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Saskatchewan Weed Survey

Herbicide-Resistant Weeds 2014-2015

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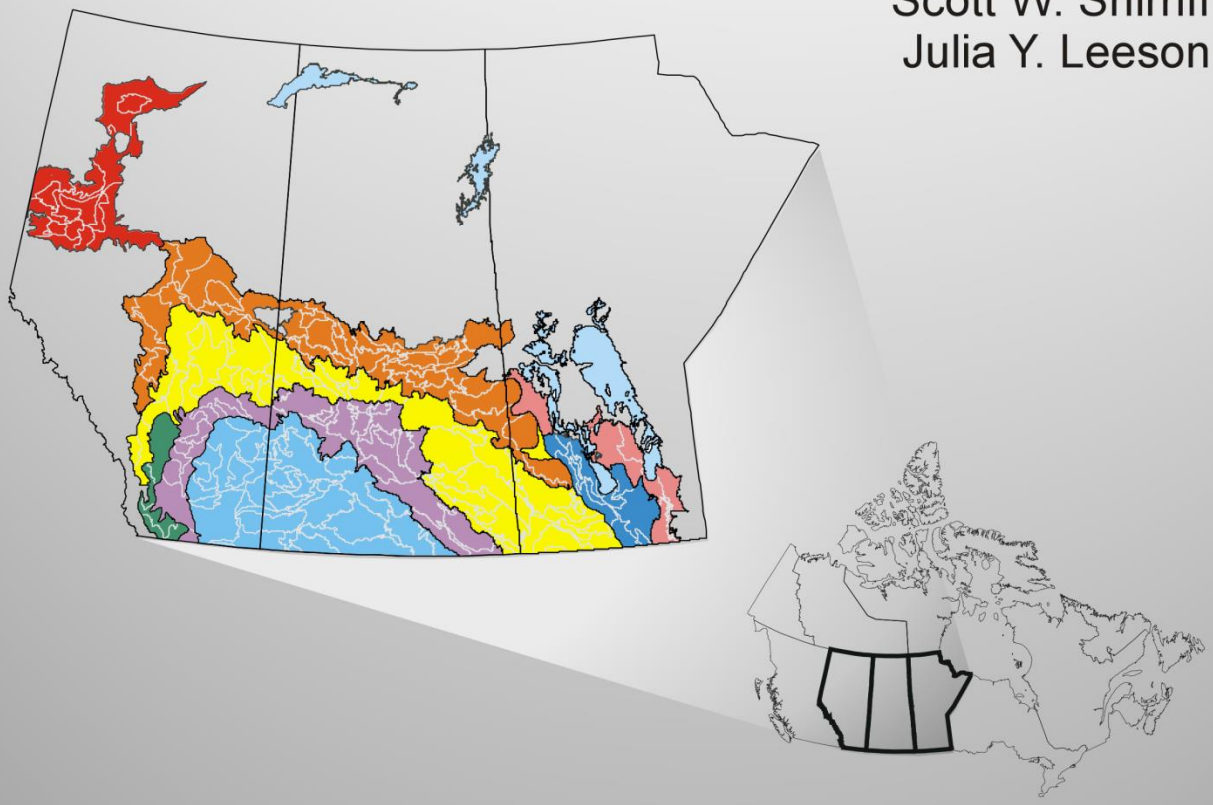

Weed Survey Series

Canada

Saskatchewan Weed Survey of Herbicide-Resistant Weeds in 2014-2015

by

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PREVIOUSLY PUBLISHED REPORTS IN THE WEED SURVEY SERIES

Number	Title
76-1	Weed survey of cultivated land in Saskatchewan (1976)
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)
79-2	Weed survey of cultivated land in Saskatchewan (1979)
79-3	Weed survey of cultivated land in Manitoba (1979)
80-2	Weed survey of grain fields in Prince Edward Island (1978)
80-3	Manitoba weed survey questionnaire data (1979)
82-1	Weed survey of cultivated land in Manitoba (1981)
82-2	Manitoba weed survey questionnaire data (1981)
83-1	Weed survey of Essex and Kent counties (1978 and 1979)
83-2	Essex and Kent counties - weed survey questionnaire data (1978 and 1979)
83-3	The 1979 weed survey of grain fields in Prince Edward Island
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86-4	Fort Vermilion Area of Alberta weed survey in cereal and oilseed fields (1985)
87-1	Weed survey of Saskatchewan cereal and oilseed crops (1986)
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PREFACE

A third round of herbicide-resistant weed surveys across the prairies was initiated in 2014 and will be concluded in 2017. This project involves a survey of resistant weeds in 800 randomly-selected fields: 400 in Saskatchewan in 2014 and 2015, 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 2009 Saskatchewan weed resistance survey report published in 2012. This report documents the nature, distribution and abundance of herbicide-resistant weeds in Saskatchewan in 2014-15. As indicated above, 400 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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Special thanks are extended to the 400 producers who participated in this survey project.

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

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EXECUTIVE SUMMARY

A survey of weeds resistant to herbicides in 400 randomly selected fields was conducted across the major agricultural ecoregions of Saskatchewan in 2014 and 2015. All residual weed species with mature seeds were mapped and sampled before harvest. Selected fields were cropped to cereals (52%), oilseeds (34%), or pulses (14%). Samples of 18 weed species (5 grass, 13 broadleaf) were subsequently screened in pot assays in the greenhouse using Group 1 or Group 2 herbicides (i.e., tier-1 screening).

Overall, 57% (227/400) of surveyed fields had an herbicide-resistant (HR) weed biotype, compared with 31% of fields in 2009 and 10% of fields in 2003. Of 301 fields where wild oat (*Avena fatua* L.) were collected, 65% had an HR population (49% of the 400 surveyed fields), compared with 35% of sampled fields in 2009 and 13% in 2003. Group 1-HR wild oat was confirmed in 59% of fields where the weed was sampled (45% of all 400 surveyed fields), compared with 32% of fields sampled in 2009 and 10% of fields in 2003. Group 2-HR wild oat was found in 32% of fields sampled (21% of all surveyed fields), compared with 7% of sampled fields in 2009 and 4% of fields in 2003. Group 1+2-HR wild oat was confirmed in 25% of fields sampled (16% of all surveyed fields), compared with 5% of fields sampled in 2009 and 1% of fields in 2003.

Of 104 fields where green foxtail [*Setaria viridis* (L.) P. Beauv.] seeds were collected, 31% had an HR population. This incidence of resistance compares to 14% of fields in 2009. Group 1-HR green foxtail was found in 17% of fields where the weed was sampled. Group 2-HR green foxtail was found in 15% of fields; this is the first survey in Saskatchewan to document Group 2 resistance in this weed. Two fields had Group 1+2-HR green foxtail. Six broadleaf weed species had Group 2-HR populations: 20% of fields sampled with HR chickweed, 20% with HR cleavers, 10% with HR redroot pigweed, 23% with HR shepherd's-purse, 14% with HR stinkweed, and 25% with HR wild mustard. This is the first survey in Saskatchewan to document redroot pigweed, shepherd's-purse and stinkweed populations with Group 2 resistance.

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 4.8 million ha in Saskatchewan are infested with HR weeds, in a total field area of 8.7 million ha. The additional cost to manage HR weeds in Saskatchewan is estimated at $258 million annually.

Past Weed Resistance Surveys in Saskatchewan

Group 1 [acetyl-CoA carboxylase (ACC) inhibitor] herbicide-resistant (HR) wild oat (*Avena fatua* L.) in the Prairies was first discovered in a population from Saskatchewan in 1984 (Joseph et al. 1990), but comprehensively characterized in three populations from Saskatchewan and Manitoba investigated in 1990 (Heap et al. 1993). In 1991, Group 3 (dinitroaniline)-HR green foxtail [*Setaria viridis* (L.) P. Beauv.] was the second HR grass weed biotype discovered in Saskatchewan (Heap 2017). A survey to characterize the nature, distribution, and abundance of HR wild oat and green foxtail was conducted across the four major agricultural ecoregions of Saskatchewan in 1996 (Beckie et al. 1998, 1999a, 1999b). An ecoregion is an area of similar climate, natural vegetation, soils, and land use (Agriculture and Agri-Food Canada 2003) (Figure 1). Information from the 1995 Saskatchewan weed survey (Thomas et al. 1996) was used to identify high-risk fields, based on: (a) ≥ 50% frequency of herbicide group use from 1990 to 1995; (b) high weed density (≥ 95th percentile in each of the four ecoregions); and (c) producer's suspicion of resistance.

The survey found that half of the 203 fields where wild oat seed was collected had Group 1-HR wild oat; resistance to aryloxyphenoxypropionate (APP) herbicides occurred more frequently than to cyclohexanedione (CHD) herbicides. Only 5% of producers suspected Group 1-HR wild oat. Eighteen percent of Group 1-HR populations exhibited Group 2 [acetolactate synthase (ALS) inhibitor] resistance as well, even though imidazolinones had generally been applied infrequently in those fields. Only one field had Group 8 (triallate)-HR wild oat, and none of the fields had Group 3-HR wild oat.

