.

Using herbarium databases, we found that most frequently collected species were *Polygonum amphibium*, *Sonchus arvensis*, and *Symphyotrichum lanceolatum* (Fig. 5). Among North Dakota counties, Ransom and Richland have the most diverse flora (more than 55% of state species), while Trail, Adams, and Towner have the least diverse flora (less than 25%). North Dakota has 139 "local endemics," e.g., *Trillium erectum, Reseda odorata*, species that do not occur in any neighboring state or province. 37 species were found in all surrounding territories but not in North Dakota (e.g., *Nymphaea odorata, Moneses uniflora*).

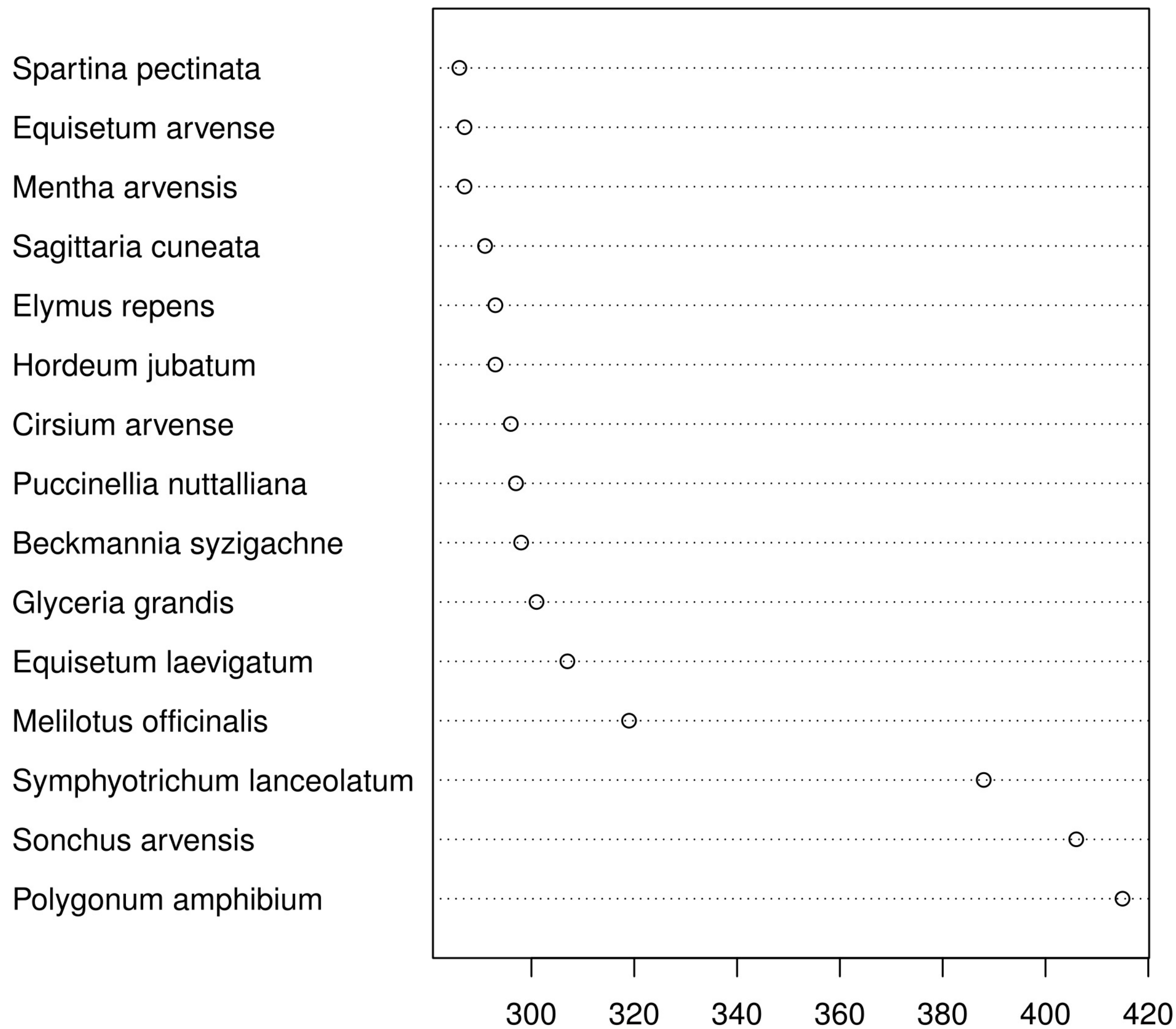

Figure 5. 15 most frequently collected species.

The proportion of plants common between North Dakota with each of the four neighboring regions (Fig. 6) is statistically equal (proportion test χ-squared = 24.35, df =3, p << 0.05). The cluster analysis of species composition consistently revealed that our flora is most similar to the flora of South Dakota (Fig. 7). The Montana flora has the significant Rocky Mountains component (evidently absent in North Dakota), whereas floras of Minnesota and Canadian provinces have many sylvan species. However, North Dakota has the biggest number of common unique plants (plants which grow only in two states) with Minnesota (58 species) and then with Montana (40 species), perhaps indicating routes of plant distribution.

