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Manitoba Weed Survey

Herbicide-Resistant Weeds
2008

Hugh J. Beckie
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Weed Survey Series

Canada

Manitoba Weed Survey of Herbicide-Resistant Weeds in 2008

by

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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
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09-1	Alberta weed survey of herbicide-resistant weeds in 2007

PREFACE

A major five-year weed survey project (April 1, 2007-March 31, 2012) entitled "Trends in herbicide-resistant weed occurrence across the prairies" was inititated in 2007. The project involves a survey of resistant weeds in 1,000 randomly-selected fields: 300 in Alberta in 2007, 300 in Manitoba in 2008, and 400 in Saskatchewan in 2009. Unfortunately, we were not able to conduct the field management questionnaire component as planned, because permission was not granted from Viterra, which purchased the assets of Agricore United; the former company had provided us access to their field database, which was used to select survey fields in the three prairie provinces.

Previously published reports in the Weed Survey Series on occurrence of herbicide-resistant weeds were: (1) 04-1: Alberta weed survey of herbicide-resistant weeds in 2001; (2) 04-2: Manitoba weed survey of herbicide-resistant weeds in 2002; (3) 06-1: Saskatchewan weed survey of herbicide-resistant weeds in 2003; and (4) 06-2: Prairie weed survey of herbicide-resistant wild oat from 2001 to 2003. These surveys established a baseline from which to compare the occurrence of herbicide resistance in the future.

This report follows the 2007 Alberta weed resistance survey report published in 2009. This report documents the nature, distribution and abundance of herbicide-resistant weeds in Manitoba in 2008. As indicated above, 300 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 resistance testing was the most extensive to date.

Two reports in 2011 will complete this survey project: (1) weed resistance in Saskatchewan in 2009, and (2) a final report that will integrate the results from the three provincial reports to facilitate a comparison of weed resistance across the major prairie ecoregions and provide "the big picture" of weed resistance in the prairies.

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Agriculture and Agri-Food Canada

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Hugh J. Beckie, Chris Lozinski, and Scott Shirriff

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EXECUTIVE SUMMARY

A survey of weeds resistant to herbicides in 300 randomly selected fields was conducted across the major agricultural ecoregions of Manitoba in 2008. All residual weed species with mature seeds were mapped and sampled before harvest. 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 (*Avena fatua* L.) 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 have herbicide-susceptible populations.

Of 91 fields where green foxtail [*Setaria viridis* (L.) Beauv.] 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 [*Stellaria media* (L.) Vill.], cleavers (*Galium* spp.), and wild mustard *(Sinapis arvensis* L.). These resistant biotypes had previously been found in Manitoba, although they were not detected in the 2002 survey.

The results of this survey highlight 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 remain low (except kochia documented previously), and weed resistance to herbicides from Groups 4, 9, or 10 was not detected.

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.

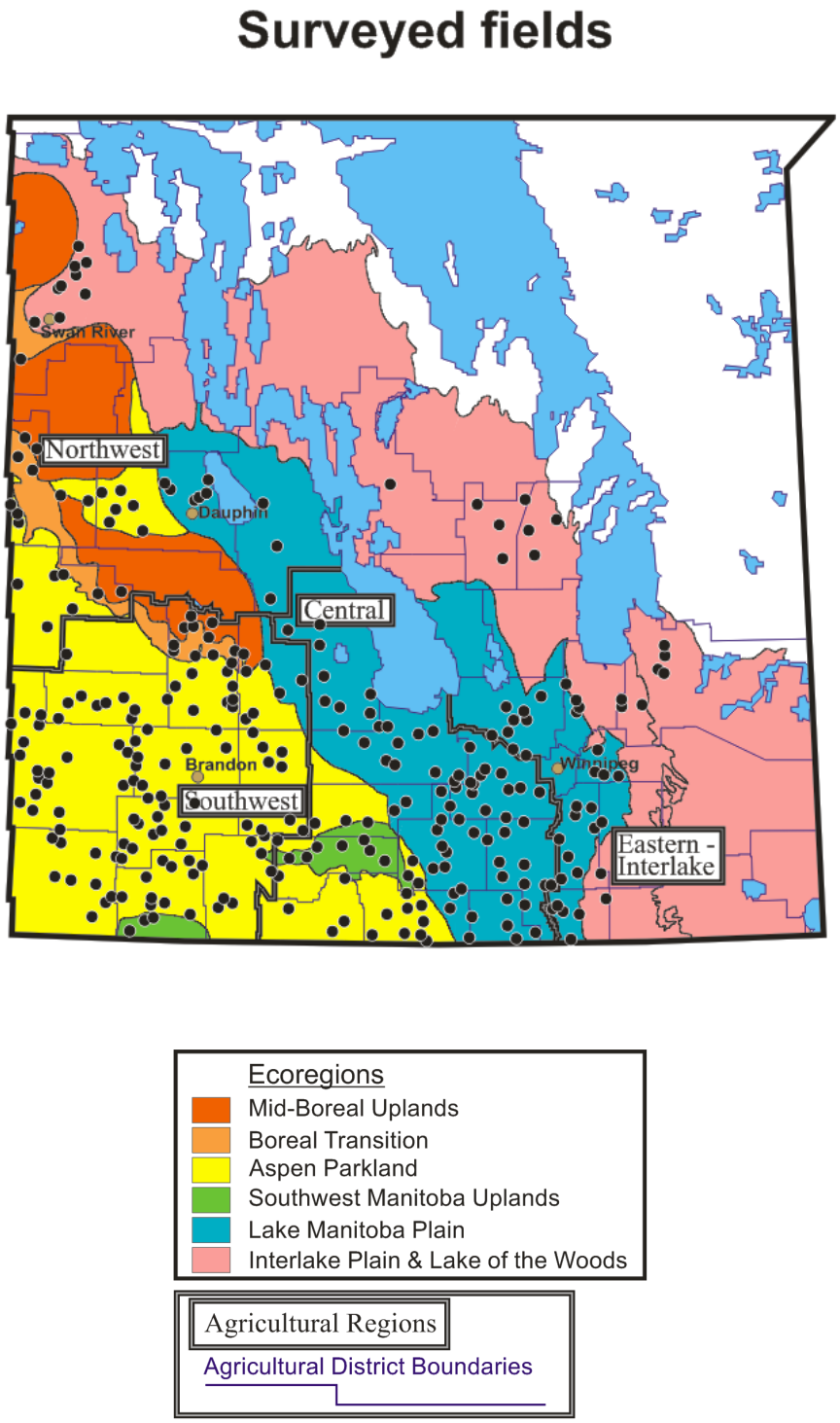

Figure 1. Ecoregions of Manitoba (map derived from Smith et al. (1998))

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 2009, 45 wild oat submissions from Manitoba were determined to be herbicide-resistant: 36 populations were Group 1-resistant (mainly APP+CHD); four populations were Group 2-resistant, and five were Group 1+2-resistant (unpublished data). In 2008 and 2009, results from another testing lab found that 20 wild oat populations were APP+CHD-resistant; four populations were APP+CHD+ phenylpyrazolin (PPZ, pinoxaden)-resistant; 18 populations were Group 2-resistant; and 17 populations were Group 1+2-resistant (Xie et al. 2011).

Group 3-resistant green foxtail [*Setaria viridis* (L.) 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 2009, five 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 2011). 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 two populations of Group 2-resistant cleavers (*Galium* spp.) originated from Manitoba between 2007 and 2009 (unpublished data). 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 2011). In 2008, two populations of Group 2-resistant cleavers were confirmed in Manitoba (Xie et al. 2011).

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 is 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.

Objective

In 2008, 300 fields were randomly selected for a weed resistance survey. 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 different groups.

Sites

A total of 300 fields were surveyed for herbicide-resistant weeds (Map 1). Each field was farmed by a different producer. Similar to the general weed survey (Leeson et al. 2002), 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 based on data from Statistics Canada (2007). Fields were randomly selected from the Agricore United database. Each sampling unit comprised 65-ha (160 ac). The crop allocation in the major agricultural 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	62	4	38	6	2	13	*125*
Barley	14	0	7	0	0	2	*23*
Oat	11	0	11	0	2	*1*	*25*
Corn	1	0	2	0	0	0	*3*
Canola	38	3	37	3	3	11	*95*
Flax10	1	4	1	0	2	*18*	
Soybean	0	0	5	0	0	0	5
Sunflower	2	0	0	0	0	0	*2*
Field pea	3	0	0	1	0	0	4
Sub-total	*141*	*8*	*104*	*11*	*7*	*29*	***300***
% of Total	*47*	*3*	*34*	*4*	*2*	*10*	*100*

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

A majority of the fields (59%) were cropped to cereals. This proportion was lower than that of the 2002 weed resistance survey (71%). Wheat occupied 71% of the 176 survey fields cropped to cereals, barley 13%, oat 14%, and corn 2%; in the 2002 survey, wheat comprised 57%, barley 22%, and oat 21% of cereal fields. Oilseeds comprised 40% of surveyed fields (vs. 29% in 2002): canola 80% of that, flax 15%, soybean 4%, and sunflower 1%. The proportion of oilseed fields cropped to canola was the same as that of the 2002 survey, although soybean and sunflower fields were not surveyed in 2002. There were only four field pea fields surveyed (none were surveyed in 2002).

