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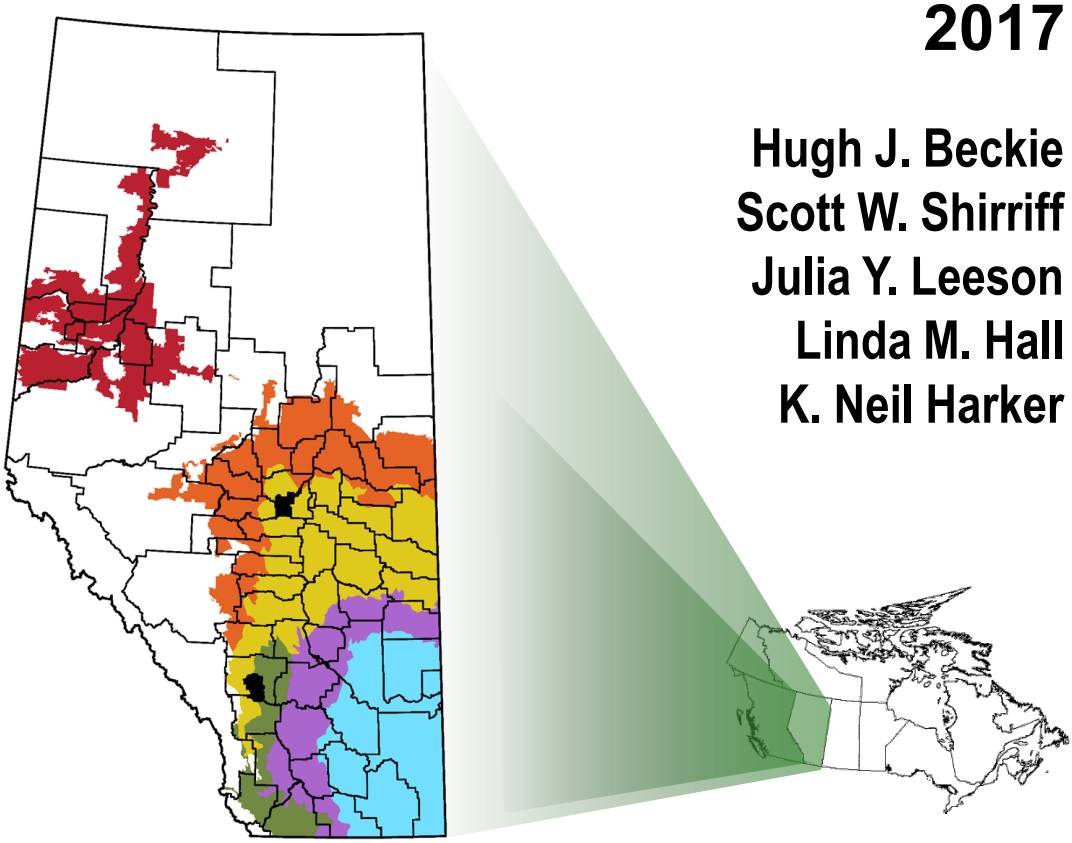
Alberta Weed Survey

Herbicide-Resistant Weeds 2017



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Weed Survey Series

UNIVERSITY OF ALBERTA
Canada

Alberta Weed Survey of Herbicide-Resistant Weeds in 2017

by

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Weed Survey Series
Publication 19-2

Published by

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

March 2019

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Number	Title
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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)
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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 about 800 randomly-selected fields: 400 in Saskatchewan in 2014 and 2015 (Weed Survey Series Publication 17-1), 150 fields in Manitoba in 2016 (Weed Survey Series Publication 17-3), 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 2007 Alberta weed resistance survey report published in 2009. This report documents the nature, distribution and abundance of herbicide-resistant weeds in Alberta in 2017. As indicated above, about 250 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 personnel and greenhouse bench space.

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Saskatoon, SK
March 2019

ACKNOWLEDGEMENTS

Financial support for this survey was provided by the Western Grains Research Foundation, Alberta Wheat Commission, Alberta Pulse Growers Commission, and the Alberta Canola Producers Commission. We gratefully acknowledge their strong financial support.

We sincerely thank Keith Topinka, University of Alberta, and Jennifer Zuidhof, AAFC Lacombe for their assistance in surveying. We thank David Giffen, AAFC Saskatoon, for producing the maps.

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

Hugh J. Beckie, Scott W. Shirriff, Julia Y. Leeson, Linda M. Hall, K. Neil Harker

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EXECUTIVE SUMMARY

A herbicide-resistant (HR) weed survey was conducted in 247 randomly selected fields across the ecoregions of Alberta in 2017. All residual weed species with mature seeds were mapped and sampled before harvest. Selected fields were cropped to cereals (55%), oilseeds (34%) or pulses (11%). Samples of 17 weed species (3 grass, 14 broadleaf) were subsequently screened in pot assays in the greenhouse using Group 1 or Group 2 herbicides (i.e., tier-1 screening).

Overall, 59% (147/247) of surveyed fields had an HR weed biotype. Of 176 fields where wild oat (*Avena fatua* L.) were collected, 69% had an HR population (49% of the 247 surveyed fields), compared with 43% of sampled fields in 2007. Group 1-HR wild oat was confirmed in 58% of fields where the weed was sampled (41% of all 247 surveyed fields), compared with 39% of fields sampled in 2007 and 11% in 2001. Group 2-HR wild oat was found in 40% of fields sampled (29% of all surveyed fields), compared with 12% of sampled fields in 2007 and 13% in 2001. Group 1+2-HR wild oat was confirmed in 29% of fields sampled (21% of all surveyed fields), compared with 8% of fields sampled in 2007 and 3% in 2001.

Of 33 fields where green foxtail [*Setaria viridis* (L.) P. Beauv.] seeds were collected, 27% had an HR population. This incidence of resistance compares to two fields in 2007. Group 1-HR green foxtail was found in 21% of fields where the weed was sampled. Group 2-HR green foxtail was found in two fields, the first cases documented in an Alberta survey.

Eight broadleaf weed species had Group 2-HR populations: 62% with smartweed (*Polygonum* spp.); 44% with cleavers (*Galium* spp.); 40% with chickweed [*Stellaria media* (L.) Vill.]; 36% with spiny annual sow-thistle [*Sonchus asper* (L.) Hill]; 29% with narrow-leaved hawk's beard (*Crepis tectorum* L.); 18% with shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.]; 16% with stinkweed (*Thlaspi arvense* L.); and one field with lamb's-quarters (*Chenopodium album* L.). This is the first confirmed case in Alberta of Group 2-HR lamb's-quarters.

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 2.6 million ha in Alberta are infested with HR weeds, in a total field area of 4.7 million ha. The additional cost to manage HR weeds in Alberta is estimated at $196 million annually.

Past Weed Resistance Surveys in Alberta

Field surveys of specific herbicide-resistant (HR) weed biotypes have been conducted in Alberta since 1990. They focused on wild oat (*Avena fatua* L.) resistance to triallate/difenzoquat (Group 8), Group 1, or Group 2 herbicides. In 1990, wild oat seed was collected from 34 fields with a history of repeated triallate use and tested for Group 8 resistance. Forty-four percent of those fields had Group 8-HR wild oat (O'Donovan et al. 1994b). In 1996, 9 of 38 fields (25%) where a Group 1 herbicide had been applied that year had Group 1-HR wild oat (O'Donovan et al. 1998). Most of the populations originated in the southern (Grassland) region of Alberta, which was attributed to greater Group 1 herbicide use.

In addition to resistance in wild oat, resistance was documented in two broadleaf weeds in Alberta from the late 1980s to mid-1990s. Group 2 resistance in multiple populations of chickweed [*Stellaria media* (L.) Vill.] had been documented since 1988 in the Parkland region of Alberta (Morrison and Devine 1994; O'Donovan et al. 1994a). Two populations of Group 2-HR spiny annual sow-thistle [*Sonchus asper* (L.) Hill] were described from that area in 1996 (Rashid et al. 2003).

In Wheatland County, Alberta located in the Fescue Grassland ecoregion (defined as an area similar in climate, soils, natural vegetation, and land use (see Figure 1; Agriculture and Agri-Food Canada 2003), 95 fields were surveyed for HR wild oat from 1997 to 1999 (Beckie et al. 1999, 2004a). These fields had been treated repeatedly with the same herbicide mode of action

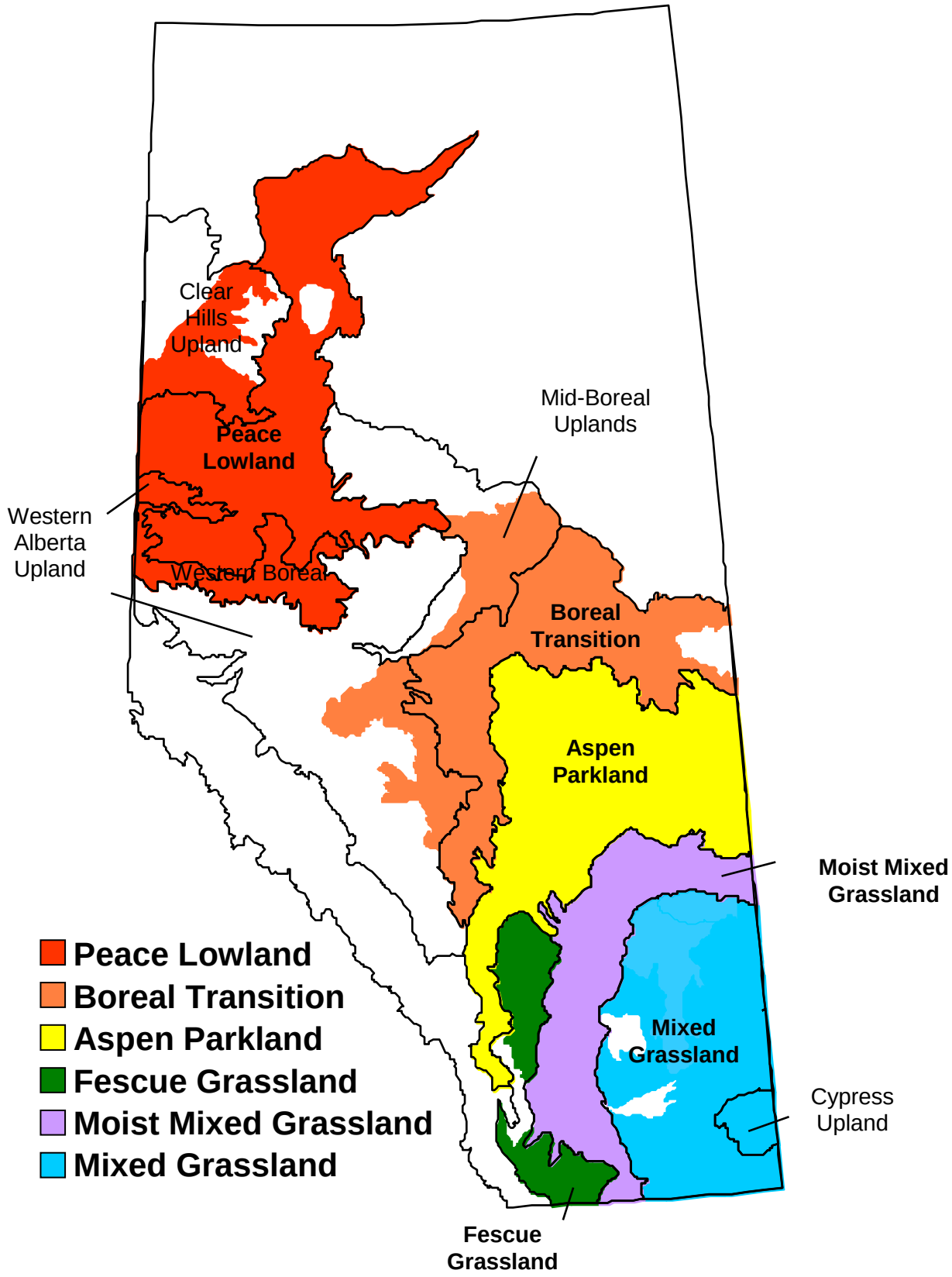


Fig 1. Ecoregions of Alberta (map derived from Agriculture and Agri-Food Canada (2003)

for wild oat control. Nearly 20% of fields had wild oat with Group 1 resistance, 10% with Group 2 resistance, and 6% with Group 8 resistance.