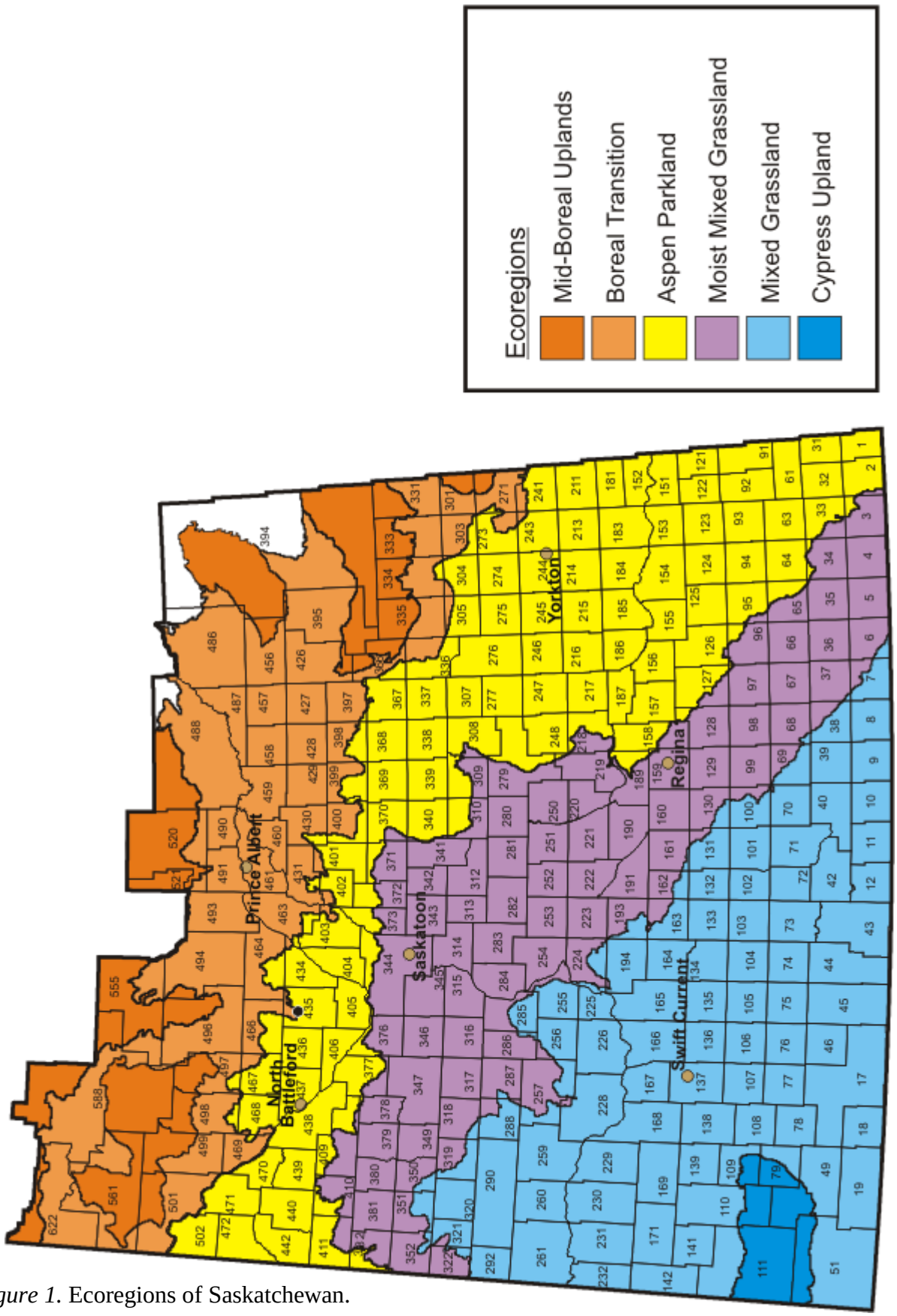

Figure 1. Ecoregions of Saskatchewan.

Of the 107 fields where green foxtail seed was collected, 18% had Group 1-HR biotypes and 11% had Group 3-HR biotypes. This was the first survey to document the occurrence of Group 1-HR green foxtail in the province. Intergroup-HR green foxtail (Groups 1 and 3) was confirmed in one field. Distribution and abundance of Group 1-HR wild oat and green foxtail reflected past Group 1 herbicide use across ecoregions. Group 1 herbicides were used in 56% of surveyed fields in Saskatchewan in 1996, with highest use in the Parkland region (Aspen Parkland and Boreal Transition ecoregions).

The nature and occurrence of herbicide resistance in wild oat in annual crops grown in the Grassland (Mixed Grassland and Moist Mixed Grassland ecoregions) and Parkland regions of Saskatchewan were determined in a systematic survey of fields in two townships in 1997 (Beckie et al. 1999c, 2002). The survey found that over half of the fields in both townships had populations resistant to Group 1, Group 2, and/or Group 8 herbicides. Forty-three percent of fields in the Grassland township and 48% of fields in the Parkland township had Group 1-HR wild oat; 30 and 17% of fields in the Grassland and Parkland township, respectively, had populations exhibiting Group 2 resistance, whereas about 15% of fields in both townships had Group 8-HR wild oat. Based on 1996 survey results, more fields with Group 2-HR wild oat in the Parkland vs. Grassland township was expected. Fields in the Parkland township had higher mean levels of Group 1 resistance (percentage HR seeds) than fields in the Grassland township, suggesting they were subjected to more Group 1 herbicide applications. Single (Groups 1, 2, or 8) and intergroup resistance (1+2; 1+8; 2+8; 1+2+8) were exhibited in populations in fields in both townships. The proportion of fields with populations exhibiting Group 1 (single) resistance was higher and Group 2 and Groups 1+2 resistance were lower in the Parkland than in the Grassland township. Frequency of occurrence of resistance was not generally affected by farm

size. The nature of resistance in wild oat populations was more diverse, differences in distribution and abundance of HR wild oat biotypes between Grassland and Parkland regions were generally less apparent, and occurrence of resistance was more prevalent than documented previously.

A grain elevator survey to characterize the nature, distribution, and abundance of HR wild oat and green foxtail was conducted across Saskatchewan in 1997 (Beckie and Juras 1998; Beckie et al. 1999a, 1999b). Seed samples were collected from a general pool of screenings at an elevator location. Wild oat screenings were received from 70 elevators and green foxtail screenings were received from 30 elevators. The average radius serviced by an elevator was 24 km. The survey found that: (a) 63% of elevator locations had wild oat resistant to Group 1 herbicides: 17% of the locations had CHD-HR wild oat and 59% had APP-HR wild oat. In all ecoregions, greater than half of the elevator sites had Group 1-HR wild oat; frequency of occurrence was highest in the Boreal Transition ecoregion (85% of elevators); (b) the level of CHD resistance in wild oat, i.e., percentage of tested seed that was HR, tended to be highest in the Moist Mixed Grassland ecoregion and adjacent areas of the Aspen Parkland ecoregion. Highest levels of APP resistance in wild oat also occurred in these ecoregions; (c) 83% of elevator locations had Group 1-HR green foxtail. Most elevators in the Mixed Grassland, Moist Mixed Grassland, and Aspen Parkland ecoregions and all locations in the Boreal Transition ecoregion had Group 1-HR green foxtail. However, only one elevator, which was located in the Aspen Parkland ecoregion, had CHD-HR green foxtail; (d) 23% of elevator locations had Group 2-HR wild oat, with highest incidence in the Parkland region. The level of Group 2 resistance was highest in the Boreal Transition ecoregion, where use of imidazolinone herbicides was highest; (e) only one elevator, which was located in the Aspen Parkland ecoregion, had Group 3-

HR green foxtail; (f) 24% of elevator locations had Group 8-HR wild oat, with highest incidence in the Moist Mixed Grassland ecoregion. The results of this grain elevator weed survey generally paralleled the findings of the 1996 field survey, except for the higher incidence of Group 8-HR wild oat documented in this survey compared with the field survey.

Based on wild oat samples submitted to the Crop Protection Lab, Saskatchewan Ministry of Agriculture from Saskatchewan producers (or industry on behalf of producers) between 1996 and 2011, 507 were HR: Group 1: 479; Group 2: 12; Group 1+2: 16 (Beckie et al. 2007; Beckie and Brenzil 2012). The cross-resistance pattern of the Group 1-HR samples were as follows: APP, 182; CHD, 11; APP+CHD, 276; APP+DEN (pinoxaden), 10; APP+CHD+DEN, 16 (DEN testing only upon request). During this period, there were 7 cases of Group 1-HR green foxtail (14 cases of Group 3-HR green foxtail) and 5 cases of Group 1-HR Persian darnel [*Lolium persicum* Boiss. & Hohen. ex Boiss.].

Group 2-HR kochia [*Kochia scoparia* (L.) Schrad.] was first discovered in Saskatchewan in 1988 (Morrison and Devine 1994). From 1996 to 2011, 27 kochia samples from Saskatchewan submitted for testing were Group 2-HR (Beckie et al. 2007; Beckie and Brenzil 2012). This HR biotype is now widespread across the Prairies (> 90% of populations) (Beckie et al. 2011); today, all tested populations are Group 2-HR. Group 2 resistance was first discovered in Russian thistle (*Salsola tragus* L.) in 1989 (Morrison and Devine 1994; Warwick et al. 2010), and in wild mustard (*Sinapis arvensis* L.) near Yorkton in 2002 (Warwick et al. 2005). From 1996 to 2011, 23 wild mustard samples from Saskatchewan submitted for testing were Group 2-HR. Additionally during this period, there were 22 cases from Saskatchewan of Group 2-HR cleavers (*Galium spurium* L.) (Beckie et al. 2012), four cases of Group 2-HR shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.], one case of Group 2-HR chickweed [*Stellaria media* (L.) Vill.], and

four cases of Group 2-HR stinkweed (*Thlaspi arvense* L.) (Beckie et al. 2007; Beckie and Brenzil 2012).

A baseline survey of weeds resistant to herbicides in 400 randomly selected fields was conducted across the major agricultural ecoregions of Saskatchewan in 2003 (Beckie et al. 2006, 2008). All residual weed species with mature seeds were mapped and sampled before harvest. Selected fields were cropped to cereals, oilseeds, and pulses. Samples of 23 weed species were subsequently screened in the greenhouse with high-risk herbicides belonging to Groups 1 and 2. Producers provided information on herbicide use, herbicide group rotation, and resistance awareness and impact by means of a questionnaire.

Over 10% of surveyed fields had an HR weed biotype. Of 291 fields where wild oat was collected, 10% had Group 1 resistance but only 4% had Group 2 resistance. Most Group 1-HR wild oat populations exhibited resistance to both APP and CHD herbicides. Group 2-HR populations exhibited broad cross-resistance across three classes of Group 2 herbicides. Most Group 1- or 2-HR wild oat populations originated in the Parkland region. Unexpectantly, resistance in green foxtail was not detected in all 141 fields where samples were collected. Of 18 broadleaf weed species, Group 2 resistance was detected only in kochia. Most of the eight fields with Group 2-HR kochia were located in the Aspen Parkland ecoregion. However, most kochia seed samples were non-viable.

Although 70% of producers who completed a management questionnaire in 2003 practiced herbicide group rotation, the application of Group 1 herbicides in nearly 50% of fields that year indicated that the use of these products was still resulting in high selection pressure for resistance. Less than 5% of producers with HR wild oat previously suspected or were aware of their occurrence. This low level of awareness was consistent with findings from previous

surveys, and may be partly attributed to the relatively small infestation area of HR biotypes in most fields. Nevertheless, it was estimated that over 300,000 ha of land in Saskatchewan was infested with HR weeds in a total field area of 1.6 million ha. In 2003, only 10% of producers believed that resistance had a significant impact on their farm. In the next 5 years, 25% producers expected herbicide resistance to pose a moderate or high impact on their farm.

A second-round survey of weeds resistant to herbicides in 400 randomly selected fields was conducted six years later across the major agricultural ecoregions of Saskatchewan in 2009. All residual weed species with mature seeds were mapped and sampled before harvest. Selected fields were cropped to cereals (52%), oilseeds (33%), or pulses (15%). Samples of 23 weed species (6 grass, 17 broadleaf) were subsequently screened in pot assays in the greenhouse using herbicides with modes of action commonly used in the Prairies.

Overall, 31% (124/400) of surveyed fields had an HR weed biotype, compared with 10% of fields in 2003. Of 300 fields where wild oat were collected, 32% had Group 1 resistance (vs. 10% in 2003), 7% had Group 2 resistance (vs. 4% in 2003), and 3% had Group 8 resistance (not tested in 2003). Most Group 1- or Group 2-HR wild oat populations exhibited broad cross-resistance across herbicide classes. Group 1+2-HR wild oat was found in 5% of fields (vs. 1% in 2003). Overall, 36% of fields where wild oat samples were collected had an HR biotype.