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.

Two-thirds of the 25 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2002 (Leeson et al. 2002). Some species 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.	10	10	4
Foxtail barley, *Hordeum jubatum* L.	5	5	56
Green foxtail, *Setaria viridis* (L.) Beauv.	91	91	1
Yellow foxtail, *Setaria pumila* (Poir.) Roem. & Schult.	36	36	32
Wild oat, *Avena fatua* L.	227	198	2
Broadleaf:			
Canada fleabane, *Conyza canadensis* (L.) Cronquist	4	4	-
Chickweed, *Stellaria media* (L.) Vill.	16	16	22
Cleavers, *Galium* spp.	23	23	15
Common groundsel, *Senecio vulgaris* L.	2	2	47
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	2	2	48
Goat's-beard, *Tragopogon dubius* Scop.	1	1	-
Hemp-nettle, *Galeopsis tetrahit* L.	3	3	24
Kochia, *Kochia scoparia* (L.) Schrad.	2	2	16
Lamb's-quarters, *Chenopodium album* L.	33	33	7
Night-flowering catchfly, *Silene noctiflora* L.	18	18	18
Pigweed (green), *Amaranthus powellii* S. Wats.	39	39	6
Sow-thistle (annual & perennial), *Sonchus* spp.	4	4	13,19
Round-leaved mallow, *Malva pusilla* Sm.	4	4	17
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	4	4	27
Annual smartweed species, *Polygonum* spp.	18	18	8
Stinkweed, *Thlaspi arvense* L.	8	8	20
Stork's-bill, *Erodium cicutarium* (L.) L'Hér.ex Aiton	1	1	31
Wild buckwheat, *Polygonum convolvulus* L.	21	21	3
Wild mustard, *Sinapis arvensis* L.	15	15	11

[a]Relative abundance rank of species in 631fields surveyed in 2002 (Leeson et al. 2002); rank of annual smartweed spp. is that of pale smartweed and green pigweed is that of redroot pigweed.

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. Weed samples were screened for resistance to various herbicides from different groups (Table 3).

Grass weed species were tested for resistance to a maximum of seven Group 1 herbicides: three aryloxyphenoxypropionate (APP or fop) herbicides, three cyclohexanedione (CHD or dim) herbicides, and pinoxaden, a phenylpyrazolin (PPZ or den) herbicide. The three fop herbicides were fenoxaprop (without safener) at 150 g/ha (wild oat) or 40 g/ha (green foxtail and other annual grasses), clodinafop at 35 g/ha, and quizalofop at 35 g/ha (70 g/ha for perennial grasses); the three dim herbicides were sethoxydim at 110 g/ha (wild oat), 50 g/ha (green or yellow foxtail), 145 g/ha (other annual grasses), or 250 g/ha (perennial grasses), tralkoxydim at 25 g/ha, and clethodim at 15 g/ha. Pinoxaden was applied at 15 g/ha. All recommended adjuvants were included in the herbicide spray solutions.

Grass or broadleaf weed species were screened for resistance using a maximum of six Group 2 herbicides. Grass species were treated with three Group 2 herbicides: imazamethabenz, imazamox, and flucarbazone. Imazamethabenz was applied at 500 g/ha, imazamox at 35 g/ha, and flucarbazone at 15 g/ha. Broadleaf weed species were treated with a maximum of five Group 2 herbicides: two imidazolinones (imazethapyr, imazamox), two sulfonylureas (metsulfuron, thifensulfuron:tribenuron mixture), and florasulam, a triazolopyrimidine herbicide. Imazethapyr was applied at 50 g/ha, imazamox at 35 g/ha, metsulfuron at 4.5 g/ha, thifensulfuron:tribenuron at 15 g/ha, and florasulam at 5 g/ha.

In addition to Group 1 and 2 herbicides, weed samples were screened with various Group 4 herbicides, triallate and difenzoquat (Group 8), glyphosate (Group 9) and glufosinate (Group 10). 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 pass over the foliage.

Table 3. Herbicides used in resistance screening[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.

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 herbicide-resistant and herbicide-susceptible biotypes, when available, were included in all tests (Beckie et al. 2000).

Grass Weed Resistance

Of the 198 fields where wild oat samples were collected, 108 (55%) had Group 1-resistant wild oat (Table 4, Map 2). In comparison, in Alberta in 2007, 39% of fields had Group 1-resistant wild oat (Beckie et al. 2009). Therefore, 36% of all fields surveyed (300) had Group 1-resistant wild oat. This field frequency of resistance is significantly greater than that documented in the 2002 survey (40%) (Beckie et al. 2004). Over half of these fields were located in the Aspen Parkland ecoregion, followed by over 25% of sites in the Lake Manitoba Plain, 12% in the Interlake Plain, with the remaining fields located in the other ecoregions. These percentages are generally similar to those noted for the 2002 survey. Resistance occurrence was proportionally greatest in the Boreal Transition, Interlake Plain, and Aspen Parkland ecoregions (80, 68, and 58% of fields, respectively, where seeds were collected). Similar trends were observed in the 2002 survey, although the frequency of fields with Group 1-resistant wild oat had increased in all three ecoregions in 2008.

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	57	58	40	12	12	9
Southwest Manitoba Uplands	3	43	38	3	43	38
Lake Manitoba Plain	30	46	29	8	12	8
Boreal Transition	4	80	36	2	40	18
Mid-Boreal Uplands	1	25	14	0	0	0
Interlake Plain[b]	13	68	45	10	53	35
Manitoba	*108*	*55*	*36*	*35*	*18*	*12*

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

The Group 1 cross-resistance pattern of the wild oat populations did not show a significant difference in resistance frequency to the seven Group 1 herbicides (data not shown). Whereas resistance frequency of fields was greater to APP than CHD herbicides in the 2002 survey, that trend was not as apparent in this survey. In the 1990s, three-quarters of Group 1-resistant wild oat populations examined were resistant to both APP and CHD herbicides (Bourgeois et al. 1997a). Similarly, the majority of Group 1-resistant populations from Manitoba submission samples between 1996 and 2006 were APP+CHD-resistant (Beckie et al. 2007). A more detailed analysis of the cross-resistance pattern to Group 1 herbicides will be completed once the 2009 Saskatchewan weed resistance survey results are determined.

Group 2 resistance was confirmed in 35 wild oat populations (18% of fields where seeds were collected or 12% of all fields surveyed (Table 4, Map 3). This frequency of resistance was five percentage points higher than that in 2002. In Alberta in 2007, 12% of fields had Group 2-resistant wild oat, unchanged from 6 years previous. The lower incidence of Group 2- vs. Group 1-resistant wild oat reflects the past relative usage of wild oat herbicides with these modes of action (Beckie et al. 2009). Similar to 2002, the majority of fields with resistance were located in the Aspen Parkland, Interlake Plain, and Lake Manitoba Plain ecoregions. Resistance occurrence was proportionally greatest in the Interlake Plain ecoregion (53% of fields where seeds were collected), similar to the results of Beckie et al. (1999). Most cases of Group 1 or Group 2 resistance in wild oat, based on samples submitted by producers between 1996 and 2006, originated in the Aspen Parkland or Lake Manitoba Plain ecoregion (Beckie et al. 2007). Broad cross-resistance was evident among populations to the Group 2 herbicides tested, imidazolinones and flucarbazone, similar to that observed in the 2002 survey (data not shown).

The incidence of Group 8-resistant wild oat was 11% of fields, compared with 15% of fields in Alberta in 2007 (Map 4; Beckie et al. 2009). Most fields were located in the Aspen Parkland and Lake Manitoba Plain ecoregions. Because of relatively low usage of these herbicides in the past decade, we may be detecting residual resistance in the wild oat seedbank.