Resistance testing of samples submitted by producers (or industry on behalf of producers) has complemented field surveys in herbicide resistance monitoring in western Canada. Joint testing is conducted by the Crop Protection Lab (CPL) of Saskatchewan Ministry of Agriculture and Agriculture and Agri-Food Canada, Saskatoon. From the 1996 to 2006 crop years (Beckie et al. 2007, 2008), 289 submission samples of wild oat from Alberta were confirmed as Group 1-HR: aryloxyphenoxypropionate (fop) only (185 samples), cyclohexanedione (dim) only (2 samples) and fop+dim (124 samples); many HR wild oat samples originated from the Aspen Parkland ecoregion, although a significant number were from the Grassland region. There were 15 Group 2-HR wild oat samples from Alberta, and 22 Group 1+2-HR wild oat samples. Most Group 2- or Group 1+2-HR samples originated from the Parkland region where Group 2 use was historically the highest (Leeson et al. 2007). Only seven wild oat samples from Alberta during this 11-year period were confirmed as Group 8-HR.

In submission samples from Alberta, there was only one case of Group 1-HR green foxtail [*Setaria viridis* (L.) Beauv.] in the Grassland region in 2006. Ten cases of Group 2-HR kochia [*Kochia scoparia* (L.) Schrad.] were mainly from the Grassland region. Other Group 2-HR broadleaf weeds included two populations of wild mustard (*Sinapis arvensis* L.) near Edmonton; one population of stinkweed (*Thlaspi arvense* L.) in central Alberta, one population of cleavers (*Galium* spp.) near Red Deer, three populations of chickweed near Edmonton and Innisfail, and one population of hemp-nettle (*Galeopsis tetrahit* L.) near Carstairs.

A baseline HR survey in 236 randomly-selected fields was conducted across the ecoregions of Alberta in 2001 (Beckie et al. 2004b, 2008). All residual weed species with viable seeds were

mapped and sampled before harvest. Selected fields were cropped to cereals, oilseeds, or pulses (field pea). Samples of 20 weed species were subsequently screened in the greenhouse with high-risk herbicides belonging to Groups 1 and 2. Producers provided information on herbicide group rotation and resistance awareness and impact via a questionnaire.

Nearly 20% of surveyed fields had an HR weed biotype. Of 190 fields where wild oat samples were collected, 11% had Group 1-HR wild oat (9% of all fields surveyed) and 13% had Group 2-HR wild oat (10% of all fields surveyed). Half of the fields with either HR biotype originated in the Aspen Parkland ecoregion, which was attributed to historically high frequency of use of products from these groups. Most Group 1-HR wild oat populations exhibited resistance to both fop and dim herbicides. Group 2-HR populations exhibited broad cross-resistance across three classes of Group 2 herbicides. Of 16 broadleaf weed species, Group 2 resistance was detected only in chickweed (17% of fields in the Aspen Parkland ecoregion) and spiny annual sow-thistle (67% of fields in the Moist Mixed Grassland, Fescue Grassland, or Aspen Parkland ecoregions).

Although 82% of producers practiced herbicide group rotation in 2001, the high frequency of use of Group 1 or 2 products (45 and 40% of fields sprayed in 2001, respectively) suggested that rotations practiced by a significant number of these producers were less than effective in delaying resistance to these herbicides. Only 5% of producers with HR biotypes previously suspected or were aware of their occurrence. This low level of awareness was consistent with findings from previous surveys, and may be attributed, in part, to the relatively small infestation area of HR biotypes in most fields. In 2001, only 12% of producers believed that resistance had a significant impact on their farm. In the next five years, about 20% of producers expected herbicide resistance to pose a moderate or high impact on their farm.

A weed resistance survey of 300 randomly-selected fields was conducted across the major ecoregions of Alberta in 2007 (second round of prairie surveys). Selected fields were cropped to cereals, oilseeds, or pulses (field pea). Samples of 35 weed species were subsequently screened in the greenhouse with herbicides belonging to various groups. In addition, an early spring survey was conducted to document resistance in kochia and Russian thistle (*Salsola tragus* L.).

Of 179 fields where wild oat samples were collected, 39% had Group 1-HR wild oat and 12% had Group 2-HR wild oat. Therefore, Group 1 resistance in wild oat had increased sharply since 2001 (11% of fields), but Group 2 resistance remained at the same field frequency. Most of the fields with either HR biotype originated in the Aspen Parkland ecoregion, attributed to historically high frequency of use of products from these groups. Most Group 1-HR wild oat populations exhibited broad cross-resistance to herbicides from the three chemical classes – fop, dim, den (pinoxaden). Group 2-HR populations also exhibited broad cross-resistance across three classes. Group 8-HR wild oat was found in 15% of fields. Group 1 resistance was documented in two green foxtail populations; resistance in this weed was not found in the 2001 survey. Group 2 resistance was documented in 40% of 30 fields with chickweed (17% in 2001), all 11 fields with spiny annual sow-thistle (67% in 2001), 17% of 30 fields with cleavers (not reported in 2001), and one field with wild buckwheat (*Polygonum convolvulus* L.), the first global report. Thus, resistance frequency steadily increased in chickweed and spiny annual sow-thistle since the 2001 baseline survey, with the first survey in 2007 to document resistance in cleavers. Of 95 fields where kochia was sampled, 85% had Group 2-HR populations, whereas only 1 of 14 fields had a Russian thistle population that was Group 2-HR. However, all broadleaf weed populations were susceptible to Group 4 herbicides. Additionally, all weed populations were susceptible to glyphosate and glufosinate. When the frequency of fields with weed resistance in this random

survey of 300 fields is extrapolated to the total annual-cropped land in Alberta (7,885,000 ha in 2007), it was estimated that 2.1 million ha (27%) were infested with HR weeds, in a total field area of 3.1 million ha (40%). In comparison, the weed resistance survey in 2001 indicated that 0.3 million ha was infested with HR weeds, in a total field area of 1.5 million ha.

Based on wild oat samples submitted for testing between 2007 and 2011 from Alberta, there were 224 cases of Group 1 resistance, 64 cases of Group 2 resistance, and 107 cases of Group 1+2 resistance (Beckie and Brenzil 2012). Fop only or fop+dim were the main cross-resistance patterns. Two cases of Group 1-HR Persian darnel (*Lolium persicum* Boiss. & Hoh.) were found in southern Alberta (Pincher Creek area) in 2009. Group 2-HR chickweed was documented at Vegreville and Airdrie between 2008 and 2010. One population of Group 2-HR wild mustard was identified in Alberta during this 5-year period, as were 14 populations of Group 2-HR cleavers.

Based on wild oat samples submitted for testing between 2012 and 2016 from Alberta, there were 195 cases of Group 1 resistance, 50 cases of Group 2 resistance, and 98 cases of Group 1+2 resistance (Beckie et al. 2017a). The top five cross-resistance patterns were fop (dim or den not tested), den (fop or dim not tested), fop+dim (den not tested), SCT (IMI or TP not tested; see Table 3 for abbreviations), and fop+dim+den. One case of Group 2-HR green foxtail was found near Olds, the first report of this biotype in the province. One case of Group 1-HR Persian darnel was found near Brooks in 2016. Group 2-HR cleavers was confirmed in 22 populations. Group 2 resistance was identified in one population of stinkweed and hemp-nettle. Three populations of Group 2-HR smartweed (*Polygonum* spp.) were confirmed near Erskine, Stettler, and Vegreville. Group 9-HR kochia was confirmed in two cases from Provost and Hilda in 2015.

Objective

In 2017, 250 fields were randomly selected for a weed resistance survey (third round of prairie surveys). 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 247 fields were surveyed for HR 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 2017 general weed survey. Fields were randomly selected from the list of qualified fields (1,232). Each sampling unit comprised 64-ha (160 ac). The crop allocation across the ecoregions of Alberta is shown in Table 1.

A majority of the fields (55%) were cropped to cereals. This proportion is greater than that of the 2007 weed resistance survey (71%). Wheat occupied 61% of the 136 fields, barley 30%,

Table 1. Field allocation by crop in Alberta ecoregions

Crop	Mixed Grassland	Moist Mixed Grassland	Fescue Grassland	Aspen Parkland	Boreal Transition	Peace Lowland	*All areas*
	No. of fields						
Wheat	19	13	5	30	3	13	83
Barley	1	8	4	21	3	4	41
Oat	1	5	0	5	1	0	12
Canola	4	20	5	30	6	19	84
Field pea	1	8	1	9	0	2	21
Lentil	6	0	0	0	0	0	6
Total	*32*	*54*	*15*	*95*	*13*	*38*	***247***

and oat 9%. Oilseed crops (canola) comprised 34% of the surveyed fields, compared with 26% in 2007. Pulse crops occupied the remaining 11% of fields (78% field pea, 22% lentil). This percentage compares with 3% in 2007 (field pea).

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 17 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2017 (Leeson et al. 2019). 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.