Of 103 fields where green foxtail seeds were collected, 14% had Group 1 resistance (vs. none detected in 2003). Group 1-HR Persian darnel was found in one field in the Moist Mixed Grassland ecoregion. Of 17 broadleaf weed species (kochia was not sampled in this survey), Group 2 resistance was confirmed in wild mustard in 25% of fields sampled and false cleavers in 21% of fields sampled. These HR biotypes had previously been found in Saskatchewan, although they were not detected in the 2003 survey.

The results of the 2009 survey highlighted the continual increase in field frequency of Group 1-HR wild oat and to a lesser extent green foxtail, and Group 2-HR cleavers (and to a lesser extent wild mustard). Group 2 resistance in kochia is already widespread, as determined from previous surveys; in recent years, all tested populations were confirmed Group 2-HR. However, incidence of Group 2- or 8-HR wild oat remains low, and weed resistance to herbicides from Groups 4, 9, or 10 was not detected. Based on the 2009 survey, it was estimated that 3.9 million ha in Saskatchewan were infested with HR weeds, in a total field area of 4.6 million ha. More recently in a random survey of 342 sites in Saskatchewan in 2013, 17 (5%) had glyphosate (and ALS)-HR kochia (Beckie et al. 2015).

Objective

In 2014 and 2015, 400 fields (ca. 200 fields each year) 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 400 fields were surveyed for HR weeds (Map 1). Each field was farmed by a different producer. Similar to the general weed survey (Leeson 2016), 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 general weed survey. Fields were randomly selected from the list of qualified fields. Each sampling unit comprised 64 ha (160 ac). The crop allocation across the ecoregions of Saskatchewan is shown in Table 1. A majority of fields (52%) were cropped to cereals. Wheat occupied 76% of the 210 cereal fields, barley 15%, and oat 9%. Oilseeds occupied 34%: canola 77% of oilseed crop area, flax 19%, and mustard 4%. Pulse crops comprised 14% of surveyed fields, with field pea at 45% and lentil at 55% of pulse crop area.

Table 1. Field allocation by crop in Saskatchewan ecoregions

Crop	Mixed Grassland[a]	Moist Mixed Grassland	Aspen Parkland	Boreal Transition	All Areas
	No. of fields				
Wheat	48	34	55	22	159
Barley	5	10	11	6	32
Oat	4	1	8	6	19
Canola	7	21	46	32	106
Flax	1	10	9	6	26
Mustard	2	3	0	0	5
Field pea	10	6	7	1	24
Lentil	14	15	0	0	29
Sub-total	*91*	*100*	*136*	*73*	*400*
% of Total	*23*	*25*	*34*	*18*	*100*

[a]The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Boreal Transition ecoregion includes the Mid-Boreal Uplands.

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.

About 60% of the 18 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2014-15 (Leeson 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.

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-tier screening to herbicides from other groups may be conducted in the future depending upon availability of greenhouse bench space.

Table 2. Weed species tested for resistance

Weed species	Samples tested	Fields	Rank[a]
	No.		
Grass:			
Barnyard grass, *Echinochloa* spp.	12	12	12
Green foxtail, *Setaria viridis* (L.) Beauv.	108	104	1
Persian darnel, *Lolium persicum* Boiss. & Hohen. ex Boiss.	3	3	54
Yellow foxtail, *Setaria pumila* (Poir.) Roem. & Schult.	4	4	81
Wild oat, *Avena fatua* L.	350	301	2
Broadleaf:			
Chickweed, *Stellaria media* (L.) Vill.	15	15	18
Cleavers, *Galium* spp.	62	62	7
Cow cockle, *Vaccaria hispanica* (Mill.) Rauschert	2	2	53
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	9	8	50
Kochia, *Kochia scoparia* (L.) Schrad.	18	18	15
Lamb's-quarters, *Chenopodium album* L.	11	11	8
Narrow-leaved hawk's beard, *Crepis tectorum* L.	5	5	9
Redroot pigweed, *Amaranthus retroflexus* L.	21	21	23
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	13	13	14
Smartweed (annual), *Polygonum* spp.	4	4	24
Stinkweed, *Thlaspi arvense* L.	29	29	11
Wild buckwheat, *Polygonum convolvulus* L.	24	24	3
Wild mustard, *Sinapis arvensis* L.	25	24	21

[a] Relative abundance rank of species in 2,242 fields surveyed in 2014-15 (Leeson 2016); rank of annual smartweed spp. is that of pale smartweed.

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 seedlings per sample were screened in each resistance test. Treatments (and untreated controls) were replicated three times and the tests were repeated. Known HR and herbicide-susceptible biotypes were included in all tests (Beckie et al. 2000).

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.

Grass Weed Resistance

Of the 301 fields where wild oat samples were collected, 196 (65%) had an HR population (49% of the 400 surveyed fields). In contrast, 35% of fields with wild oat had an HR population in the 2009 survey (Beckie et al. 2012, 2013) and 13% of fields in the 2003 survey (Beckie et al. 2006, 2008). Group 1-HR wild oat was confirmed in 178 fields (59%) (Table 4, Map 2) or 45% of all 400 surveyed fields. This incidence of Group 1 resistance compares with 32% of fields in 2009 and 10% of fields in 2003. Of fields with wild oat, incidence was proportionally greatest in the Grassland than Parkland region (especially Boreal Transition ecoregion), which differs from the trend found in the previous two surveys, i.e., incidence greatest in the Parkland region.

Group 2-HR wild oat was found in 83 fields (32%) where the weed was sampled (21% of the 400 surveyed fields), with greatest occurrence in the Moist Mixed Grassland ecoregion (Table 4, Map 3). Of populations screened for Group 1 resistance, 42 fewer populations were screened for Group 2 resistance because of lack of sufficient seed. Incidence of Group 2-HR wild oat has increased sharply since 2009 (7% of fields) and 2003 (4% of fields), largely attributed to

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.	%	
Mixed Grassland[b]	55	68	60	18	23	20
Moist Mixed Grassland	48	71	48	30	46	30
Aspen Parkland	55	59	40	24	33	18
Boreal Transition	20	34	27	11	27	15
Saskatchewan	*178*	*59*	*45*	*83*	*32*	*21*

[a]Tested: fields where seeds were collected (Gp 1: n=301; Gp 2: n=259); surveyed: all fields surveyed (n=400).
[b]The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Boreal Transition includes the Mid-Boreal Uplands ecoregion.

increased Group 2 wild oat herbicide use to manage Group 1-HR wild oat.

Group 1+2-HR wild oat was found in 65 fields (25%) where the weed was present: 14 fields (18%) in the Mixed Grassland ecoregion, 25 fields (39%) in the Moist Mixed Grassland ecoregion, 18 fields (25%) in the Aspen Parkland ecoregion, and 8 fields (20%) in the Boreal Transition ecoregion (Map 4). The occurrence of this HR biotype compares with 5% of fields sampled in 2009 and 1% of fields in 2003. Therefore, of the 196 fields with HR wild oat populations, 113 had Group 1 resistance only, 18 had Group 2 resistance only, and 65 had Group 1 plus 2 resistance. 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 3% of fields in 2009 (Beckie et al. 2012, 2013). 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.

Of 104 fields where green foxtail was sampled, 32 fields (31%) had an HR population (Table 5). This incidence of resistance compares to 14% of fields in 2009 (Beckie et al. 2012, 2013), and no fields detected with resistance in 2003 (Beckie et al. 2006, 2008). Group 1-HR green foxtail was found in 18 fields (17%) where the weed was sampled (Map 5). Group 2-HR green foxtail was found in 16 fields (15%) (Table 5, Map 6) with most sites located in the Parkland region. This is the first survey in Saskatchewan to document Group 2 resistance in this

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.	%	
Mixed Grassland[b]	1	4	1	0	0	0
Moist Mixed Grassland	8	20	8	2	5	2
Aspen Parkland	6	19	4	10	32	7
Boreal Transition	3	38	4	4	50	6
Saskatchewan	*18*	*17*	*5*	*16*	*15*	*4*

[a]Tested: fields where seeds were collected (n=104); surveyed: all fields surveyed (n=400).
[b]The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Boreal Transition includes the Mid-Boreal Uplands ecoregion.

weed. Of the 32 fields with HR green foxtail, 16 had Group 1 resistance only, 14 had Group 2 resistance only, and 2 had Group 1 plus 2 resistance (Map 7). Similar to multiple group resistance in wild oat, herbicide options to control Group 1+2-HR green foxtail become very limited in cereals.

Broadleaf Weed Resistance

Of 15 fields where chickweed was sampled, three (20%) had an HR population (Map 8). The three populations were located in the Parkland region where this weed is most abundant. Group 2-HR chickweed was not documented previously in the 2009 or 2003 surveys (Beckie et al. 2006, 2008, 2012, 2013). Group 2-HR cleavers was found in 12 of 62 fields (20%), located mostly in the Parkland region where the weed is most abundant (Map 9). Although not documented in the 2003 survey, this biotype was found in 21% of fields in the 2009 survey. Therefore, incidence of HR cleavers has not changed in the intervening 5-year period. Herbicide options to control this biotype in field pea is limited to bentazon (Group 6) (Government of Saskatchewan 2017).

This is the first survey in Saskatchewan to document three broadleaf weed species with Group 2-HR populations: redroot pigweed, shepherd's-purse, and stinkweed (Maps 10-12). Group 2-HR redroot pigweed was found in 2 of 21 fields (10%), in the Moist Mixed Grassland and Aspen Parkland ecoregions. Group 2-HR shepherd's-purse was found in 3 of 13 fields (23%), all in the Aspen Parkland ecoregion. Group 2-HR stinkweed was found in 4 of 29 fields (14%), one in the Mixed Grassland ecoregion, one in the Moist Mixed Grassland ecoregion, and two in the Aspen Parkland ecoregion.

Group 2-HR wild mustard was found in 6 of 24 fields (25%), a frequency of occurrence similar to that determined in 2009 (not detected in the 2003 survey). All HR populations were located in the Grassland ecoregion (Map 13). Herbicide options to control this biotype in lentil is limited to metribuzin (Group 5) (Government of Saskatchewan 2017).

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 Saskatchewan, densities of all weed species except redroot pigweed and kochia were greatest in the most recent field survey in 2014-2015 (Table 6). Of

Table 6. Post-herbicide treatment mean weed densities (no m^{-2}) in surveyed fields in Saskatchewan: 1995, 2003, and 2014-15 (Thomas et al. 1996; Leeson et al. 2003; Leeson 2016)

Weed	1995	2003	2014-15
Wild oat	7.6	7.4	8.3
Green foxtail	16.8	24.4	26.6
Chickweed	10.1	4.1	10.7
Cleavers	4.1	2.1	5.0
Redroot pigweed	1.9	6.6	4.3
Shepherd's-purse	4.3	2.4	4.4
Stinkweed	6.8	5.5	10.1
Wild mustard	2.7	3.2	8.6
Kochia	2.3	4.2	2.7

particular concern are species such as green foxtail and wild mustard that have consistently increased in density over the 20-year period.

