

A synopsis of lycophytes in Manitoba, Canada: their status, distribution, abundance, and habitats

RICHARD J. STANIFORTH¹ and DANIEL F. BRUNTON^{2,*}

¹Department of Biology, University of Winnipeg, 515 Portage Avenue, Winnipeg, Manitoba R3B 2E9 Canada (deceased 12 January 2022)

²Beaty Centre for Species Discovery and Botany Section, Canadian Museum of Nature, Ottawa, Ontario K1P 6P4 Canada

*Corresponding author: dbrunton@nature.ca

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Abstract

A steady increase in the number of lycophyte taxa discovered in Manitoba over the last 20 years prompted a determination of which species should be included in an updated provincial list. Collections made throughout the province since 2008 and a critical examination of over 1000 herbarium specimens enabled a substantive review and update of Manitoba's lycophyte flora. It now comprises 22 taxa: 14 species and two hybrid clubmosses (Lycopodiaceae), three spikemosses (Selaginellaceae), and two species and one hybrid quillwort (Isoetaceae). Thirteen of the 21 species are designated to be of conservation concern, with NatureServe ranks of Critically Imperilled (S1; three), Imperilled (S2; two), or Vulnerable (S3; nine). Based on verified specimens, we describe the abundance and habitats, and summarize recent changes in nomenclature and systematics for all Manitoba lycophyte taxa.

Key words: Status; distribution; abundance; habitat; lycophytes; Lycopodiaceae; Selaginellaceae; Isoetaceae; Manitoba

Introduction

The lycophytes, class Lycopodiopsida (PPG I 2016), are spore-bearing vascular plants (i.e., tracheophytes) represented in Manitoba and in Canada by three families: clubmosses (Lycopodiaceae), spikemosses (Selaginellaceae), and quillworts (Isoetaceae). Lycophytes first appeared about 400 million years ago and are the oldest extant lineage of vascular plants, evolving long before the seed plants (Moran 2004). The class was diverse and abundant 350–300 million years ago, but many of its lineages became extinct at the end of the Carboniferous Period when the climate became drier and coastal swamps became more saline (Moran 2004). Contemporary members of the three living lycophyte families are often overlooked, being small, unobtrusive inhabitants of forest floors, dry grasslands, and tundra, or submerged aquatics (Cody and Britton 1989).

This study was motivated by uncertainty about which lycophyte taxa occur in Manitoba. New species have been discovered in the province intermittently since the publication of the provincial flora (Scoggan 1957) and the most recent review of their diversity (Staniforth 2012). Many long-established taxa have also been redefined based on new research (e.g., Wagner and Beitel 1992, 1993; Haines 2003),

providing a more contemporary understanding of the group. The primary purpose of our study was to examine herbarium and recently collected field specimens of Manitoba lycophytes critically to determine the distribution, abundance, and habitats of each verifiable taxon documented in the province.

As was typical of that time, Scoggan (1957) considered clubmosses (Lycopodiaceae) to be taxa within one large genus, *Lycopodium* L. More recently, however, Holub (1975), Wagner and Beitel (1992), and Haines (2003) divided *Lycopodium sensu lato* (*s.l.*, in the broader sense) into several genera. In Manitoba, *Lycopodium* (*s.l.*) is now considered to consist of six genera: tree-clubmosses (*Dendrolycopodium* Haines), ground-cedars (*Diphasiastrum* Holub), firmosses (*Huperzia* Bernhardt), bog clubmosses (*Lycopodiella* Holub), clubmosses (*Lycopodium* L. *sensu stricto* [*s.s.*, in the narrower sense]), and interrupted clubmosses (*Spinulum* Haines). This division has received widespread acceptance (PPG I 2016) and is incorporated into most recent field guides (e.g., Cobb *et al.* 2005; Chadde 2013; Walewski 2016; Palmer 2018). The genera are readily distinguishable in the field, but individual taxa within particular genera can be more challenging to identify, and some have undergone taxonomic revisions.

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The circumscriptions of the three species of spike-mosses listed by Punter (1995) have remained unchanged, but the quillworts have increased from a single species to three (see Annotated Checklist).

Methods

A total of 981 specimens of Manitoba lycophytes in the University of Manitoba (WIN), University of Winnipeg (UWPG), the Manitoba Museum (MMM) herbaria (acronyms according to Thiers 2020), and the personal collection of R.J.S. were examined and documented by R.J.S. between 2008 and 2020. An additional 61 specimens defied identification, mostly because they were vegetative. Determinations, identification confirmations, and label information for all specimens examined were documented in a spreadsheet (Table S1). Each taxon accepted in the present study is supported by at least one Manitoba specimen verified and annotated

by one or more lycophyte specialists (see Acknowledgements).

The herbarium specimen data were supplemented by extensive collecting throughout the province between 2008 and 2020 by R.J.S. and D. Staniforth. This involved many thousands of kilometres of travel through southern Manitoba and as far north as Lynn Lake in the west and Split Lake, Berens River, and Churchill in the east (Figure 1), visiting provincial parks and provincial forest reserves as well as roadside plant communities. Between 2010 and 2014, travel to remote northern communities to gather data for the Manitoba breeding bird atlas (MBBA 2014) enabled access to areas previously poorly or unsurveyed (Figure 1, Table S2). This resulted in a substantial improvement in both the quantity of Manitoba lycophyte records and their geographic distribution. Specimens collected during those trips are deposited in various herbaria, including MMMN, WIN, and