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

Table 2. Weed species tested for resistance

Weed species	Samples tested	Fields	Rank[a]
	No.		
Grass:			
Barnyard grass, *Echinochloa* spp.	4	4	30
Green foxtail, *Setaria viridis* (L.) P. Beauv.	34	33	8
Wild oat, *Avena fatua* L.	176	176	5
Broadleaf:			
Chickweed, *Stellaria media* (L.) Vill.	15	15	1
Cleavers, *Galium* spp.	40	39	6
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	9	9	52
Hemp-nettle, *Galeopsis tetrahit* L.	19	19	13
Lamb's-quarters, *Chenopodium album* L.	35	34	3
Narrow-leaved hawk's beard, *Crepis tectorum* L.	8	7	16
Redroot pigweed, *Amaranthus retroflexus* L.	16	16	23
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	29	28	17
Smartweed (annual), *Polygonum* spp.	8	8	20
Spiny annual sow-thistle, *Sonchus asper* (L.) Hill	13	11	11
Stinkweed, *Thlaspi arvense* L.	51	50	14
Tumble pigweed, *Amaranthus albus* L.	4	4	39
Wild buckwheat, *Polygonum convolvulus* L.	20	20	2
Wild mustard, *Sinapis arvensis* L.	1	1	45

[a]Relative abundance rank of species in 1,232 fields surveyed in 2017 (Leeson et al. 2019); rank of annual smartweed spp. is that of pale smartweed; barnyard grass is that of western barnyard grass; cleavers spp. is that of false cleavers.

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 personnel and 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 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 HR or herbicide-susceptible at 21 to 28 d after treatment. A minimum of 100

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 (TP)	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; TP: triazolopyrimidine.

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 176 fields where wild oat samples were collected, 122 (69%) had an HR population (49% of the 247 surveyed fields). In contrast, 43% of fields with wild oat had an HR population in the 2007 survey (Beckie et al. 2009). Group 1-HR wild oat was confirmed in 102 fields (58%) (Table 4, Map 2) or 41% of all 247 surveyed fields. This incidence of Group 1 resistance compares with 39% of fields in 2007 and 11% of fields in 2001 (Beckie et al. 2004b). Occurrence of Group 1-HR wild oat was proportionally greatest in the Fescue Grassland ecoregion (Table 4).

Group 2-HR wild oat was found in 71 fields (40%) where the weed was sampled (29% of surveyed fields), with greatest occurrence in the Aspen Parkland and Moist Mixed Grassland ecoregions, but proportionally greatest in the Fescue Grassland ecoregion (Table 4, Map 3). Incidence of Group 2-HR wild oat has increased sharply since 2007 (12% of fields) and 2001 (13% of fields), likely attributed to increased Group 2 herbicide use to manage Group 1-HR wild oat.

Table 4. Fields with wild oat resistance (Group 1 or 2) by ecoregion

	Group 1-resistant wild oat			Group 2-resistant wild oat		
Ecoregion	Resistant	Tested[a]	Surveyed[a]	Resistant	Tested	Surveyed
	No.	%		No	%	
Mixed Grassland	11	42	31	6	23	16
Moist Mixed Grassland	27	58	50	17	36	32
Fescue Grassland	12	86	80	10	71	67
Aspen Parkland	34	65	36	28	54	30
Boreal Transition	4	67	23	3	50	23
Peace Lowland	14	45	34	7	23	18
Alberta	*102*			*71*		

[a]Tested -fields where seeds were collected; surveyed – all fields surveyed.

Table 5. Fields with wild oat resistance (Group 1+2) by ecoregion

Ecoregion	Resistant	Tested[a]	Surveyed[a]
	No.	_____ %	_____
Mixed Grassland	3	12	9
Moist Mixed Grassland	10	21	18
Fescue Grassland	10	71	67
Aspen Parkland	22	42	23
Boreal Transition	3	50	23
Peace Lowland	3	10	8
Alberta	*51*		

[a]Tested -fields where seeds were collected; surveyed – all fields surveyed.

Group 1+2-HR wild oat was found in 51 fields (29%) where the weed was sampled (21% of the 247 surveyed fields), with greatest occurrence in the Aspen Parkland ecoregion, but proportionally greatest in the Fescue Grassland ecoregion (Table 5, Map 4). Incidence of Group 1+2-HR wild oat has increased markedly since 2007 (8%) and 2001 (3%). Therefore, of the 122 fields with HR wild oat populations, 52 had Group 1 resistance only, 19 had Group 2 resistance only, and 51 had Group 1 plus 2 resistance. From 2012 to 2016, 343 wild oat submissions from Alberta were HR: 195 Group 1, 50 Group 2 and 98 Group 1+2 (Beckie et al. 2017a). 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 (Anonymous 2018). 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 15% of fields in the 2007 survey (Beckie et al. 2009).

The incidence of Group 1-HR wild oat in Alberta (58% of sampled fields) compares with 59% of fields in Saskatchewan (2014/15 survey; Beckie et al. 2017b) and 78% of fields in Manitoba (2016 survey; Beckie et al. 2018). The incidence of Group 2-HR wild oat in Alberta (40% of sampled fields) compares with 32 and 43% of fields in Saskatchewan and Manitoba,

respectively. Therefore, Group 1-HR wild oat occurrence in Alberta is similar to that in Saskatchewan, while occurrence of Group 2 resistance in Alberta is greater than Saskatchewan but relatively similar to Manitoba. The frequency of fields with multiple-HR wild oat in Alberta (29%) compares with 25% in Saskatchewan and 42% in Manitoba. With 69, 65, and 79% of sampled fields in Alberta, Saskatchewan, and Manitoba, respectively, with an HR wild oat biotype, susceptibility of this grass weed to Group 1 or 2 herbicides is rapidly diminishing.

Of 33 fields where green foxtail was sampled, 9 (27%) had an HR population. Group 1-HR populations were found in 7 fields (21%) (Map 5); in the 2007 survey, this biotype was found in 2 fields (no fields in the 2001 survey). Two fields were located in the Grassland ecoregion, two in the Moist Mixed Grassland ecoregion, two in the Aspen Parkland ecoregion, and one in the Boreal Transition ecoregion. Group 2-HR populations were found in 2 of the 33 fields (6%), the first cases confirmed in an Alberta survey (Map 6). However, a submission sample that originated near Olds, Alberta was previously confirmed as Group 2-HR (Beckie et al. 2017a). Both fields were located in the Aspen Parkland ecoregion. However, no populations were multiple (Group 1+2)-HR. In the 2014/15 Saskatchewan survey, Group 1- and 2-HR green foxtail were found in 17 and 15% of fields sampled, respectively (two fields with Group 1+2-HR biotype). That survey had also documented the first cases of Group 2 resistance in the weed. In the 2016 Manitoba survey, Group 1-HR green foxtail was found in 44% of sampled fields, whereas Group 2-HR green foxtail was found in only 6% of fields (one field with Group 1+2-HR biotype).

Broadleaf Weed Resistance

Group 2-HR chickweed was found in 6 of 15 fields sampled (40%; Map 7), a field frequency similar to that of the 2007 survey (17% in 2001). Similar to the previous two surveys, all HR populations were located in the Aspen Parkland ecoregion. Therefore, the rate of evolution or spread of this HR biotype appears to be relatively slow (biotype first confirmed in 1988). In contrast, Group 2-HR cleavers (likely false cleavers, *Galium spurium*, based on the general weed survey) had increased in frequency from 17% in 2007 (no fields in 2001) to 44% (17 of 39 fields sampled) (Map 8). Similar to HR chickweed, most of the fields with Group 2-HR cleavers originated in the Aspen Parkland ecoregion, with two in the Boreal Transition ecoregion and one in the Moist Mixed Grassland ecoregion. This survey is the first to document the biotype in these latter two ecoregions. Based on submission samples between 2012 and 2016 from Alberta, there were 22 confirmed cases of Group 2 resistance in the weed (with 14 cases between 2007 and 2011) (Beckie et al. 2017a).

Group 2-HR lamb's-quarters was documented in one of 34 fields sampled (Moist Mixed Grassland ecoregion; Map 9) – the first case confirmed in Alberta. Group 2-HR narrow-leaved hawk's beard was found in two of seven fields sampled (29%) (Map 10). Both fields were located in the Aspen Parkland ecoregion. Group 2 resistance was not detected in this weed in 2007. Group 2-HR shepherd's purse was found in 5 of 28 fields sampled (18%) (Map 11). Resistance to Group 2 herbicides was also not found in this weed in previous surveys. Three of the five fields were located in the Aspen Parkland ecoregion, with one field in each of the Fescue Grassland and Peace Lowland ecoregions. Although the sample size was small, there was a high frequency of Group 2 resistance in smartweed (five of eight fields or 62%; Map 12); resistance was not found in 2007. All HR populations were located in the Aspen Parkland ecoregion.

However, three cases of resistance in the weed from submission samples were confirmed between 2012 and 2016. Surprisingly, frequency of Group 2 resistance in spiny annual sow-thistle (four of 11 fields or 36%) was down from 100% of populations sampled in 2007 and 67% in 2001 (Map 13). Two of the fields were located in the Aspen Parkland ecoregions, with one field each in the Moist Mixed Grassland and Peace Lowland ecoregions. However, a larger sample size will be needed to confirm this apparent downward trend.

Group 2-HR stinkweed was found in eight of 50 fields sampled (16%) (Map 14). This biotype was not found in the 2007 survey. Two of the eight fields were located in the Mixed Grassland ecoregion, four in the Moist Mixed Grassland ecoregion, and two in the Aspen Parkland ecoregion. Based on submission samples tested from Alberta, one stinkweed population was confirmed between 2012 and 2016 (with one HR population also in 2000). The good news – herbicide resistance was not detected in barnyard grass, flixweed, hemp-nettle, redroot pigweed, tumble pigweed, wild buckwheat, or wild mustard (Table 2). Nevertheless, Group 2-HR biotypes of hemp-nettle, wild buckwheat, and wild mustard in Alberta were previously reported as described previously.

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 Alberta, there is no clear increase in densities of weeds with HR biotypes over the intervening 16 years (Table 6). However, densities of green foxtail, chickweed, lamb's-quarters, and kochia (post-harvest survey; Beckie et al. 2019a), were highest in the 2017 survey relative to the previous two surveys. Species with a trend of declining densities over time include wild oat, narrow-leaved hawk's beard, spiny annual sow-thistle, and Russian thistle (post-harvest survey; Beckie et al. 2019b).

Table 6. Post-herbicide treatment mean weed densities (no. m^{-2}) in surveyed fields in Alberta: 2001, 2010, and 2017 (Leeson et al. 2002, 2012, 2019)

Weed	2001	2010	2017
Wild oat	10.9	10.1	9.0
Green foxtail	18.6	9.8	28.7
Chickweed	30.9	11.2	33.4
Cleavers	8.7	9.7	6.3
Lamb's-quarters	5.6	5.3	12.9
Narrow-leaved hawk's beard	5.0	4.3	3.8
Shepherd's-purse	4.8	3.5	3.5
Smartweed	6.6	4.3	4.5
Spiny annual sow-thistle	13.1	5.5	2.9
Stinkweed	6.2	4.4	6.4
Kochia	5.0	3.0	7.7
Russian thistle	5.9	4.8	2.6

Land Area Impacted by Herbicide-Resistant Weeds

When the frequency of fields with weed resistance in this random survey of 247 fields is extrapolated to total land cropped to spring wheat, barley, oat, canola, field pea, and lentil in Alberta (7,933,781 ha or 19,596,439 ac in 2016) (Statistics Canada 2017), it is estimated that 2.6 million ha (33%) are infested with HR weeds, in a total field area of 4.7 million ha (59%) (Table 7). In comparison, the weed resistance survey in 2007 indicated that 2.1 million ha was infested with HR weeds, in a total field area of 3.1 million ha; the weed resistance survey in 2001 indicated that 0.3 million ha was infested with HR weeds, in a total field area of 1.5 million ha. Therefore, the actual area infested with HR weeds has increased by 24%, while the total field area affected has increased by 52% since the last survey.