Land Area Impacted by Herbicide-Resistant Weeds

When the frequency of fields with weed resistance in this random survey of 400 fields is extrapolated to the total annual-cropped land in Saskatchewan (15,369,634 ha or 37,963,022 ac in 2014-2015) (Statistics Canada 2017), it is estimated that 4.8 million ha (31%) are infested with HR weeds, in a total field area of 8.7 million ha (57%) (Table 7). In comparison, the weed resistance survey in 2009 indicated that 3.9 million ha was infested with HR weeds, in a total field area of 4.6 million ha; the weed resistance survey in 2003 indicated that 0.3 million ha was infested with HR weeds, in a total field area of 1.6 million ha. Therefore, the actual area infested

Table 7. Estimated annual-cropped land area in Saskatchewan impacted by herbicide-resistant (HR) weeds in 2014-2015[a]

Biotype	Infestation area (ac/ha)	Field area (ac/ha)
Gp 1-HR wild oat	4,684,333 / 1,896,491	10,724,504 / 4,341,904
Gp 2-HR wild oat	1,139,143 / 461,192	1,708,349 / 691,639
Gp 1+2-HR wild oat	3,340,364 / 1,352,374	6,168,956 / 2,497,553
Gp 1-HR green foxtail	666,051 / 269,656	1,518,467 / 614,764
Gp 2-HR green foxtail	380,056 / 153,869	1,328,732 / 537,948
Gp 1+2-HR green foxtail	94,941 / 38,438	189,882 / 76,875
Gp 2-HR chickweed	284,676 / 115,253	284,676 / 115,253
Gp 2-HR cleavers	380,056 / 153,869	1,138,850 / 461,073
Gp 2-HR redroot pigweed	189,882 / 76,875	189,882 / 76,875
Gp 2-HR shepherd's-purse	95,087 / 38,497	284,676 / 115,253
Gp 2-HR stinkweed	284,822 / 115,313	379,617 / 153,691
Gp 2-HR wild mustard	284,822 / 115,313	569,498 / 230,566
Total	11,824,233 / 4,787,140	21,544,094 / 8,722,305

[a] Gp 2 (4,9)-HR kochia, not included in these data, is estimated to infest 1,100,623 ac or 445,596 ha, in a field area of 5,732,412 ac or 2,320,815 ha; the area calculation is based on the general weed survey data (Leeson 2016) since all populations are assumed Gp-2-HR. Total field area is adjusted downward because some fields contain more than one HR biotype.

with HR weeds has increased by 23%, while the total field area affected has increased by 89% since the last survey.

Management Practices of Producers with Resistance

Based on the Saskatchewan weed survey questionnaire data, four 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, and use of preemergence herbicides (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 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

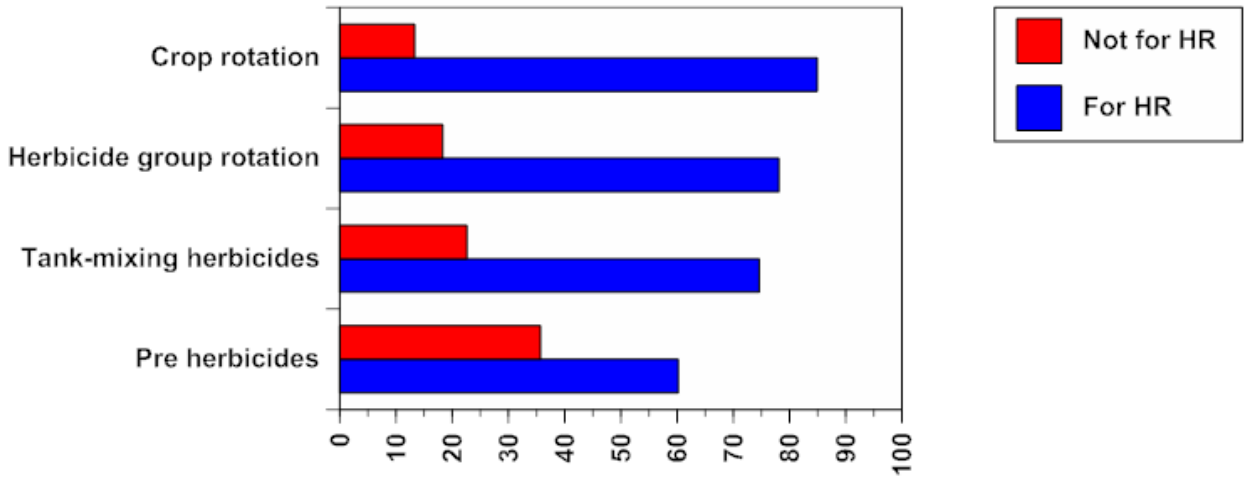

Figure 2. Targeted weed management practices: those with suspected or confirmed weed resistance (n=250 respondents; source: J.Y. Leeson, unpublished weed survey questionnaire data).

Table 8. The perceived cost of weed resistance to Saskatchewan producers (n=250 respondents; source: J.Y. Leeson, unpublished 2014-2015 weed survey questionnaire data).

Cost	% of respondents
No additional cost	7
$10/ac or less	41
$11-20/ac	23
$21-30/ac	11
$31-40/ac	6
$41-50/ac	4
Unknown cost	8

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) increasing crop seeding rates vs. those without resistance (G-test statistic; J. Leeson, unpublished data).

Cost of Weed Resistance

The perceived cost of weed resistance to Saskatchewan producers averages $12/ac or $30/ha, based on the 2014-2015 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 with the estimated field area affected by weed resistance, the total cost is estimated at $258 million annually.

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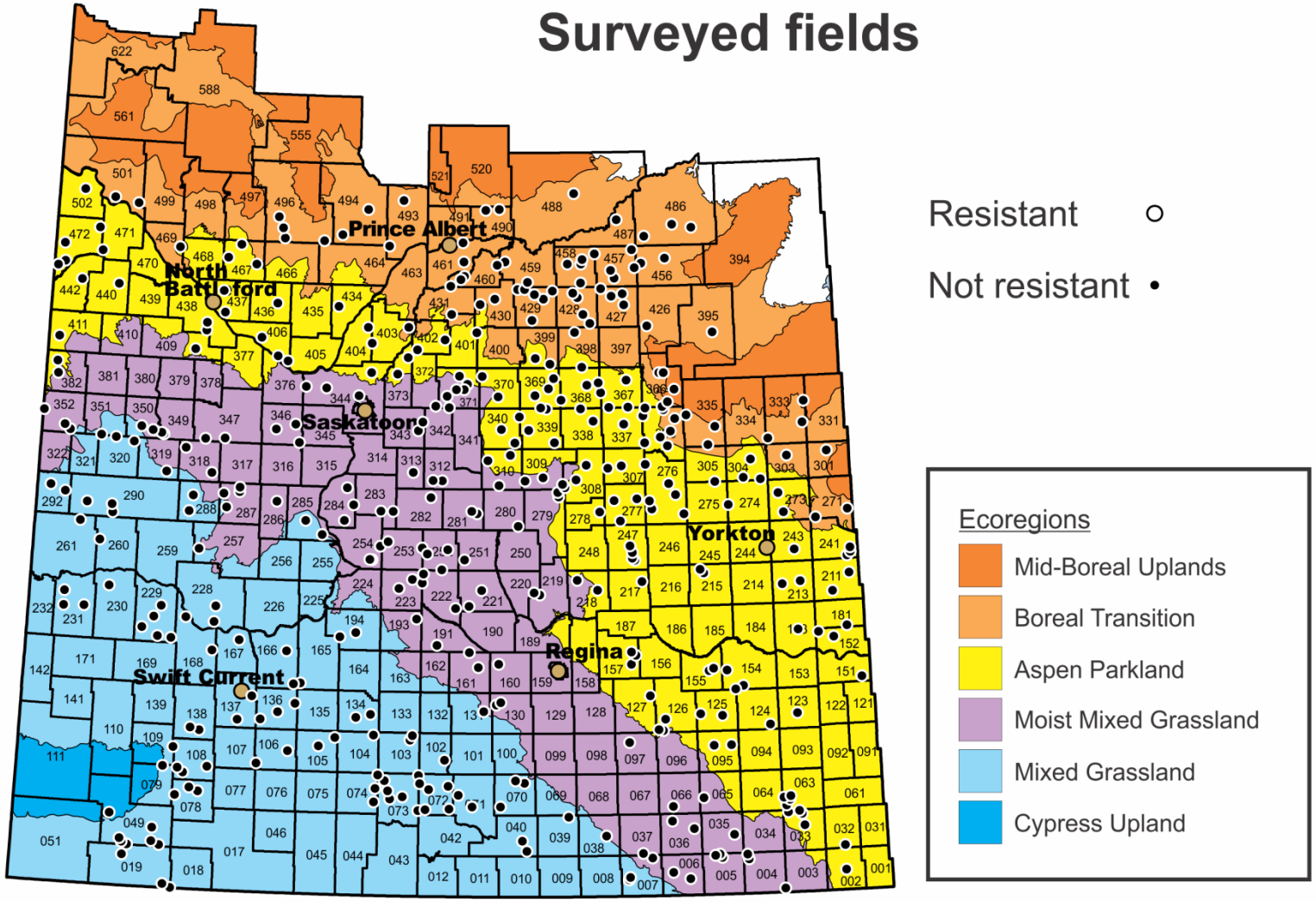
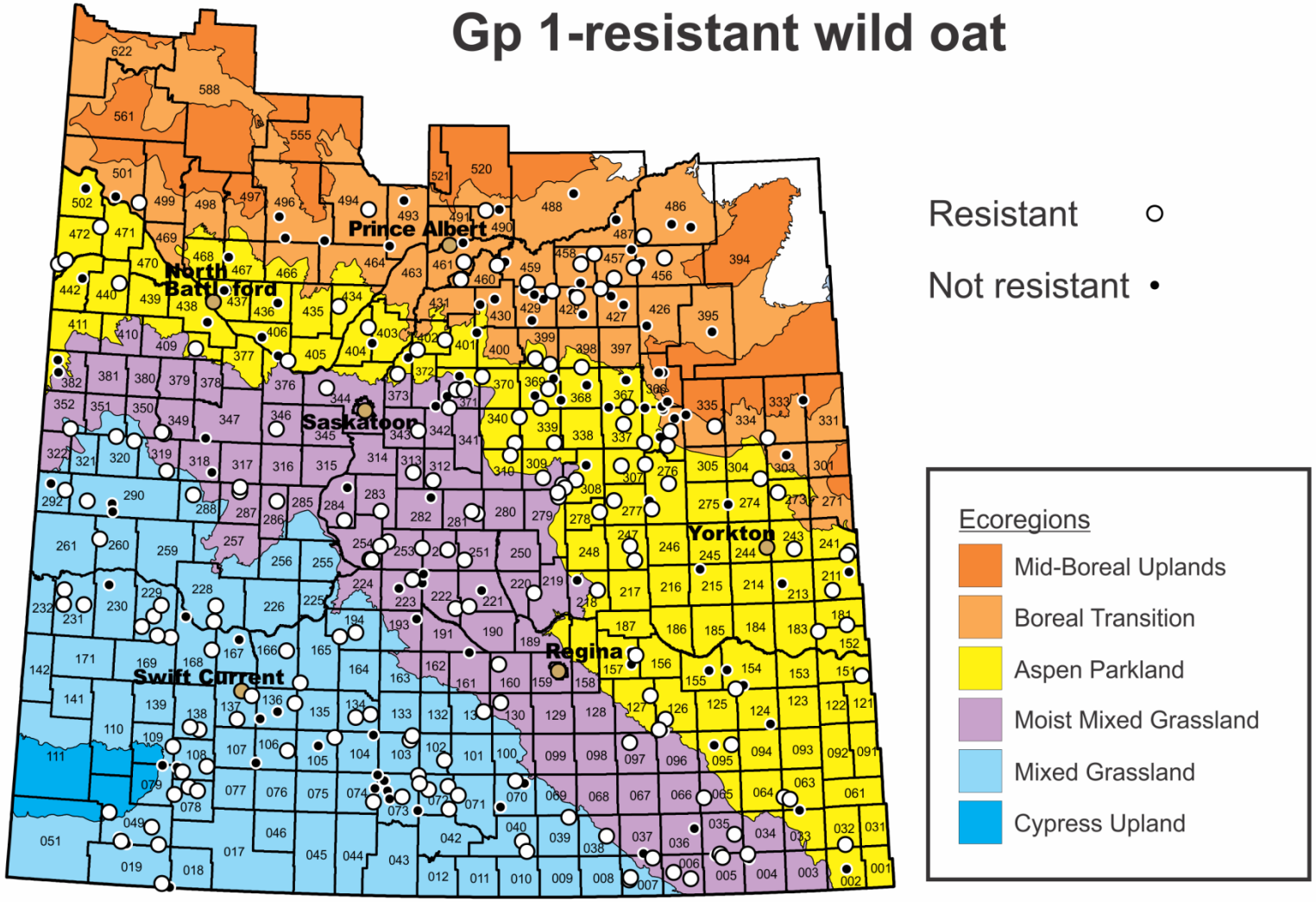
LIST OF MAPS