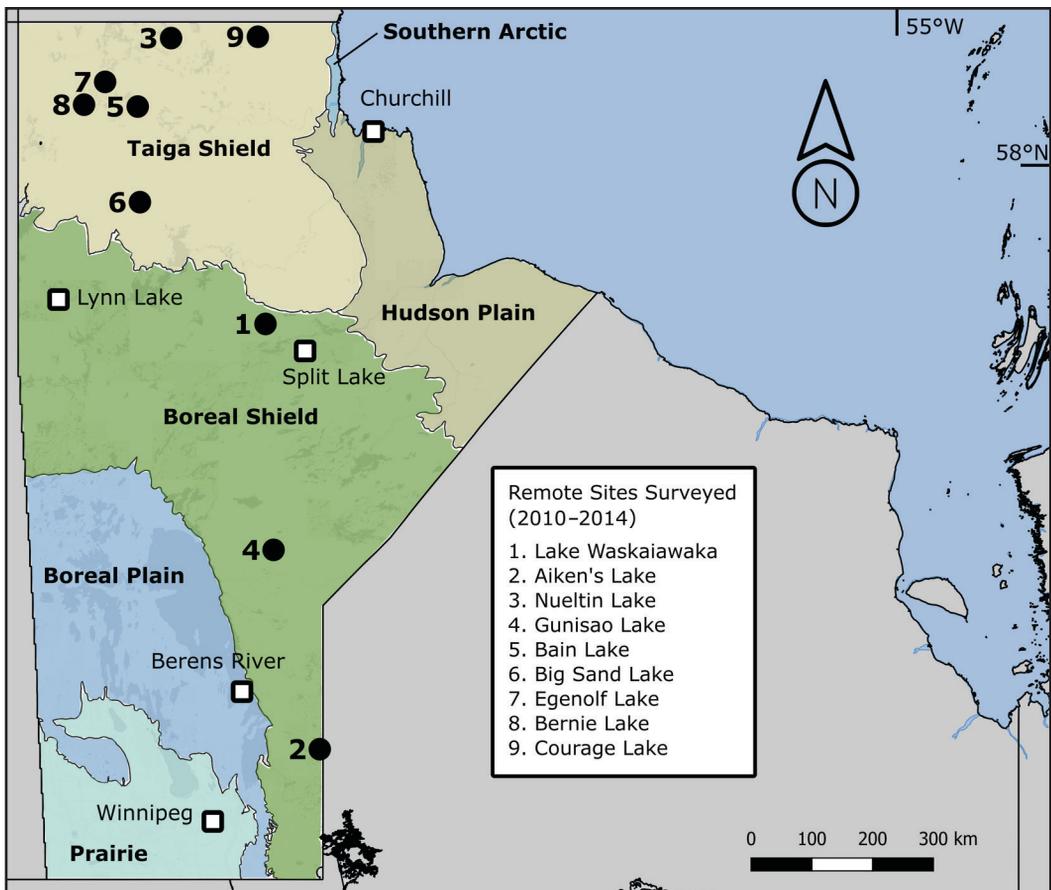


FIGURE 1. Manitoba ecozones and key geographic locations, including recently investigated remote sites (see Table S2). Ecozone delineation adapted (simplified) from Manitoba's Protected Areas Initiative (2013). Basemap from SimpleMappr (Shorthouse 2010).

UWPG. The first set of vouchers from the 2008–2020 surveys is currently in the R.J.S. personal collection (here designated RS), which is to be deposited in a public Manitoba herbarium.

Based on these data, we compiled and summarized the distribution, abundance, and habitat of each lycophyte taxon (see Annotated Checklist).

Results

Twenty-two taxa (19 species and three hybrids) have been documented from the examination of the 981 museum specimens and recent collections with supporting vouchers as occurring (or having occurred) in Manitoba (Annotated Checklist, below; some representatives are shown in Figure 2). We report two species for the first time in the province: Alpine Ground-cedar (*Diphasiastrum alpinum* (L.) Holub; Figure 2c) and Continental Firmoss (*Huperzia continentalis* Testo, Haines and Gilman; Figure 2d). Hickey's Quillwort (*Isoetes ×hickeyi* Taylor and Luebke) is added to the list of Manitoba's flora based on the report in Brunton and Britton (1991). Savin-leaved Ground-cedar (*Diphasiastrum ×sabinifolium* (Wille-now) Holub, *pro sp.* [*pro specie* – originally described as a distinct species]) is excluded from the flora.

Annotated Checklist of Manitoba Lycophytes

The list is organized by family then alphabetically by genus and species. VASCAN (Brouillet *et al.* 2010+) is the default authority for nomenclature and taxonomy, unless otherwise stated. For consistency's sake, common names also typically are those recommended by VASCAN. Thus *Dendrolycopodium* spp. are tree-clubmosses, *Diphasiastrum* spp. are ground-cedars, *Huperzia* spp. are firmosses, *Lycopodiella* sp. is bog clubmoss, *Lycopodium* spp. are clubmosses, *Spinulum* spp. are interrupted clubmosses, *Selaginella* spp. are spikemosses, and *Isoetes* spp. are quillworts (Figure 2).

The relative abundance of lycophyte species was measured by the number of specimens examined in Manitoba herbaria (Table 1). For specimens that lack a collection number, the accession number and herbarium acronym of the hosting collection are noted.

This checklist is a complete representation of the Manitoba lycophyte specimen record. Substantial collections preserved in out-of-province herbaria (e.g. Canadian Museum of Nature [CAN]) are almost completely duplicated in Manitoba herbaria.

The Annotated Checklist also cites the current subnational (i.e., Manitoba [MB]) conservation status rank (S-rank) assigned to each of the lycophyte taxa (NatureServe 2022). S-ranks provide information on the conservation evaluation (level of risk) for that species and include the following categories: S1 (Critically Imperilled), S2 (Imperilled), S3 (Vulnerable),

S4 (Apparently Secure), and S5 (Secure). Taxa that are yet to be ranked are cited as “unranked”; hybrids are not included in conservation status rankings but recognized as “unranked hybrids” (NatureServe 2022). Only one synonym (syn.) is included for most species.

Species reported for MB for the first time are indicated by an asterisk (*).

Lycopodiaceae, clubmosses

Dendrolycopodium, tree-clubmosses (Figure 2a)

Historically (e.g., Scoggan 1957), the scientific name of the common tree-clubmoss in MB was *Lycopodium obscurum* Michaux. Haines (2003) reclassified the taxon, placing it in the new genus *Dendrolycopodium* as *Dendrolycopodium obscurum* (Michaux) Haines. This has caused confusion in MB and western Canada because *D. obscurum* (s.s.) is exclusively an eastern species (Wagner and Beitel 1993). Only Prickly Tree-clubmoss (*Dendrolycopodium dendroideum* (Michaux) Haines) and Hickey's Tree-clubmoss (*Dendrolycopodium hickeyi* (Wagner, Beitel, and Moran) Haines) have been confirmed from MB. *Dendrolycopodium hickeyi* was only recently recognized as occurring here (Staniforth 2012). Putative hybrids between tree-clubmosses have been recorded from New England where they are considered rare (Haines 2011). Such hybrids are not yet known in MB.

Dendrolycopodium dendroideum (syn. *Lycopodium dendroideum* Michaux). Prickly Tree-clubmoss, lycopode dendroide (Figure 2a). Moist, mixed, and coniferous forests throughout MB (Figure 3a). Very common and S4. Number of specimens seen: 141 (Table 1). Northernmost MB record: Big Sand Lake, Sand Lake Provincial Park, 57.614°N, 99.850°W, mixed woodland on clay, 12 June 2011, R.J. Staniforth 00699 (RS).

Dendrolycopodium hickeyi (syn. *Lycopodium hickeyi* (Wagner, Beitel, and Hickey) Moran; *Lycopodium obscurum* var. *isophyllum* Hickey). Hickey's Tree-clubmoss, lycopode de Hickey. Moist mixed forests and coniferous forests throughout MB (Figure 3b). Uncommon and S3. Number of specimens seen: 42 (Table 1). Northernmost MB record: Nueltin Lake, central area, 59.797°N, 99.782°W, open White Spruce (*Picea glauca* (Moench) Voss) woods, lichen, and birch on sandy gravel, 1 July 2012, R. Staniforth 00825 (RS).

Diphasiastrum, ground-cedars (Figures 2b,c)

We follow Haines (2003) in recognizing *Diphasiastrum* as a distinct genus within *Lycopodium* (s.l.). Zeiller's Ground-cedar (*Diphasiastrum ×zeilleri* (Rouy) Holub), the most frequently encountered *Diphasia-*



FIGURE 2. Representative lycophytes verified as occurring in Manitoba, Canada. a. Prickly Tree-clubmoss (*Dendrolycopodium dendroideum* (Michaux) Haines), Hecla Provincial Park. b. Zeiller's Ground-cedar (*Diphasiastrum ×zeileri* (Rouy) Holub), Whiteshell Provincial Park. c. Alpine Ground-cedar (*Diphasiastrum alpinum* (L.) Holub), Bain Lake. d. Continental Firmoss (*Huperzia continentalis* Testo, Haines, and Gilman), Courage Lake. e. Northern Bog Clubmoss (*Lycopodiella inundata* (L.) Holub), Gunisao Lake. f. One-cone Clubmoss (*Lycopodium lagopus* (Laestadius) Zinserling), Black Lake, Nopiming Provincial Park. g. Interrupted Clubmoss (*Spinulum annotinum* (L.) Haines), Hecla Provincial Park. h. Spiny-spored Quillwort (*Isoetes echinospora* Durieu), Hunt Lake, Whiteshell Provincial Park. i. Rock Spikemoss (*Selaginella rupestris* (L.) Spring), Whiteshell Provincial Park. Photos: R.J. Staniforth.