Group 1- and 2-resistant wild oat were found in 25 fields (13%): 8 fields in the Lake Manitoba Plain ecoregion, 7 in the Interlake Plain, 6 in the Aspen Parkland, 2 in the Boreal Transition, and 2 in the Southwest Manitoba Uplands ecoregion (Map 5). Resistance was proportionally greatest in the Interlake Plain ecoregion, similar to results of Beckie et al. (1999). In 2002, 8% of fields had Group 1- and 2-resistant wild oat. The most likely reason for selection of this double-resistant biotype was frequent use of Group 1 herbicides resulting in resistance, followed by selection of Group 2 resistance after switching to products with that mode of action. Infestation of this biotype in a field significantly reduces postemergence herbicide options in a number of crops. Other patterns of intergroup herbicide resistance were also documented: Group 1- and 8-resistant wild oat (8% of fields; Map 6), Group 2- and 8-resistant wild oat (5% of fields; Map 7), and Group 1- and 2- and 8-resistant wild oat (4% of fields; Map 8).

Group 1-resistant green foxtail was found in 44% (40/91) of fields (Table 5) where seeds

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

Ecoregion	Resistant	Tested[a]	Surveyed[a]
	No.	%	
Aspen Parkland	23	56	16
Southwest Manitoba Uplands	2	50	25
Lake Manitoba Plain	14	35	14
Boreal Transition	0	0	0
Mid-Boreal Uplands	0	0	0
Interlake Plain[b]	1	20	3

Manitoba	*40*	*44*	*13*

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

were collected (Map 9). Therefore, the incidence of Group 1 resistance in this weed has doubled in 6 years. Over half of the fields were located in the Aspen Parkland ecoregion, where resistance was proportionally the greatest among ecoregions. In the 2002 survey, frequency of occurrence of this biotype was proportionally greatest in the Lake Manitoba Plain ecoregion. Most populations exhibited broad cross resistance to various Group 1 herbicides tested, similar to results of Beckie et al. (2007). Group 2 resistance in this weed was not detected; in the 2002 survey, one resistant population was found near Swan River, Manitoba. Herbicide resistance was not found in any other grass weed species tested (Table 2).

Broadleaf Weed Resistance

In contrast to the results from the Alberta survey in 2007, there were relatively few cases of broadleaf weed resistance, and all cases were Group 2 resistance. Six of 39 fields (16%) had Group 2-resistant pigweed, identified as green pigweed (*Amaranthus powellii*). All resistant populations were located in the Lake Manitoba Plain ecoregion (Map 10). In the 2002 survey, one population of redroot pigweed (*Amaranthus retroflexus*) was found in the Aspen Parkland ecoregion. Only a single population of Group 2-resistant (1) chickweed was found in the Mid-Boreal Uplands ecoregion (Map 11); (2) cleavers in the Interlake Plain ecoregion (Map 12); and wild mustard in the Lake Manitoba Plain ecoregion (Map 13). Resistant biotypes of these species had not been detected in the 2002 survey. However, Group 2 resistance in Manitoba populations of these weed species has been documented previously. Although two populations of kochia were confirmed Group 2-resistant (Aspen Parkland and Lake Manitoba Plain ecoregions), most samples collected consisted of green seed that was not

viable. A spring survey is needed to accurately document resistance in this weed; in 2007, most kochia populations tested from Manitoba were Group 2-resistant (Beckie et al. 2011). Resistance to Group 2 herbicides in the other broadleaf weed species tested was not detected.

No populations were found to be resistant to herbicides from Groups 4, 9, or 10. The lack of Group 4 resistance in broadleaf weeds is somewhat surprising albeit good news, given the generally long history of selection pressure with herbicides of this mode of action.

Land Area Impacted by Herbicide-Resistant Weeds

When the frequency of fields with weed resistance in this random survey of 300 fields is extrapolated to the total annual-cropped land in Manitoba (3,763,000 ha or 9,294,610 ac in 2008) (Statistics Canada 2008), it is estimated that 1.6 million ha (44%) is infested with herbicide-resistant weeds, in a total field area of 2.2 million ha (58%) (Table 6). In comparison, the weed resistance survey in 2002 indicated that 0.4 million ha was infested with herbicide-resistant weeds, in a total field area of 1.3 million ha. Therefore, the actual area infested with herbicide-resistant weeds has increased 4-fold, while the total field area affected has increased by 1.7-fold over this intervening 6-year period.

Table 6. Estimated annual-cropped land area in Manitoba impacted by herbicide-resistant (HR) weeds in 2008

Biotype	Infestation area (ac/ha)	Field area (ac/ha)
Gp 1-HR wild oat	1,582,180 / 640,560	2,331,660 / 943,990
Gp 2-HR wild oat	248,710 / 100,690	310,890 / 125,870
Gp 8-HR wild oat	93,740 / 37,950	155,440 / 62,930
Gp 1+2-HR wild oat	383,110 / 155,100	528,510 / 213,970
Gp 1+8-HR wild oat	139,180 / 56,350	217,620 / 88,110
Gp 2+8-HR wild oat	14,350 / 5,810	31,100 / 12,590
Gp 1+2+8-HR wild oat	248,710 / 100,690	248,710 / 100,690

Gp 1-HR green foxtail	1,025,930 / 415,360	1,243,550 / 503,460
Gp 2-HR broadleafs	310,890 / 125,870	341,980 / 138,450
Total	**4,046,800 / 1,638,380**	**5,409,460 / 2,190,060**