Table 7. Estimated annual-cropped land area in Alberta impacted by herbicide-resistant (HR) weeds in 2017[a]

Biotype	Infestation area (ac/ha)	Field area (ac/ha)
Gp 1-HR wild oat	1,700,000/688,259	4,076,059/1,650,226
Gp 2-HR wild oat	500,934/202,807	1,489,329/602,967
Gp 1+2-HR wild oat	1,772,253/717,511	3,997,674/1,618,491
Gp 1-HR green foxtail	275,699/111,619	548,700/222,146
Gp 2-HR green foxtail	78,346/31,719	156,772/63,470
Gp 2-HR chickweed	470,314/190,410	470,314/190,410
Gp 2-HR cleavers	595,034/240,904	1,332,558/539,497
Gp 2-HR lamb's-quarters	78,346/31,719	78,346/31,719
Gp 2-HR narrow-leaved hawk's beard	78,346/31,719	156,772/63,470
Gp 2-HR shepherd's-purse	273,125/110,577	391,929/158,676
Gp 2-HR smartweed	156,772/63,470	391,929/158,676
Gp 2-HR spiny annual sow-thistle	129,916/52,598	313,543/126,940
Gp 2-HR stinkweed	274,211/111,016	627,086/253,881
Total	6,383,296/2,584,330	11,522,706/4,665,063

[a]Total field area is adjusted downward because some fields contain more than one HR biotype.

Management Practices of Producers with Resistance

Based on the Alberta 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 site-of-action (SOA; i.e., group) rotation, tank-mixing herbicides, use of preemergence herbicides, and scouting after herbicide treatment (Figure 2). These targeted practices are consistent with best practices recommended to manage weed resistance (Beckie and Harker 2017). Overall, those with HR weeds rely more on herbicides at all application windows. Preemergence herbicides can reduce weed population recruitment and abundance in-crop, thereby potentially reducing in-crop herbicide selection pressure for resistance evolution. Crop rotation, tank-mixing herbicides, and

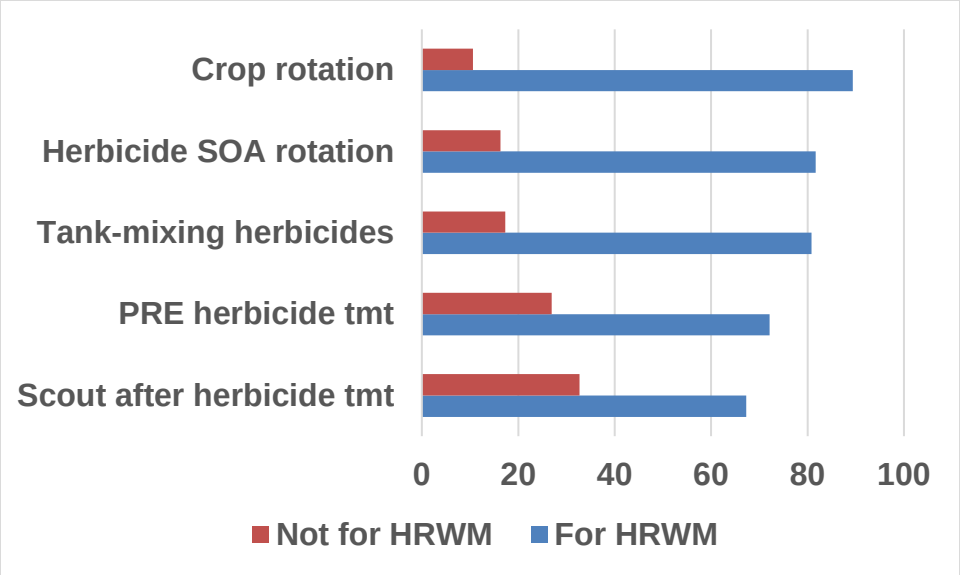


Fig. 2. Herbicide-resistant weed management (HRWM) practices: those with suspected or confirmed weed resistance (*n*=104 respondents; J.Y. Leeson, unpublished weed survey questionnaire data).

herbicide group rotation are ranked 1st, 4th, and 5th, respectively, in the top 10 HR weed management practices. Additionally, Alberta producers with HR weeds have greater adoption of higher crop seeding rate and managing weed patches (i.e., sanitation) vs. those without resistance.

Cost of Weed Resistance

The perceived cost of weed resistance to Alberta producers averages $17/ac or $42/ha, based on the 2017 weed survey questionnaire data (Table 8). 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 to the estimated field area affected by weed resistance, the total cost is estimated at $196 million annually.

Table 8. The perceived cost of weed resistance to Alberta producers (*n*=104 respondents; source: J.Y. Leeson, unpublished 2017 weed survey questionnaire data).

Cost	% of respondents
No additional cost	4
$10/ac or less	39
$11-20/ac	21
$21-30/ac	17
$31-40/ac	8
$41-50/ac	10
Unknown cost	1

LITERATURE CITED

Agriculture and Agri-Food Canada. 2003. A National Ecological Framework for Canada: GIS Data. [Online] Available: http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html.

Anonymous. 2018. Guide to crop protection. Saskatchewan Ministry of Agriculture, Regina, SK. 651 p.

Beckie, H. J. and C. A. Brenzil. 2012. Herbicide resistance testing: 2007-2011 results of samples submitted to the Crop Protection Lab, SMA. Agriculture and Agri-Food Canada, Saskatoon, SK. 24 p.

Beckie, H. J., C. Brenzil, and G. Holzgang. 2007. Herbicide resistance testing: 1996-2006 results of samples submitted to the Crop Protection Lab, SAF. Agriculture and Agri-Food Canada, Saskatoon, SK. 22 p.

Beckie, H. J., L. M. Hall, S. Meers, J. J. Laslo, and F. C. Stevenson. 2004a. Management practices influencing herbicide resistance in wild oat (*Avena fatua*). Weed Technol. 18:853–859.

Beckie, H. J., L. M. Hall, S. W. Shirriff, E. Martin, and J. Y. Leeson. 2019a. Triple-resistant kochia [*Kochia scoparia* (L.) Schrad.] in Alberta. Can. J. Plant Sci. (in press).

Beckie, H. J., L. M. Hall, S. W. Shirriff, E. Martin, and J. Y. Leeson. 2019b. Acetolactate synthase inhibitor resistance in Russian thistle (*Salsola tragus* L.) in Alberta. Can. J. Plant Sci. (in press).

Beckie, H. J. and K. N. Harker. 2017. Our top 10 herbicide-resistant weed management practices. Pest Manag. Sci. 73:1045–1052.

Beckie, H. J., I. M. Heap, R. J. Smeda, and L. M. Hall. 2000. Screening for herbicide resistance in weeds. Weed Technol. 14:428–445.

Beckie, H. J., J. Y. Leeson, and A. G. Thomas. 2004b. Alberta weed survey of herbicide-resistant weeds in 2001. Weed Survey Series Publ. 04-1. Agriculture and Agri-Food Canada, Saskatoon, SK. 66 p.

Beckie, H. J., J. Y. Leeson, A. G. Thomas, C. A. Brenzil, L. M. Hall, G. Holzgang, C. Lozinski, and S. Shirriff. 2008. Weed resistance monitoring in the Canadian Prairies. Weed Technol. 22:530–543.

Beckie, H. J., C. Lozinski, and S. Shirriff. 2009. Alberta weed survey of herbicide-resistant

weeds in 2007. Weed Survey Series Publ. 09-1. Agriculture and Agri-Food Canada, Saskatoon, SK. 36 p.

Beckie, H. J., S. W. Shirriff, F. Dokken-Bouchard, and C. A. Brenzil. 2017a. Herbicide resistance testing: 2012-2016 results of samples submitted to the Crop Protection Lab, SMA. Agriculture and Agri-Food Canada, Saskatoon, SK. 26 p.

Beckie, H. J., S. W. Shirriff, and J. Y. Leeson. 2017b. Saskatchewan weed survey of herbicide-resistant weeds in 2014-2015. Weed Survey Series Publ. 17-1. Agriculture and Agri-Food Canada, Saskatoon, SK. 37 p.

Beckie, H. J., S. W. Shirriff, and J. Y. Leeson. 2018. Manitoba weed survey of herbicide-resistant weeds in 2016. Weed Survey Series Publ. 17-3. Agriculture and Agri-Food Canada, Saskatoon, SK. 39 p.

Beckie, H. J., A. G. Thomas, A. Légère, D. J. Kelner, R. C. Van Acker, and S. Meers. 1999. Nature, occurrence, and cost of herbicide-resistant wild oat (*Avena fatua*) in small-grain production areas. Weed Technol. 13:612–625.

Leeson, J. Y., C. Neeser, and N. Kimmel. 2019. Alberta weed survey of annual crops in 2017. Weed Survey Series Publ. 19-1. Agriculture and Agri-Food Canada, Saskatoon, SK. xxx p.

Leeson, J. Y., C. Neeser, N. Kimmel, and M. Vadnais. 2012. Alberta weed survey of dryland crops in 2010. Weed Survey Series Publ. 12-1. Agriculture and Agri-Food Canada, Saskatoon, SK. 493 p.

Leeson, J. Y., A. G. Thomas, H. J. Beckie, L. M. Hall, C. Brenzil, R. C. Van Acker, K. R. Brown, and T. Andrews. 2007. Group 2 herbicide use in the prairie provinces. Proc. 2004 Canadian Weed Science Society annual meeting, Sainte-Anne-de-Bellevue, QC. [Online] Available: http://www.weedscience.ca.

Leeson, J. Y., A. G. Thomas, and L. M. Hall. 2002. Alberta weed survey of cereal, oilseed and pulse crops in 2001. Weed Survey Series Publ. 02-1. Agriculture and Agri-Food Canada, Saskatoon, SK. 263 p.

Morrison, I. N. and M. D. Devine. 1994. Herbicide resistance in the Canadian prairie provinces: five years after the fact. Phytoprotection 75 (Suppl.):5–16.

O'Donovan, J. T., K. N. Harker, R. E. Blackshaw, A. Rashid, M. P. Sharma, A. Khan, D. Maurice, and S. Kibite. 1998. Investigation of herbicide resistant wild oat populations in Alberta. Final Report Project No. 920037. Alberta Research Council, Vegreville, AB. 134 p.

O’Donovan, J. T., G. M. Jeffers, D. Maurice, and M. P. Sharma. 1994a. Investigation of a chlorsulfuron-resistant chickweed [*Stellaria media* (L.) Vill.] population. Can. J. Plant Sci. 74:693–697.

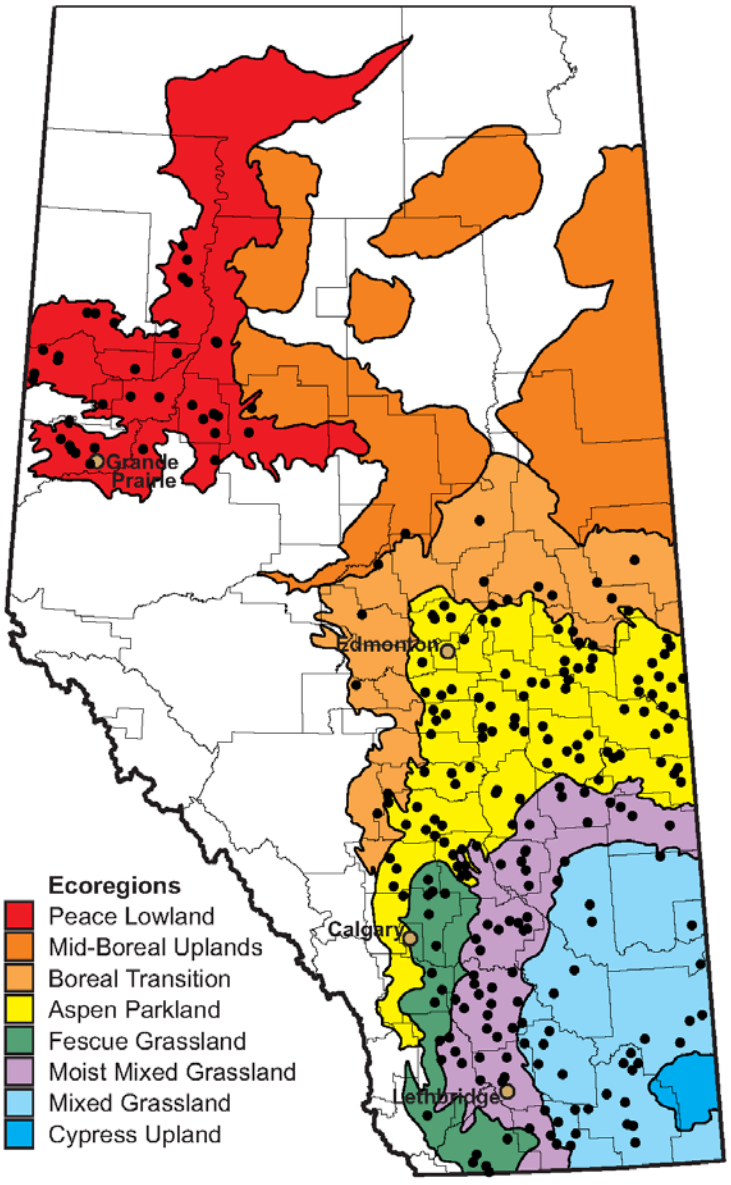
O'Donovan, J. T., M. P. Sharma, K. N. Harker, D. Maurice, M. N. Baig, and R. E. Blackshaw. 1994b. Wild oat (*Avena fatua*) populations resistant to triallate are also resistant to difenzoquat. Weed Sci. 42:195–199.

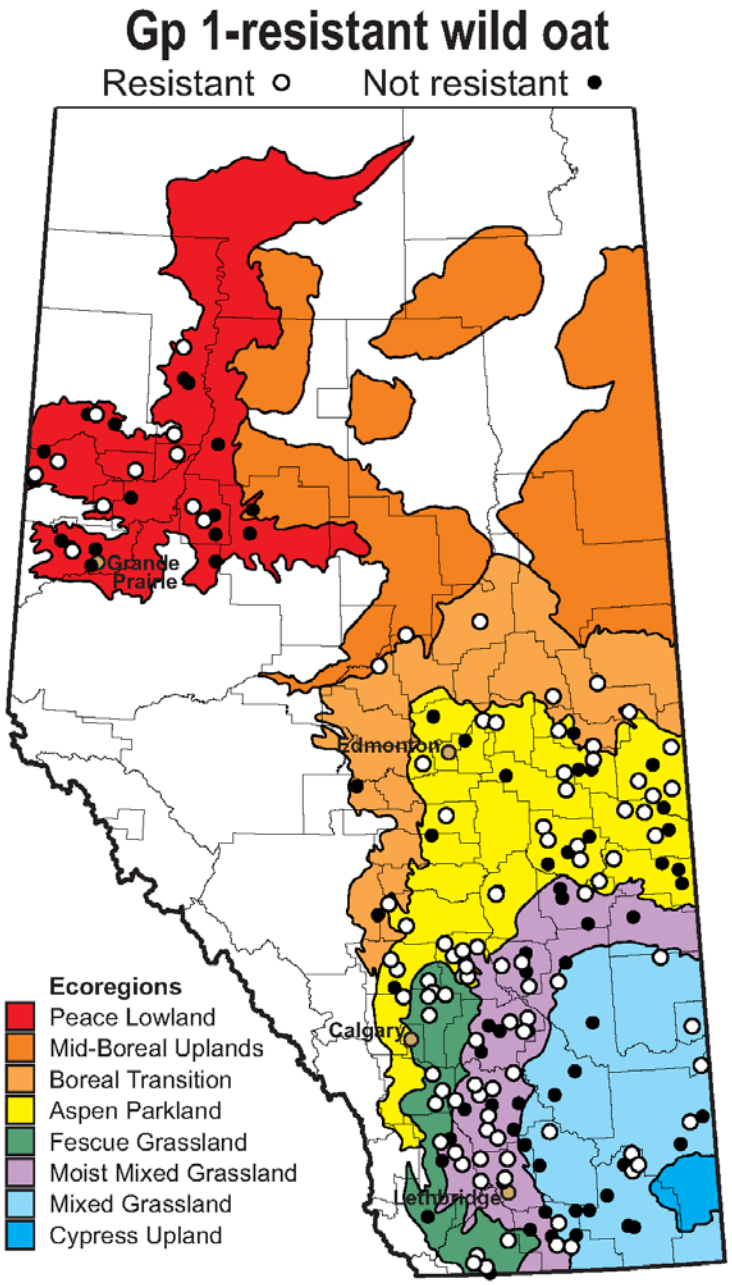
Rashid, A., J. C. Newman, J. T. O’Donovan, D. Robinson, D. Maurice, D. Poisson, and L. M. Hall. 2003. Sulfonylurea herbicide resistance in *Sonchus asper* biotypes in Alberta, Canada. Weed Res. 43:214–220.

Statistics Canada. 2017. Census of agriculture 2016. [Online] Available: http://www.statcan.gc.ca.

Thomas, A. G. 1985. Weed survey system used in Saskatchewan for cereal and oilseed crops. Weed Sci. 33:34–43.

Surveyed fields

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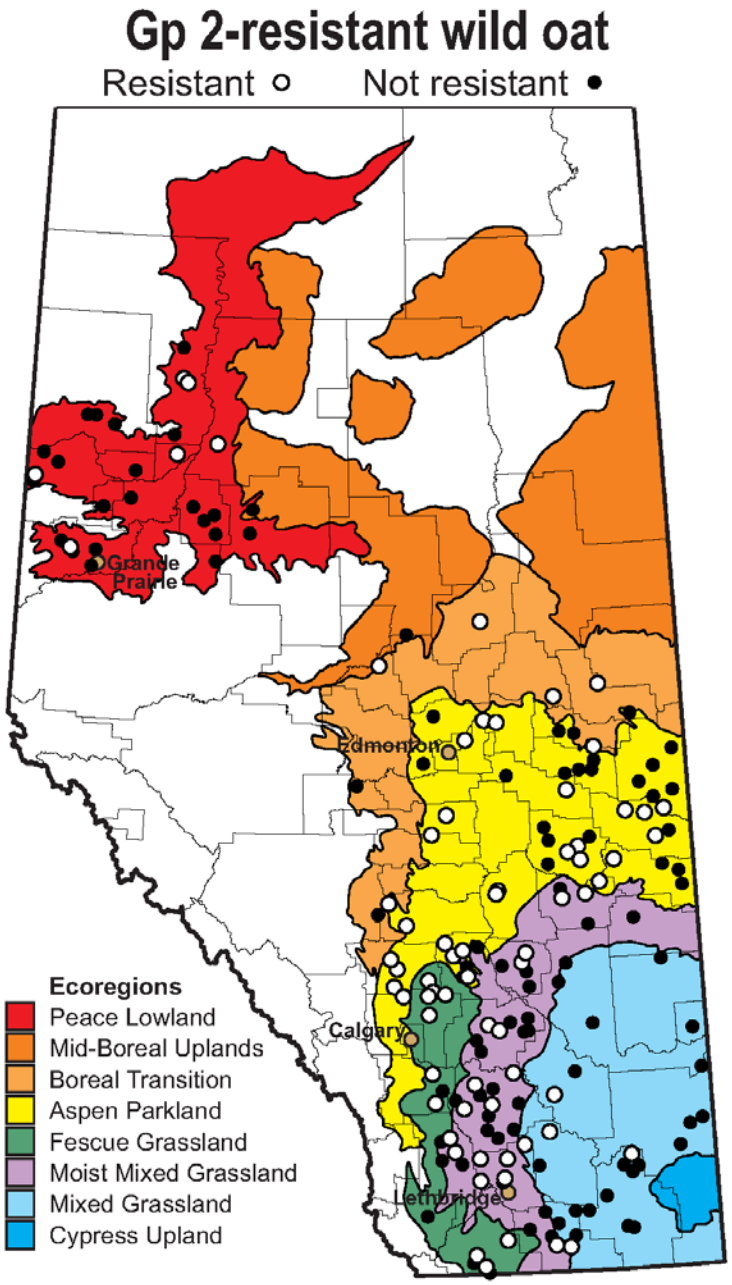
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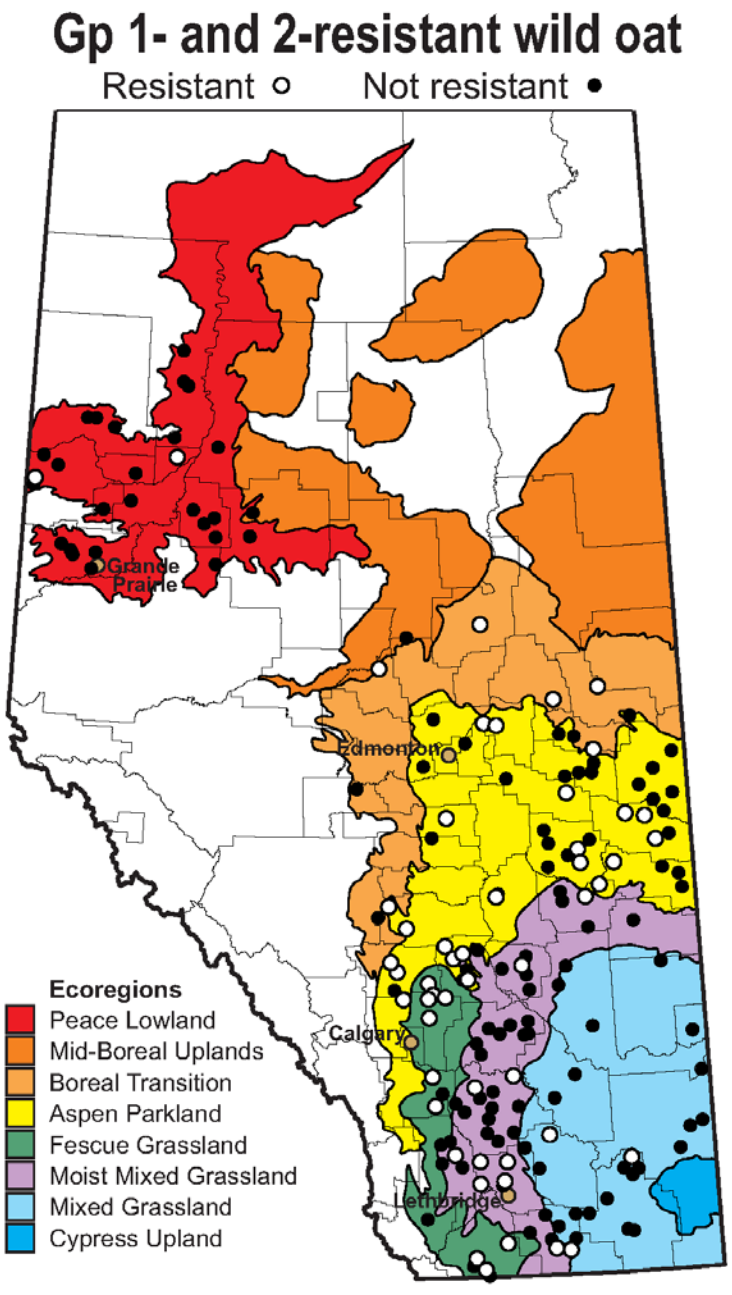
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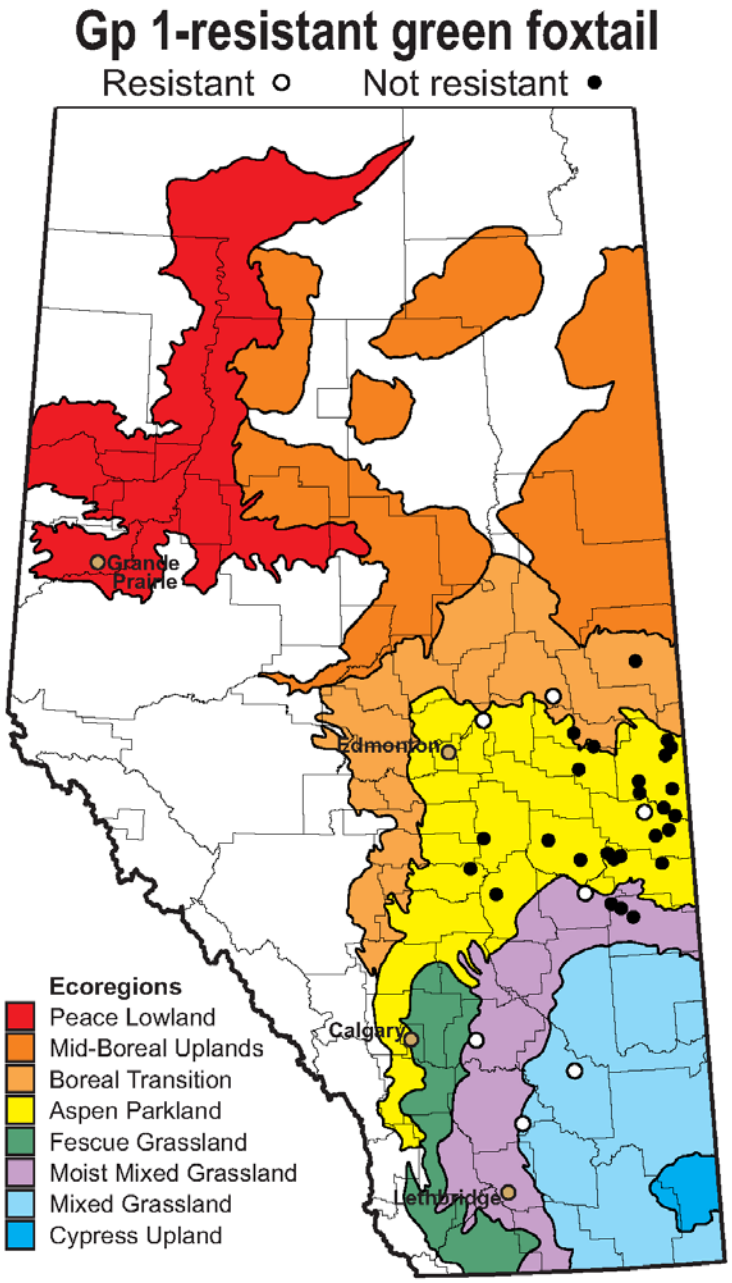
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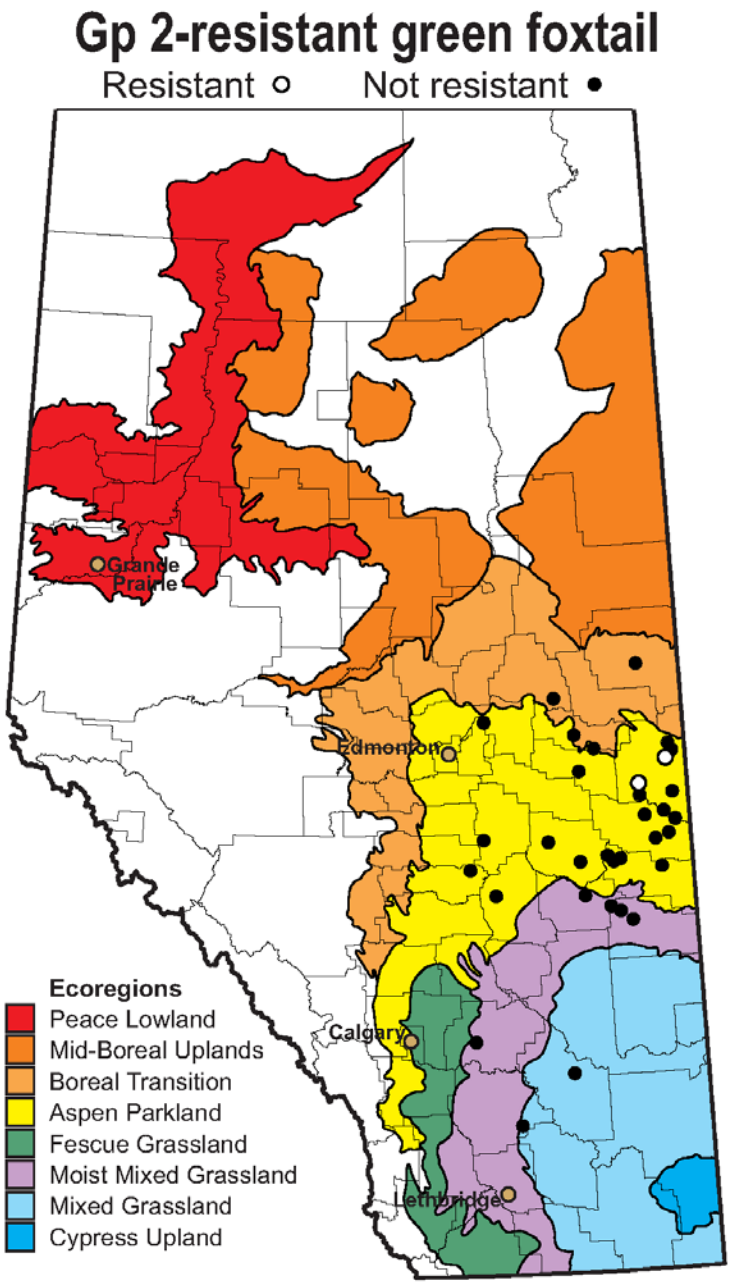
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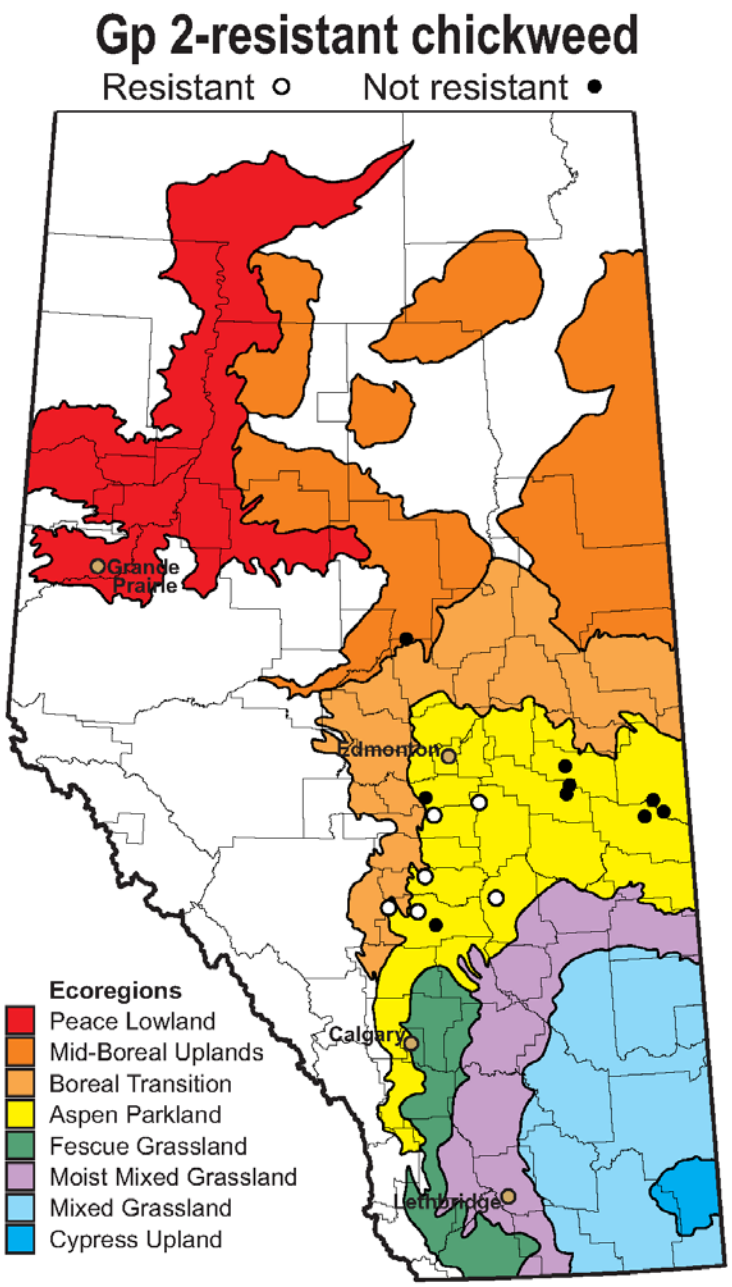
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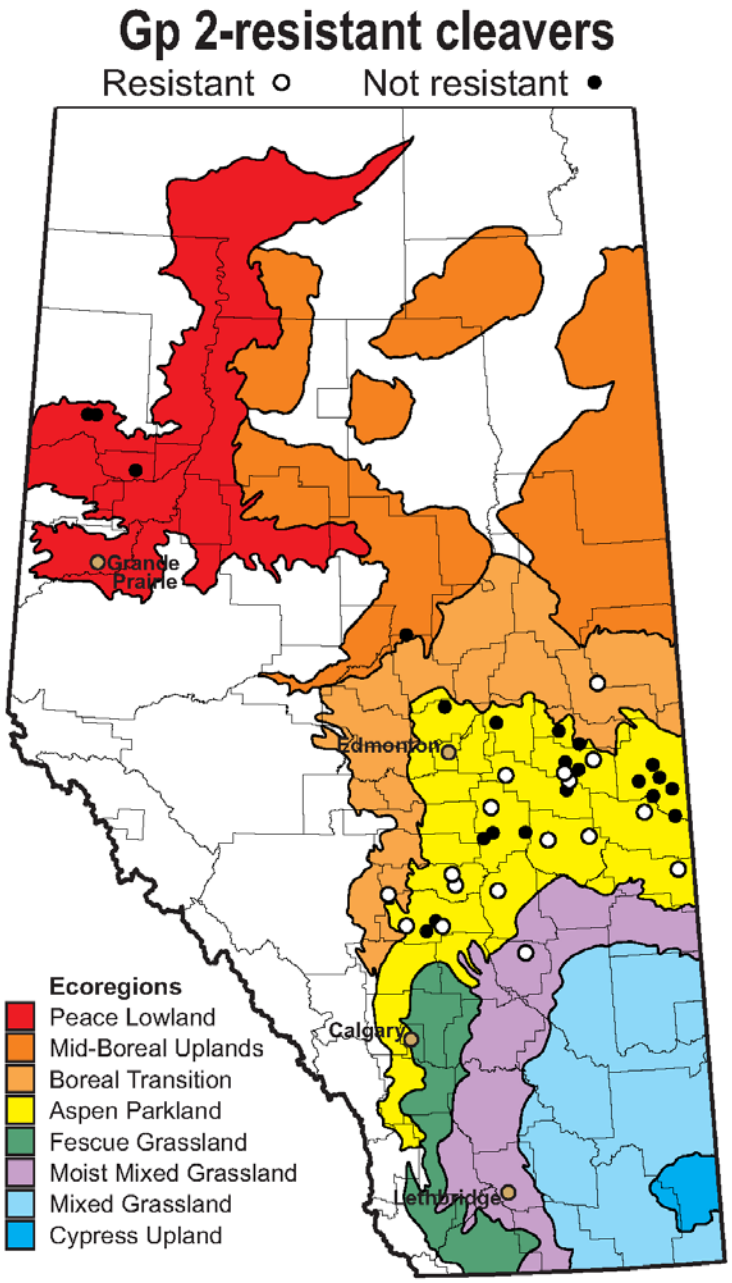
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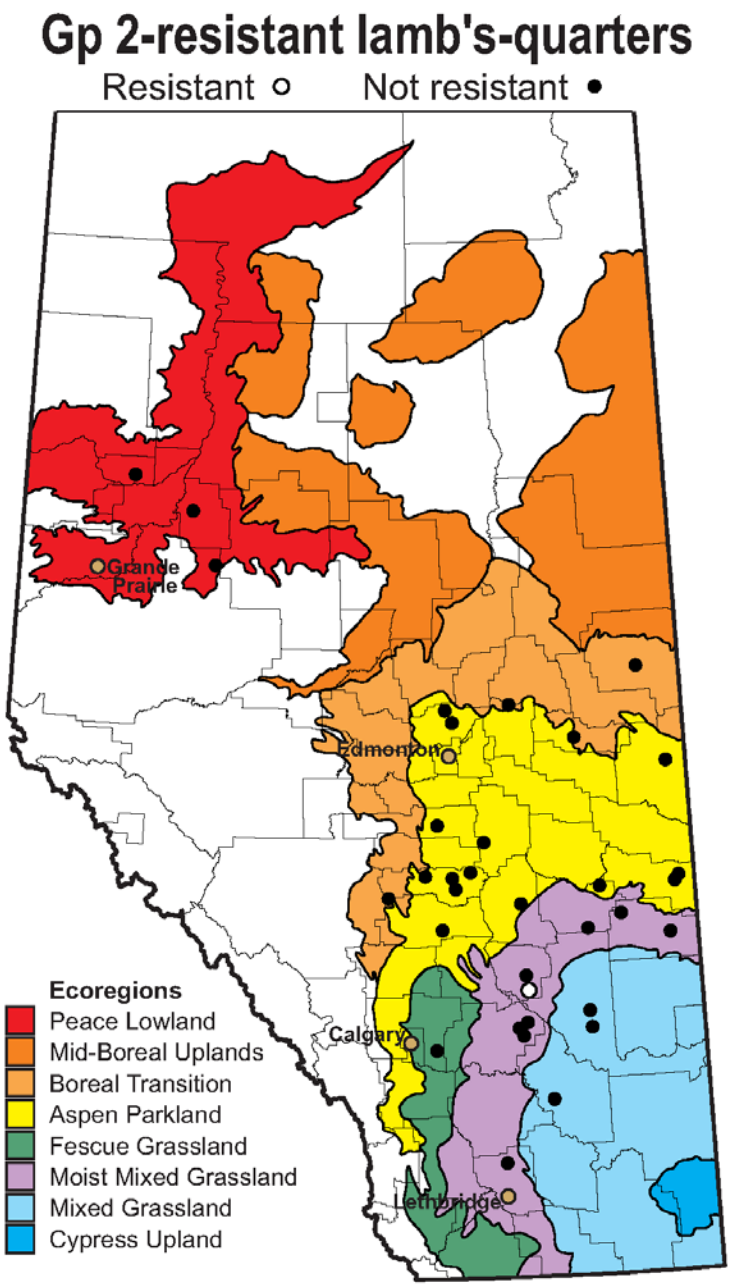
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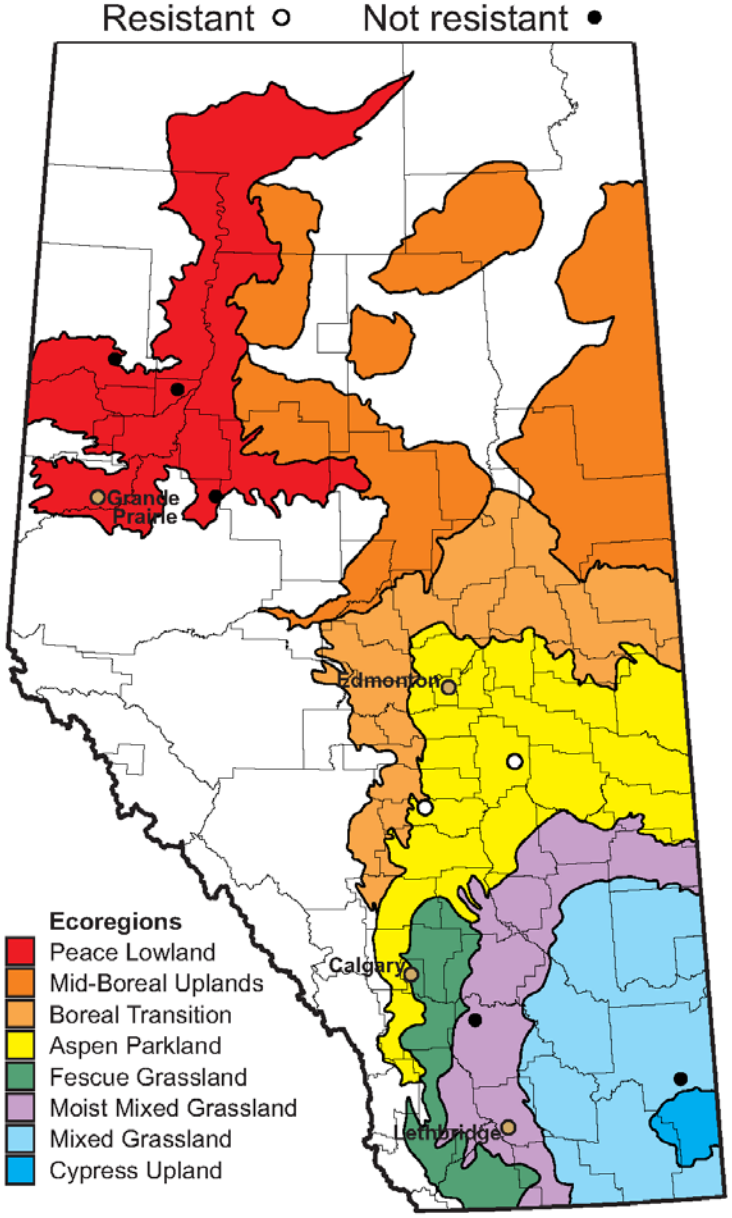

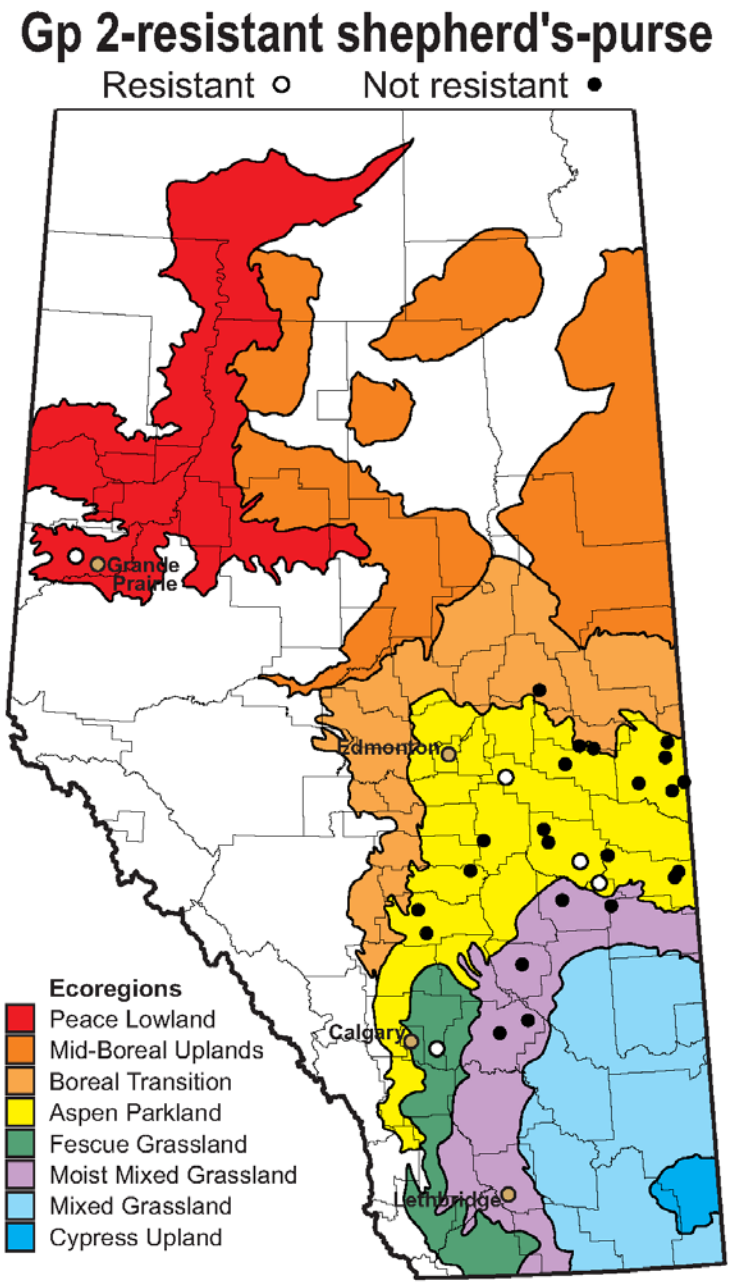
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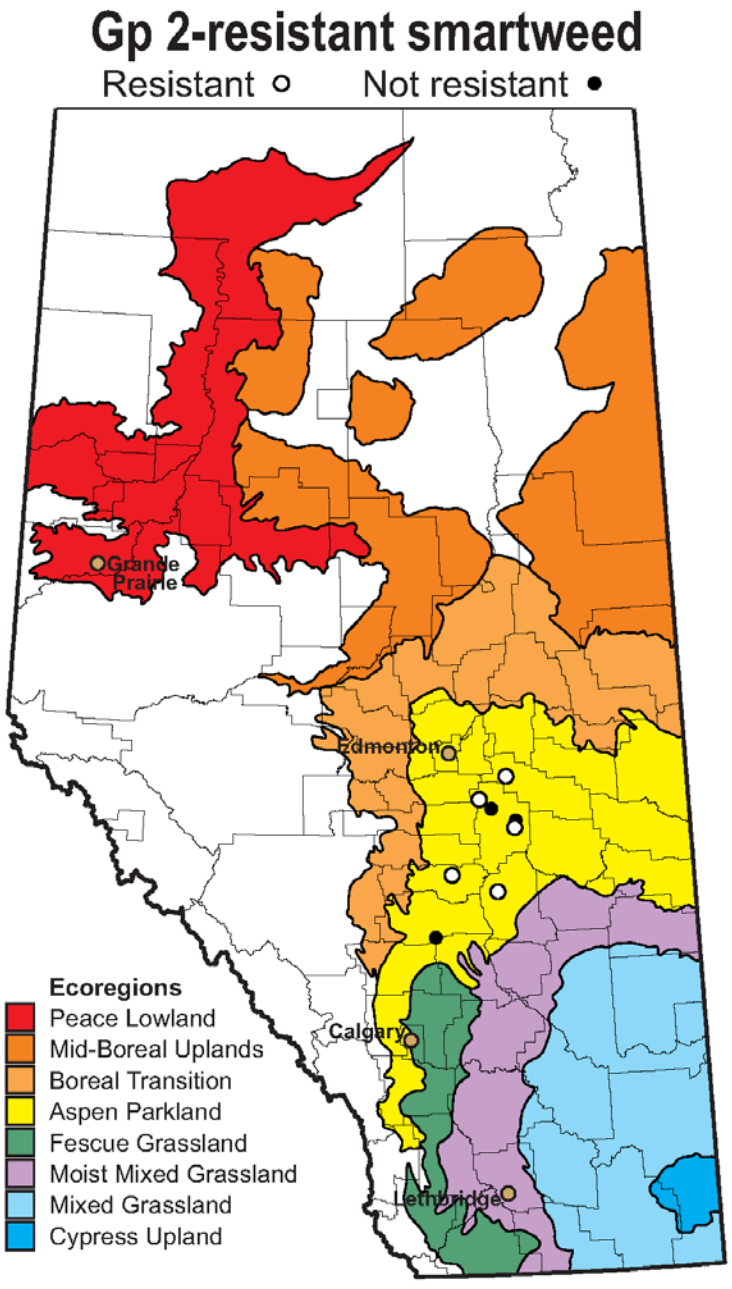
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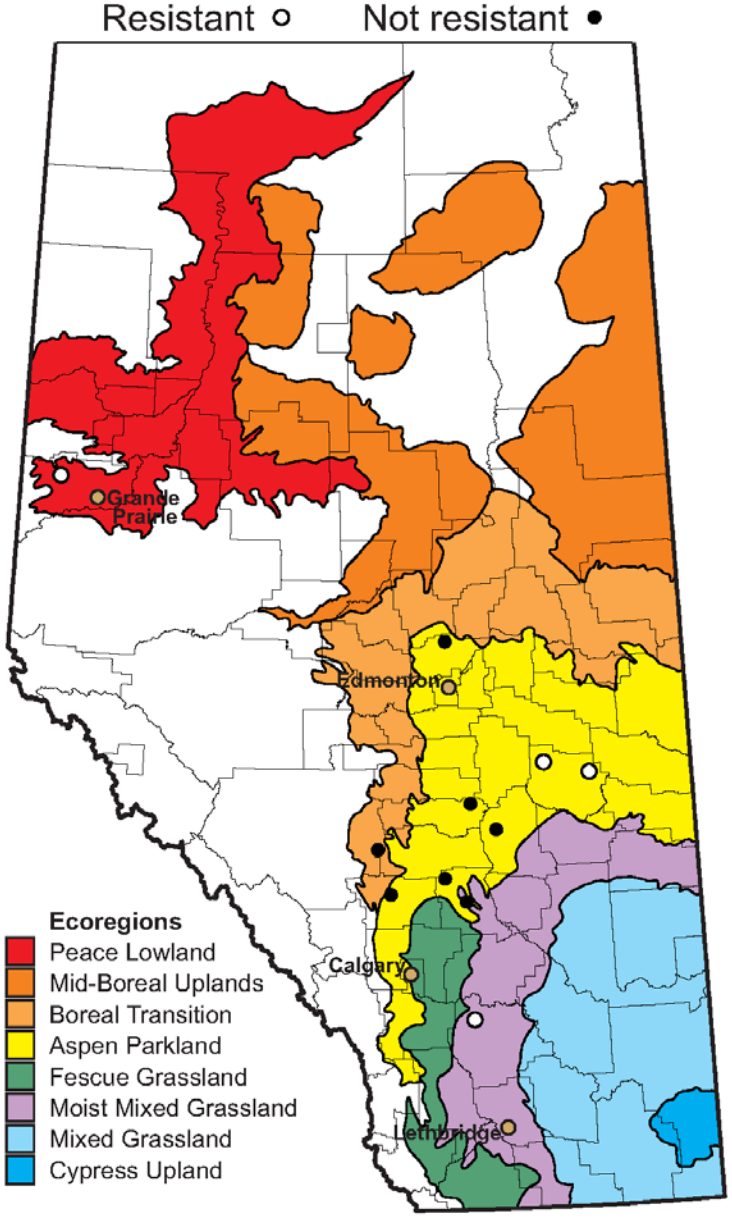

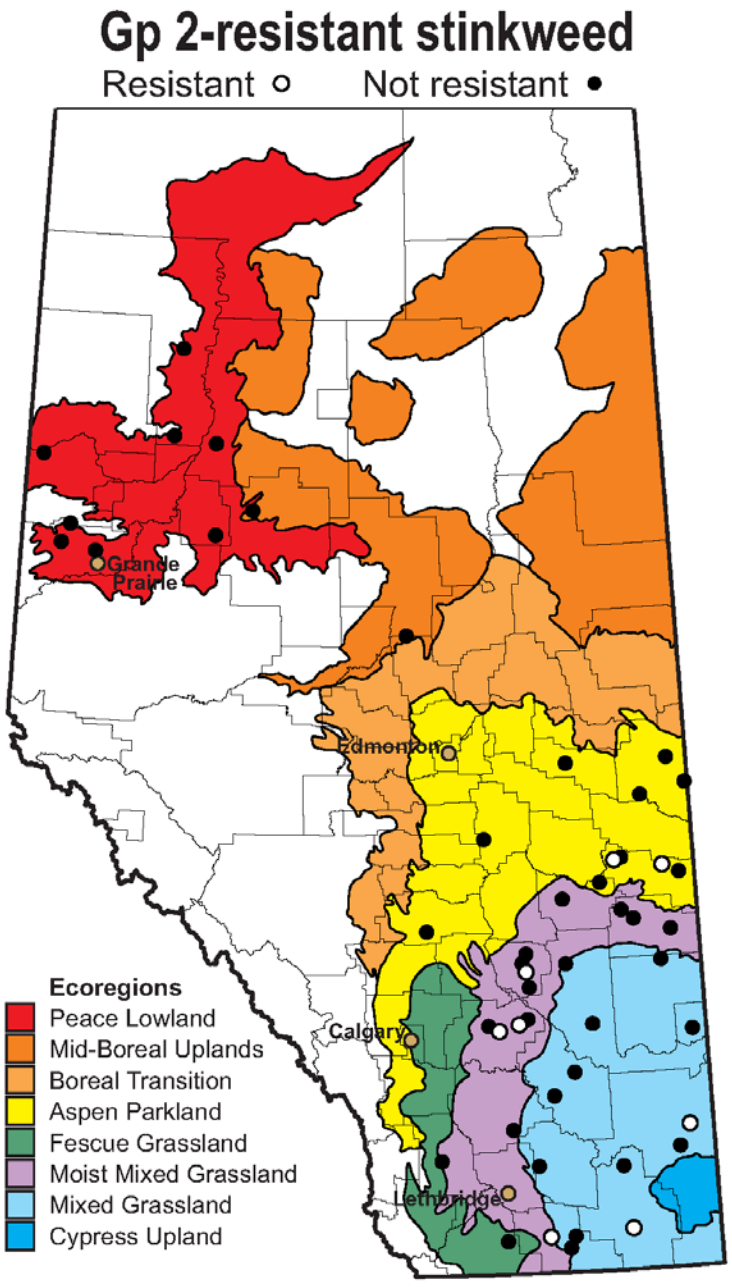
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