Surveyed fields



Gp 1-resistant wild oat



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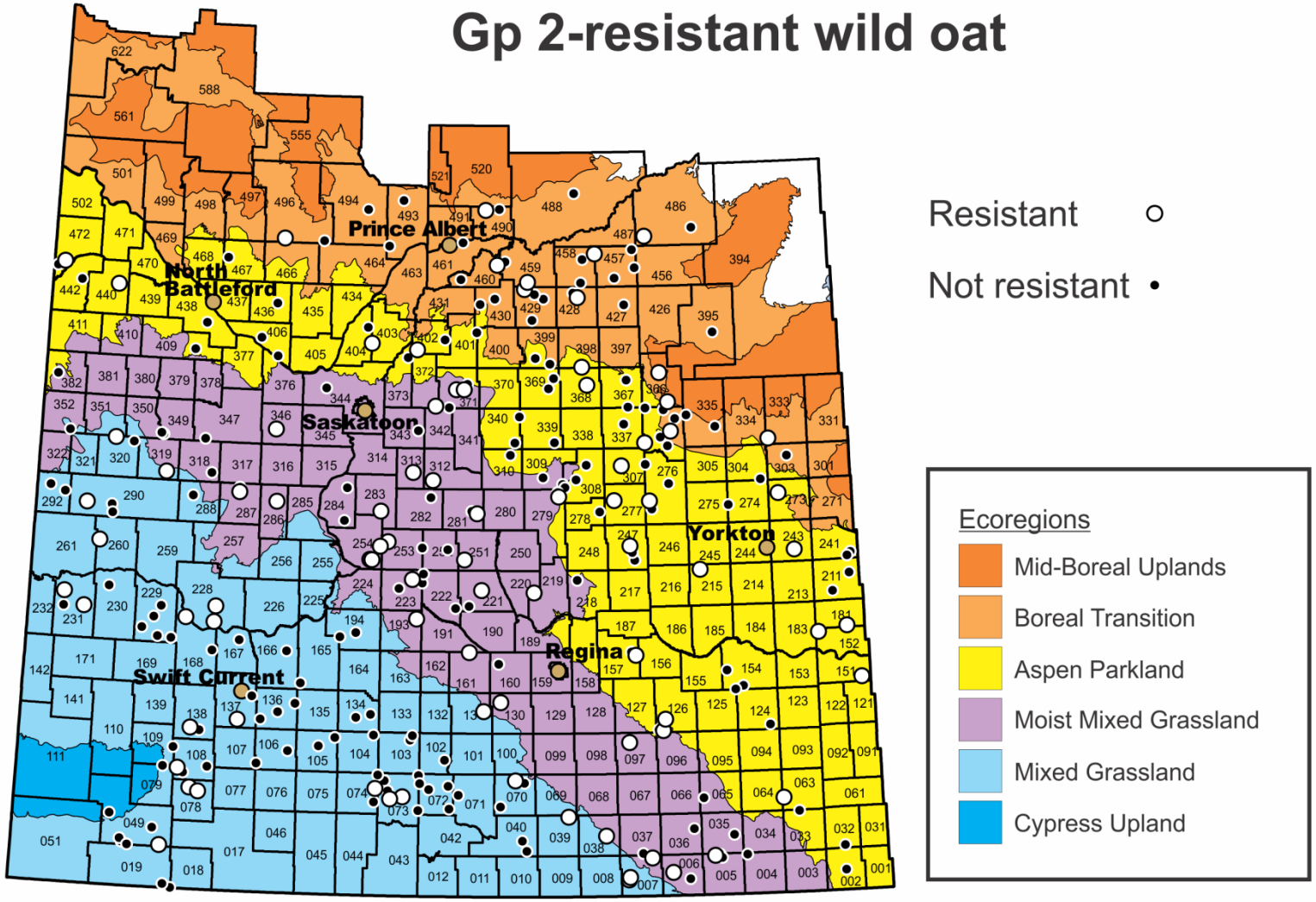