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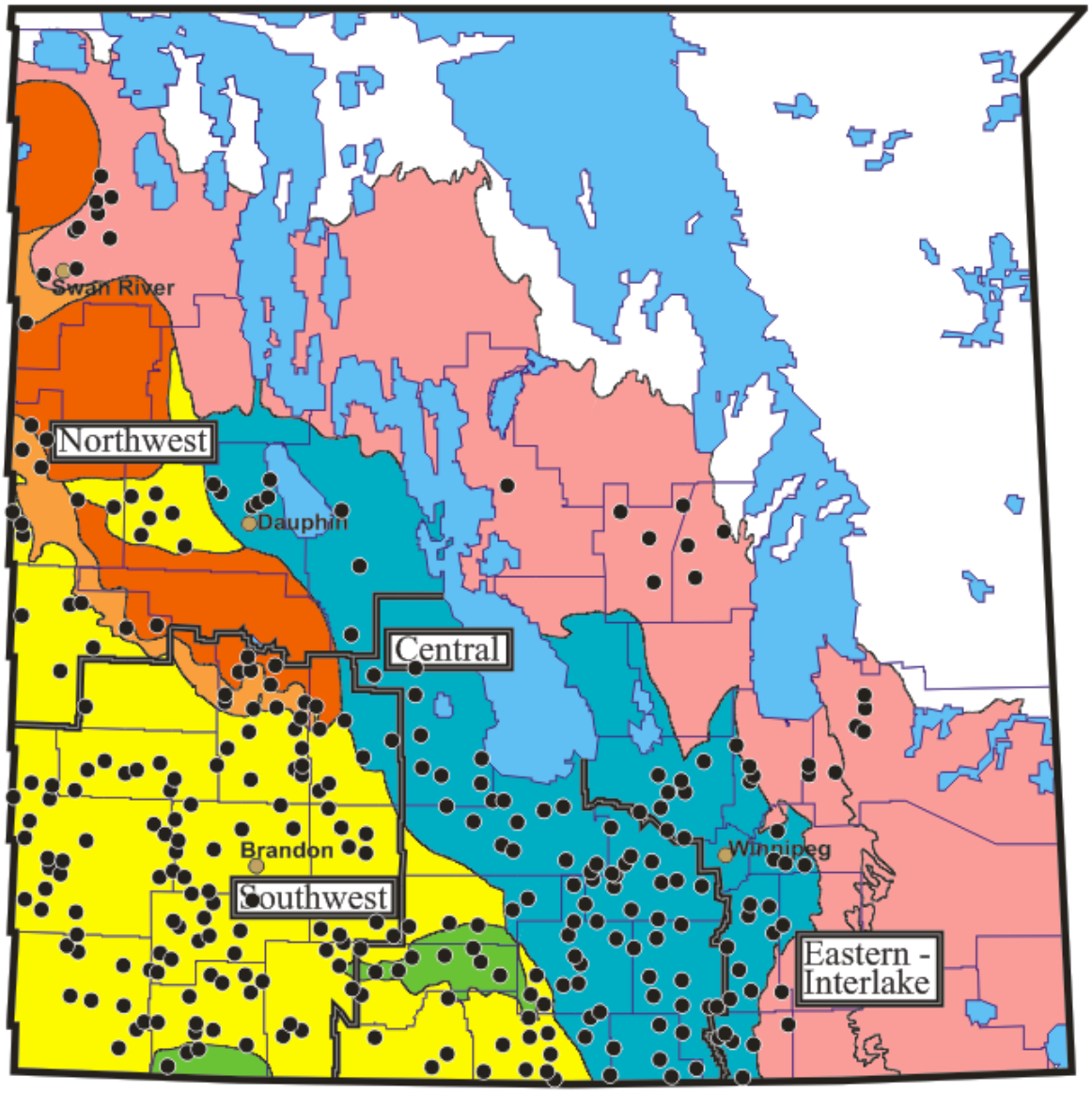
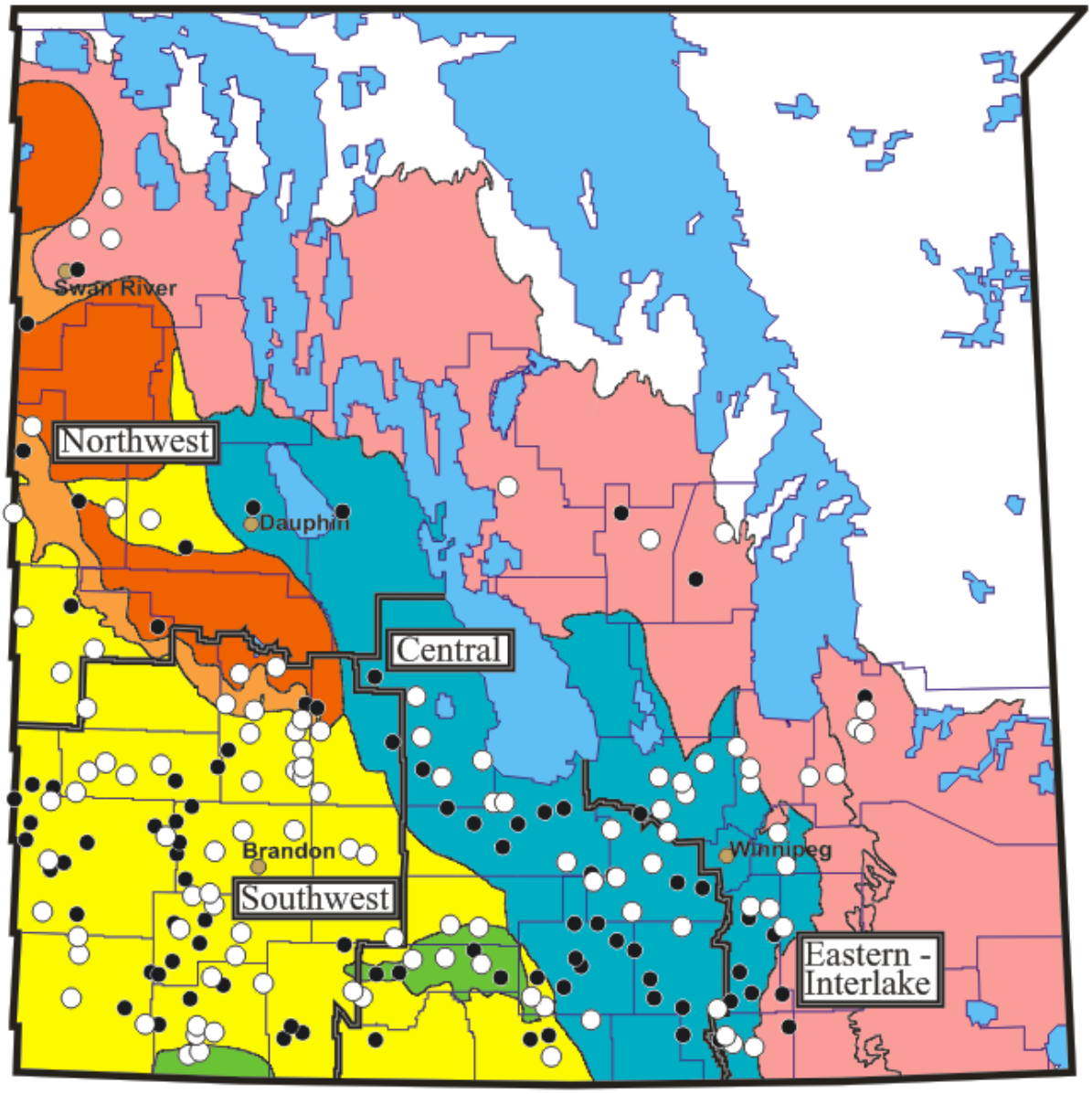
LIST OF MAPS

Surveyed fields



Gp 1-resistant wild oat

Resistant ○ Not resistant •



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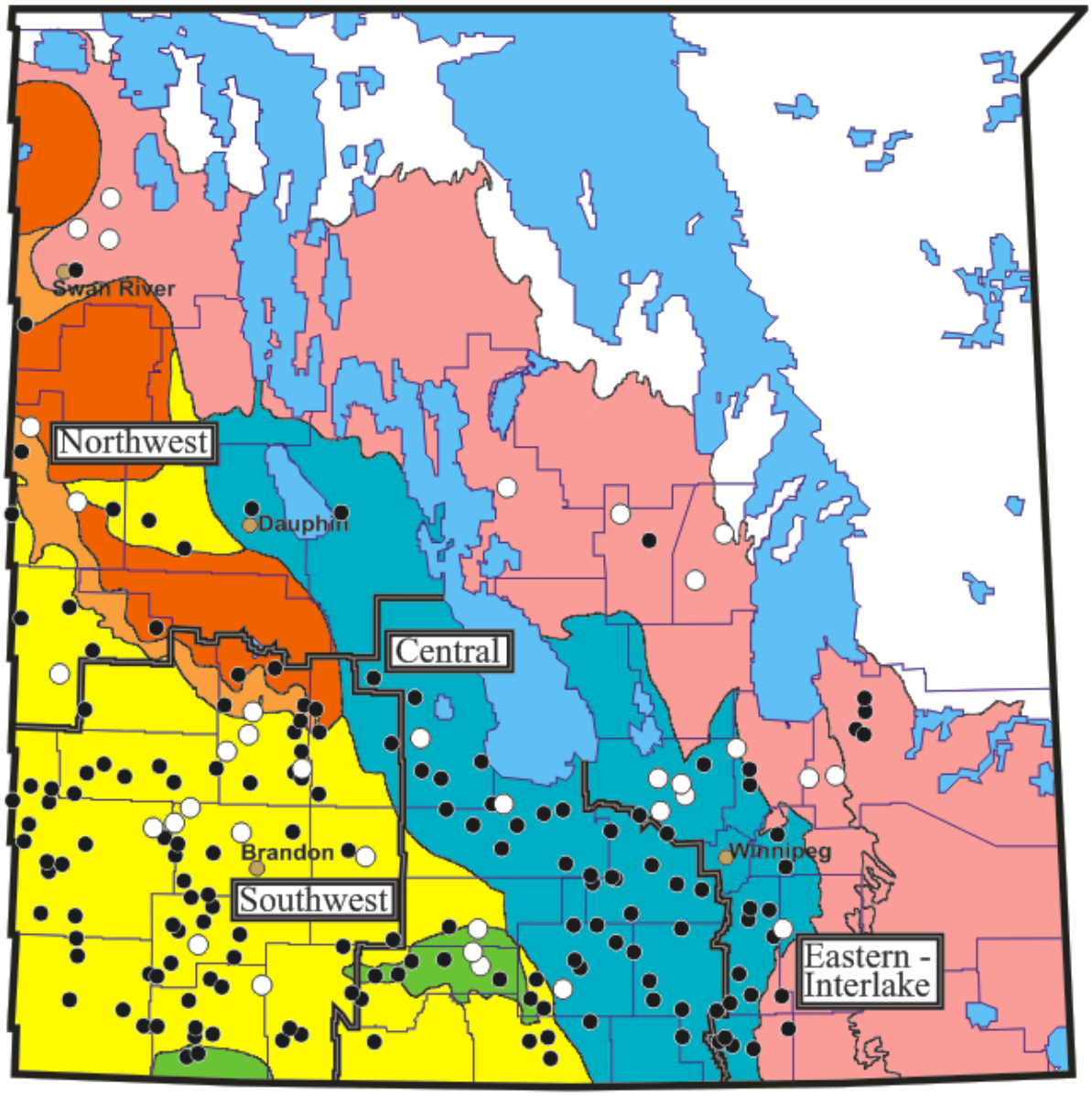
Resistant ○ Not resistant •