TABLE 1. Numbers of Manitoba lycophte specimens, based on verified herbarium specimens in Manitoba herbaria up to 2020*, arranged in descending order of NatureServe (2022) subnational conservation rank (status ranks) for Manitoba.

Taxon	No. specimens in Manitoba herbaria (excluding duplicates)	Status rank†
Interrupted Clubmoss (<i>Spinulum annotinum</i>)	192	S4
Prickly Tree-clubmoss (<i>Dendrolycopodium dendroideum</i>)	141	S4
Zeiller's Ground-cedar (<i>Diphasiastrum ×zeillerti</i>)	80	—
Northern Interrupted Clubmoss (<i>Spinulum canadense</i>)	58	—
Rock Spikemoss (<i>Selaginella rupestris</i>)	93	S4
Prairie Spikemoss (<i>Selaginella densa</i>)	18	—
Northern Ground-cedar (<i>Diphasiastrum complanatum</i>)	74	S3
Running Clubmoss (<i>Lycopodium clavatum</i>)	58	S3
One-cone Clubmoss (<i>Lycopodium lagopus</i>)	73	S3
Spiny Quillwort (<i>Isoetes echinospora</i>)	20	S3
Hickey's Tree-clubmoss (<i>Dendrolycopodium hickeyi</i>)	42	S3
Blue Ground-cedar (<i>Diphasiastrum tristachyum</i>)	10	S3
Northern Spikemoss (<i>Selaginella selaginoides</i>)	8	S3
Northern Firmoss (<i>Huperzia selago</i>)	30	S2
Large-spored Quillwort (<i>Isoetes macrospora</i>)	6	S2
Northern Bog Clubmoss (<i>Lycopodiella inundata</i>)	5	S1
Butters' Firmoss (<i>Huperzia ×buttersii</i>)	3	—
Hickey's Quillwort (<i>Isoetes ×hickeyi</i>)	2	—
Shining Firmoss (<i>Huperzia lucidula</i>)	3	—
Continental Firmoss (<i>Huperzia continentalis</i>)	1	S1
Sika Ground-cedar (<i>Diphasiastrum sitchense</i>)	2	S1
Alpine Ground-cedar (<i>Diphasiastrum alpinum</i>)	1	S1

*See Table S1.

†S5 = Secure, S4 = Apparently Secure, S3 = Vulnerable, S2 = Imperilled, S1 = Critically Imperilled, — = not ranked.

strum taxon in southeast MB (R.J.S. pers. obs.), has previously been widely misidentified as Northern Ground-cedar (*Diphasiastrum complanatum* (L.) Holub).

**Diphasiastrum alpinum* (syn. *Lycopodium alpinum* L.). Alpine Ground-cedar, lycopode alpin (Figure 2c). Lichen–spruce woodland in northern MB (Figure 3c). Very rare and S1. Single specimen known (Table 1). Photographed on an esker top near Bain Lake, south of Egenolf Lake, 58.92°N, 99.17°W, 9 July 2013. R.J. Staniforth RS01422. Herbarium specimens consist of herbarium sheets with photographs, identified by A. Gilman and W. Testo pers. comm. 17 December 2018 (MMMN, RS, UWPG, WIN).

Diphasiastrum complanatum (syn. *Lycopodium complanatum* L.). Northern Ground-cedar, lycopode aplati. Moist, mixed forests, and dry coniferous forests and barrens; throughout MB (Figure 3d). Common and S3. Northern Ground-cedar is morphologically variable in MB. Plants in southern mixed forests are tall (to 30 cm) with long side

branches, whereas plants from exposed northern sites are short (<5 cm) and tufted. This variation has led to some MB populations being confused with Savin-leaved Ground-cedar (*Diphasiastrum ×sabinifolium* (Willdenow) Holub, *pro sp.*; Staniforth 2012), but specimens in RS have recently been revised to *D. complanatum* by A. Gilman. Number of specimens seen: 74 (Table 1). Northernmost MB record: Simon's Point Esker, near Nueltin Lake 59.862°N, 100.078°W, lichen-Dwarf Birch [*Betula pumila* L.] community on moist sand and gravel, 3 July 2012. R. Staniforth RS00832 (RS).

Diphasiastrum sitchense (Ruprecht) Holub (syn. *Lycopodium sitchense* Ruprecht; *Lycopodium sabinaefolium* var. *sitchense* (Ruprecht) Fernald). Sitka Ground-cedar, lycopode de Sitka. Occurs locally among dry lichen and shrubs in northern MB (Figure 3e). Very rare and S1. Collected from two sites (Table 1). Manitoba Hydro North Central Project Site #26, 54°12'N, 94°14'W, mineral dry soil, 11 July 1991, E. Punter (WIN52607); north