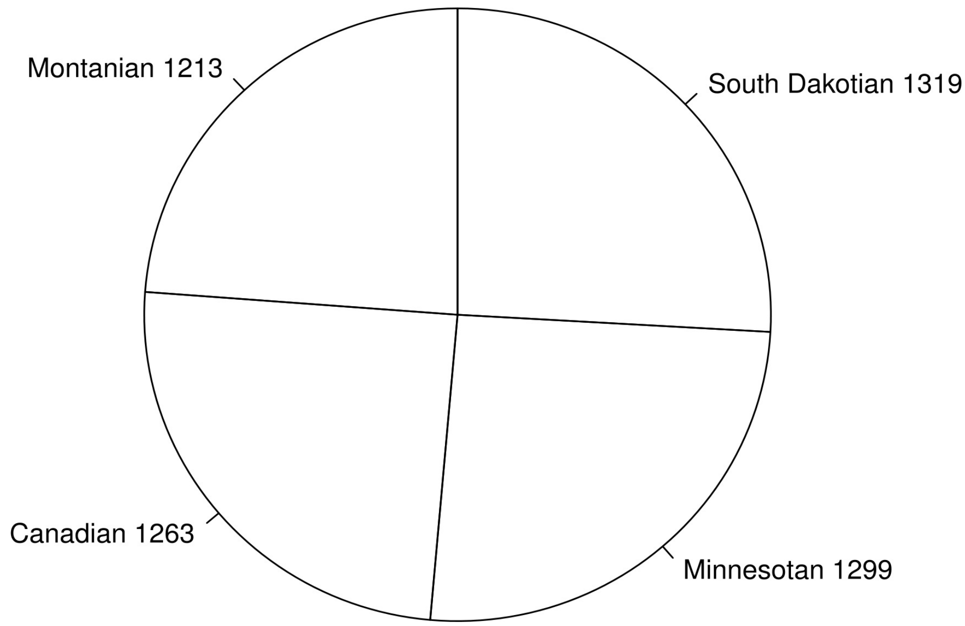

Figure 6. Proportions of plants common between North Dakota and neighboring territories. Numbers on the plot indicate numbers of common species.

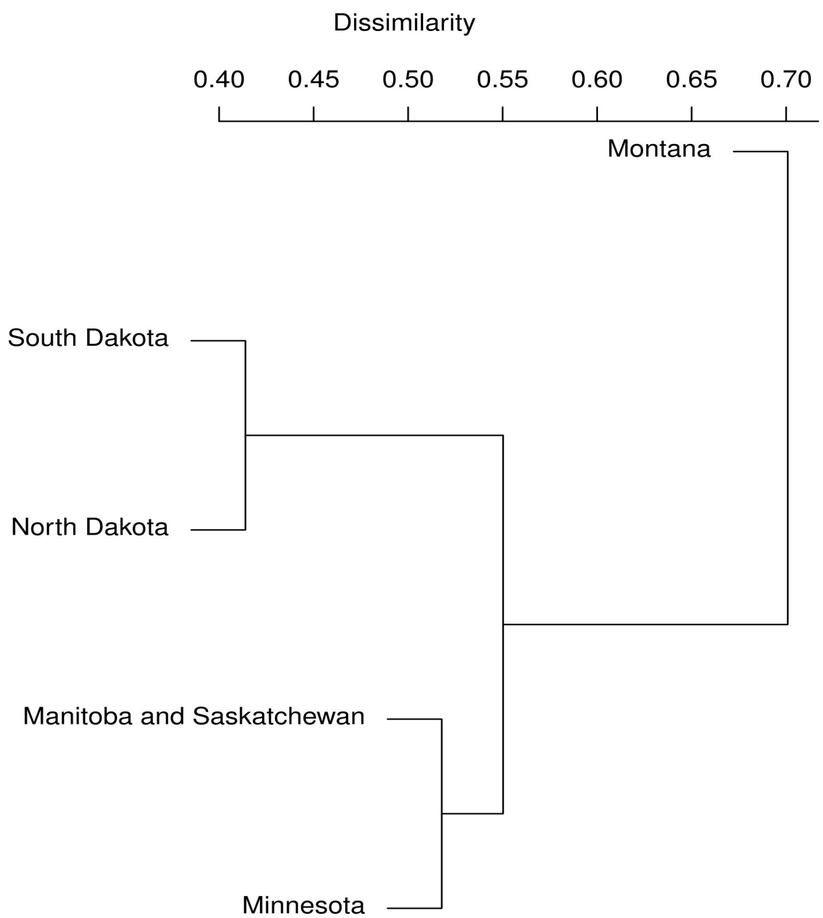

Figure 7. Dendrogram-represented results of the hierarchical cluster analysis (based on Jaccard similarity) of floras.

In 2011–2014, we were able to find 18 species that were never previously mentioned for the North Dakota, including, for example, *Iris germanica* (Pembina Gorge, Cavalier County). In the Lake George environs (McHenry County), we discovered the putatively easternmost location of the *Pinus ponderosa*.

Discussion

The flora of North Dakota project has several unique biodiversity informatics features. First, digitization starts at the time of collection and databasing precedes labeling. Second, the flora checklist is a semi-static Web service based on scripts that "filter" flat tables. Third, the flora manual (downloadable public domain PDF) with associated floristic data is self-growing. We hope that some of these concepts will be useful for other biodiversity projects.

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