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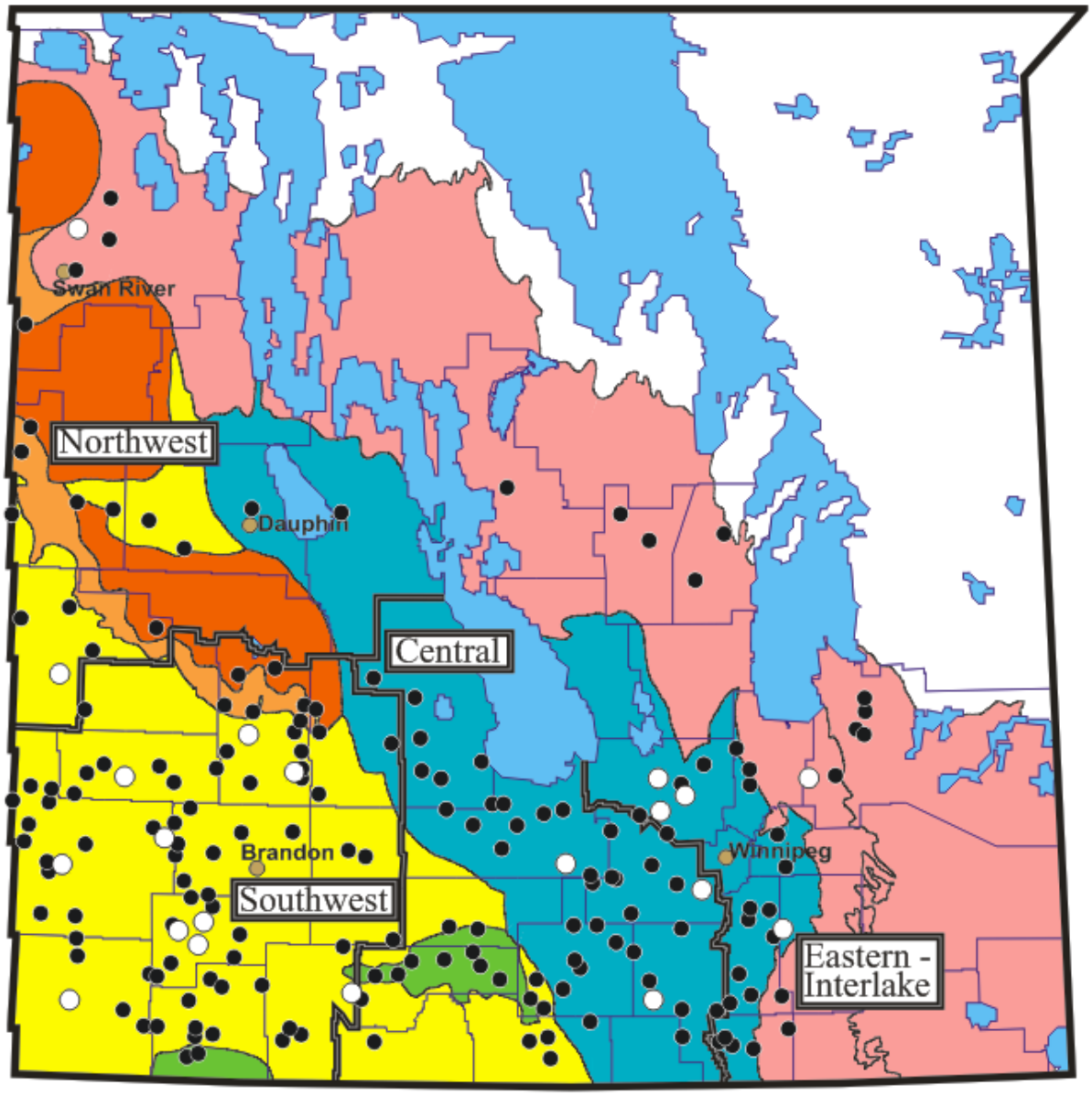
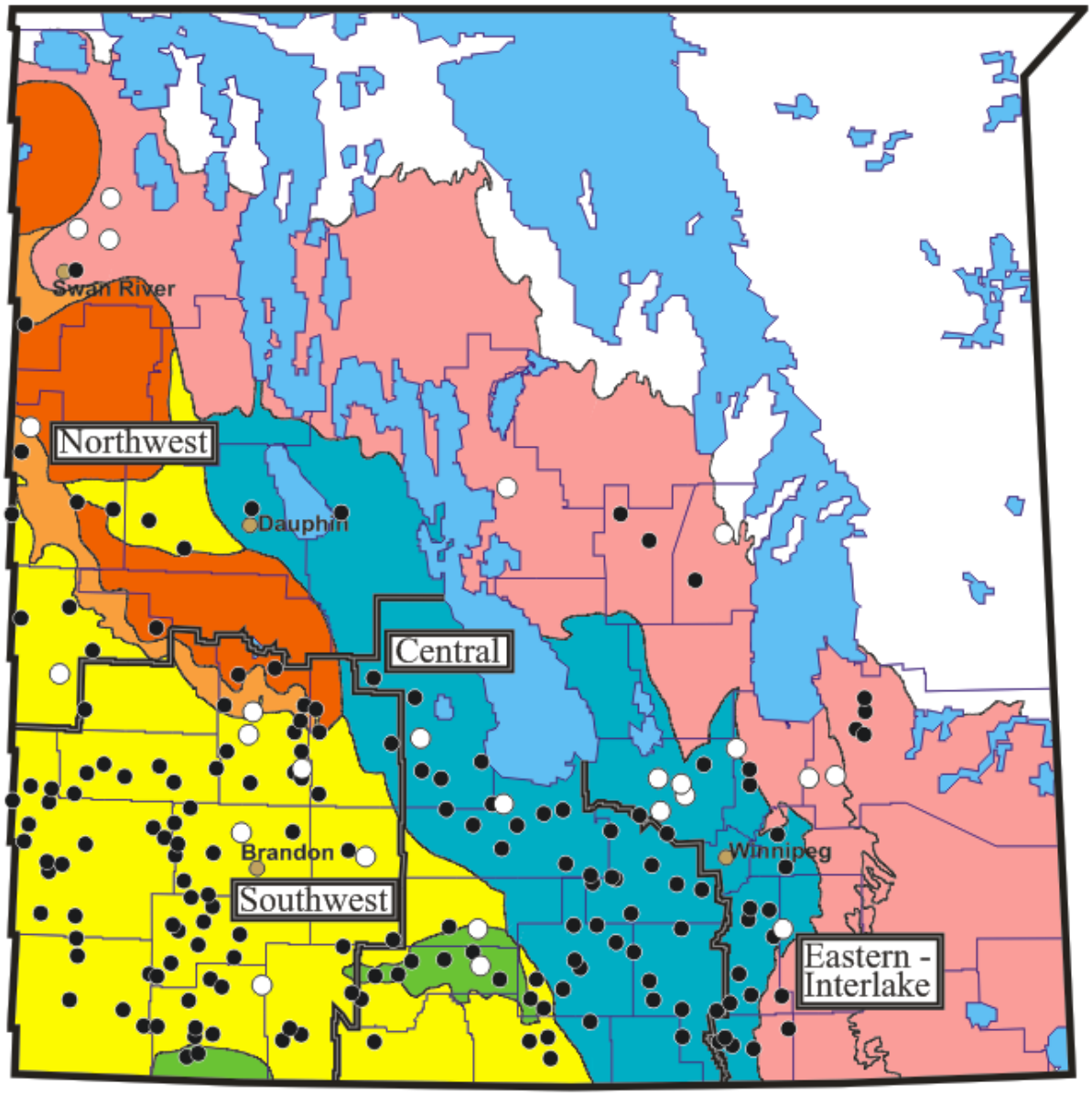


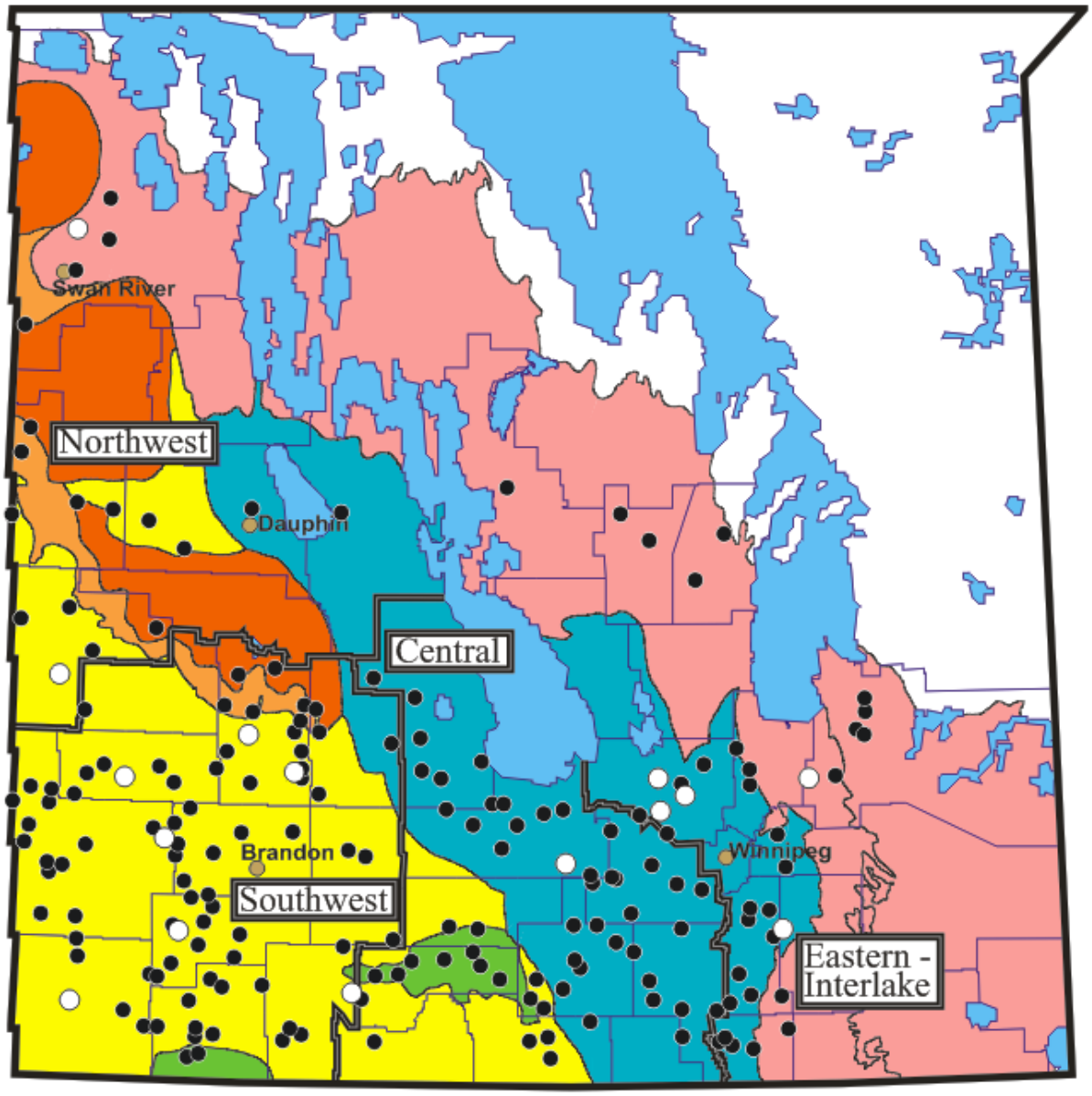
Gp 1- and 2-resistant wild oat

Resistant ○ Not resistant •



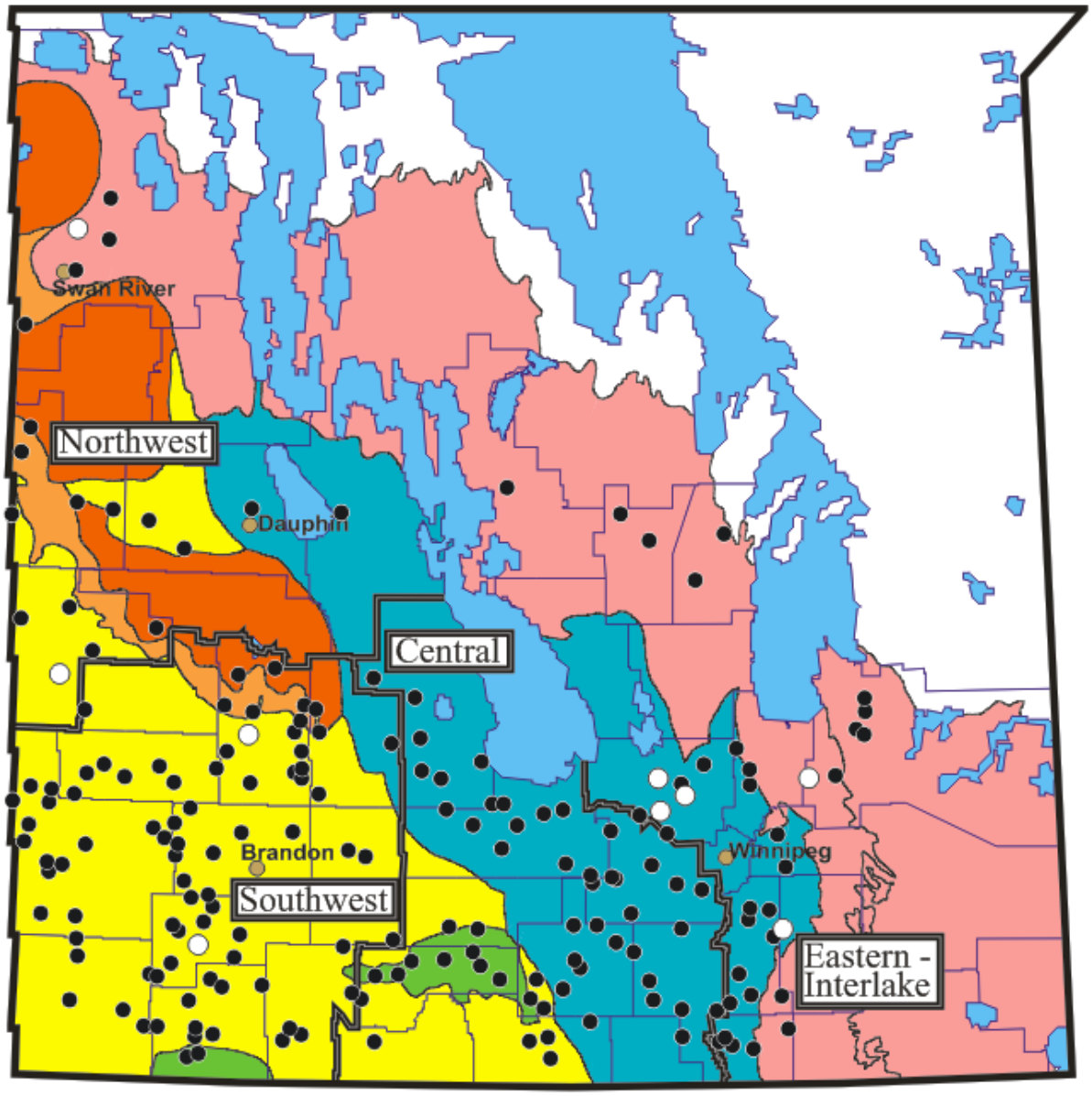
Gp 1- and 8-resistant wild oat

Resistant ○ Not resistant •



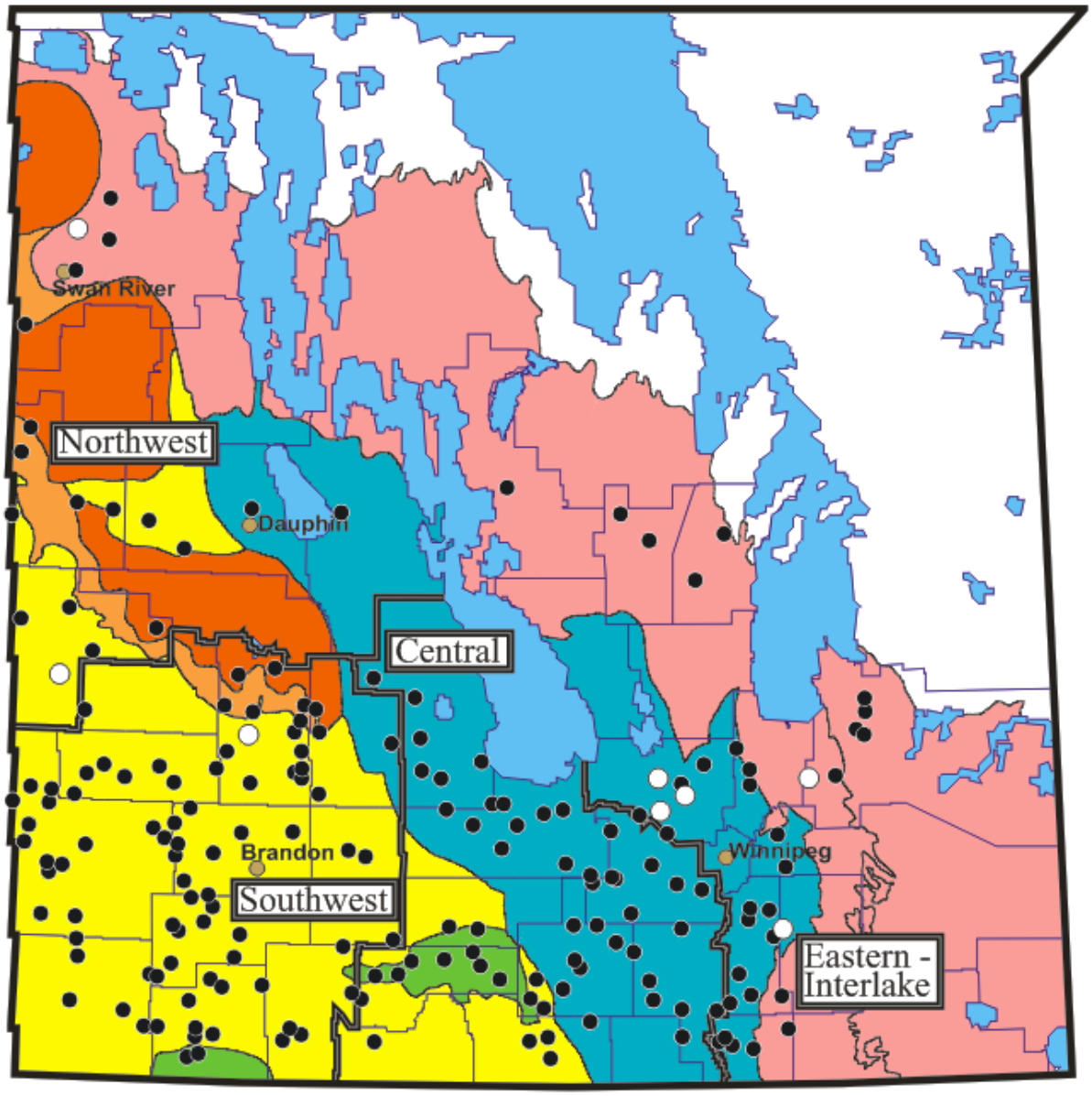
Gp 2- and 8-resistant wild oat

Resistant ○ Not resistant •