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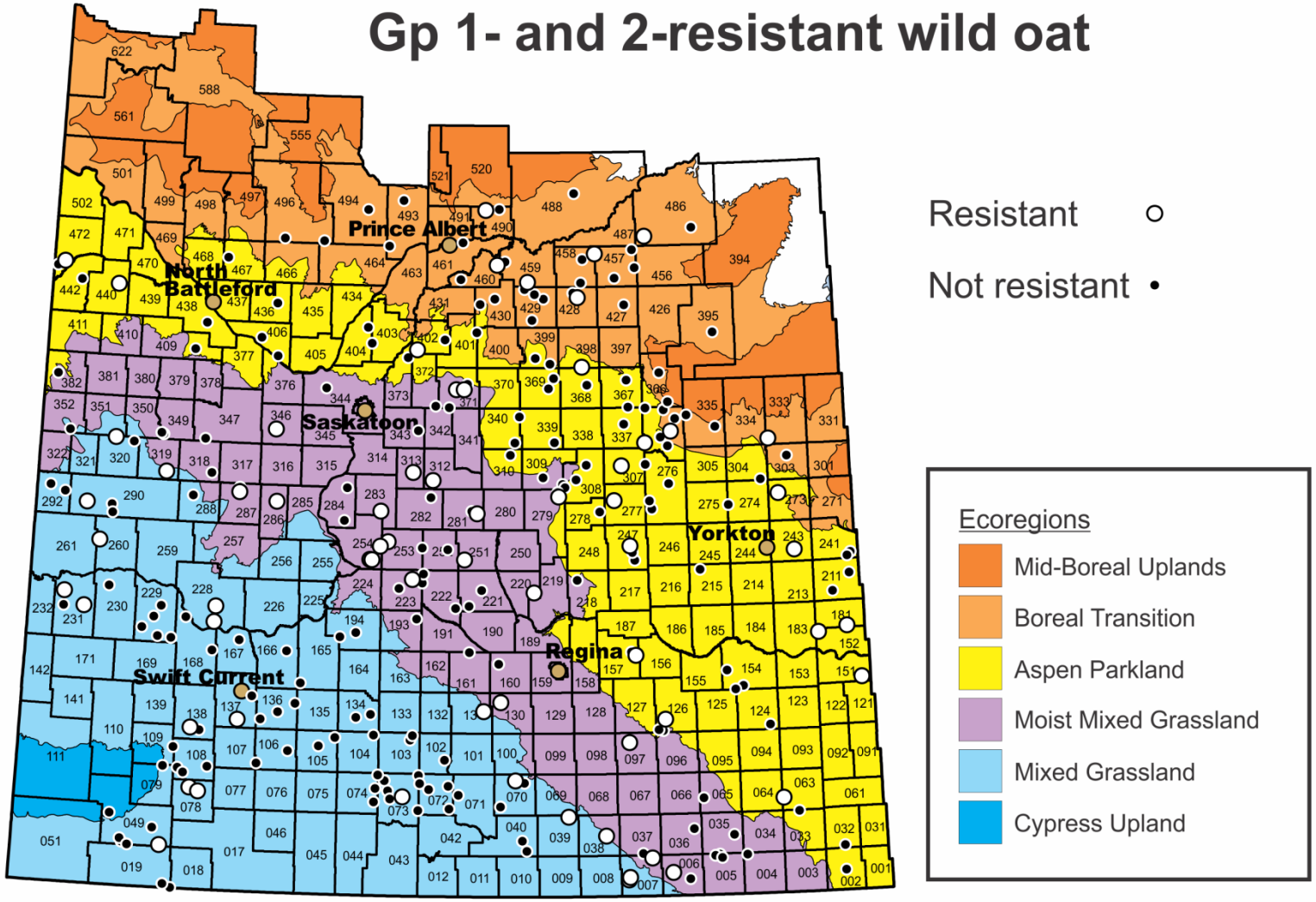
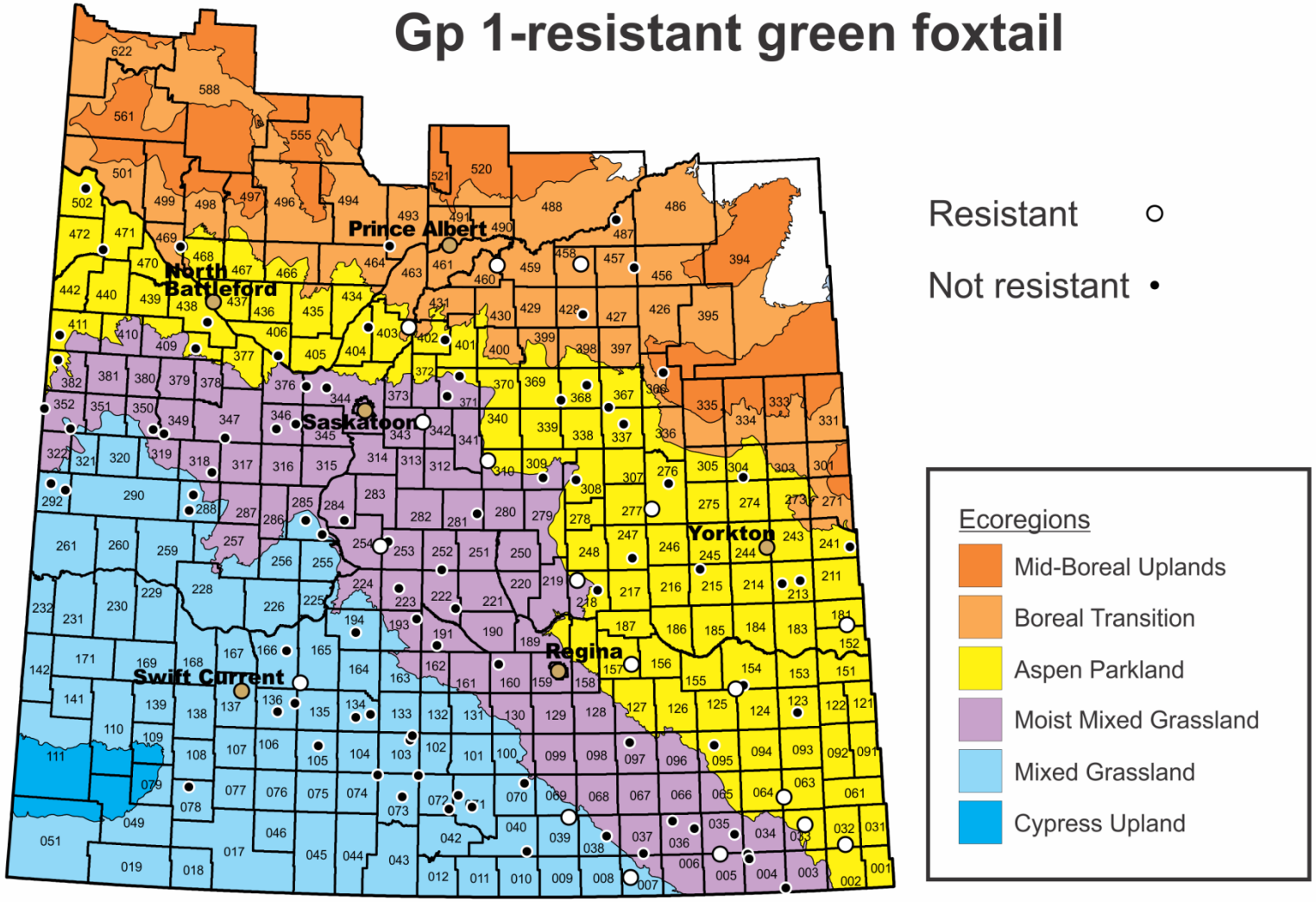
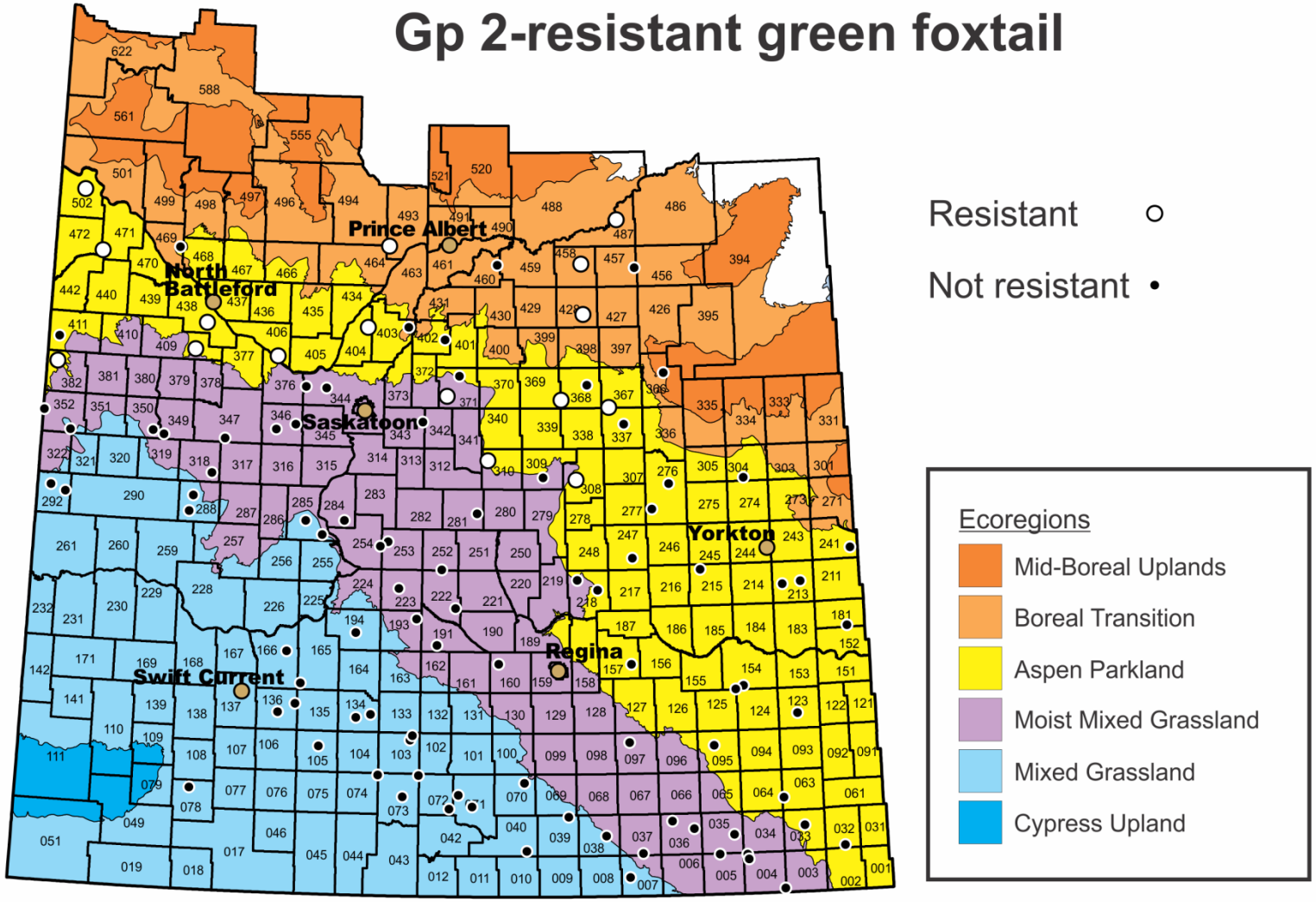