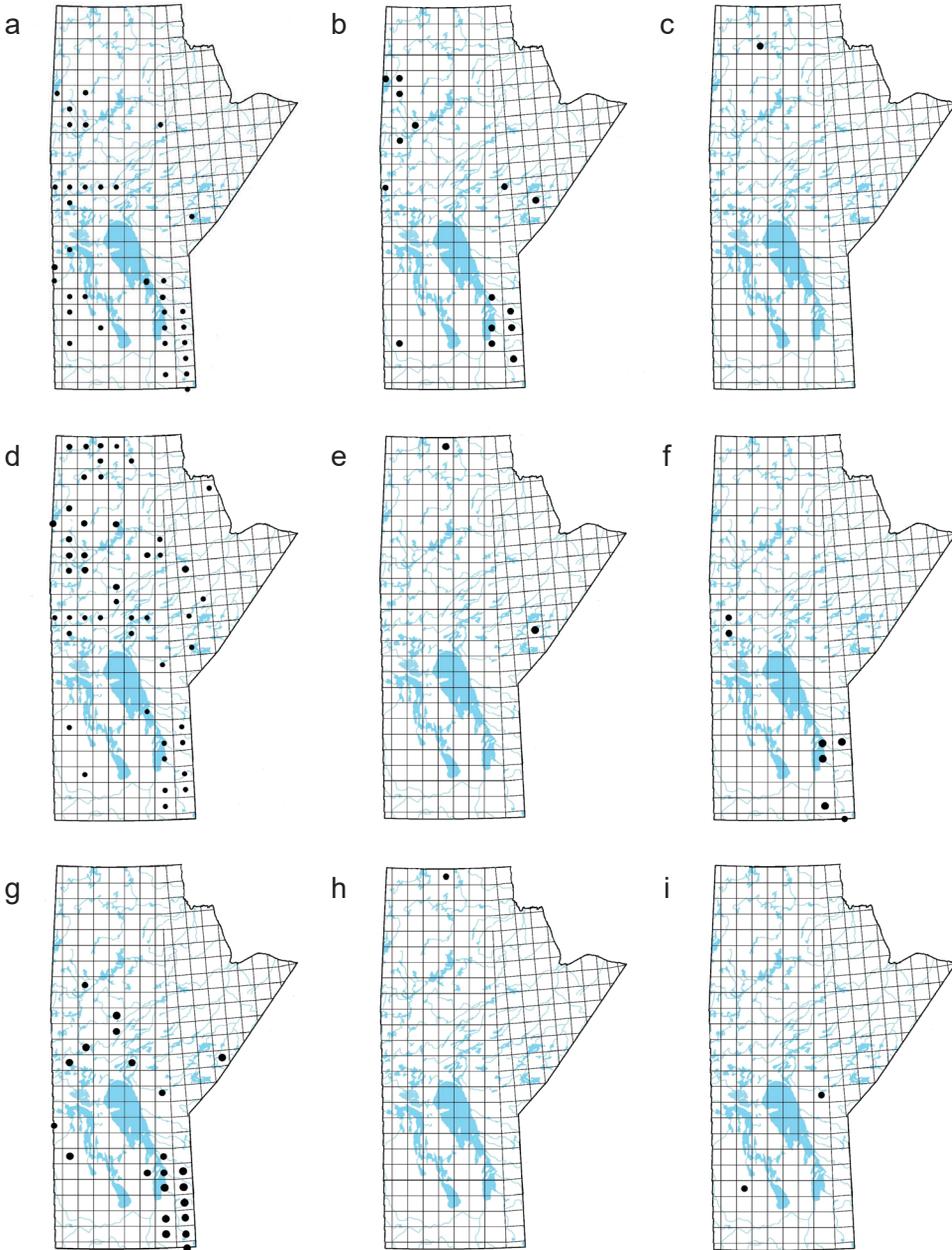


FIGURE 3. Distribution of Manitoba lycophytes. Maps indicate presence (dots) in 50×50 km universal transverse Mercator grid squares as indicated by data in Table S1. a. Prickly Tree-clubmoss (*Dendrolycopodium dendroideum*). b. Hickey's Tree-clubmoss (*Dendrolycopodium hickeyi*). c. Alpine Ground-cedar (*Diphasiastrum alpinum*). d. Northern Ground-cedar (*Diphasiastrum complanatum*). e. Sitka Ground-cedar (*Diphasiastrum sitchense*). f. Blue Ground-cedar (*Diphasiastrum tristachyum*). g. Zeiller's Ground-cedar (*Diphasiastrum \times zeileri*). h. Continental Firmoss (*Huperzia continentalis*). i. Shining Firmoss (*Huperzia lucidula*). j. Northern Firmoss (*Huperzia selago* (s.s.)). k. Butters' Firmoss (*Huperzia \times buttersii*). l. Northern Bog Clubmoss (*Lycopodiella inundata*). m. Running Clubmoss (*Lycopodium clavatum*). n. One-cone Clubmoss (*Lycopodium lagopus*). o. Interrupted Clubmoss (*Spinulum annotinum*). p. Northern Interrupted Clubmoss (*Spinulum canadense*). q. Spiny-spored Quillwort (*Isoetes echinospora*). r. Large-spored Quillwort (*Isoetes macrospora*). s. Hickey's Quillwort (*Isoetes \times hickeyi*). t. Prairie Spikemoss (*Selaginella densa*). u. Rock Spikemoss (*Selaginella rupestris*). v. Northern Spikemoss (*Selaginella selaginoides*).

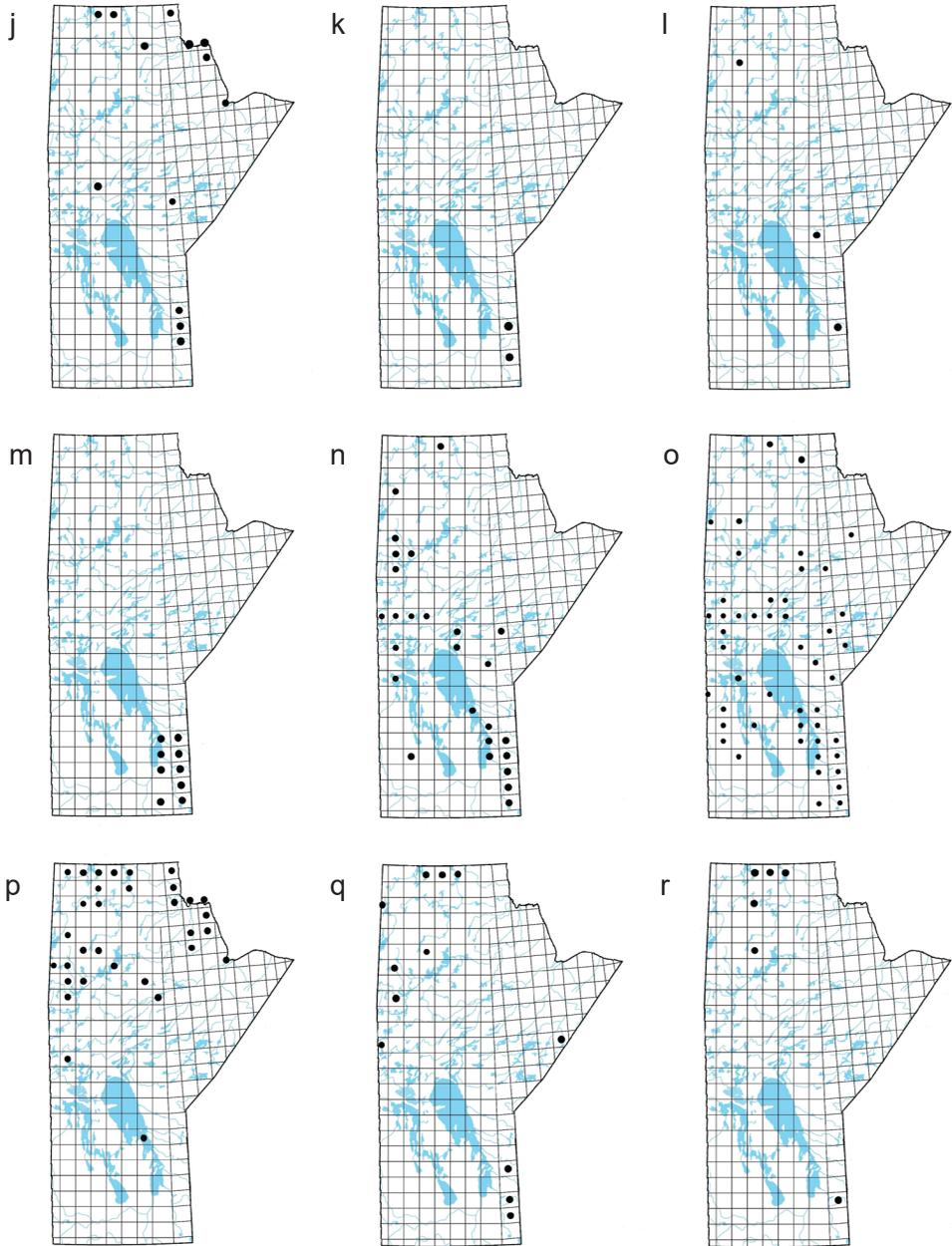


FIGURE 3. *Continued.*

of Courage Lake, near Nunavut border 59.99°N: 98.38°W, regenerating post-burn spruce forest, *R. Staniforth 00895* (RS).