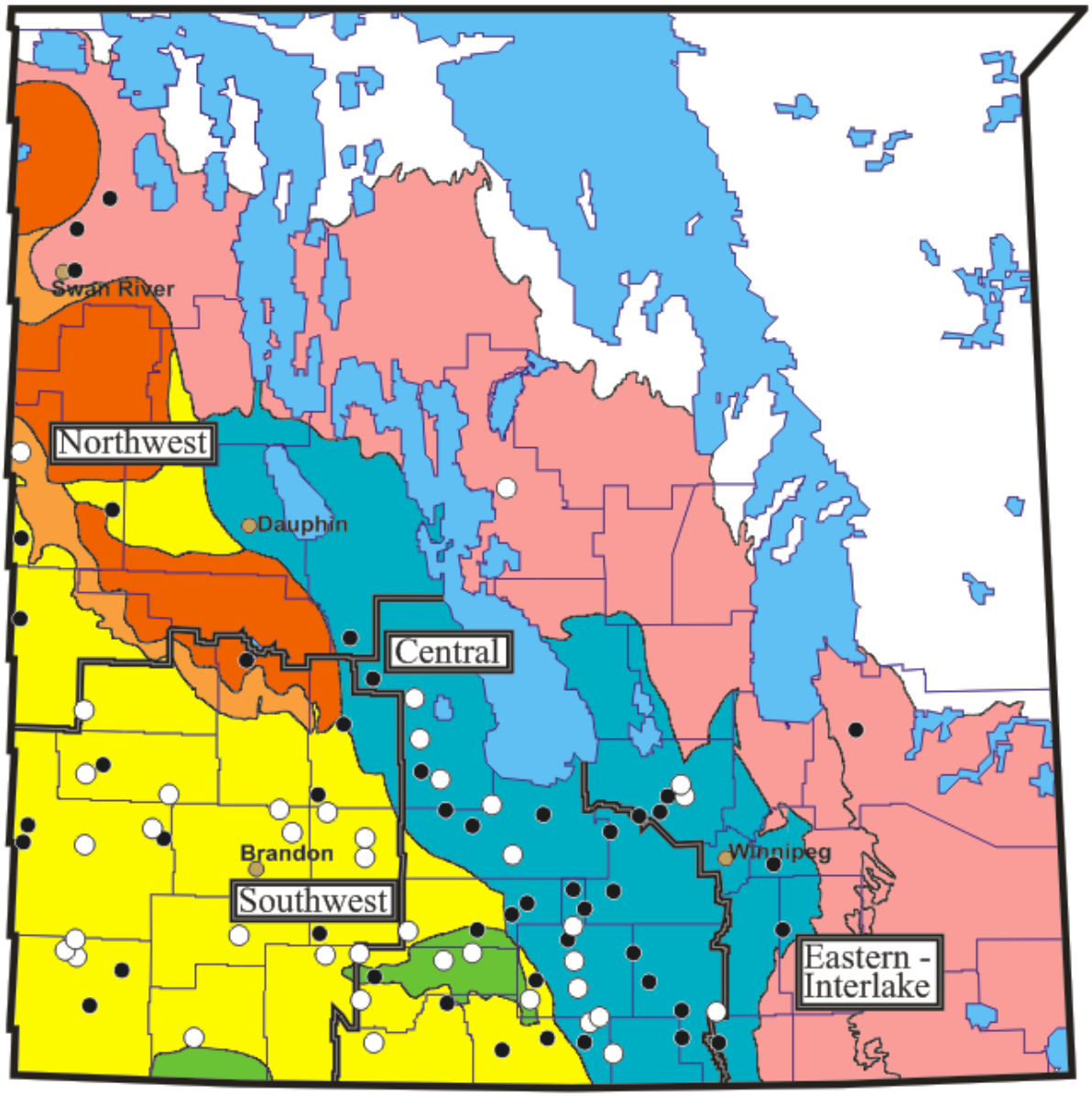
Gp 1- and 2- and 8-resistant wild oat

Resistant ○ Not resistant •



Gp 1-resistant green foxtail

Resistant ○ Not resistant •



Gp 2-resistant pigweed

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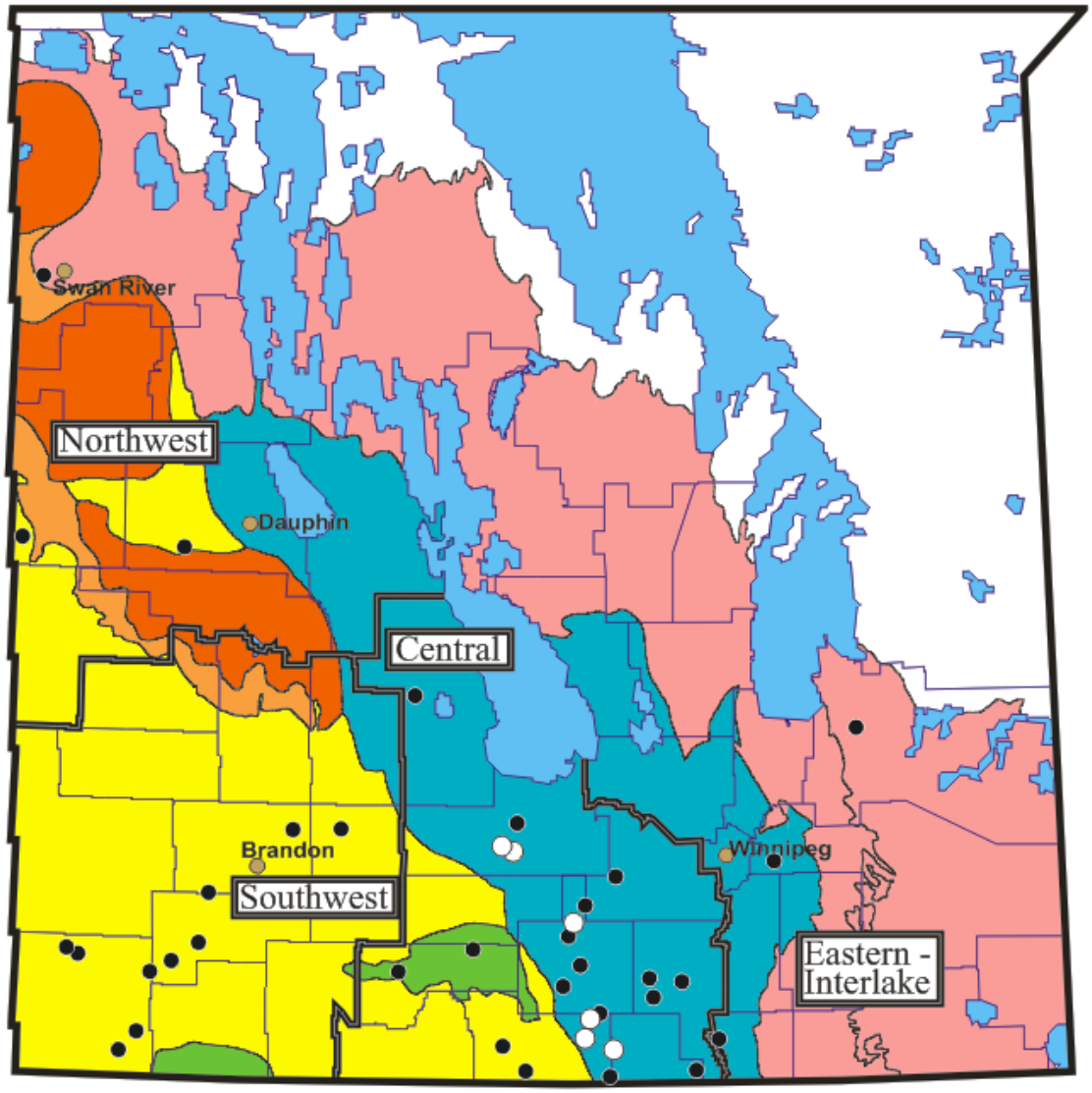


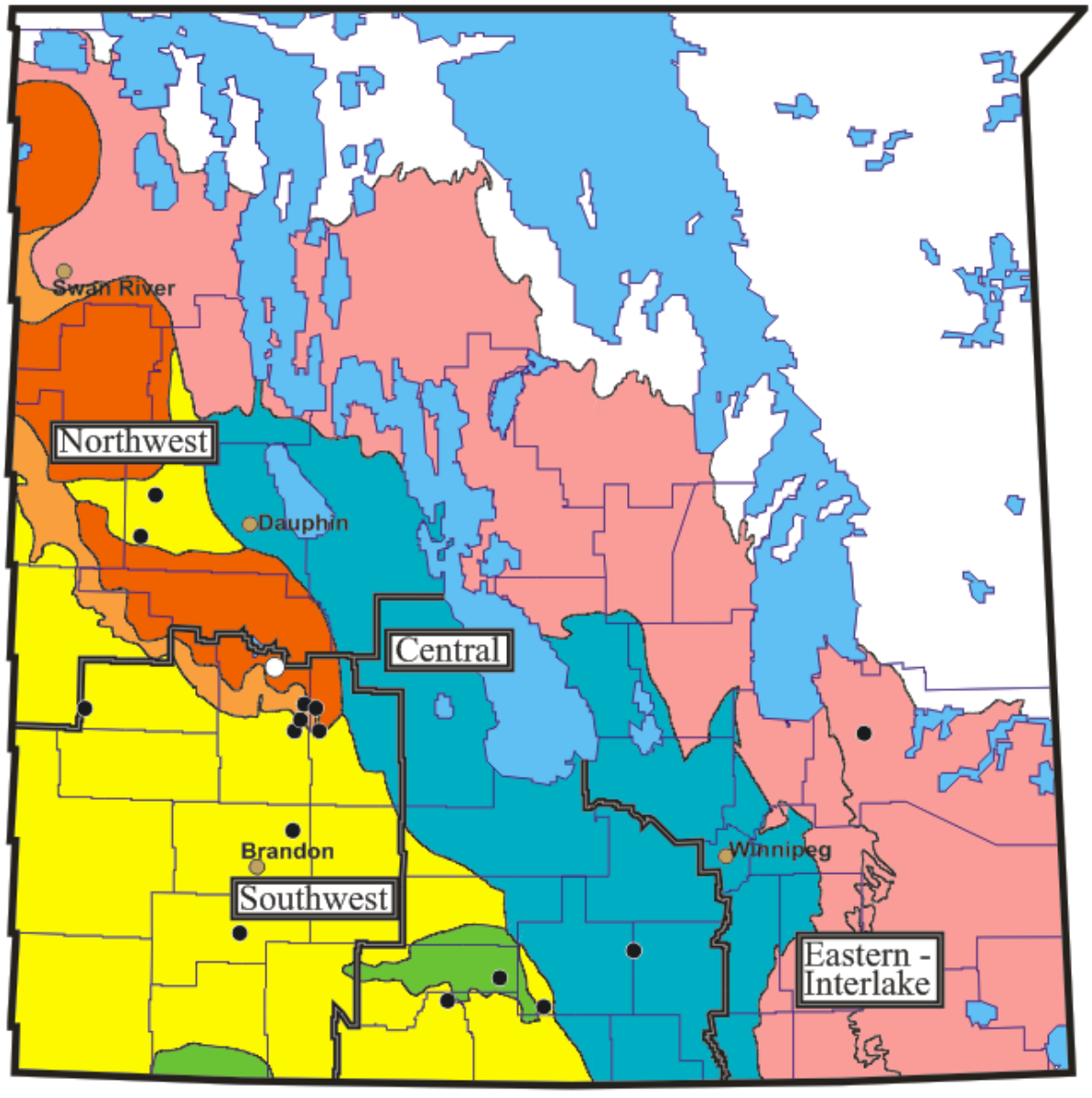
Ecoregions
- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Southwest Manitoba Uplands
- Lake Manitoba Plain
- Interlake Plain & Lake of the Woods

Agricultural Regions

Agricultural District Boundaries

Gp 2-resistant chickweed

Resistant ○ Not resistant •



Gp 2-resistant cleavers

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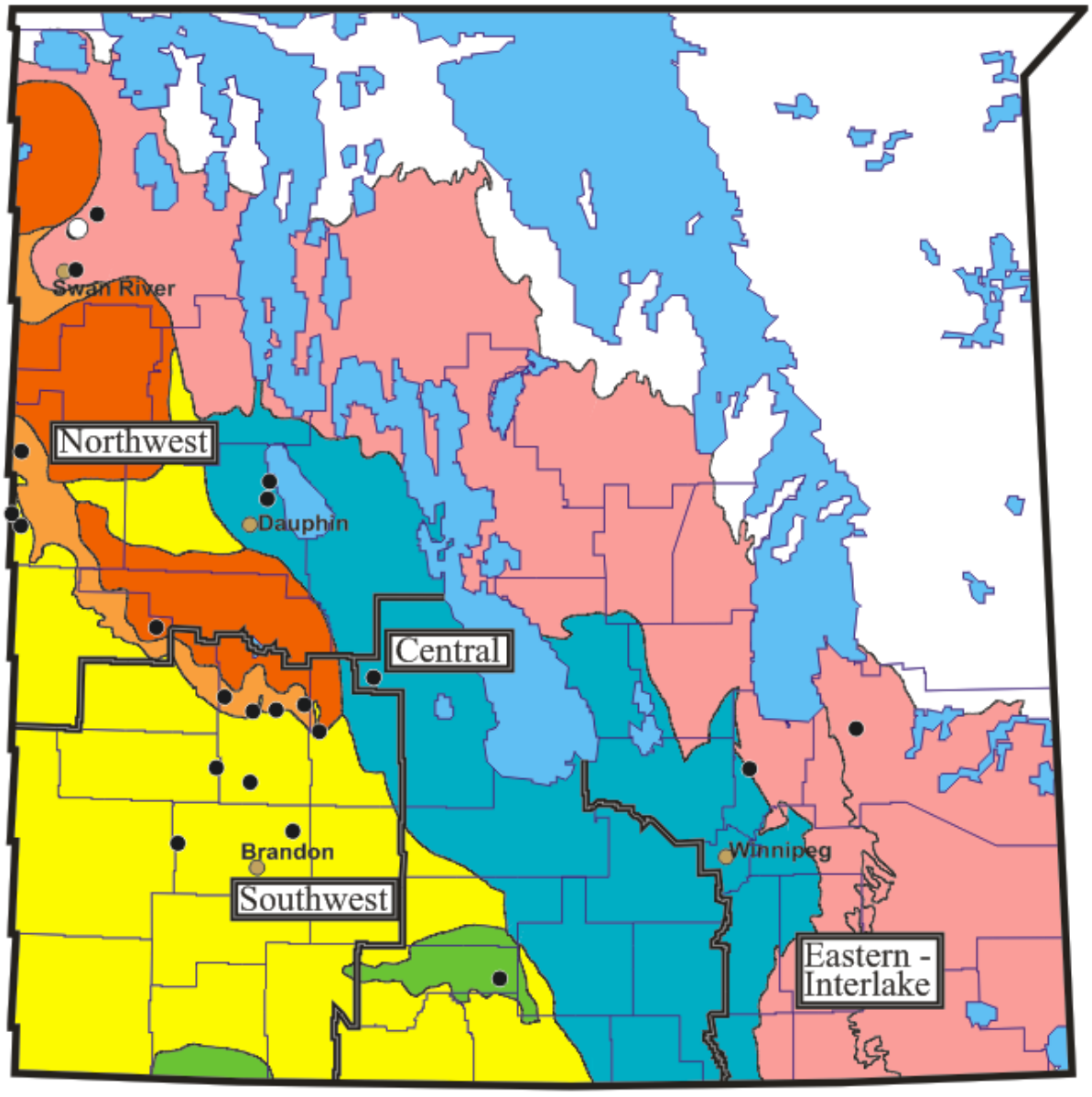

Gp 2-resistant wild mustard

Resistant ○ Not resistant •