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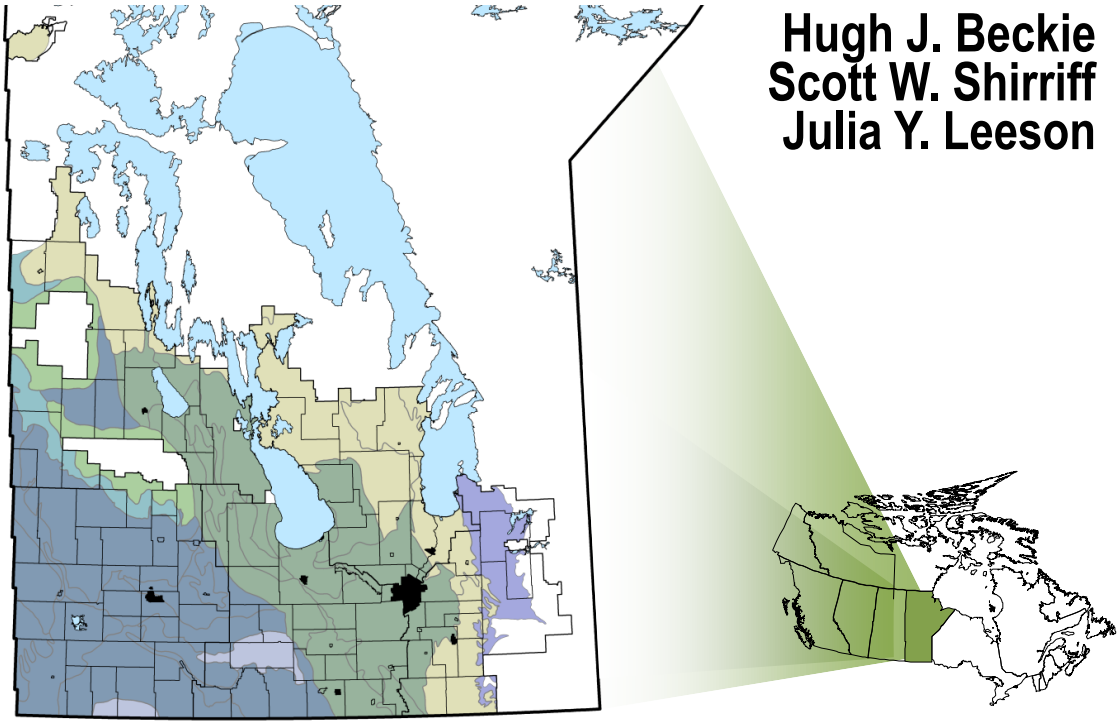
Manitoba Weed Survey

Herbicide-Resistant Weeds

2016



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Weed Survey Series

Canada

Manitoba Weed Survey of Herbicide-Resistant Weeds in 2016

by

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Weed Survey Series
Publication 17-3

Published by

Agriculture and Agri-Food Canada
Saskatoon Research & Development Centre
107 Science Place, Saskatoon, Saskatchewan, S7N 0X2, Canada

February 2018

PREVIOUSLY PUBLISHED REPORTS IN THE WEED SURVEY SERIES

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77-1	Weed survey of cultivated land in Saskatchewan (1977)
78-1	Report on the 1977 weed survey and questionnaire in Saskatchewan
78-2	Weed survey of cultivated land in Saskatchewan (1978)
78-3	Weed survey of cultivated land in Manitoba (1978)
79-1	Manitoba weed survey questionnaire data (1978)
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PREFACE

A third round of herbicide-resistant weed surveys across the prairies was initiated in 2014 and was concluded in 2017. This project involves a survey of resistant weeds in 800 randomly-selected fields: 400 in Saskatchewan in 2014 and 2015 (Weed Survey Series Publication 17-1), 150 fields in Manitoba in 2016, and 250 fields in Alberta in 2017. Surveyed fields are a subset of those included in the general weed surveys led by Julia Leeson, with accompanying producer management questionnaires.

Previously published reports in the Weed Survey Series on occurrence of herbicide-resistant weeds in the last (second) round of surveys were: (1) 09-1: Alberta weed survey of herbicide-resistant weeds in 2007; (2) 10-2: Manitoba weed survey of herbicide-resistant weeds in 2008; (3) 12-2: Saskatchewan weed survey of herbicide-resistant weeds in 2009; and (4) 12-3: Prairie weed survey of herbicide-resistant weeds from 2007 to 2009. These surveys followed baseline surveys conducted in the prairie provinces from 2001 to 2003. Therefore, results from this latest round of surveys will more accurately discern trends in occurrence of herbicide resistance over time.

This report follows the 2008 Manitoba weed resistance survey report published in 2010. This report documents the nature, distribution and abundance of herbicide-resistant weeds in Manitoba in 2016. As indicated above, 150 fields were surveyed across the province. The sites in this survey were selected randomly, weighted only according to crop type and ecodistrict similar to methodology used in the general weed survey. All weed species with viable seed were sampled, and first-tier (Group 1 and 2) resistance testing was conducted. Second-tier resistance screening (other herbicide groups) may be completed in the future, depending upon availability of greenhouse bench space.

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Saskatoon, SK
February 2018

ACKNOWLEDGEMENTS

Financial support for this survey was provided by Manitoba Agri-Research and Development Fund (GF2), Western Grains Research Foundation, Manitoba Pulse & Soybean Growers, Manitoba Wheat & Barley Growers Association, Manitoba Canola Growers, Manitoba Oat Growers Association, Manitoba Corn Growers Association, Manitoba Seed Growers Association, Manitoba Flax Growers Association, and National Sunflower Association of Canada. We gratefully acknowledge their strong financial support.

We thank David Giffen, AAFC Saskatoon, for producing the maps.

Special thanks are extended to the 151 producers who participated in this survey project.

Hugh J. Beckie, Scott W. Shirriff and Julia Y. Leeson

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EXECUTIVE SUMMARY

A herbicide-resistant (HR) weed survey was conducted in 151 randomly selected fields across the ecoregions of Manitoba in 2016. All residual weed species with mature seeds were mapped and sampled before harvest. Selected fields were cropped to cereals (44%) or oilseeds (56%). Samples of 14 weed species (4 grass, 10 broadleaf) were subsequently screened in pot assays in the greenhouse using Group 1 or Group 2 herbicides (i.e., tier-1 screening).

Overall, 68% (102/151) of surveyed fields had a HR weed biotype, compared with 48% of fields in 2008 and 32% in 2002. Of 101 fields where wild oat (*Avena fatua* L.) were collected, 79% had an HR population (53% of the 151 surveyed fields), compared with 60% of sampled fields in 2008 and 44% in 2002. Group 1-HR wild oat was confirmed in 78% of fields where the weed was sampled (67% of all 151 surveyed fields), compared with 55% of fields sampled in 2008 and 40% in 2002. Group 2-HR wild oat was found in 43% of fields sampled (29% of all surveyed fields), compared with 18% of sampled fields in 2008 and 13% in 2002. Group 1+2-HR wild oat was confirmed in 42% of fields sampled (28% of all surveyed fields), compared with 13% of fields sampled in 2008 and 8% in 2002.

Of 50 fields where green foxtail [*Setaria viridis* (L.) P. Beauv.] seeds were collected, 48% had an HR population. This incidence of resistance compares to 44% of fields in 2008 and 22% in 2002. Group 1-HR green foxtail was found in 44% of fields where the weed was sampled. Group 2-HR green foxtail was found in 6% of fields. One field had Group 1+2-HR green foxtail. Of 60 fields where yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.] seeds were collected, 42% had an HR population; this is the first survey in Canada to document Group 1 or 2 resistance in this weed. Group 1-HR yellow foxtail was found in 32% of fields where the weed was sampled. Group 2-HR yellow foxtail was found in 17% of fields. Four fields had Group 1+2-HR yellow foxtail. Group 2-HR barnyard grass species [*Echinochloa crus-galli* (L.) P. Beauv.; *E. muricata* var. *microstachya*] were found in 27% of fields, the first occurrence of these biotypes in Canada.

Four broadleaf weed species had Group 2-HR populations: 11% with HR cleavers (*Galium* spp.), 25% with HR wild mustard (*Sinapis arvensis* L.), 5% with HR redroot pigweed (*Amaranthus retroflexus* L.), and one field with HR shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.]. This is the first survey in Manitoba to document Group 2-HR shepherd's-purse.

The results of this survey highlight the continual increase in field frequency of HR weeds, now comprising the majority of annually-cropped land. Based on this survey, it is estimated that 2.2 million ha in Manitoba are infested with HR weeds, in a total field area of 2.7 million ha. The additional cost to manage HR weeds in Manitoba is estimated at $74 million annually.

Past Weed Resistance Surveys in Manitoba

Group 1-resistant wild oat (*Avena fatua* L.) in the prairies was first discovered in 1990 in three fields near Swan River in northwestern Manitoba and in one field in Saskatchewan (Heap et al. 1993). Based on Group 1 herbicide use between 1990 and 1993, 47% of townships in Manitoba were considered to be at high risk for Group 1 resistance (herbicide use in over 50% of sprayed fields, i.e., on average, fields were sprayed with a Group 1 herbicide more than once every two years), whereas only 6% of townships were at low risk (Group 1 herbicide use in less than 30% of sprayed fields) (Bourgeois and Morrison 1997a). In 1993, 50% of cropped fields in Manitoba had received a Group 1 herbicide application. By then, more than 100 Group 1-resistant wild oat populations had been reported throughout the province (Morrison and Devine 1994). In a high-risk township in Manitoba, Group 1-resistant wild oat occurred in 20 of 30 (67%) fields that were systematically surveyed in 1993 (Bourgeois and Morrison 1997b). A roadside survey of six high-risk, five medium-risk, and five low-risk townships in Manitoba in 1994 indicated that 21, 2, and 3% of fields, respectively, had Group 1-resistant wild oat (Bourgeois et al. 1997b). Thus, based on the proportion of high-, medium-, and low-risk townships and the frequency of resistant wild oat determined in the roadside survey in 1994, one field in nine in Manitoba was estimated to have Group 1-resistant wild oat. However, based on results of the systematic survey of the high-risk township in 1993, incidence of Group 1-resistant wild oat in Manitoba may be as high as one in three fields. The cross-resistance pattern of Group 1-resistant biotypes indicated that three-quarters of the populations tested were resistant to both aryloxyphenoxypropionate (APP) and cyclohexanedione (CHD) herbicides, whereas one-quarter were resistant to APP herbicides only (Bourgeois et al. 1997a).

The surveys conducted in Manitoba in 1993 and 1994 only documented the occurrence of Group 1 resistance in wild oat. In 1994, two populations of wild oat from northwestern Manitoba were found to be resistant to herbicides from three groups - 1, 2, and 25 (Morrison et al. 1995). A survey in 1997 of 75 wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.) fields that received a postemergence application of imazamethabenz that year found that 68% of fields had resistant wild oat (Beckie et al. 1999). Of those fields with resistance, 41% had wild oat resistant to herbicides from either Group 1, 2, 8, or 25, and 27% had wild oat resistant to herbicides from more than one group. Group 1-resistant wild oat occurred in 53% of the fields surveyed: 29% having single-group resistance and 24% having intergroup resistance. Occurrence of wild oat resistance to APP or APP+CHD herbicides was high (40 and 58% of fields with Group 1-resistant wild oat, respectively), whereas resistance to CHD herbicides alone was rare (one field). Twenty-one percent of fields had Group 2-resistant wild oat, 19% had Group 8-resistant wild oat, and 28% had Group 25-resistant wild oat (single or intergroup resistance). Group 1-resistant wild oat occurred frequently in all ecoregions, whereas resistance to Groups 2, 8, or 25 tended to occur most frequently in the Interlake Plain ecoregion. An ecoregion is an area of similar climate, natural vegetation, soils, and land use (Smith et al. 1998) (Figure 1). The Interlake Plain ecoregion also had the highest frequency of occurrence of intergroup-resistant wild oat. Four fields in the Interlake Plain ecoregion near Swan River had wild oat resistant to all herbicides registered for use in wheat (Groups 1, 2, 8, and 25). Herbicide-use histories in three of those fields indicated a high frequency of use of Group 1 herbicides, but not of herbicides from the other groups.