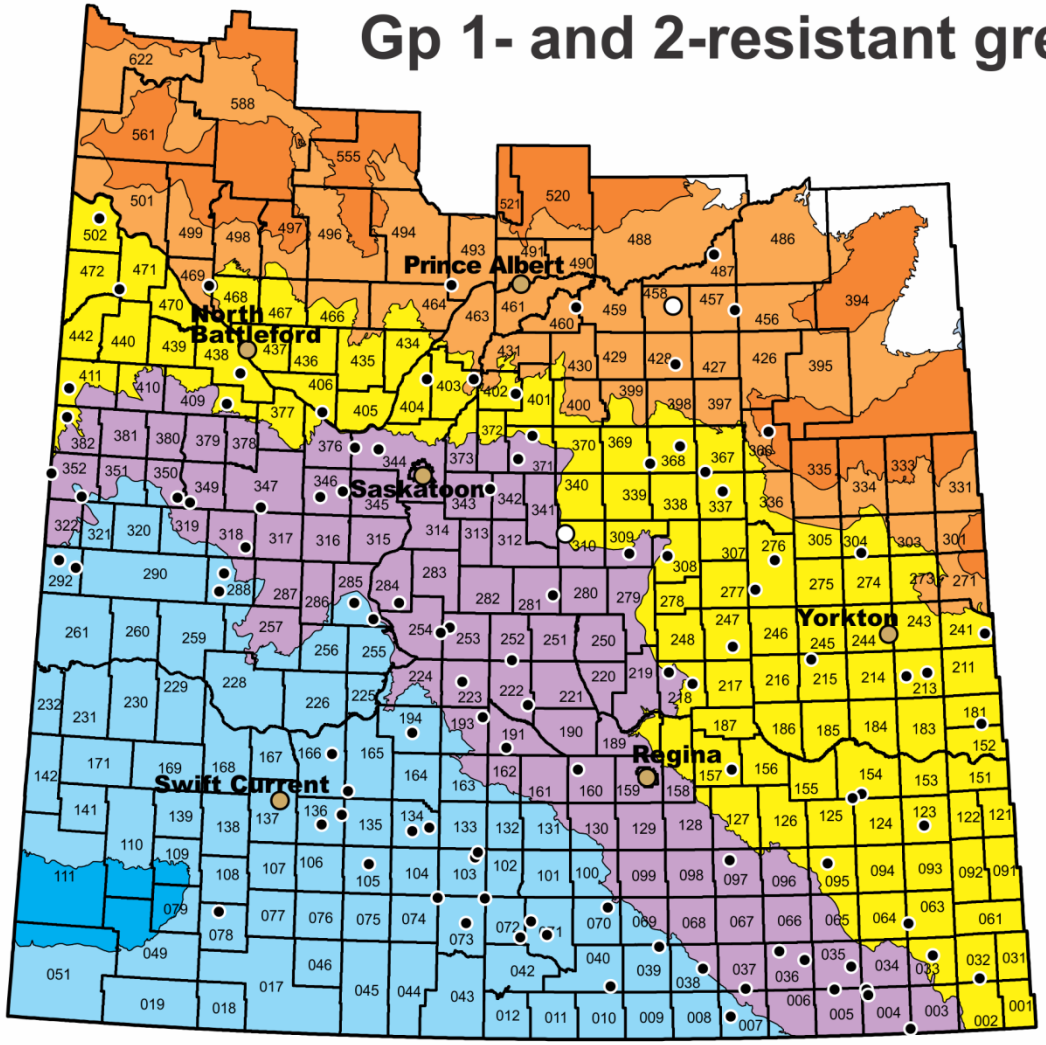
Gp 1-resistant green foxtail



Gp 2-resistant green foxtail



Gp 1- and 2-resistant green foxtail



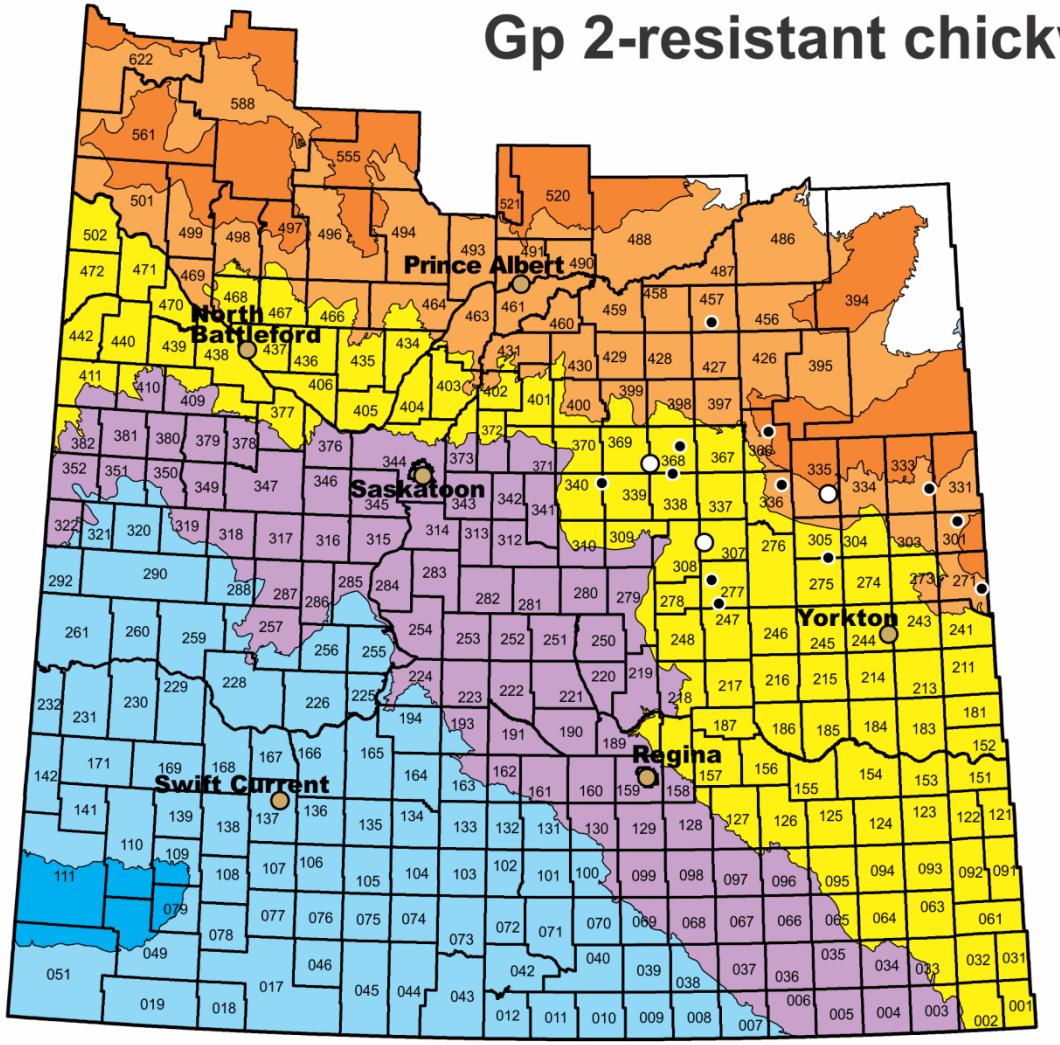
Resistant ○

Not resistant •

Ecoregions

- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

Gp 2-resistant chickweed



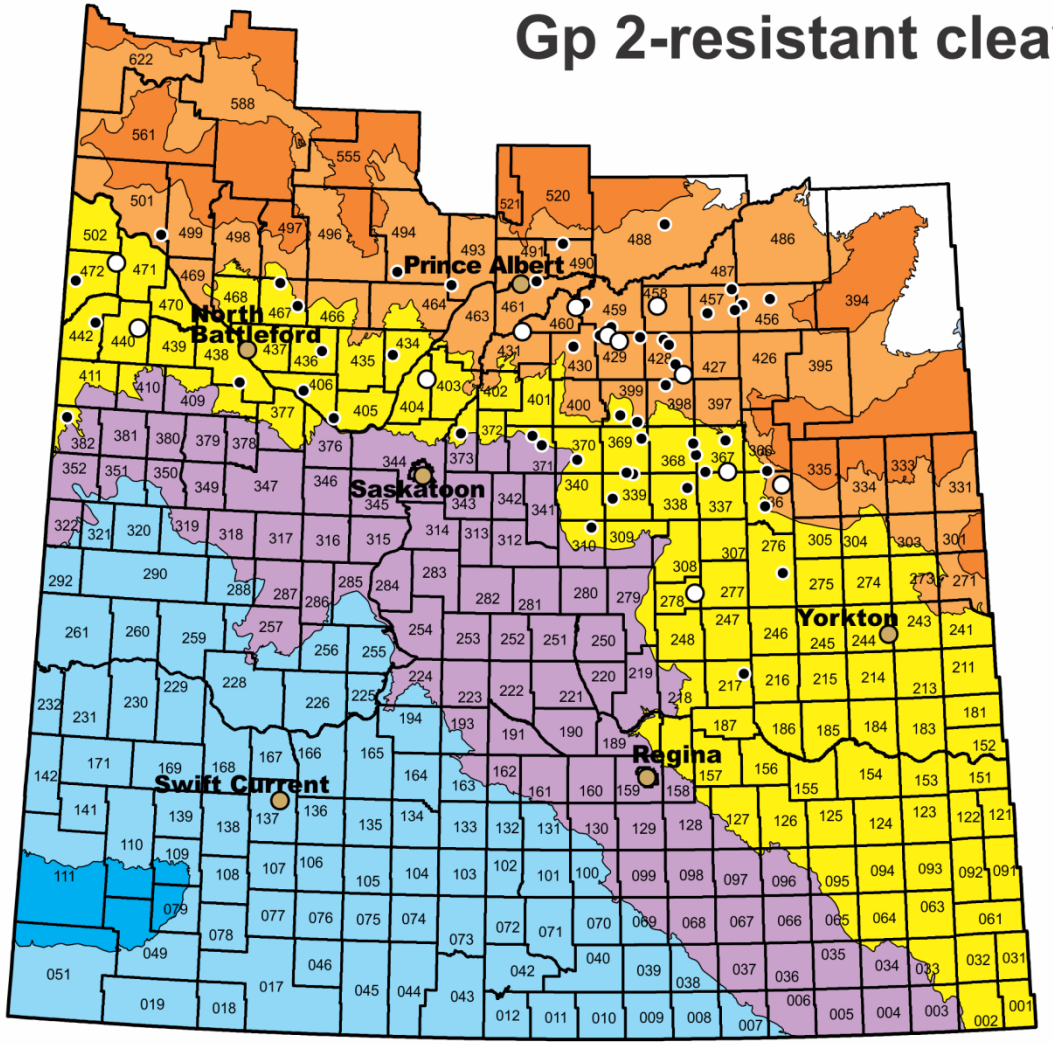
Resistant ○

Not resistant •

Ecoregions

- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

Gp 2-resistant cleavers



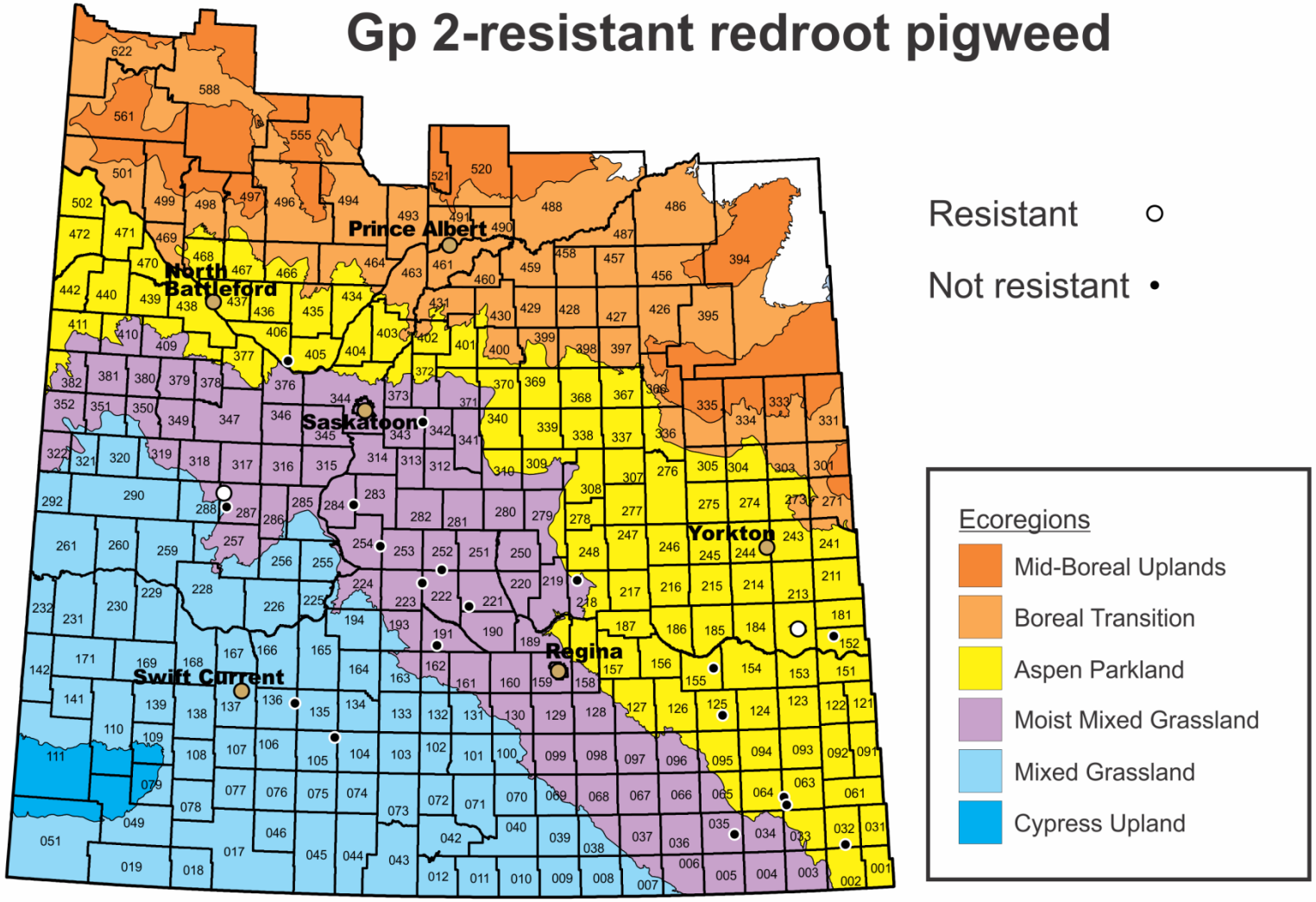
Resistant ○

Not resistant •