Diphasiastrum tristachyum (Pursh) Holub (syn. *Lycopodium tristachyum* Pursh). Blue Ground-cedar, lycopode à trois épis. Locally on dry sand hills and rock outcrops in southeast to mid-west MB (Figure

3f). Rare and S3. Number of specimens seen: 10 (Table 1). Northernmost MB record: Grass River Provincial Park, 54.642°N, 100.804°W, rock island in Iskwasum Lake, on thin organic layer with Jack Pine (*Pinus banksiana* Lambert)—White Spruce, 26 July 2008, *R.J. Staniforth 00386* (RS).

Diphasiastrum ×zeileri (*Lycopodium zeileri* (Rouy)

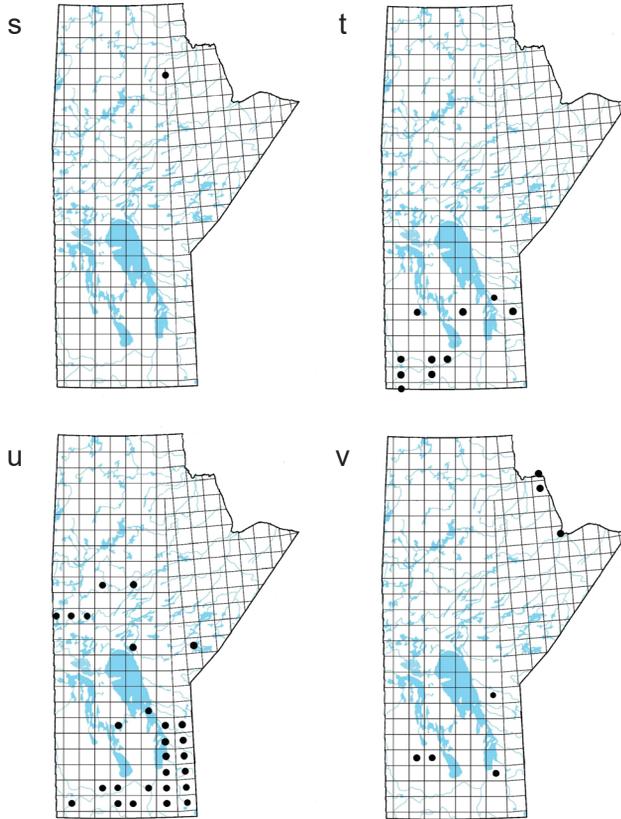


FIGURE 3. *Continued.*

Victorin; *D. complanatum* × *D. tristachyum*). Zeiller's Ground-cedar, lycopode de Zeiller (Figure 2b). Moist mixed and coniferous forests, especially in southeast MB, rarer northwards (Figure 3g). Common. Unranked. Number of specimens seen: 80 (Table 1). This hybrid appears to be self-sustaining in numerous populations in southeast MB (R.J.S. pers. obs.). As is typical of hybrids, the plants have a mixture of morphological features of each putative parent species. The most obvious difference between *D. ×zeileri* and *D. complanatum* is the deeply buried rhizome found in the former versus the superficial rhizomes in the latter. *Diphasiastrium ×zeileri* has also been reported in nearby northwestern Minnesota (Chayka and Dziuk 2020) and adjacent northwestern Ontario (D.F.B. pers. obs.). Northernmost MB record: Hwy 391 about 10 km north of Leaf Rapids, 56.518°N, 99.976°W, at edge of conifer-lichen woodland on sand substrate with thin organic layer, 14 July 2011, R.J. Staniforth 00711 (RS).

Huperzia, firmosses (Figure 2d)

All members of the genus *Huperzia* are scarce in MB. Plants in the Northern Firmoss (*Huperzia selago* (L.) Bernhardt) complex can be difficult to identify in the field and often require microscopic study of their gemmae (Gilman and Testo 2015). Gemmae in firmosses are modified buds (actually, six-leaved plantlets) that separate from parent plants and may develop into new individuals. Their formation in firmosses is unique among the clubmosses (Haines 2003).

**Huperzia continentalis* (syn. *Huperzia selago* (L.) Bernhardt, *p.p.* [*pro parte*, in part]; *Huperzia appressa* auct. non [*auctorum non*, not as the original authors] (Desvaux) Löve & Löve), Continental Firmoss, lycopode du continent (Figure 2d). Tundra heath in northern MB (Figure 3h). Very rare and S1. Known from one specimen (Table S1). All *Huperzia* specimens in RS were critically examined by W. Testo in August 2015 but those from other herbaria need to be critically examined to clarify the range of *Huperzia* species in northern MB. Plants of this recently recognized taxon

(Testo *et al.* 2016) have perhaps been misinterpreted in the field in MB as representing *H. selago* (*s.l.*). Northernmost MB record: north of Courage Lake, 59.995°N, 98.387°W, open lichen tundra in damp depressions on moist organic substrate, 17 July 2014, *R.J. Staniforth 00889* (RS).

Huperzia lucidula (Michaux) Trevisan (syn. *Lycopodium lucidulum* Michaux). Shining Firmoss, lycopode brilliant. Dry outcrops in northern MB (Figure 3i). Very rare. Not ranked. Known from three specimens (Table 1; see also Staniforth 2022). Two records from Riding Mountain National Park, 50.680°N, 99.560°W (*J.C. Ritchie 3325*, DAO337594; *Walker 213*, WIN) and one from Gunisao Lake. Northernmost MB record: Gunisao Lake, near lodge, 53.521°N, 96.371°W, granite outcrop, with Jack Pine, spruce, birch forest, shady, moist peat, 24 June 2013, *R.J. Staniforth 00849* (RS) confirmed by W. Testo (August 2015).

Huperzia selago (L.) Bernhardt (*s.s.*) (syn. *Lycopodium selago* L., *p.p.*). Northern Firmoss, lycopode sélagine. Damp, shady non-calcareous outcrops and boulders in eastern MB, and on damp sedge tundra in northern MB (Figure 3j). Rare and S2. Number of specimens seen: 30 (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.167°W, hummocky sedge-heath tundra, 10 July 1950, *H.J. Scoggan 8214* (WIN4718).

Huperzia ×battersii (Abbe) Kartez and Gandhi (*H. lucidula* × *H. selago*). Butters' Firmoss, lycopode de Butters. Mixed and coniferous forests, on non-calcareous outcrops and boulders in southeast MB (Figure 3k). Very rare. Unranked hybrid. Known from three specimens (Table 1). Northernmost MB record: Quesnel (Caribou) Lake, 50.917°N, 95.650°W, rock outcrop with mosses and lichens, 4 August 1974, *G.M. Keleher 74-242* (WIN 28636).

Lycopodiella, bog clubmosses (Figure 2e)

Bog clubmosses are small inconspicuous plants of wet open sites usually within boreal forests. They grow close to the substrate; their strobili are upright and leafy.

Lycopodiella inundata (L.) Holub (syn. *Lycopodium inundatum* L.). Northern Bog Clubmoss, lycopode inondé (Figure 2e). Disturbed, wet, boggy sites in the boreal forest in north and central MB (Figure 3l). Very rare and S1. Known from five specimens (Table 1). Northernmost MB record: Singleton Lake, 58.333°N, 100.079°W, peaty substrate between cobbles, just above the waterline with *Sphagnum*, *Drosera*, and *Juncus*, 6 July 1996, *E. Punter 96-627* (WIN76000).

Lycopodium, clubmosses (Figure 2f)

Both clubmoss species in MB were formerly considered within *Lycopodium clavatum* L. (*s.l.*). They can usually be distinguished by the number of strobili per peduncle and by leaf characteristics. In the few colonies of *L. clavatum* (*s.s.*) in MB that consistently possess single strobili instead of two or more (R.J.S. pers. obs.), leaf arrangement, size, and shape facilitate identification.

Lycopodium clavatum L. Running Clubmoss, lycopode claviforme. Mixed and conifer forests in southeastern MB (Figure 3m). Uncommon and S3. Number of specimens seen: 58 (Table 1). Northernmost MB record: Aikens Lake, 35 km northeast of Bissett, 51.201°N, 95.309°W, mixed forest, birch, Trembling Aspen (*Populus tremuloides* Michaux), White Spruce, on sandy loam, 1 June 2012, *R.J. Staniforth 00816* (RS). Westernmost MB record: Manitoba Model Forest, Grindstone Provincial Park, 51.165°N, 96.833°W, Black Spruce (*Picea mariana* (Miller) Britton, Sterns, and Poggenburg) site, 25 July 1994, *W.S. Morgan 94-143* (WIN56750).

Lycopodium lagopus (Laestadius) Zinserling (syn. *Lycopodium clavatum* var. *megastachyon* Fernald; *Lycopodium clavatum* var. *monostachyon* (Hooker and Greville)). One-cone Clubmoss, lycopode patte-de-lapin (Figure 2f). Boreal forest, often close to non-calcareous outcrops and boulders, in a wide band from southeastern to northwestern MB (Figure 3n). In northern MB, it can be found in open sites on the sides and tops of sandy eskers. Uncommon and S3. Number of specimens seen: 73 (Table 1). Northernmost MB record: south of Courage Lake, 59.929°N, 98.353°W, slope between eskers (under) Black Spruce and birch, on moist sandy gravel in shade, 17 July 2014, *R.J. Staniforth 00890* (RS, WIN).

Spinulum, interrupted clubmosses (Figure 2g)

The genus *Spinulum* is the most recent segregate of the former genus *Lycopodium* (Haines 2003) and is represented in MB by two species. At Courage Lake in northern MB in July 2014, plants of both taxa were found growing within 150 m of each other while maintaining their distinct identities (R.J.S. pers. obs.).

Spinulum annotinum (L.) Haines (syn. *Lycopodium annotinum* L., *p.p.*; *Spinulum annotinum* ssp. *alpestre* (Hartman) Uotila). Interrupted Clubmoss, lycopode innovant (Figure 2g). Moist, mixed and coniferous woodlands on organic substrates. The commonest lycophyte in MB. It is found throughout MB except for the agricultural south but is rare in the extreme north (Figure 3o) where it is largely

replaced by *Spinulum canadense* (next species). Very common and S4. Number of specimens seen: 192 (Table 1). Northernmost MB record: south of Courage Lake, 59.929°N, 98.353°W, base of esker, under spruce and bushes on moist, well-drained gravel, 17 July 2014, *R.J. Staniforth 00891* (RS).

Spinulum canadense (Nessel) Haines (syn. *Lycopodium annotinum* variety *pungens* (La Pylae) Desvaux). Northern Interrupted Clubmoss, lycopode innovant boreal. Forest-tundra, tundra, and barrens. Throughout the northern half of MB (Figure 3p). Uncommon. Not ranked. Number of specimens seen: 58 (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.100°W, hummocky sedge tundra, 29 July 1950, *H.J. Scoggan 8217* (WIN4663). Southernmost MB record: Rice River Road, between Princess Harbour and Berens River, 52.131°N, 96.831°W, 18 June 2018, *R.J. Staniforth 01380* (RS).

Isoetaceae, Quillworts

Isoetes, quillworts (Figure 2h)

In MB, the two species of quillworts and their hybrid are aquatic or emergent plants. They resemble tufted graminoid plants but grow submerged in a few centimetres to several metres of water in clear freshwater ponds, lakes, and slow rivers. Their quill-like leaves are made buoyant by large air chambers. Their deciduous nature floats them into the flotsam lines of beaches in late summer and gives an indication of the local presence of deep-water populations. Like spike-mosses, quillworts are heterosporous, i.e., they produce both megaspores and microspores. The size and (especially) sculpturing on the megaspores constitute key identification characters for *Isoetes* identification.

Isoetes echinospora Durieu. Spiny-spored Quillwort, isoète à spores épineuses (Figure 2h). A submerged or emergent species of acidic substrate in shallow ponds, lakes, and slow-moving rivers in the boreal region of MB. Rare and S3, although undoubtedly overlooked (Figure 3q). Number of specimens seen: 20 (Table 1). Northernmost MB record: north shore of Courage Lake, 59.990°N, 98.380°W, sandy beach, shallow lake, washed up, 15 July 2014, *R.J. Staniforth 00894* (RS).

Isoetes macrospora Durieu (syn. *Isoetes lacustris* auct. non L.). Large-spored Quillwort, isoète lacustre. A submerged species of acidic substrate in lakes in the boreal forest region of Manitoba (Figure 3r). Very rare and S2; possibly disjunct from a predominately eastern range (Brunton and Britton 1991; Grigoryan *et al.* 2020). Known from six specimens (Table 1). Northernmost MB record: Baralzon Lake, 60.000°N, 98.167°W,

shallow water, 30 July 1980, *H.J. Scoggan 8241* (WIN4774).

Isoetes ×hickeyi Taylor and Luebke. Hickey's Hybrid Quillwort, isoète de Hickey. Submerged aquatic in mixed *I. echinospora* and *I. macrospora* population in the Boreal region of MB (Figure 3s). Known currently only from Seal River, west of Great Island. 58.00°N, 96.00°W, 8 July 1956 (Britton and Brunton 1991). Very rare. Unranked hybrid. Two specimens reported (Table 1), suggesting that sterile hybrids are (were) well represented in this population.

Selaginellaceae, spikemosses

Selaginella, spikemoss (Figure 2i)

There are three species of spikemosses in MB, all small, creeping moss-like plants, covered by densely overlapping, tiny leaves. Their upright strobili possess megasporangia and microsporangia in the leaf axils.

Selaginella densa Rydberg (syn. *Selaginella rupestris* var. *densa* (Rydberg) Clute). Prairie Spikemoss, sélaginelle dense. Prairie grassland in southwest MB, in an alvar region in the Interlake, and rare east of Lake Winnipeg on boreal outcrops (Figure 3t), although considered uncommon in adjacent Ontario in Woodland Caribou Park (D.F.B. pers. obs.). Rare. Not ranked. Number of specimens seen: 18 (Table 1). Northernmost MB record: Brokenpipe Lake, 51.283°N, 100.367°W, glacial beach, 5 August 1983, *J.L. Parker 83-11* (MMM39455).

Selaginella rupestris (L.) Spring (syn. *Lycopodium rupestre* L.). Rock Spikemoss, sélaginelle des rochers (Figure 2i). Non-calcareous outcrops, sandy road edges and dry grassy fields in the lower two thirds of MB (Figure 3u). Common and S4. Number of specimens seen: 93 (Table 1). Northernmost MB record: Hwy 391, about 12 km west of Notigi, 55.833°N, 99.484°W, rock outcrop with Jack Pine, 15 July 2011, *R.J. Staniforth 00717* (RS).

Selaginella selaginoides (L.) Beauvois (syn. *Lycopodium selaginoides* L.). Northern Spikemoss, sélaginelle fausse-sélagine. Wet, mossy stream banks and calcareous fens in the Hudson Bay lowlands, but also in southern MB (Figure 3v). Very rare and S3. Known from eight specimens (Table 1). Northernmost MB record: Churchill area, Spaceport Project, 58.44°N, 93.47°W, streambank through White Spruce forest, 28 July 1994, *G.M. Keleher & E. Punter 94/82* (WIN57178).

Key to Lycophytes of Manitoba

The following key includes all lycophyte taxa confirmed from MB. It is based on the keys in Staniforth (2012) as modified by subsequent literature (e.g., Gilman and Testo 2015; Testo *et al.* 2016; Palmer 2018; Grigoryan *et al.* 2020) and personal experience of D.F.B. Each taxon is individually addressed in the Annotated Checklist (above).

1. Terrestrial, creeping; with above-ground or subterranean rhizomes (horizontal stems); upright shoots covered by numerous small, evergreen leaves **4**
 - Submerged aquatic; globose corm topped by a crown of long, quill-like leaves (Isoetaceae) **2**
2. Individuals larger than typical plants of the population; megaspores polymorphic, often lens-shaped (aborted); densely congested ornamentation pattern includes both spines and muri (ridges) ***Isoetes* × *hickeyi***
 - Plants uniform in size within the population; megaspores uniformly globose (viable); ornamentation either exclusively echinate or with muri **3**
3. Leaves light green; moderately to strongly reflexed; megaspores small (450–525 µm), ornamentation uniformly, densely echinate (spiny); no equatorial band ***Isoetes echinospora***
 - Leaves dark green to green-brown; straight to slightly recurved; megaspores large (650–800 µm), broken reticulate pattern ornamentation of thin-walled muri; prominent equatorial band of densely distributed papillae (minute tubercles) ***Isoetes macrospora***
4. Sporangia in the axils of specialized leaves (sporophylls) clustered into strobili (cones) at shoot summit; no gemmae (vegetative buds) **5**
 - Sporangia in the axils of ordinary stem leaves and not arranged in strobili; gemmae conspicuous on shoots (*Huperzia*) **17**
5. Plants tall (>4 cm), resemble large moss plants or miniature coniferous trees; strobili cylindrical, megaspores small (<100 µm) **6**
 - Plants short (<4 cm), resemble small (often matted) moss plants; strobili typically four-sided, megaspores large (>300 µm) (Selaginellaceae) **20**
6. Plants annual, small; stem prostrate and creeping; strobili “bushy” with green leaves; spores rugulate ***Lycopodiella inundata***
 - Plants perennial, robust; sprawling or erect; stem upright or low arching, strobili narrow with appressed scales, on thin, erect stems; spores reticulate **7**
7. Leafy shoots (branches) narrow (2–6 mm), flat; leaves 4–5 ranked along stem (*Diphasiastrum*) **8**
 - Leafy shoots wide (5–12 mm), round; leaves many-ranked along stem **11**
8. Horizontal stems on or near soil surface (often hidden under litter); peduncles with 1–2 strobili **9**
 - Horizontal stems deeply buried in soil; peduncles with 2–4 strobili **10**
9. Solitary strobilus sessile; abaxial (underside) leaves arched, trowel-shaped, slightly shorter than other branch leaves ***Diphasiastrum alpinum***
 - 1–2 strobili peduncled; abaxial leaves appressed, narrowly deltoid, much shorter than other branch leaves ***Diaphasiastrum complanatum***
10. Plants short (<10 cm); strobili sessile or stalked <1 cm; leaves divergent, ascending, separate or partially overlapping ***Diphasiastrum sitchense***
 - Plants short (10–15 cm tall); strobili long stalked (2–10 cm); leaves strongly appressed, overlapping ... **11**
11. Branches narrow (<2 mm), round to square in cross-section; strongly ascending (“popped-umbrella” form); leaves glaucous blue-green colour ***Diphasiastrum tristachyum***
 - Branches wide (>2 mm), flat; sprawling arrangement; leaves glossy dark-green colour ***Diphasiastrum* × *zeilleri***
12. Strobili long stalked; leaves densely arranged about stem in groups of 6–10, softly hair-tipped (not prickly) (*Lycopodium*) **13**
 - Strobili sessile; leaves loosely arranged about stem in groups of 3–5, acute to spine-tipped (prickly) **14**
13. Peduncles typically with solitary strobilus; stems sparsely branched, ascending to erect; leaves 3–5 mm long, appressed ***Lycopodium lagopus***

- Peduncles typically with 1–5 strobili; stems frequently branched, sprawling; leaves 4–6 mm long, divergent *Lycopodium clavatum*
- 14. Leaves about the stem in groupings of 4–5; leafy rhizome superficial (*Spinulum*) **15**
- Leaves about the stem in groupings of 3; naked rhizome subterranean (*Dendrolycopodium*) **16**
- 15. Strobili 1.5–4.5 cm long; leaves toothed, 5–10 mm long; those immediately above annual constriction widest at or near mid-length *Spinulum annotinum*
- Strobili <1.7 cm long; leaves entire, 3–6 mm long; those immediately above annual constriction widest at or near base *Spinulum canadense*
- 16. Leaves along stem strongly appressed (stem smooth); single rank (row) of leaves on abaxial side of branches *Dendrolycopodium hickeyi*
- Leaves along stem strongly divergent (stem prickly); double rank (rows) of leaves on abaxial side of branches *Dendrolycopodium dendroideum*
- 17. Leaves wide (1.5–2.0 mm), toothed, parallel-sided or widest above middle, dark green; always shiny; annual constrictions on stem conspicuous **18**
- Leaves narrow (1.0–1.25 mm) entire, widest near base; yellow-green to green; dull to somewhat shiny; annual constrictions on stem inconspicuous **19**
- 18. Leaves coarsely toothed, widest above middle; spore regular in shape (viable) *Huperzia lucidula*
- Leaves entire or with few teeth, parallel sided; spores misshaped (aborted) *Huperzia ×butter sii*
- 19. Gemmae arranged in single whorl at apex of annual growth segment *Huperzia selago*
- Gemmae scattered along stem or arranged in several whorls at apex of annual growth segment *Huperzia continentalis*
- 20. Delicate, mat-forming; leaves divergent, flat, narrow, acute-tipped and with numerous coarse marginal cilia *Selaginella selaginoides*
- Dense tufted clumps; leaves strongly appressed, oblong, bristle-tipped, with few fine marginal cilia **21**
- 21. Leaf tip bristles 1.25–2.0 mm long; dense clumps appearing “frosty”; upper leaves longer than lower *Selaginella densa*
- Leaf tip bristles 0.5–1.0 mm long, loosely arranged to dense clumps green; upper and lower leaves approximately equal in length *Selaginella rupestris*

Discussion

We update and expand on the earlier synopsis of MB lycophytes presented by Staniforth (2012) and report new taxa and provide more precise information about their taxonomy, distribution, abundance, and habitats. Nineteen species and three hybrids of lycophytes are now documented for the province. This is a substantial increase over previous published reports: eight species in Scoggan (1957), 13 species in Punter (1995), and 18 taxa in Staniforth (2012). The circumscriptions of the three lycophyte families have remained unchanged in recent years, although the firmosses have increasingly been treated (e.g., Haines 2003) as a distinct family (Huperziaceae). However, we retain them within Lycopodiaceae for consistency purposes. We also make two exceptions from the scientific nomenclature employed in Brouillet *et al.* (2010+). Following Haines (2003), we treat *S. annotinum* ssp. *alpestre* as *S. canadensis*, and following Grigoryan *et al.* (2020), we treat the North American *I. macrospora* as distinct from *I. lacustris* of Europe.

Most MB lycophytes have North American northern pan-boreal distributions (Cody and Britton 1989).

Exceptions to this are *D. tristachyum*, which is primarily eastern boreal (Cody and Britton 1989), *I. macrospora*, which is primarily eastern and central boreal (Britton and Brunton 1991), and *S. densa*, which is primarily Great Plains in distribution (Valdespino 1993).

Several MB lycophyte taxa have their most northern, southern, and, in some cases, northwestern continental boundaries within the province. Knowledge of the status and trends of such edge populations is important as changes may reflect large-scale, long-term variations in climate and other environmental factors (Maslovat *et al.* 2021). The tradition of reporting “Northernmost collection” in MB was started by Scoggan (1957), but at that time he probably did not fully appreciate the value of extreme geographic records for informing on potential environmental change. Between 1950 and 1999, the northernmost MB collections for *D. complanatum*, *H. selago*, *S. canadense*, and *I. macrospora* were all from Baralzon Lake (60°00'N) or Nueltin Lake (59°49'N). Since 2000, additional collections of these species have been made from similar latitudes, indicating

their continued persistence in the far north. In 2011, *S. rupestris* was collected over 300 km further to the northwest from its previously known range limit, as identified by Scoggan (1957). In such a sparsely investigated area of the province, however, this range extension more likely reflects a gap in distributional knowledge than a dramatic, short-term phyto-geographic change.

Three taxa, *D. tristachyum*, *D. ×zeilleri*, and *S. densa*, have ranges that reach north to mid-Manitoba, while *S. canadensis* is at its known southern boundary in that region. Similarly, both *L. clavatum* and *H. ×battersii* reach their most northerly known continental limits in southeast MB (see Annotated Checklist). Documenting changes to their ranges could be valuable for evaluating if environmental changes are occurring within the respective habitats of these taxa.

Taxa not recorded from MB but with potential to be found in the province occur in the adjacent provinces (i.e. Saskatchewan and northwest Ontario; Harms and Leighton 2011; Oldham and Brinker 2009, respectively), Nunavut Territory, and the north central United States (i.e., North Dakota, northern Minnesota, or northwest Wisconsin; Chadde 2013; Wagner and Beitel 1993; Palmer 2018, respectively). These include Flat-branched Tree-clubmoss (*Dendrolycopodium obscurum* (L.) Haines (s.s.)), Southern Ground-cedar (*Dendrolycopodium digitatum* (Dillenius) Holub), Haberer's Ground-cedar (*Dendrolycopodium ×habereri* (House) Holub), Mountain Firmoss (*Huperzia appressa* (Desvaux) Löve and Löve), and Rock Firmoss (*Huperzia porophila* (Lloyd and Underwood) Holub).

No lycophytes are currently listed under MB's *Endangered Species and Ecosystems Act* (C. Friesen pers. comm. 2021). However, some taxa are documented as regionally rare (Table 1). Thirteen species are formally designated as having NatureServe S1, S2, or S3 ranks while *H. lucidula*, *S. canadense*, and *S. densa* remained unranked. Based on the findings of our study, the S3 status ranks for *S. selaginoides* underestimates the rarity of that species in MB; conversely the designated S3 rank overestimates the rarity of *D. complanatum*, *L. lagopus*, and *L. clavatum* (see Annotated Checklist). Accordingly, the S3 ranks of these taxa warrant review. Unranked hybrids *D. ×zeilleri*, *H. ×battersii*, and *I. ×hickeyi* are noted in Table 1 with a dash.

In 2012, the Manitoba Association of Plant Biologists, the Manitoba Conservation Data Centre, and the Nature Conservancy of Canada developed a plan to identify and map sites of alvars and their plant communities (Neufeld *et al.* 2018). That areal protection initiative indirectly resulted in protection for rare pteridophytes Gastony's Cliffbrake (*Pellaea gastonyi*

Windham) and Western Cliffbrake (*P. occidentalis* (Nelson) Rydberg) along with a population of S3 lycophyte *S. densa* (Friesen and Murray 2015). This is an example of how protection of ecosystems can be successful in protecting "non-target" rare species as well. Such incidental protection may also be effective for conservation of *S. selaginoides* (S2) populations near Churchill and York Factory (Table 1). Other rare species, such as *D. alpinum*, *H. continentalis*, and *I. macrospora*, may be secure from at least direct physical impact by their remote locations in extreme northern Manitoba.

Complicating conservation management for *L. inundata* is the possibility that it might be ruderal in Manitoba (R.J.S. pers obs.). Similarly, it is difficult to conceive site protection measures for certain *Huperzia* taxa which appear to be short-lived in their locations (see Annotated Checklist).

Most species of MB lycophytes inhabit various terrestrial and aquatic ecozones within the boreal forest. The variety of plant communities found in the boreal forest in Boreal Shield, Boreal Plain, Hudson Plain, Taiga Shield, and Southern Arctic ecozones (Manitoba's Protected Areas Initiative 2013) provides a diversity of suitable lycophyte habitats. Within these broad ecozones (Figure 1), plant communities range from the tundra–forest transition in the far north to the deciduous–coniferous forest transition in mid- and southeast MB. There are also wide differences within each plant community in terms of moisture, edaphic, and geologic regimes. This ecological variation allows for heterogeneous plant associations, thus expanding the potential diversity of lycophyte representation. Manitoba Provincial Parks and Provincial Forests provide an important diversity of habitats for most of MB's lycophytes, excluding species from the far north or those that are extremely rare.

Author Contributions

Tragically, R.J.S. died as the manuscript was in an advanced stage of review. In January 2022, D.F.B., a reviewer of the original manuscript, was invited by Diana Staniforth to see the manuscript through to completion and was honoured to do so.

Conceptualization: R.J.S.; Data Curation: R.J.S.; Methodology: R.J.S.; Data Analysis: R.J.S.; Investigation: R.J.S.; Writing – Original Draft: R.J.S.; Writing – Key: D.F.B.; Writing – Review & Editing: R.J.S. and D.F.B.

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SUPPLEMENTARY MATERIALS:

TABLE S1. Records of examined lycophyte vouchers found in Manitoba, Canada.

TABLE S2. Locations of remote lycophyte collection sites, Manitoba, Canada, 2010–2014.