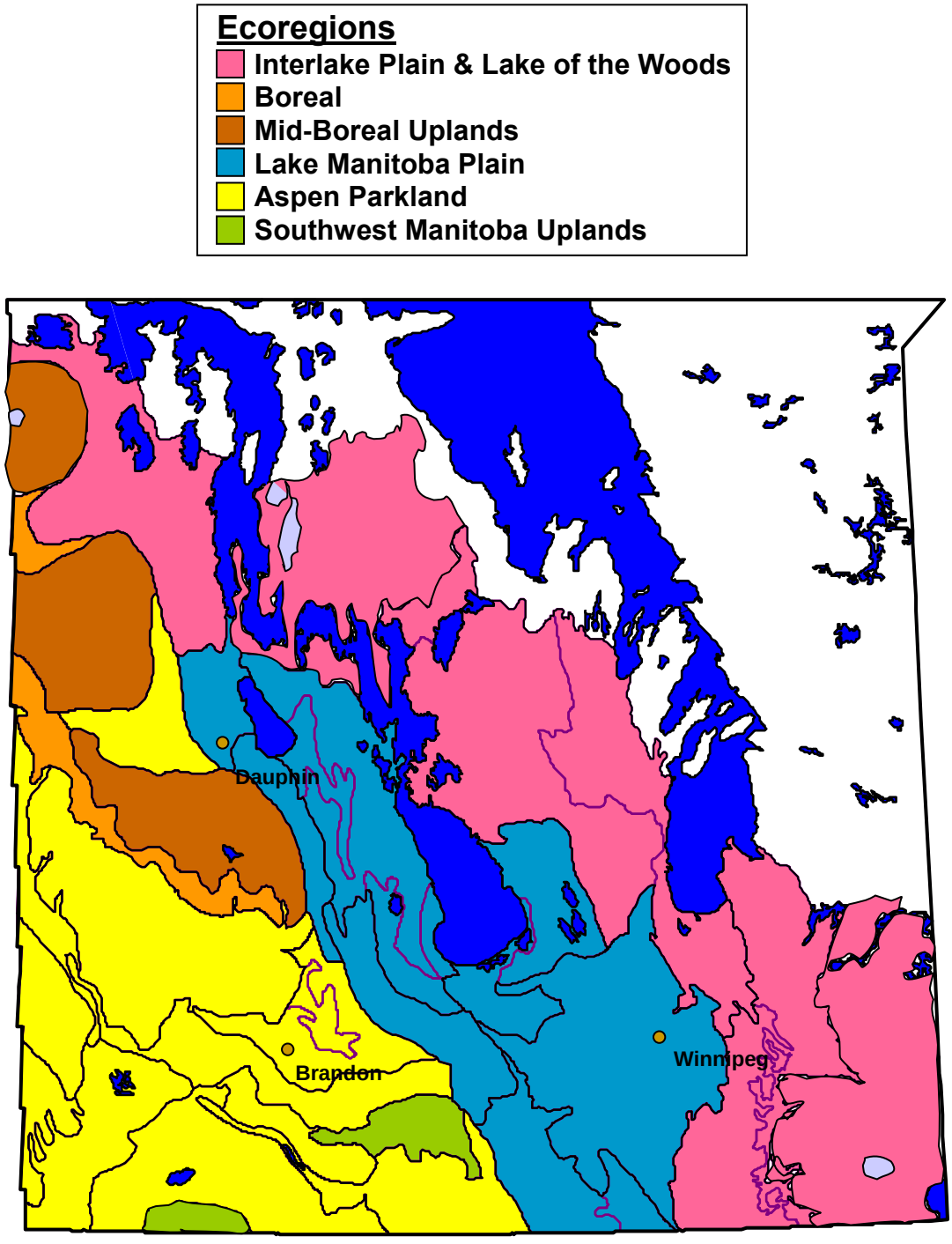

Figure 1. Ecoregions of Manitoba (map derived from Smith et al. (1998))

Based on samples submitted to the Crop Protection Lab, Saskatchewan Ministry of Agriculture (SMA) from Manitoba producers (or industry on behalf of producers) between 1996 and 2006, most of the 292 Group 1- or Group 2-resistant wild oat populations originated in the Aspen Parkland or Lake Manitoba Plain ecoregions (Beckie et al. 2007). In Petri dish testing, wild oat and green foxtail were screened for Group 1 resistance using fenoxaprop and sethoxydim. However, clodinafop replaced fenoxaprop beginning in the 2006 crop year. In pot assays, imazamethabenz was typically used to screen wild oat for Group 2 resistance. Of the 244 Group 1-resistant wild oat populations, 109 were APP (only)-resistant, 161 were APP+CHD-resistant, and 6 were CHD (only)-resistant. Sixteen populations were Group 2-resistant, whereas 32 populations were confirmed as Group 1+2-resistant. From 2007 to 2011, 110 wild oat submissions from Manitoba were determined to be herbicide-resistant: 52 populations were Group 1-resistant (mainly APP+CHD); 48 populations were Group 2-resistant, and 10 were Group 1+2-resistant (Beckie and Brenzil 2012).

Group 3-resistant green foxtail [*Setaria viridis* (L.) P. Beauv.] was first discovered in Manitoba in 1988 (Morrison et al. 1989), whereas Group 1 resistance was confirmed in the species in 1991 (Heap and Morrison 1996). Based on Manitoba samples submitted to the Crop Protection Lab, SMA from 1996 to 2006, 22 samples of Group 1-resistant green foxtail originated in the southern area of the Aspen Parkland ecoregion or Lake Manitoba Plain ecoregion. Only three samples were Group 3-resistant. From 2007 to 2011, six populations from Manitoba were determined to be Group 1-resistant. Most samples were resistant to APP and CHD herbicides.

Group 2-resistant kochia [*Kochia scoparia* (L.) Schrad.] was first discovered in Manitoba in 1988 (Morrison and Devine 1994). By 2004, 102 of 114 fields (90%) had kochia populations that

were Group 2-resistant (B. Murray and L. Friesen, unpublished data). Group 2 resistance in wild mustard (*Sinapis arvensis* L.) was first discovered in northwestern Manitoba in 1992 (Morrison and Devine 1994), and in hemp-nettle (*Galeopsis tetrahit* L.) in 1995 (Heap 2017). Three Group 2-resistant wild mustard populations near Swan River, Dauphin, and Winnipeg in 2002 were identified (Beckie et al. 2007); additionally, one population of Group 2-resistant chickweed [*Stellaria media* (L.) Vill.] and four populations of Group 2-resistant cleavers (*Galium* spp.) originated from Manitoba between 2007 and 2011 (Beckie and Brenzil 2012). Group 4-resistant biotypes of wild mustard were discovered in 1990 in west-central Manitoba (Heap and Morrison 1992), and a Group 5 (triazine)-resistant biotype in 1994 in southern Manitoba (Heap 2017).

A survey of weeds resistant to herbicides in 150 randomly selected fields was conducted across the major agricultural ecoregions of Manitoba in 2002 (Beckie et al. 2004). Selected fields were cropped to cereals or oilseeds. One-third of surveyed fields had a herbicide-resistant weed biotype. Of 84 fields where wild oat were collected, 40% had Group 1 resistance (22% of all fields surveyed) and 13% had Group 2 resistance (7% of fields surveyed). Most Group 1-resistant wild oat populations exhibited resistance to both APP and CHD herbicides. Group 2-resistant populations exhibited broad cross resistance across three classes of Group 2 herbicides. Of 59 fields where green foxtail seeds were collected, 22% had Group 1 resistance (9% of fields surveyed). Group 2 resistance was confirmed in one population - the first case in western Canada. Of 11 broadleaf weed species, Group 2 resistance was detected only in redroot pigweed (*Amaranthus retroflexus* L.) in one field in the Aspen Parkland ecoregion. Similar to green foxtail, Group 2 resistance in this species had not been reported previously in western Canada.

Although 91% of producers who completed a management questionnaire in 2002 practiced herbicide group rotation, the application of Group 1 or 2 herbicides in about 40% of fields that

year indicated that the use of these products was still resulting in high selection pressure for resistance. Only 10% of producers with resistant wild oat previously suspected or were aware of their occurrence; no producers with resistant green foxtail suspected resistance. This low level of awareness was consistent with findings from previous surveys, and may be partly attributed to the relatively small infestation area of resistant biotypes in most fields. In 2002, only 14% of producers believed that resistance had a significant impact on their farm. In the next five years, 36% of producers expected herbicide resistance to pose a moderate or high impact on their farm.

The next weed resistance survey in Manitoba was conducted in 2008 in 300 randomly selected fields located across the major agricultural ecoregions (Beckie et al. 2010). Selected fields were cropped to cereals (59%), oilseeds, including soybean (40%), or pulses (field pea) (1%). Samples of 25 weed species (5 grass, 20 broadleaf) were subsequently screened in pot assays in the greenhouse using herbicides with modes of action commonly used in the Prairies. Overall, 48% (143/300) of surveyed fields had a herbicide-resistant weed biotype, compared with one-third of fields in 2002. Of 198 fields where wild oat were collected, 55% had Group 1 resistance (vs. 40% in 2002), 18% had Group 2 resistance (vs. 13% in 2002), and 11% had Group 8 resistance (not tested in 2002). Most Group 1- or Group 2-resistant wild oat populations exhibited broad cross-resistance across herbicide classes. Group 1+2-resistant wild oat was found in 13% of fields (vs. 8% in 2002), Group 1+8 resistance in 8%, Group 2+8 resistance in 5%, and Group 1+2+8 resistance in 4% of fields. Overall, 62% of fields where wild oat samples were collected had a herbicide-resistant biotype. Therefore, just over one-third of fields with wild oat in Manitoba had herbicide-susceptible populations.

Of 91 fields where green foxtail seeds were collected, 44% had Group 1 resistance (vs. 22% in 2002). Of 20 broadleaf weed species, Group 2 resistance was detected in pigweed

(*Amaranthus*) spp. (16% of fields), compared with only one field with this biotype detected in the 2002 survey. Group 2 resistance was confirmed in only one field each of chickweed, cleavers, and wild mustard. These resistant biotypes had previously been found in Manitoba, although they were not detected in the 2002 survey.

The results of the 2008 survey highlighted the continuing rapid decline in field frequency of herbicide-susceptible wild oat and green foxtail, the two most abundant weeds in Manitoba. However, incidence of herbicide resistance in broadleaf weeds remained low (except kochia documented previously), and weed resistance to herbicides from Groups 4, 9, or 10 was not detected.

Objective

In 2016, 151 fields were randomly selected for a weed resistance survey (3rd round). In the weed resistance survey reported herein, all residual weed species with viable seed were mapped and sampled. Samples were subsequently screened in the greenhouse with various herbicides from Groups 1 or 2 (i.e., tier-1 testing).

Sites

A total of 151 fields were surveyed for herbicide-resistant weeds (Map 1). Each field was farmed by a different producer. Similar to the general weed survey, a stratified-randomized design was used to select fields (Thomas 1985). The proportional allocation of fields among the major crops grown in each ecodistrict (geographic area within an ecoregion similar in landform, relief, surficial material, climate, soils, natural vegetation, and land use; Agriculture and Agri-Food Canada 2003) was similar to that of the 2016 general weed survey (Leeson et al. 2016). Fields were randomly selected from the list of qualified fields (659). Each sampling unit comprised 64-ha (160 ac). The crop allocation across the ecoregions of Manitoba is shown in Table 1.

Table 1. Field allocation by crop in Manitoba ecoregions

Crop	Aspen Parkland	Southwest Manitoba Uplands	Lake Manitoba Plain	Boreal Transition	Mid-Boreal Uplands	Interlake Plain[a]	All areas
	No. of fields						
Wheat	18	0	19	4	1	5	*47*
Barley	5	0	0	1	0	0	*6*
Oat	4	0	2	0	0	0	*6*
Corn	3	0	1	0	0	3	*7*
Canola	24	1	15	1	1	3	*45*
Flax	4	1	2	0	0	1	*8*
Soybean	9	0	16	0	0	5	30
Sunflower	1	0	1	0	0	0	*2*
Sub-total	*68*	*2*	*56*	*6*	*2*	*17*	***151***
% of Total	*45*	*1*	*37*	*4*	*1*	*12*	*100*

[a]The Interlake Plain ecoregion includes Lake of the Woods ecoregion.

A majority of the fields (56%) were cropped to oilseeds. This proportion is greater than that of the 2008 weed resistance survey (40%). Canola occupied 53% of the 85 survey fields, soybean 35%, flax 10%, and sunflower 2%. The proportion of oilseed fields cropped to canola was less than that of the 2008 survey (80% that year), soybean was greater (only 4% in 2008), flax was slightly less (15% in 2008) and sunflower was similar. Cereals comprised 44% of surveyed fields. Wheat occupied 71% of the 66 survey fields cropped to cereals, barley 9%, oat 9%, and corn 11%; in the 2008 survey, wheat comprised 71%, barley 13%, oat 14%, and corn 2% of cereal fields. There were no field pea fields surveyed (vs. four in 2008).

Field Survey

Fields were surveyed using the inverted 'W' pattern (Thomas 1985) in August or September immediately before crop harvest. About 1,000 viable seeds of a weed species were collected, when available, from mature plants occurring in a patch (each patch sampled separately) and placed in an unsealed paper bag (Beckie et al. 2000). If the weed population was widely disseminated across the field with no visible patchiness (i.e., single plants), at least 100 plants were sampled to obtain an estimate of the level of resistance in the weed population. The approximate infestation area of a weed species in a field was recorded. Samples were dried and stored at room temperature before conducting the resistance tests. The number of weed samples tested is shown in Table 2.

Over two-thirds of the 14 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2016 (Leeson et al. 2016). Some species (not listed) whose seeds had been collected were not tested because of limited seed, no known response to herbicides used in screening, or non-viable seed.

Table 2. Weed species tested for resistance

Weed species	Samples tested	Fields	Rank[a]
	No.		
Grass:			
Barnyard grass, *Echinochloa* spp.	11	11	3
Green foxtail, *Setaria viridis* (L.) P. Beauv.	50	50	1
Yellow foxtail, *Setaria pumila* (Poir.) Roem. & Schult.	60	60	6
Wild oat, *Avena fatua* L.	104	101	4
Broadleaf:			
Chickweed, *Stellaria media* (L.) Vill.	2	2	18
Cleavers, *Galium* spp.	18	18	17
Hemp-nettle, *Galeopsis tetrahit* L.	4	4	32
Lamb's-quarters, *Chenopodium album* L.	6	6	14
Redroot pigweed, *Amaranthus retroflexus* L.	22	22	8
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	2	2	27
Smartweed (annual), *Polygonum* spp.	5	5	12
Stinkweed, *Thlaspi arvense* L.	4	4	33
Wild buckwheat, *Polygonum convolvulus* L.	11	11	2
Wild mustard, *Sinapis arvensis* L.	12	12	23

[a]Relative abundance rank of species in 659 fields surveyed in 2016 (Leeson et al. 2016); rank of annual smartweed spp. is that of pale smartweed.

Resistance Tests

Resistance tests were initiated 4 months after seeds were collected to reduce the level of innate dormancy. All tests were conducted using pot assays in the greenhouse. Weed species were sprayed at growth stages (usually two to four leaves) for optimum herbicide efficacy. All recommended adjuvants were included in the herbicide spray solutions. Weed samples were screened for resistance to high-risk herbicides from Groups 1 or 2 or both (Tier-1 screening; Table 3). Second- or tertiary-tier screening to herbicides from other groups may be conducted in the future depending upon availability of greenhouse bench space.

Herbicides were applied using a moving-nozzle cabinet sprayer equipped with a flat-fan spray tip (TeeJet 8002VS) calibrated to deliver 200 L/ha of spray solution at 275 kPa in a single

Table 3. Herbicides for resistance screening (Tier 1: Group 1 or 2 herbicides)[a]

Herbicide	Group	Weed species	Rate (gai or gae/ha)
Fenoxaprop	1 (Fop)	Wild oat, green foxtail, other annual grass	150, 40, 40
Clodinafop	1 (Fop)	Wild oat, green foxtail, yellow foxtail	35, 35,35
Quizalofop	1 (Fop)	Wild oat, green foxtail, perennial grass	35, 35, 70
Sethoxydim	1 (Dim)	Wild oat, green foxtail, other annual grass, perennial grass	110, 50, 145 250
Tralkoxydim	1 (Dim)	Wild oat, green foxtail	25, 25
Clethodim	1 (Dim)	Wild oat, green foxtail	15, 15
Pinoxaden	1 (Den)	Wild oat, green foxtail	15, 15
Imazamethabenz	2 (Imi)	Wild oat	500
Imazethapyr	2 (Imi)	Broadleaf	50
Imazamox	2 (Imi)	Grass, broadleaf	35, 35
Metsulfuron	2 (SU)	Broadleaf	4.5
Thifensufuron: tribenuron	2 (SU)	Broadleaf	15
Flucarbazone	2 (SCT)	Wild oat	15
Florasulam	2 (TZP)	Broadleaf	5
2,4-D	4 (Auxin)	Broadleaf	560-930
Dicamba	4 (BA)	Broadleaf	140-600
Fluroxypyr	4 (CA)	Broadleaf	80
Triallate	8	Wild oat	1,180
Difenzoquat	8	Wild oat	700
Glyphosate	9	Grass and broadleaf	450-900
Glufosinate	10	Grass and broadleaf	500

[a]For each herbicide, only weed species listed on the label as being controlled were screened.
Abbreviations: BA: benzoic acid; CA: carboxylic acid; Dim: cyclohexanedione; Den: phenylpyrazolin; Fop: aryloxyphenoxypropionate; Imi: imidazolinone; SCT: sulfonylaminocarbonyltriazolinone; SU: sulfonylurea; TZP: triazolopyrimidine.

pass over the foliage. Thirty-six plants were grown in flats measuring 52 by 26 by 5 cm that were filled with a commercial potting mixture amended with a slow-release fertilizer. Plants were visually assessed as herbicide-resistant or herbicide-susceptible at 21 to 28 d after treatment. A minimum of 100 seedlings per sample were screened in each resistance test. Treatments (and untreated controls) were replicated three times and the tests were repeated. Known resistant and susceptible biotypes were included in all tests (Beckie et al. 2000).

Grass Weed Resistance

Of the 101 fields where wild oat samples were collected, 80 (79%) had a herbicide-resistant (HR) population (53% of the 151 surveyed fields). In contrast, 60% of fields with wild oat had an HR population in the 2008 survey (Beckie et al. 2010) and 44% of fields in the 2002 survey (Beckie et al. 2004). Group 1-HR wild oat was confirmed in 79 fields (78%) (Table 4, Map 2) or 52% of all 151 surveyed fields. This incidence of Group 1 resistance compares with 55% of fields in 2008 and 40% of fields in 2002. Of fields with wild oat, incidence was proportionally greatest in all ecoregions (small sample size in the Southwest Manitoba Uplands and Mid-Boreal Uplands ecoregions).

Group 2-HR wild oat was found in 43 fields (43%) where the weed was sampled (29% of the 151 surveyed fields), with greatest occurrence in the Aspen Parkland and Lake Manitoba Plain ecoregions (Table 4, Map 3). Incidence of Group 2-HR wild oat has increased sharply since 2008 (18% of fields) and 2002 (13% of fields), largely attributed to increased Group 2 wild oat herbicide use to manage Group 1-HR wild oat.

Table 4. Fields with Group 1- or 2-resistant wild oat by ecoregion

	Group 1-resistant wild oat			Group 2-resistant wild oat		
Ecoregion	Resistant	Tested[a]	Surveyed[a]	Resistant	Tested	Surveyed
	No.	%		No.	%	
Aspen Parkland	34	83	50	21	41	68
Southwest Manitoba Uplands	2	100	100	2	2	2
Lake Manitoba Plain	27	71	48	8	38	56
Boreal Transition	4	80	67	5	5	6
Mid-Boreal Uplands	1	50	50	1	2	2
Interlake Plain[b]	11	85	65	6	13	17
Manitoba	*79*	*78*	*67*	*43*	*43*	*29*

[a]Tested - fields where seeds were collected; surveyed - all fields surveyed.
[b]The Interlake Plain ecoregion includes Lake of the Woods ecoregion.

Group 1+2-HR wild oat was found in 42 fields (42%) where the weed was present: 21 fields (44%) in the Aspen Parkland ecoregion, 2 fields in the Southwest Manitoba Uplands (100%), 8 fields (21%) in the Lake Manitoba Plain ecoregion, 4 fields (80%) in the Boreal Transition ecoregion, 1 field (50%) in the Mid-Boreal Uplands, and 6 fields (46%) in the Interlake Plain ecoregion (Map 4). The occurrence of this HR biotype compares with 13% of fields sampled in 2008 and 8% of fields in 2002. Therefore, of the 80 fields with HR wild oat populations, 37 had Group 1 resistance only, 1 had Group 2 resistance only, and 42 had Group 1 plus 2 resistance. From 2012 to 2016, 55 wild oat submissions from Manitoba were HR: 12 Group 1, 33 Group 2 and 10 Group 1+2 (Beckie et al. 2017). The following number of wild oat sample submissions from Manitoba were Group 1, Group 2, and Group 1+2-HR – 2014: 51, 39, 54; 2015: 101, 14, 72; 2016: 105 26, 85 (Xie and Doell 2017).

In fields with Group 1+2-HR wild oat, only preplant triallate (Group 8) or triallate/trifluralin (Groups 8/3) are left to manage this biotype in wheat and barley (Government of Saskatchewan 2017). In lentil, only trifluralin is left to control multiple-HR wild oat, while in field pea, only trifluralin or triallate remain. Although not included in this tier-1 testing, Group 8-HR wild oat was found in only 11% of fields in 2008 (Beckie et al. 2010). Group 8-HR wild oat generally evolves after 18 applications of this herbicide mode of action, thereby considered a moderate risk for selection for resistance. Group 3-HR wild oat has not been documented in the prairies, likely because of its relatively low selection pressure (efficacy) on this grass weed or low mutation rate.

Of 50 fields where green foxtail was sampled, 24 (48%) had an HR population (Table 5). This incidence of resistance compares to 44% of fields in 2008 (Beckie et al. 2010), and 22% of fields in 2002 (Beckie et al. 2004). Group 1-HR green foxtail was found in 22 fields (44%) where the weed was sampled (Map 5), mainly in the Aspen Parkland and Lake Manitoba Plain

Table 5. Fields with Group 1- or 2-resistant green foxtail by ecoregion

Ecoregion	Group 1-resistant green foxtail			Group 2-resistant green foxtail		
	Resistant	Tested[a]	Surveyed[a]	Resistant	Tested	Surveyed
	No.	%		No.	%	
Aspen Parkland	9	43	13	2	10	3
Southwest Manitoba Uplands	1	100	50	0	0	0
Lake Manitoba Plain	12	55	21	0	0	0
Boreal Transition	0	0	0	0	0	0
Mid-Boreal Uplands	0	0	0	0	0	0
Interlake Plain[b]	0	0	0	1	17	6
Manitoba	*22*	*44*	*15*	*3*	*6*	*2*

[a]Tested - fields where seeds were collected; surveyed - all fields surveyed.
[b]The Interlake Plain ecoregion includes Lake of the Woods ecoregion.

ecoregions. Group 2-HR green foxtail was found in 3 fields (6%) (Table 5, Map 6) in the Aspen Parkland or Interlake Plain ecoregions. Of the 24 fields with HR green foxtail, 21 had Group 1 resistance only, 2 had Group 2 resistance only, and 1 had Group 1 plus 2 resistance (Map 7).

Of 60 fields where yellow foxtail was sampled, 25 fields (42%) had an HR population (Table 6). Resistance in this weed has not been reported previously in Canada. Group 1-HR yellow foxtail was found in 19 fields (32%) where the weed was sampled (Map 8), mainly in the Aspen Parkland and Lake Manitoba Plain ecoregions. Group 2-HR yellow foxtail was found in 10 fields (17%) (Table 6, Map 9) in the Aspen Parkland, Lake Manitoba Plain, or Interlake Plain ecoregions. Of the 25 fields with HR yellow foxtail, 15 had Group 1 resistance only, 6 had

Table 6. Fields with Group 1- or 2-resistant yellow foxtail by ecoregion

Ecoregion	Group 1-resistant yellow foxtail			Group 2-resistant yellow foxtail		
	Resistant	Tested[a]	Surveyed[a]	Resistant	Tested	Surveyed
	No.	%		No.	%	
Aspen Parkland	6	29	9	4	19	6
Southwest Manitoba Uplands	0	0	0	0	0	0
Lake Manitoba Plain	10	32	18	5	16	9
Boreal Transition	0	0	0	0	0	0
Mid-Boreal Uplands	0	0	0	0	0	0
Interlake Plain[b]	3	38	18	1	12	6
Manitoba	*19*	*32*	*13*	*10*	*17*	*7*

[a]Tested - fields where seeds were collected; surveyed - all fields surveyed.
[b]The Interlake Plain ecoregion includes Lake of the Woods ecoregion.

Group 2 resistance only, and 4 had Group 1 plus 2 resistance (Map 10). The rapid evolution of this high incidence (42% of sampled fields) of Group 1 or Group 2 resistance in this weed is alarming, and may help explain why the species has risen in relative abundance from 32nd place in 2002 to 6th place in 2016 (Leeson et al. 2016) due to sub-optimum control. Conversely, a greater selection pressure for resistance is enabled by greater population abundance.

Group 2-HR barnyard grass was found in three of 11 fields sampled (27%), located in the Aspen Parkland, Southwest Manitoba Uplands, and Mid-Boreal Uplands (Map 11). At least one population was western barnyard grass [*Echinochloa muricata* var. *microstachya*], not *E. crus-galli* (L.) P. Beauv. Because these HR biotypes have not been reported in Canada previously, close monitoring of their occurrence in the future is warranted.

Broadleaf Weed Resistance

Group 2-HR cleavers was found in 2 of 18 fields sampled (11%), located in the Boreal Transition ecoregion (Map 12). This biotype was found in only one field in the Interlake Plain ecoregion in the 2008 survey (Beckie et al. 2010) (no fields in the 2002 survey). Therefore, incidence of this biotype is slowly increasing in the province. Group 2-HR wild mustard was found in 3 of 12 fields sampled (25%) (Map 13). This biotype was found in only one field in the Lake Manitoba Plain ecoregion in the 2008 survey (Beckie et al. 2010) (no fields in the 2002 survey). Therefore, similar to cleavers, incidence of resistance in wild mustard is slowly increasing in Manitoba.

Group 2-HR redroot pigweed was found in only 1 of 22 fields (5%), located in the Lake Manitoba Plain ecoregion (Map 14). In the 2002 survey, one HR population was found in the Aspen Parkland ecoregion. Group 2-HR shepherd's-purse was found in one of the two fields

sampled (Interlake Plain ecoregion; Map 15). Although found in Saskatchewan, this is the first survey in Manitoba to document its occurrence.

An important indicator of the possible impact of HR weeds is their densities in-crop (occurrence fields) after all herbicide treatments have been applied, i.e., pre-harvest. Based on the past three weed surveys in Manitoba, densities of all weed species except yellow foxtail and wild mustard were lowest in the most recent field survey in 2016 (Table 7). Of particular concern is yellow foxtail, which has consistently increased in density over the ca. 20-year period.

Land Area Impacted by Herbicide-Resistant Weeds

When the frequency of fields with weed resistance in this random survey of 151 fields is extrapolated to the total annual-cropped land in Manitoba (4,055,778 ha or 10,017,771 ac) in 2016) (Statistics Canada 2017), it is estimated that 2.2 million ha (55%) are infested with HR weeds, in a total field area of 2.7 million ha (68%) (Table 8). In comparison, the weed resistance survey in 2008 indicated that 1.6 million ha was infested with HR weeds, in a total field area of 2.2 million ha; the weed resistance survey in 2002 indicated that 0.4 million ha was infested with

Table 7. Post-herbicide treatment mean weed densities (no. m^{-2}) in surveyed fields in Manitoba: 1997, 2002, and 2016 (Thomas et al. 1998; Leeson et al. 2002; Leeson et al. 2016)

Weed	1997	2002	2016
Wild oat	10.8	11.7	4.4
Green foxtail	43.1	23.8	14.6
Yellow foxtail	2.3	4.4	10.6
Barnyard grass	8.1	12.0	4.8
Cleavers	6.1	3.8	1.9
Wild mustard	3.1	2.1	5.9
Redroot pigweed	4.0	3.4	2.1
Shepherd's-purse	5.1	1.3	0.9
Kochia	4.4	6.2	1.1

Table 8. Estimated annual-cropped land area in Manitoba impacted by herbicide-resistant (HR) weeds in 2016[a]

Biotype	Infestation area (ac/ha)	Field area (ac/ha)
Gp 1-HR wild oat	1,423,260/576,219	2,454,686/993,800
Gp 2-HR wild oat	66,344/26,860	66,344/26,860
Gp 1+2-HR wild oat	1,542,470/624,482	2,786,400/1,128,097
Gp 1-HR green foxtail	701,784/284,123	1,393,201/564,049
Gp 2-HR green foxtail	132,686/53,719	132,686/53,719
Gp 1+2-HR green foxtail	1,037/420	1,037/420
Gp 1-HR yellow foxtail	549,402/222,430	995,143/402,892
Gp 2-HR yellow foxtail	218,723/88,552	398,058/161,157
Gp 1+2-HR yellow foxtail	199,028/80,578	265,372/107,438
Gp 2-HR barnyard grass	199,028/80,578	265,372/107,438
Gp 2-HR cleavers	67,379/27,279	132,686/53,719
Gp 2-HR wild mustard	199,028/80,578	199,028/80,578
Gp 2-HR redroot pigweed	66,344/26,860	66,344/26,860
Gp 2-HR shepherd's-purse	66,344/26,860	66,344/26,860
Total	5,432,859/2,199,538	6,766,973/2,739,665

[a] Gp 2 (9)-HR kochia, not included in these data, is estimated to infest 72,809 ac or 29,477 ha, in a field area of 460,818 ac or 186,566 ha; the area calculation is based on the general weed survey data (Leeson et al. 2016) since all populations are assumed Gp-2-HR. Total field area is adjusted downward because some fields contain more than one HR biotype.

HR weeds, in a total field area of 1.2 million ha. Therefore, the actual area infested with HR weeds has increased by 34%, while the total field area affected has increased by 25% since the last survey.

Management Practices of Producers with Resistance

Based on the Manitoba weed survey questionnaire data, five practices were found to be preferentially used by producers with suspected or confirmed HR weeds vs. those who did not suspect or have confirmed HR weeds. These practices were crop rotation, herbicide group rotation, tank-mixing herbicides, use of preemergence herbicides, and tillage (spring or fall) (Figure 2). These targeted practices are consistent with best management practices recommended to manage weed resistance (Beckie and Harker 2017). Preemergence herbicides can reduce weed

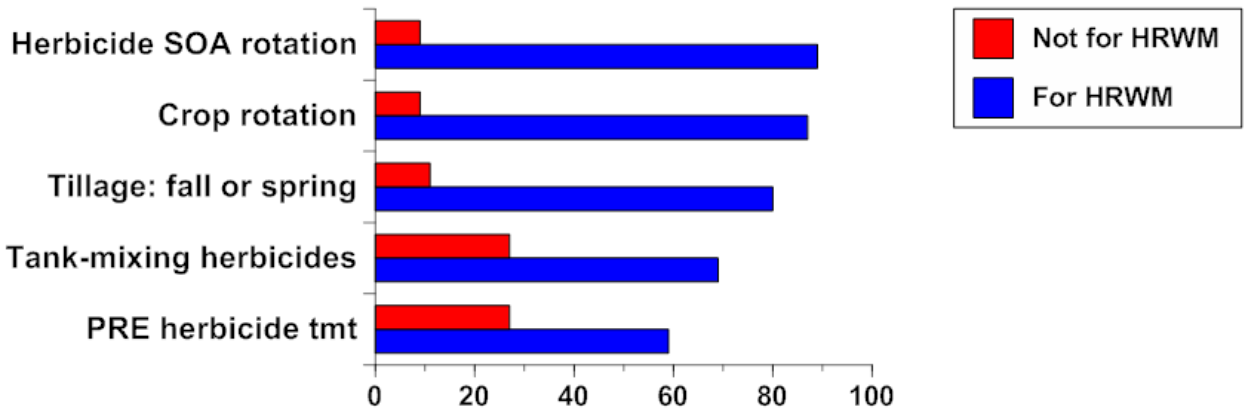

Figure 2. Targeted weed management practices: those with suspected or confirmed weed resistance (n=48 respondents; source: J.Y. Leeson, unpublished weed survey questionnaire data).

population recruitment and abundance in-crop, thereby potentially reducing in-crop herbicide selection pressure for resistance evolution. Crop rotation, tank-mixing herbicides, and herbicide-group rotation are ranked 1st, 4th, and 5th, respectively, in the top 10 HR weed management practices. Overall, those with HR weeds rely more on herbicides at all application windows, and have greater adoption of (1) scouting before in-crop herbicide treatment; (2) tank-mixing herbicides; (3) herbicide group rotation; (4) growing weed-competitive crops; and (5) tillage vs. those without resistance.

Cost of Weed Resistance

The perceived cost of weed resistance to Manitoba producers averages $11/ac or $27/ha, based on the 2016 weed survey questionnaire data (Table 9). This additional expense for producers to manage HR weeds includes both herbicide costs and estimated decreased crop yield and quality. If this mean cost is extrapolated with the estimated field area affected by weed resistance, the total cost is estimated at $74 million annually.

Table 9. The perceived cost of weed resistance to Manitoba producers (n=50 respondents; source: J.Y. Leeson, unpublished 2016 weed survey questionnaire data).

Cost	% of respondents
No additional cost	5
$10/ac or less	56
$11-20/ac	23
$21-30/ac	9
$31-40/ac	7
$41-50/ac	0
Unknown cost	0

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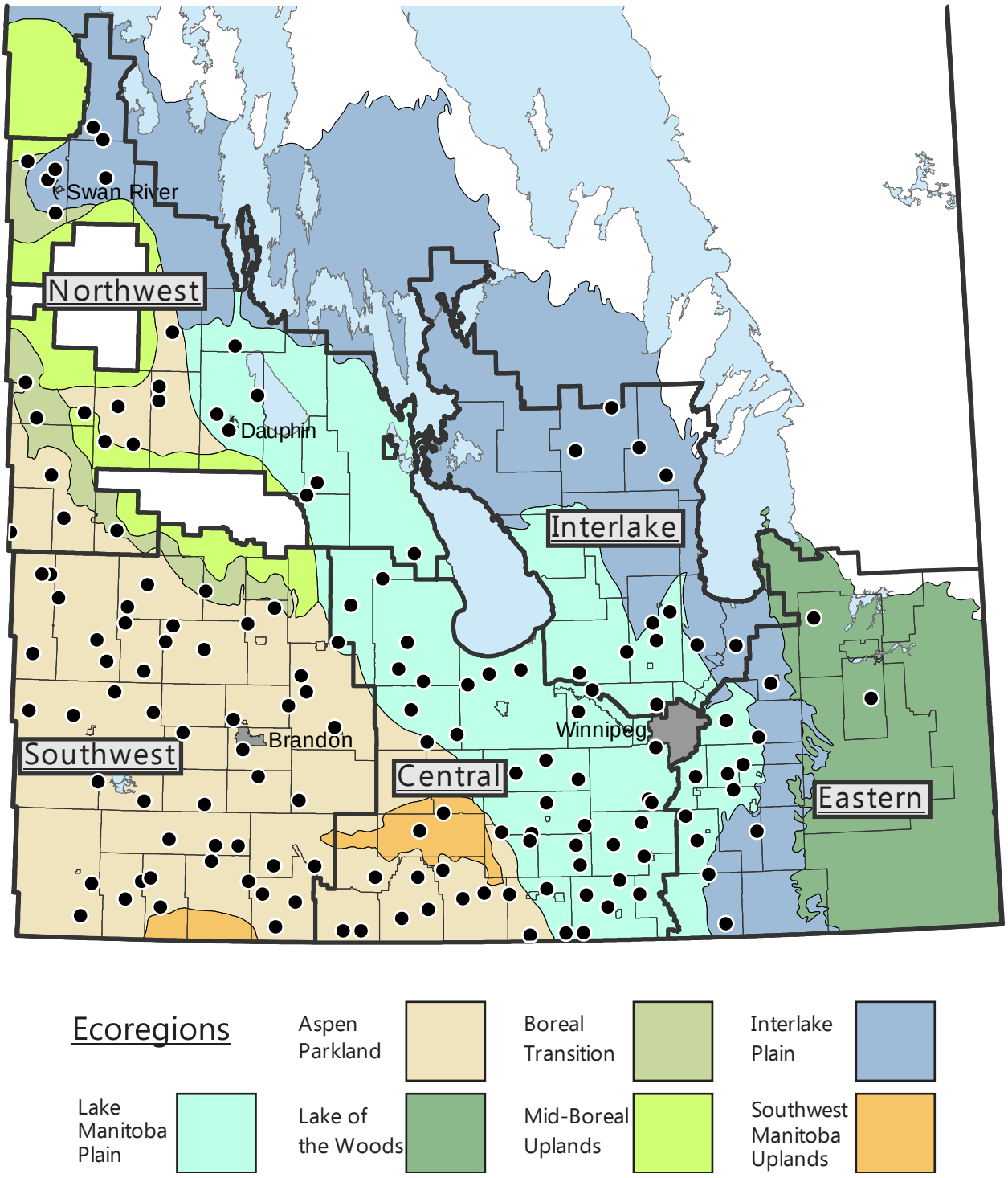
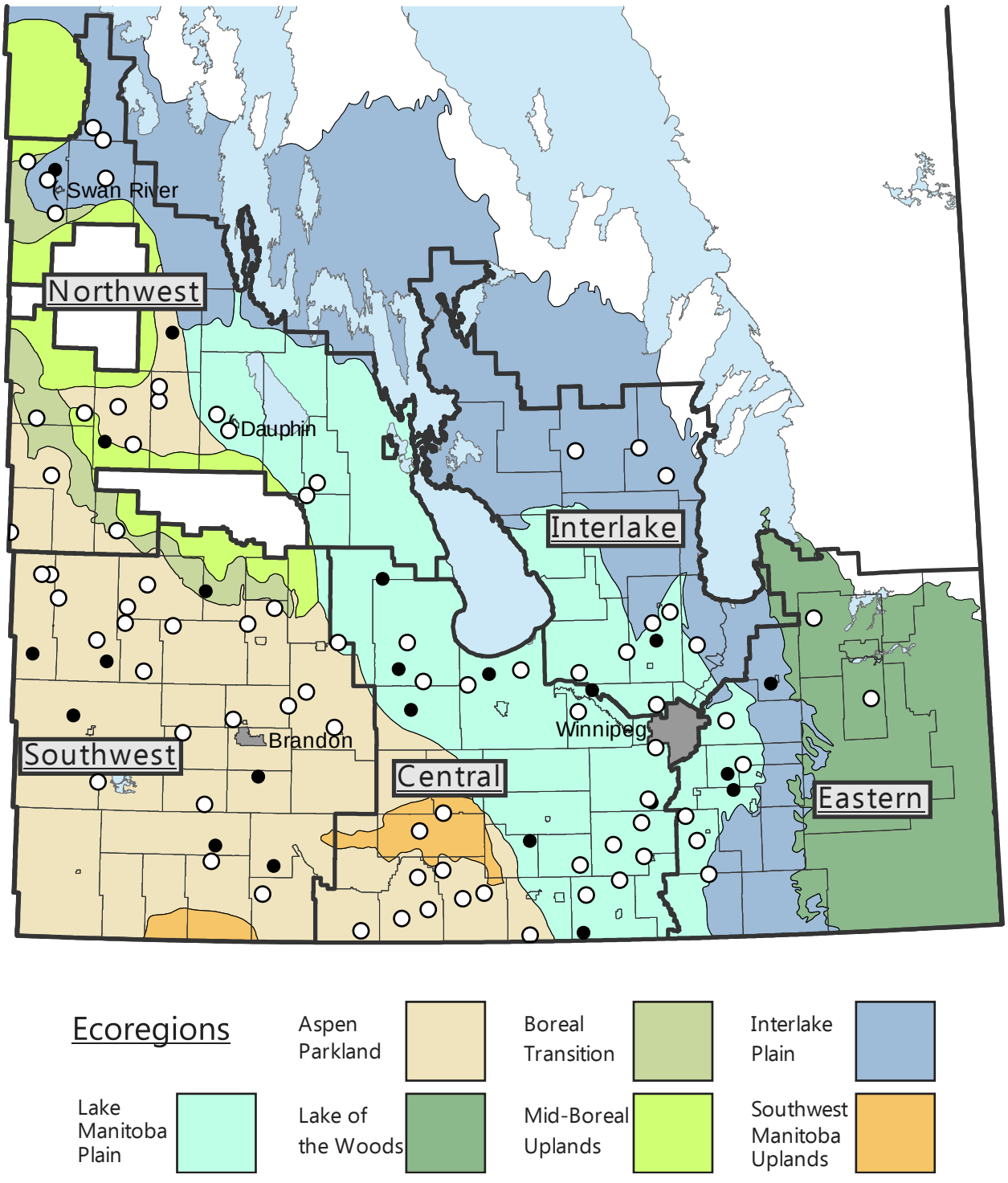
LIST OF MAPS

Surveyed fields



Gp-1 resistant wild oat

Resistant ○ Not resistant •



Gp 2-resistant wild oat

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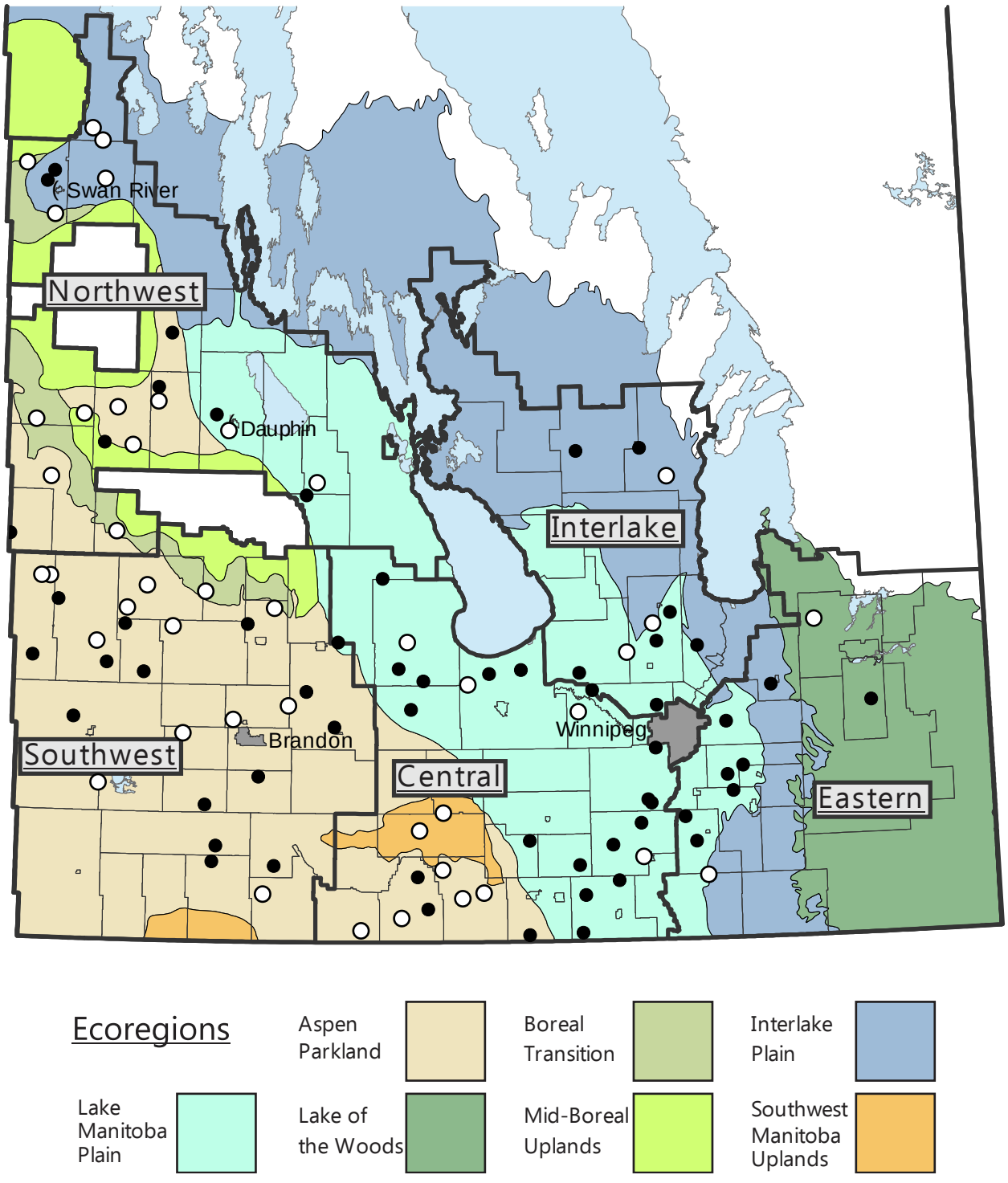

Gp 1- and 2-resistant wild oat

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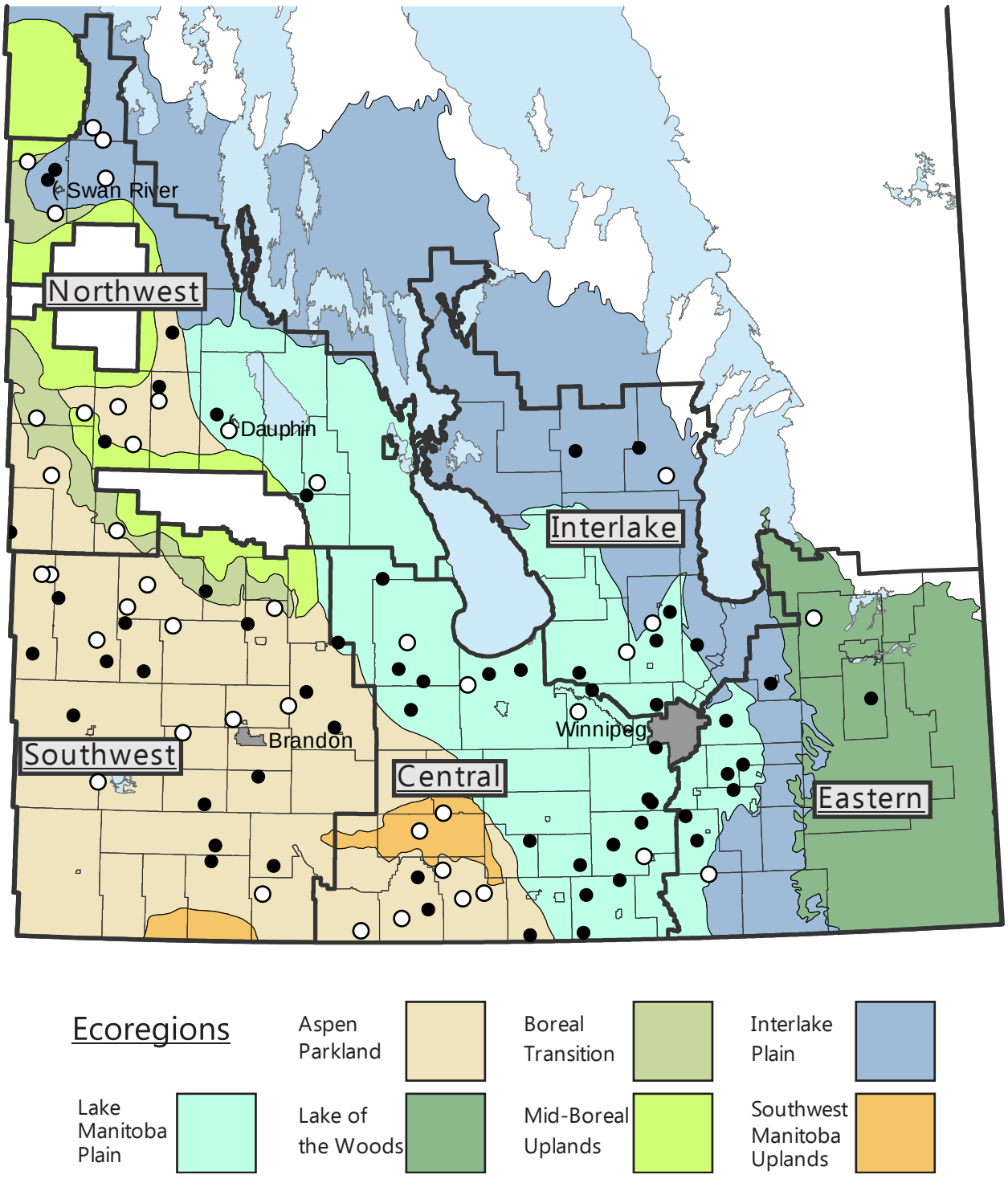

Gp 1-resistant green foxtail

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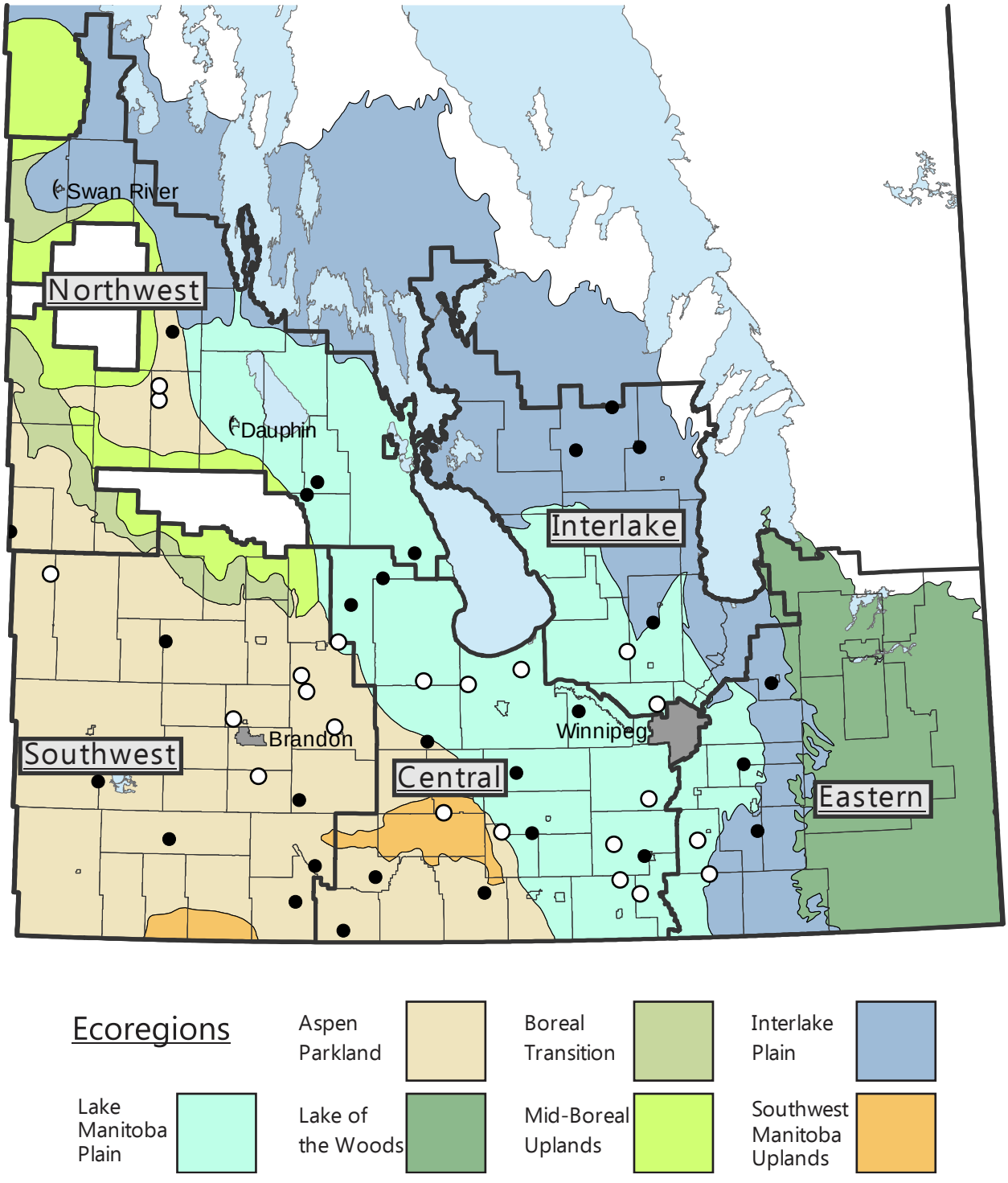

Gp 2-resistant green foxtail

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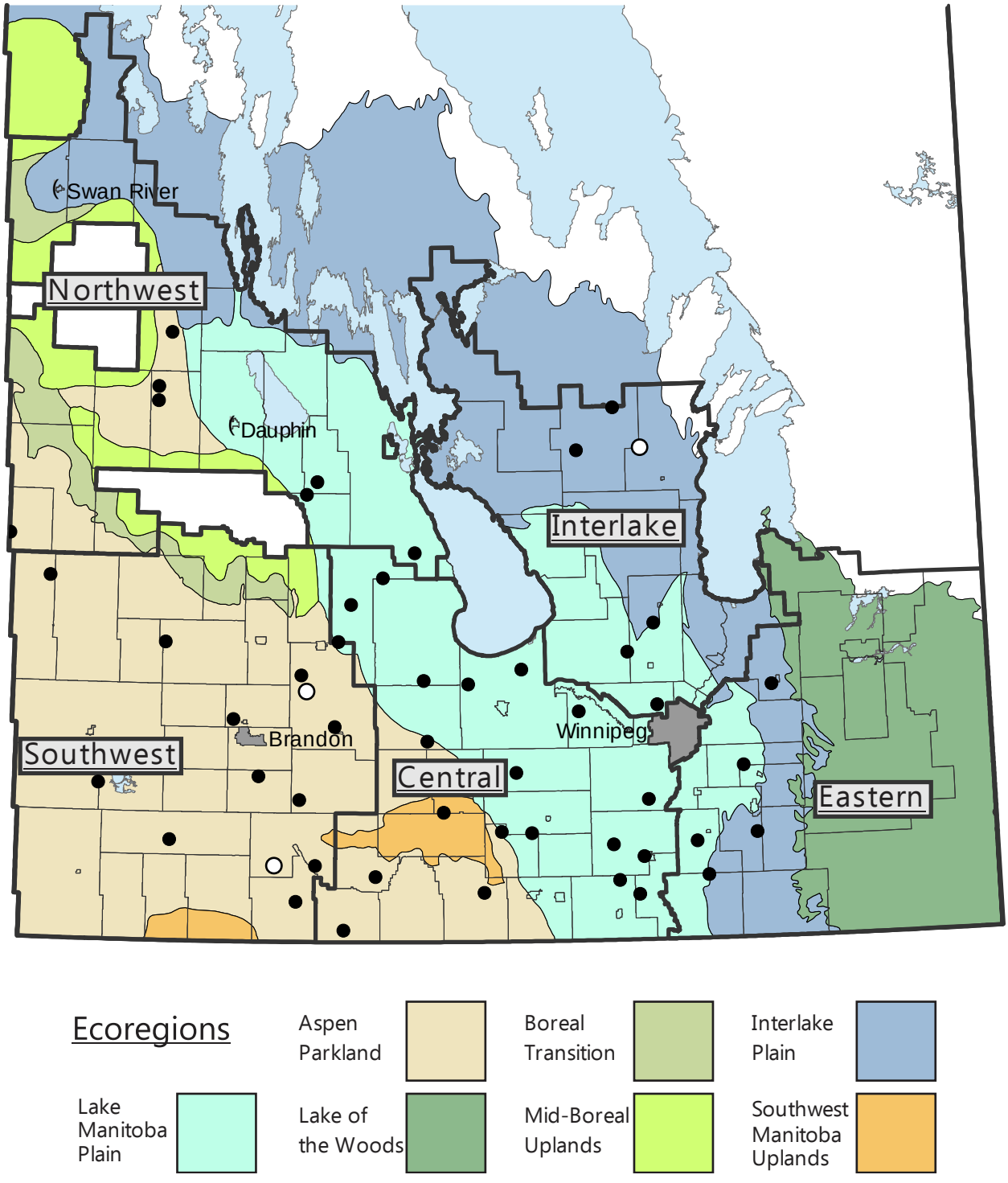

Gp 1- and 2-resistant green foxtail

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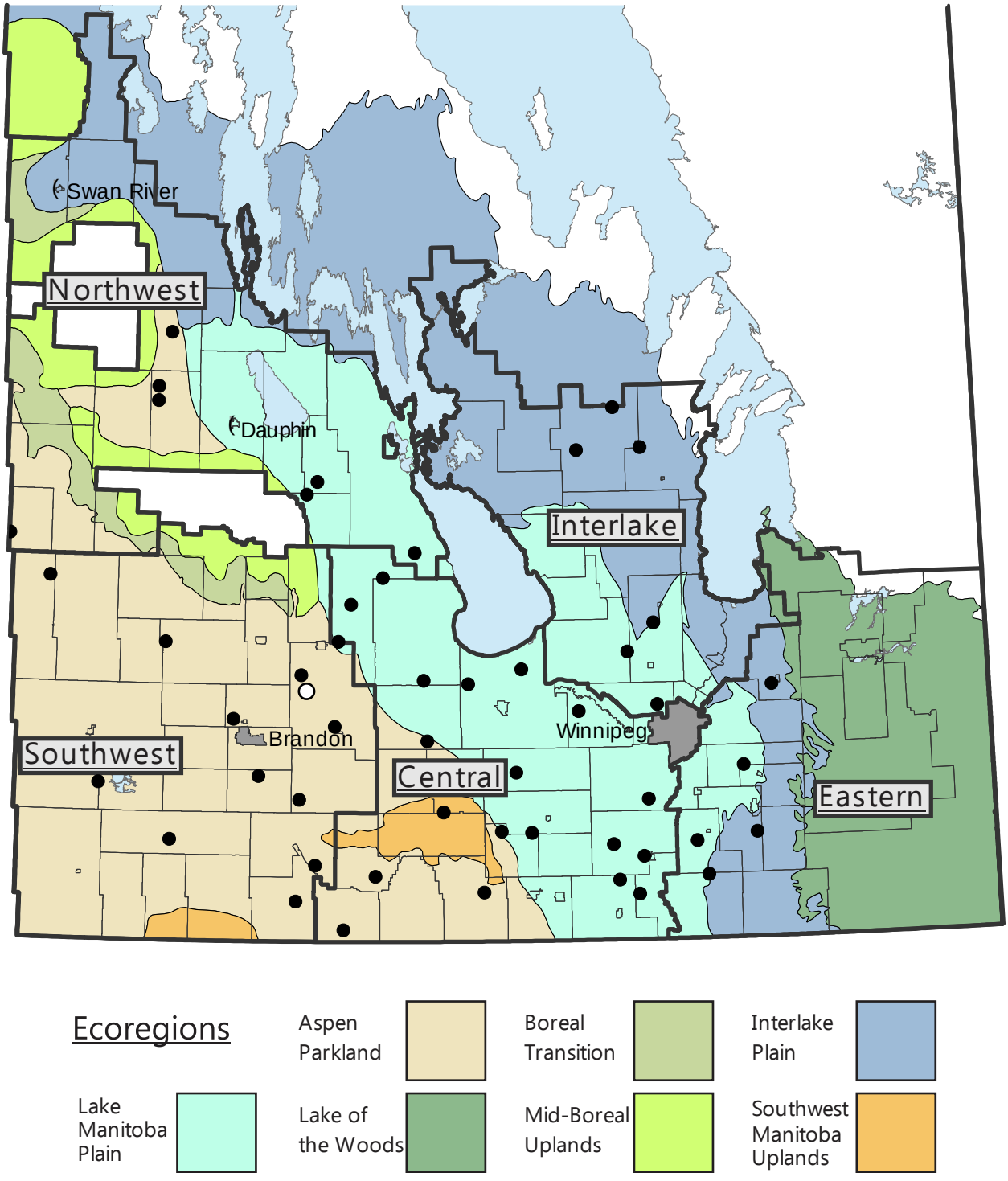

Gp 1-resistant yellow foxtail

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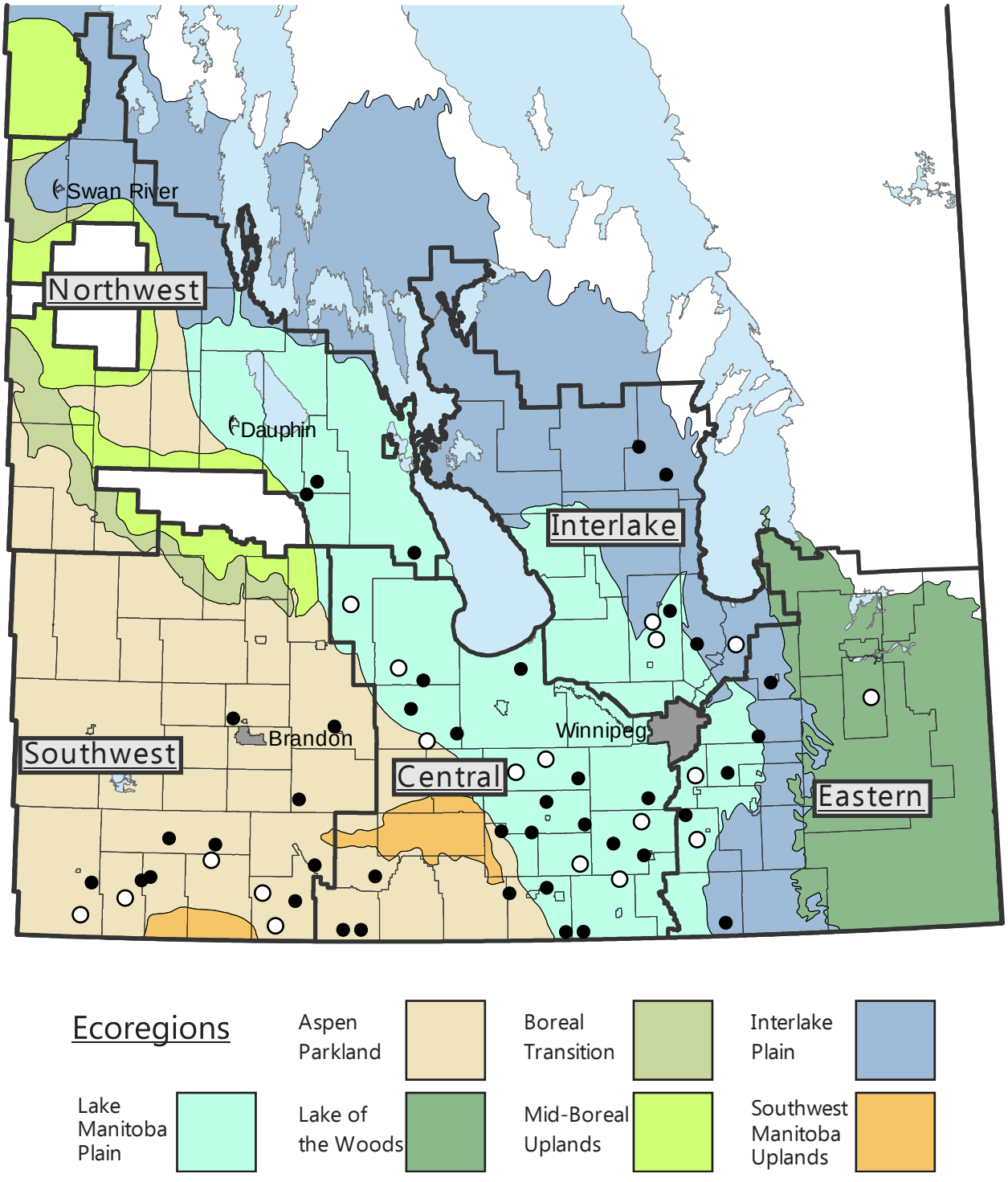

Gp 2-resistant yellow foxtail

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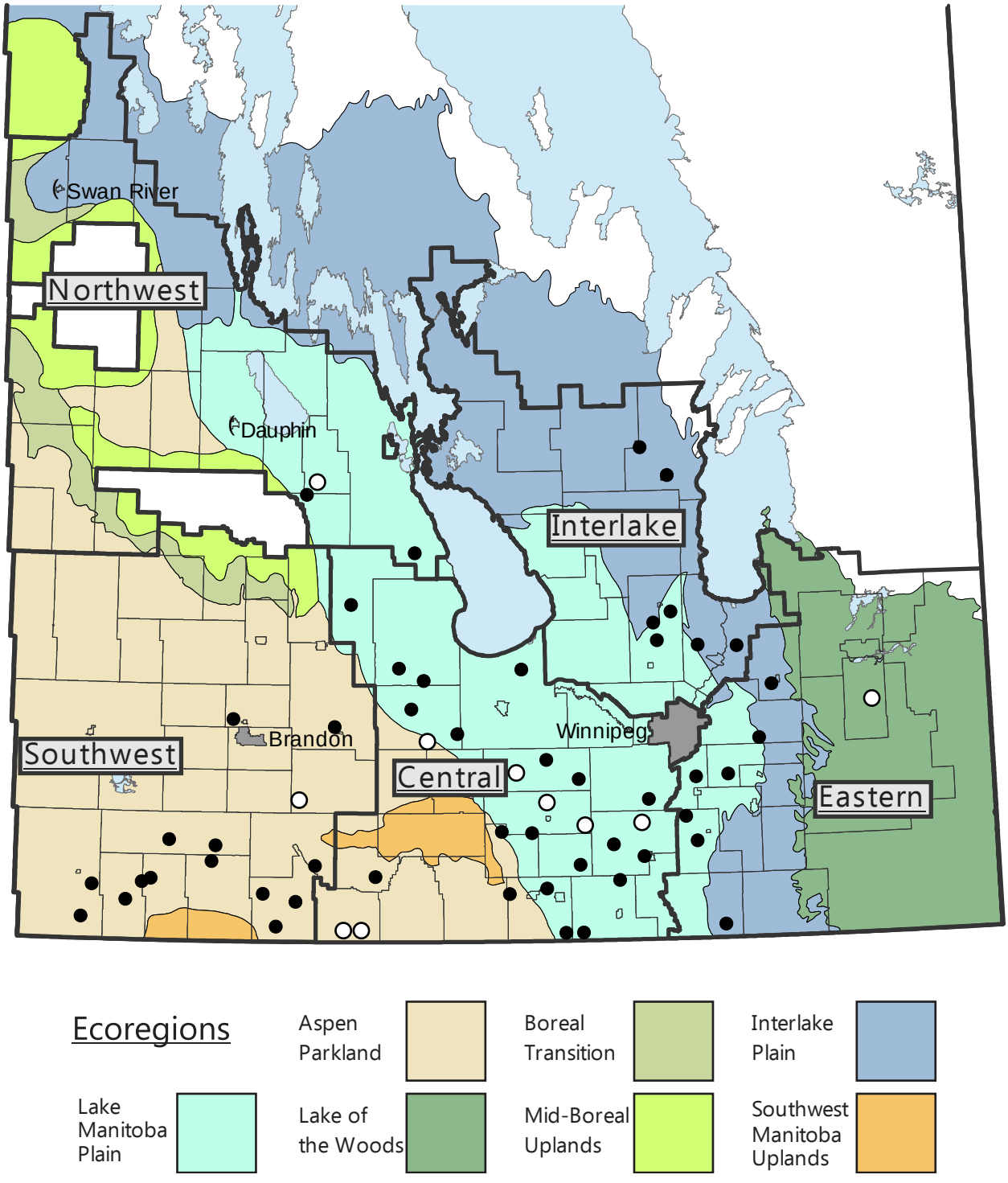

Gp 1- and 2-resistant yellow foxtail

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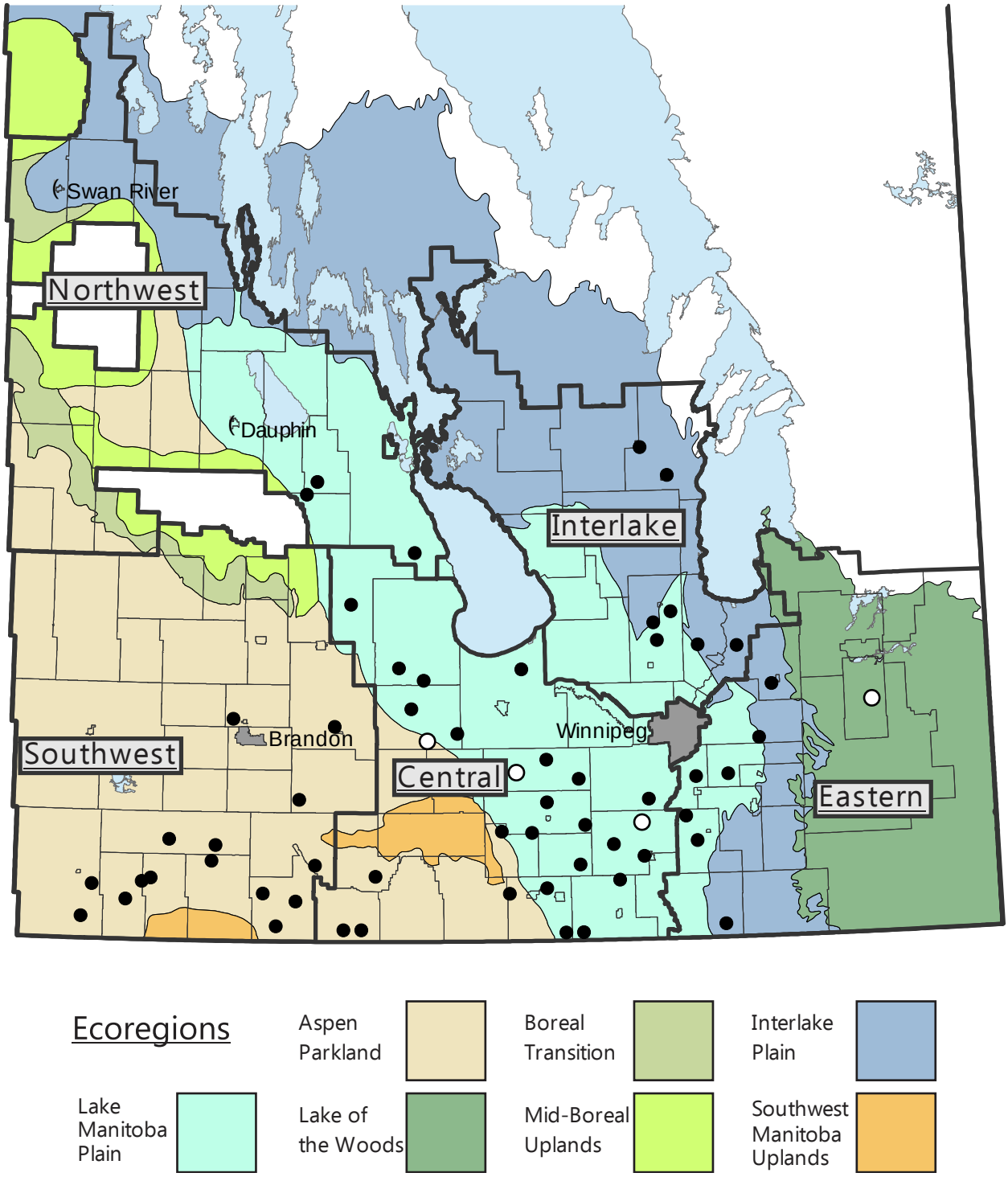

Gp 2-resistant barnyard grass

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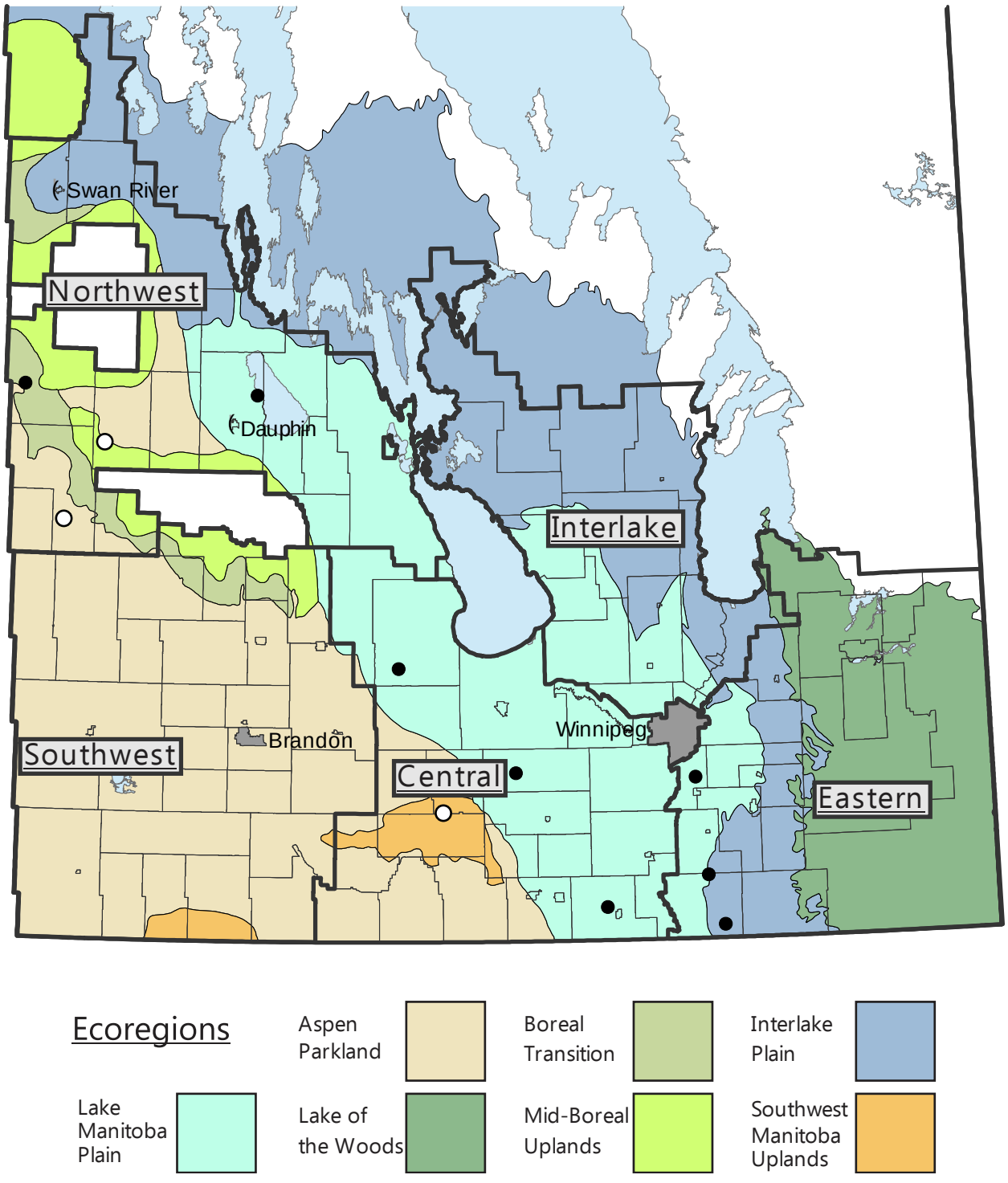

Gp 2-resistant cleavers

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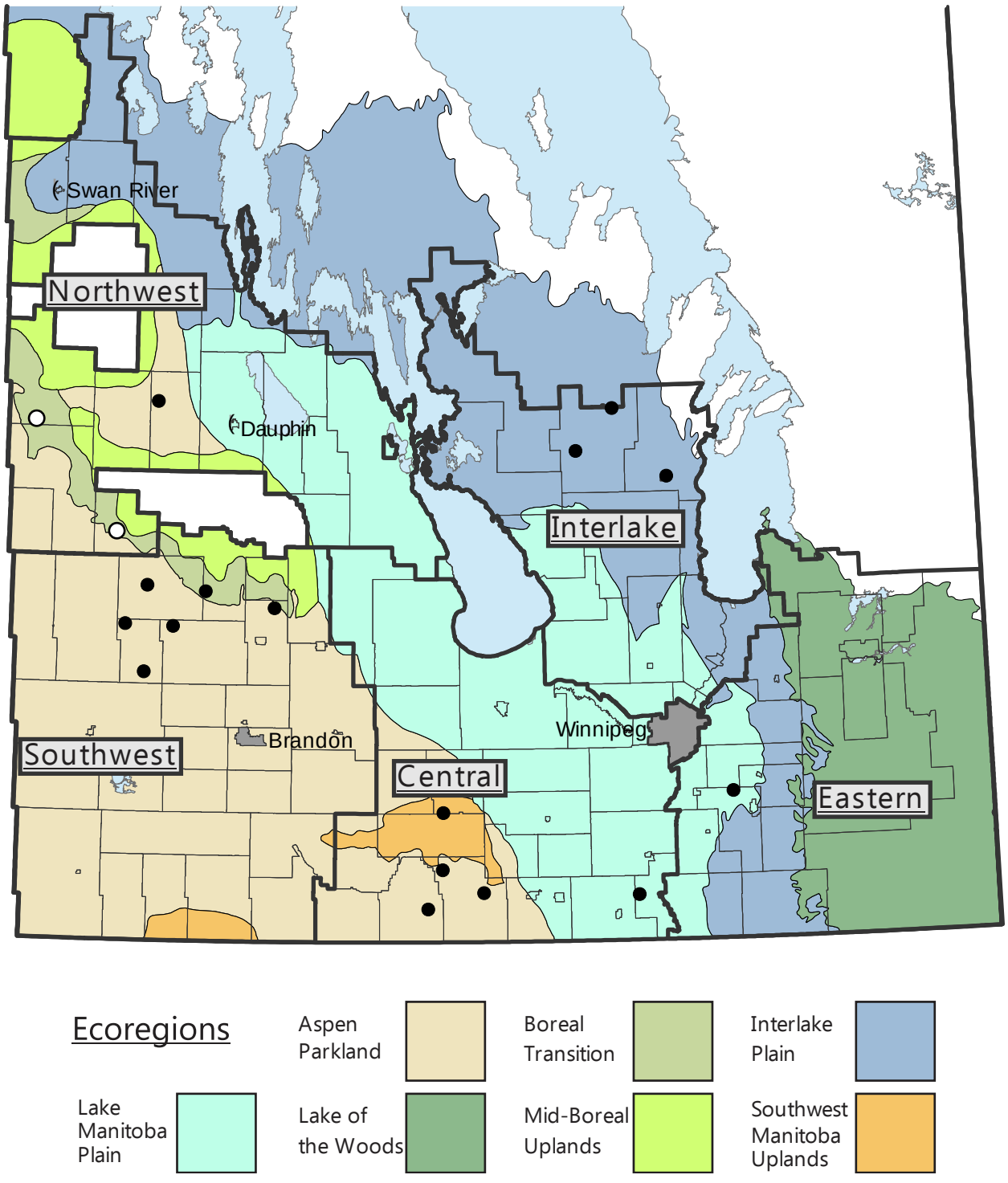

Gp 2-resistant wild mustard

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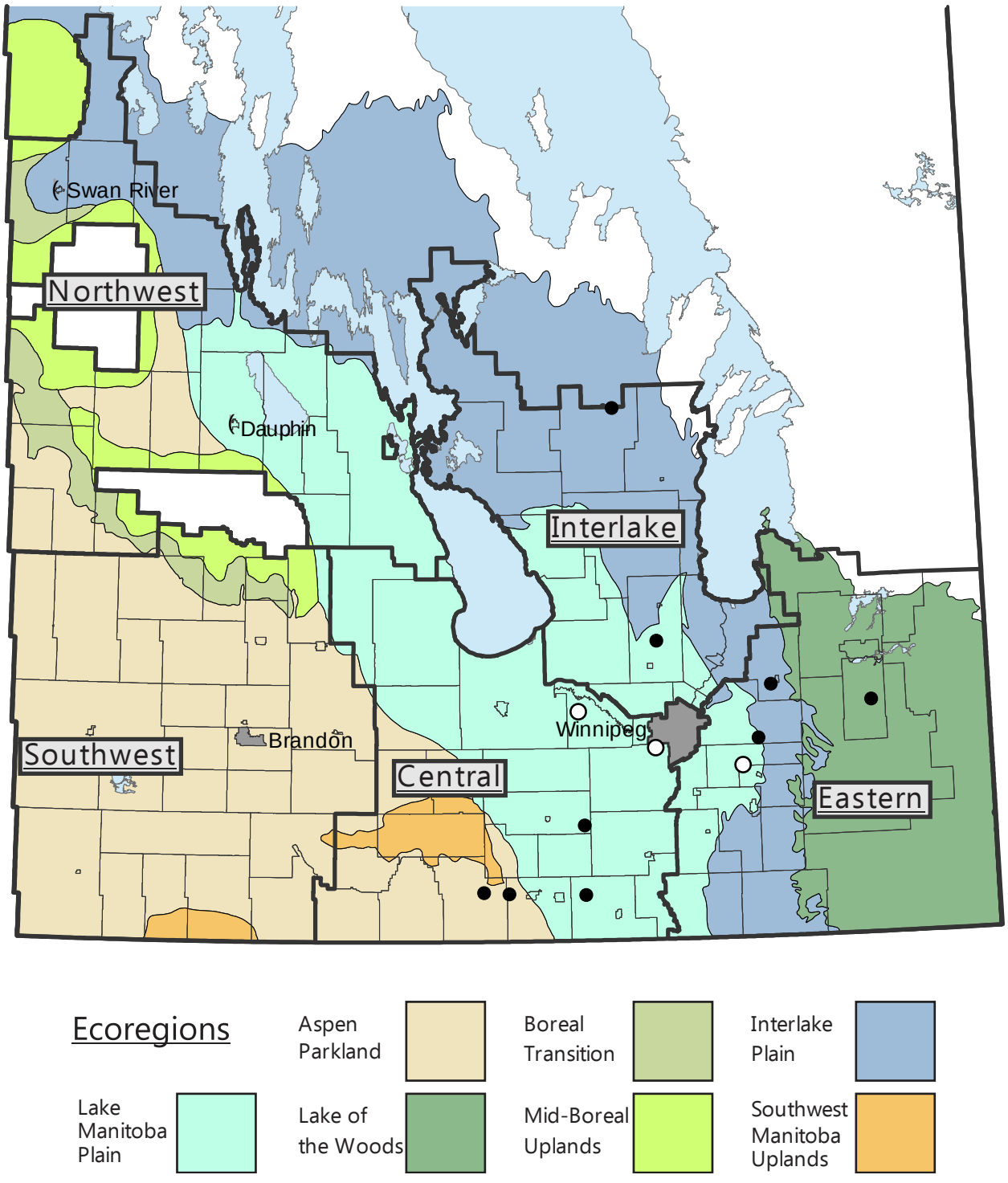

Gp 2-resistant redroot pigweed

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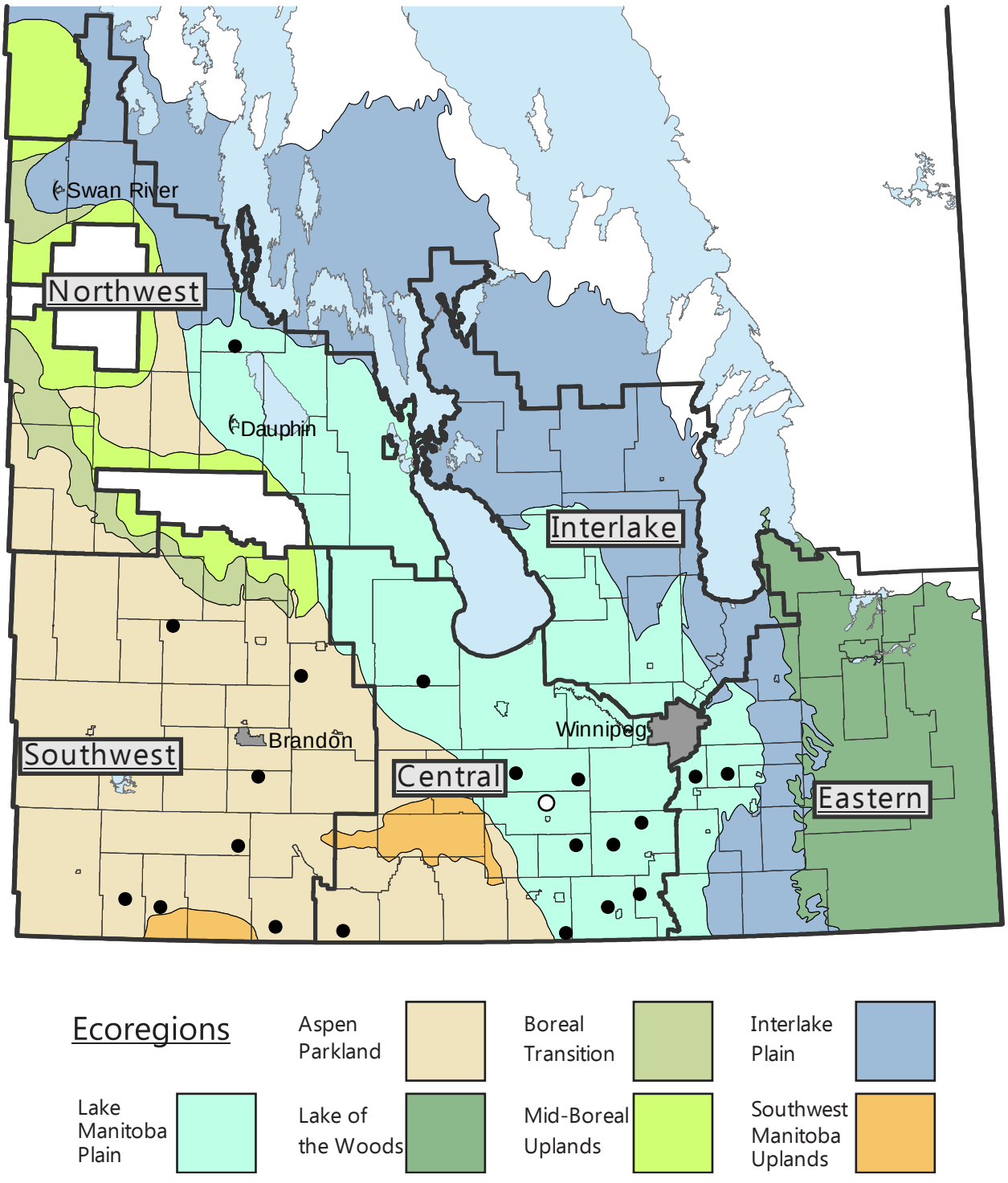

Gp 2-resistant shepherd's-purse

Resistant ○ Not resistant •