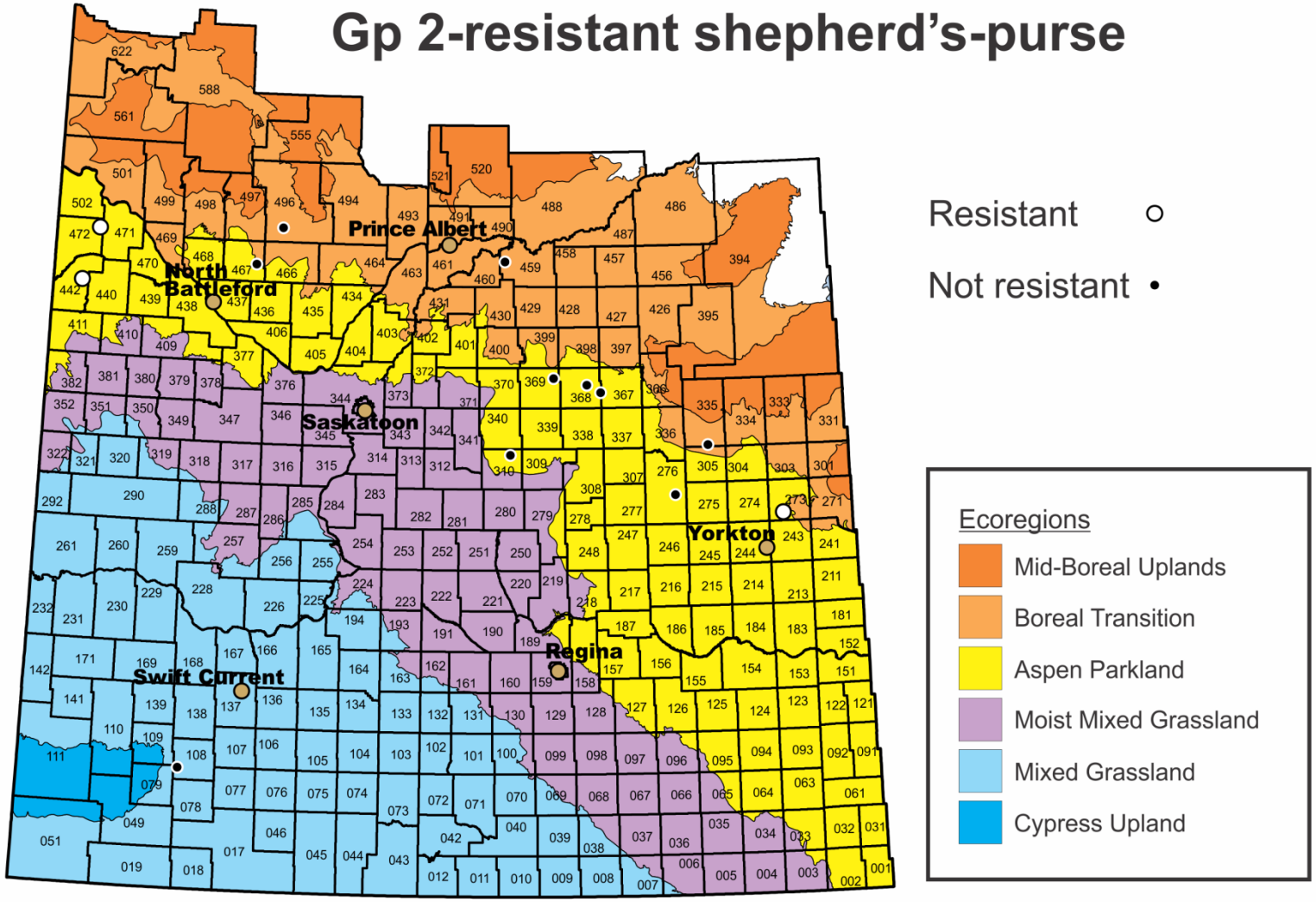
Ecoregions

- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

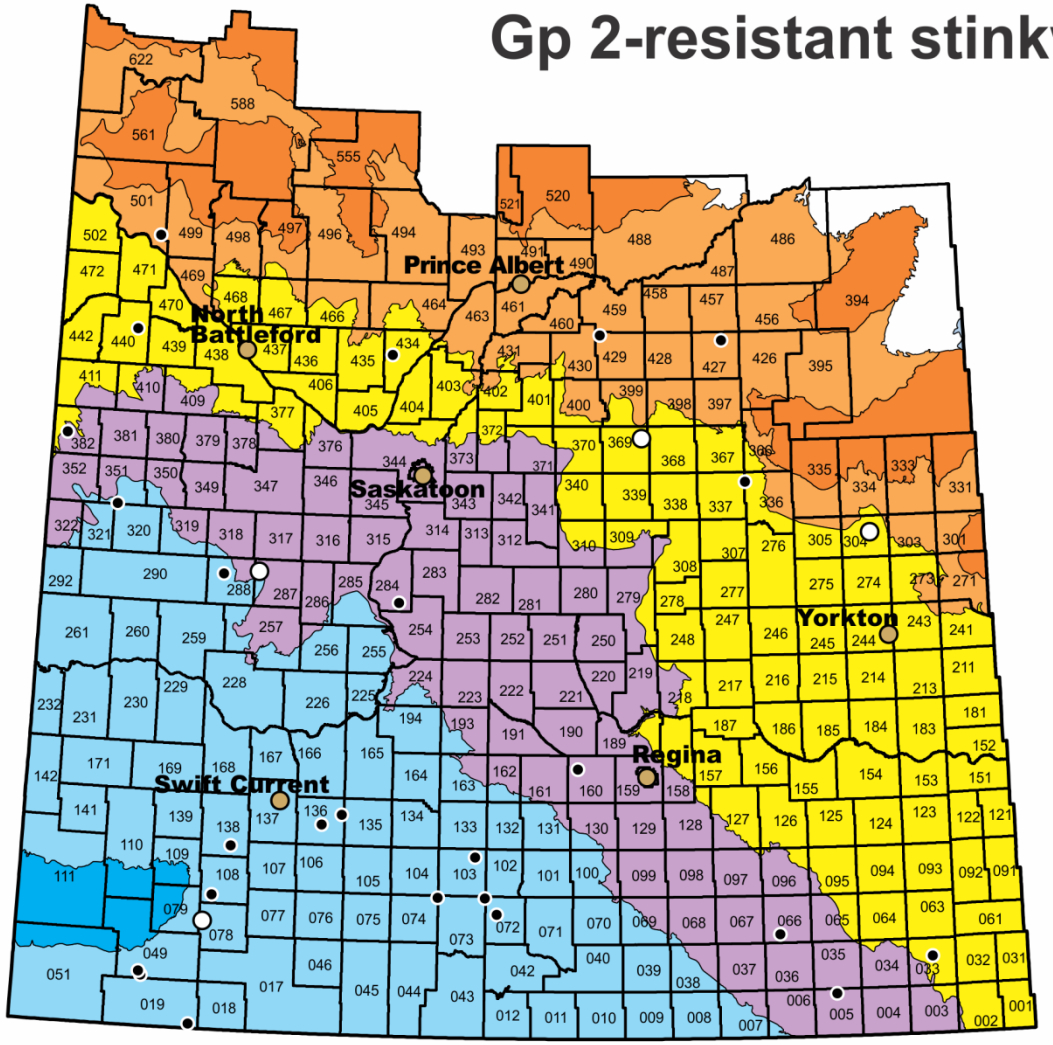
Gp 2-resistant redroot pigweed



Gp 2-resistant shepherd's-purse



Gp 2-resistant stinkweed



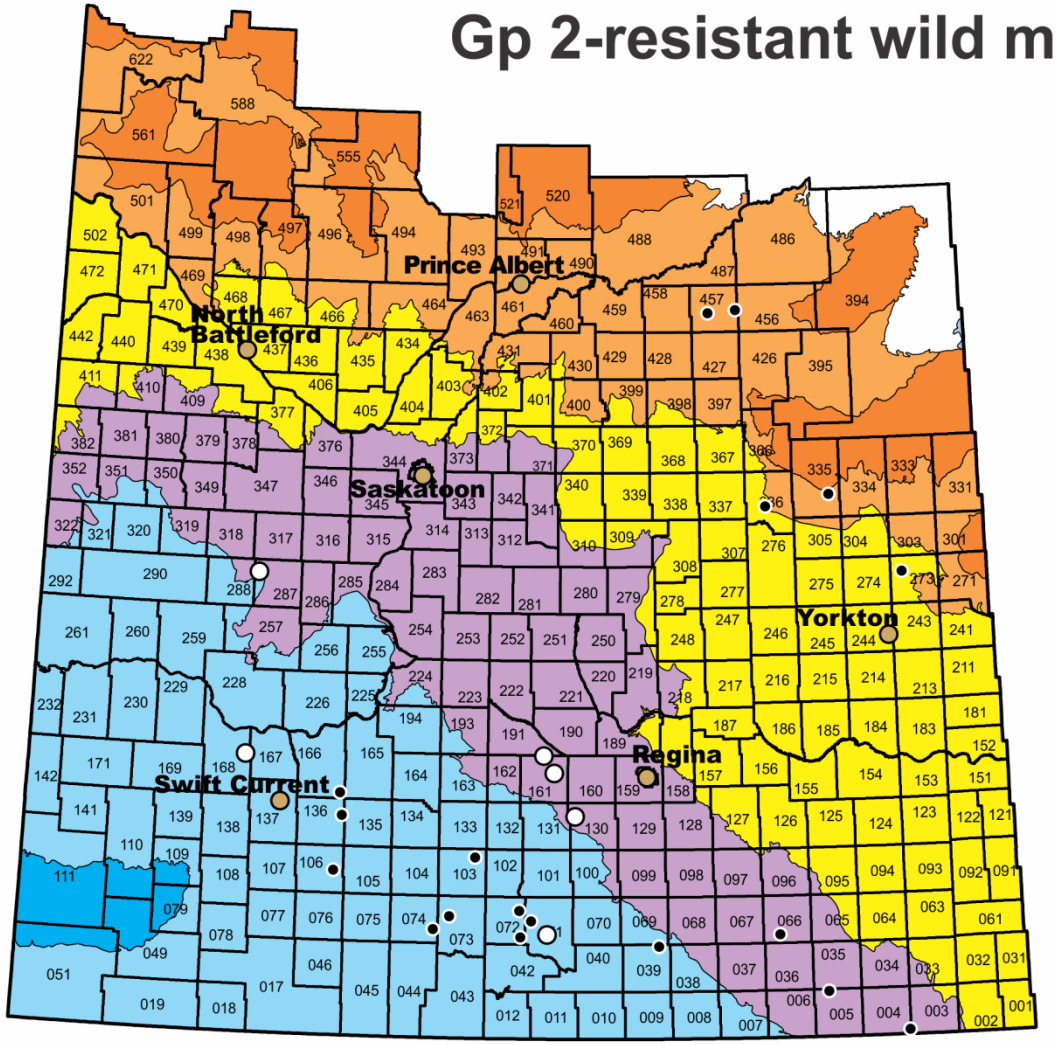
Resistant ○

Not resistant •

Ecoregions

- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

Gp 2-resistant wild mustard



Resistant ○

Not resistant •

Ecoregions

- Mid-Boreal Uplands
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland