Saskatchewan Weed Survey of Herbicide-Resistant Weeds in 2009

by

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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)
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82-2	Manitoba weed survey questionnaire data (1981)
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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
83-4	Peace River Region of British Columbia weed survey of cereal and oilseed crops (1978, 1979 and 1980)
83-5	Peace River Region of British Columbia weed survey of forage crops (1978-1980)
83-6	Weed survey of Saskatchewan cereal and oilseed crops from 1976 to 1979
84-1	Weed surveys of Manitoba cereal and oilseed crops from 1978, 1979 and 1981
85-1	Weed surveys of alfalfa seed fields in Manitoba (1983)
85-2	Survey for weeds in corn and soybean fields of Essex and Kent Counties in Ontario
85-3	Dew's Alberta weed survey (1973-1977)
86-1	Weed survey of Saskatchewan sunflower fields (1985)
86-2	Weed survey of Saskatchewan mustard, lentil and dry pea crops (1985)
86-3	Weed survey of Saskatchewan winter wheat fields (1985)
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)
87-2	Weed survey of Saskatchewan winter wheat fields (1986)
87-3	Saskatchewan cereal and oilseed crops weed survey questionnaire (1986)
88-1	Weed survey of cereal and oilseed crops in Manitoba (1986)

(Table continued on next page)

Previously published reports in the Weed Survey Series *(continued)*

Number	Title
88-2	Weed survey of Saskatchewan winter wheat fields (1987)
88-3	Manitoba cereal and oilseed crops weed survey questionnaire (1986)
89-1	Weed survey of Saskatchewan winter wheat fields (1985-1988)
90-1	Weeds of corn, soybean, and winter wheat fields under conventional, conservation, and no-till management systems in southwestern Ontario (1988 and 1989)
96-1	Saskatchewan weed survey of cereal, oilseed and pulse crops (1995)
97-1	Manitoba weed survey comparing zero and conventional tillage crop production systems (1994)
98-1	Manitoba weed survey of cereal and oilseed crops in 1997
98-2	Alberta weed survey of cereal and oilseed crops in 1997
98-3	Saskatchewan weed survey of herbicide-resistant wild oat and green foxtail in 1996
98-4	Saskatchewan grain elevator weed survey of herbicide-resistant wild oat and green foxtail in 1997
98-5	Manitoba weed survey of herbicide-resistant wild oat in 1997
99-3	Farm management practices in Manitoba - 1997 Manitoba weed survey questionnaire results
99-4	Saskatchewan weed survey of herbicide-resistant wild oat in 1997
02-1	Alberta weed survey of cereal, oilseed and pulse crops in 2001
02-2	Manitoba weed survey of cereal and oilseed crops in 2002
03-1	Saskatchewan weed survey of cereal, oilseed and pulse crops in 2003
04-1	Alberta weed survey of herbicide-resistant weeds in 2001
04-2	Manitoba weed survey of herbicide-resistant weeds in 2002
05-1	Prairie weed surveys of cereal, oilseed and pulse crops from the 1970s to the 2000s
05-2	Farm management practices in Alberta - 1997 weed survey questionnaire results
05-3	Farm management practices in Alberta - 2001 weed survey questionnaire results
06-1	Saskatchewan weed survey of herbicide-resistant weeds in 2003
06-2	Prairie weed survey of herbicide-resistant wild oat from 2001 to 2003
09-1	Alberta weed survey of herbicide-resistant weeds in 2007
10-1	Manitoba weed survey of herbicide-resistant weeds in 2008

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 2008 Manitoba weed resistance survey report published in 2010. This report documents the nature, distribution and abundance of herbicide-resistant weeds in Saskatchewan in 2009. 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 resistance testing was the most extensive to date.

To complete this survey project, a final report this year 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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Hugh J. Beckie, Chris Lozinski, and Scott Shirriff

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

EXECUTIVE SUMMARY

A survey of weeds resistant to herbicides in 400 randomly selected fields was conducted 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 a herbicide-resistant weed biotype, compared with 10% of fields in 2003. Of 300 fields where wild oat (*Avena fatua* L.) 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-resistant wild oat populations exhibited broad cross-resistance across herbicide classes. Group 1+2-resistant wild oat was found in 5% of fields (vs. 1% in 2003). Overall, 36% of fields where wild oat samples were collected had a herbicide-resistant biotype.

Of 103 fields where green foxtail [*Setaria viridis* (L.) Beauv.] seeds were collected, 14% had Group 1 resistance (vs. none detected in 2003). Group 1-resistant Persian darnel [*Lolium persicum* Boiss. & Hohen. ex Boiss.] was found in one field in the Moist Mixed Grassland ecoregion. Of 17 broadleaf weed species (kochia [*Kochia scoparia* (L.) Schrad.] not sampled in this survey), Group 2 resistance was confirmed in wild mustard (*Sinapis arvensis* L.) in 25% of fields sampled and false cleavers (*Galium spurium* L.) in 21% of fields sampled. These resistant biotypes had previously been found in Saskatchewan, although they were not detected in the 2003 survey.

The results of this survey highlight the continual increase in field frequency of Group 1-resistant wild oat and to a lesser extent green foxtail, and Group 2-resistant cleavers (and to a

lesser extent wild mustard). Group 2 resistance in kochia is already widespread (>90% of populations), as determined from previous surveys. However, incidence of Group 2- or 8-resistant wild oat remains low, and weed resistance to herbicides from Groups 4, 9, or 10 was not detected. Based on this survey, it is estimated that 3.9 million ha in Saskatchewan are infested with herbicide-resistant weeds, in a total field area of 4.6 million ha.

Past Weed Resistance Surveys in Saskatchewan

Group 1 [acetyl-CoA carboxylase (ACC) inhibitor]-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.) Beauv.] was the second HR grass weed biotype discovered in Saskatchewan (Heap 2012). 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.

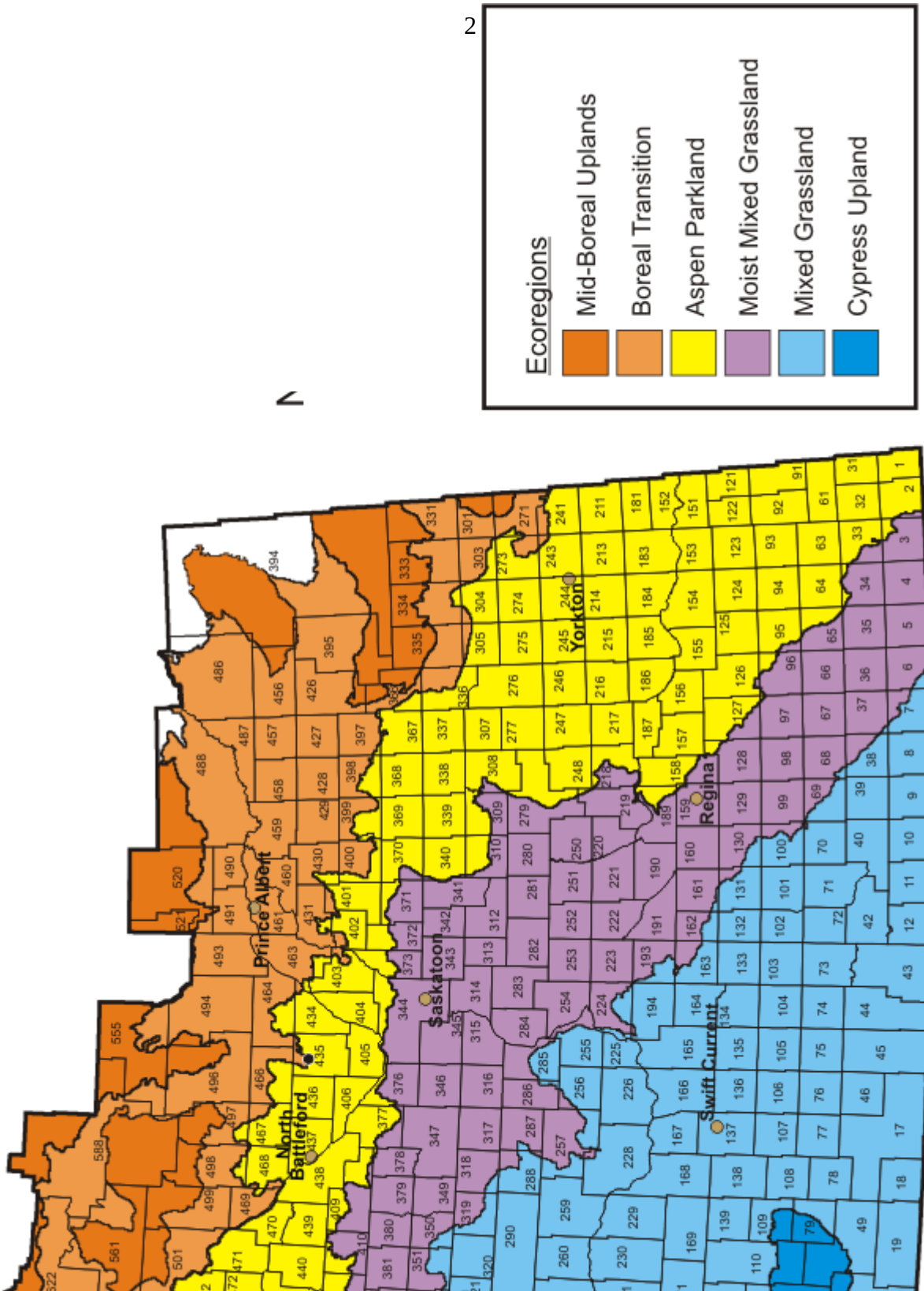

Figure 1. Ecoregions of Saskatchewan.

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.

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 samples submitted to the Crop Protection Lab, Saskatchewan Ministry of Agriculture from Saskatchewan producers (or industry on behalf of producers) between 1996 and 2010, 458 were HR: Group 1: 438; Group 2: nine; Group 1+2: 11 (Beckie et al. 2007, unpubl. data). The cross-resistance pattern of the Group 1-HR samples were as follows: APP, 161; CHD, nine; APP+CHD, 254; APP+DEN (pinoxaden), four; APP+CHD+DEN, 10 (DEN testing only upon request). During this period, there were 16 cases of Group 1-HR green foxtail (5 cases of Group 3-HR green foxtail) and 2 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 2010, 27 kochia samples from Saskatchewan submitted for testing were Group 2-HR; this HR biotype is now widespread across the Prairies (>90% of populations) (Beckie et al. 2011). 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 2010, 23 wild mustard samples from Saskatchewan submitted for testing were Group 2-HR.

Additionally during this period, there were 18 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 one case of Group 2-HR stinkweed (*Thlaspi arvense* L.) (Beckie et al. 2007, unpubl. data).

A 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 ar 7

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.

Objective

In 2009, 400 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 400 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. 2003), 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 (2008). 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 Saskatchewan is shown in Table 1.

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	36	51	20	155
Barley	7	6	12	7	32
Oat	3	1	12	2	18
Canary seed	1	0	2	0	3
Canola	6	19	44	34	103
Flax	2	7	11	3	23

Mustard	2	4	0	0	6
Field pea	10	5	11	2	28
Lentil	12	20	0	0	32
Sub-total	*91*	*98*	*143*	*68*	*400*
% of Total	*23*	*24*	*36*	*17*	*100*

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

A majority of the fields (52%, were cropped to cereals. This proportion was lower than that of the 2003 weed resistance survey (70%) (Beckie et al. 2006). Wheat occupied 75% of the 208 survey fields cropped to cereals, barley 15%, oat 9%, and canary seed 1%; in the 2003 survey, wheat comprised 65%, barley 26%, oat 6% , and canary seed 3% of cereal fields. Oilseeds comprised 33% of surveyed fields (vs. 25% in 2003): canola 78% of that, flax 17%, and mustard 5%. The proportion of oilseed fields cropped to canola, flax, and mustard was the same as that of the 2003 survey. Pulse crops comprised 15% of surveyed fields (vs. 5% in 2003), with field pea at 47% and lentil at 53% of pulse crop area.

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 half of the 23 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2003 (Leeson et al. 2003). 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		Fields	Rank[a]
	No.		
Grass:			
Barnyard grass, *Echinochloa* spp.	7	7	11
Foxtail barley, *Hordeum jubatum* L.	3	3	25
Green foxtail, *Setaria viridis* (L.) Beauv.	112	103	1
Persian darnel, *Lolium persicum* Boiss. & Hohen. ex Boiss.	1	1	30
Yellow foxtail, *Setaria pumila* (Poir.) Roem. & Schult.	1	1	93
Wild oat, *Avena fatua* L.	346	300	2
Broadleaf:			
Chickweed, *Stellaria media* (L.) Vill.	24	21	27
Cleavers, *Galium* spp.	55	52	14
Common groundsel, *Senecio vulgaris* L.	1	1	52
Cow cockle, *Vaccaria hispanica* (Mill.) Rauschert	5	5	26
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	11	11	21
Hemp-nettle, *Galeopsis tetrahit* L.	6	6	24
Lamb's-quarters, *Chenopodium album* L.	29	28	5
Narrow-leaved hawk's beard, *Crepis tectorum* L.	12	12	20
Night-flowering catchfly, *Silene noctiflora* L.	16	16	32
Redroot pigweed, *Amaranthus retroflexus* L.	19	19	6
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	23	23	18
Smartweed (annual), *Polygonum* spp.	7	7	23
Sow-thistle (annual), *Sonchus* spp.	15	15	38
Stinkweed, *Thlaspi arvense* L.	60	58	7
Stork's-bill, *Erodium cicutarium* (L.) L'Her. ex Aiton	2	2	59
Wild buckwheat, *Polygonum convolvulus* L.	27	26	3
Wild mustard, *Sinapis arvensis* L.	9	8	15

[a] Relative abundance rank of species in 2,046 fields surveyed in 2003 (Leeson et al. 2003); rank of annual smartweed spp. is that of pale smartweed.

Resistance Tests

Resistance tests were initiated 4 months after seeds were collected to reduce the level of innate dormancy. All tests were conducted using pot assays in the greenhouse. Weed species were sprayed at growth stages (usually two to four leaves) for optimum herbicide efficacy. 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 aryloxyphenoxypropic 11 clohexanedione (CHD or Dim) herbicides, and pinoxaden, a phenylpyrazolin (PPZ or Den) herbicide. The three APP 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 CHD 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 re: 12

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 300 fields where wild oat samples were collected, 109 (36%) had an HR biotype. Group 1-HR wild oat was confirmed in 97 fields (32%) (Table 4, Map 2). In comparison, in Saskatchewan in 2003, 10% of fields had Group 1-HR wild oat (Beckie et al. 2006, 2008). Therefore, 24% of all fields surveyed (400) had Group 1-HR wild oat. This field frequency of resistance is significantly greater than that documented in the 2003 survey (8%) (Beckie et al. 2006, 2008). Over half of fields with Group 1-HR wild oat were located in the Aspen Parkland ecoregion; this HR biotype was found in 41% of sampled sites in the Boreal Transition ecoregion, 21% in the Moist Mixed Grassland ecoregion, and 11% of fields in the Mixed Grassland ecoregion. Similar trends were observed in the 2003 survey, although the frequency of fields with Group 1-HR wild oat had increased in all ecoregions in 2009. The greater incidence of Group 1-HR wild oat in the Parkland vs. Grassland ecoregions has been attributed to greater frequency of use of Group 1 herbicides with more continuous cropping, and greater wild oat population abundance (Beckie et al. 1999b). In the other Prairie provinces, Group 1-HR wild oat was found in 39% of fields in Alberta in 2007 and 55% of fields in Manitoba 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.	%	
Mixed Grassland[b]	8	11	9	2	3	2
Moist Mixed Grassland	17	21	17	2	3	2
Aspen Parkland	53	53	37	14	14	10
Boreal Transition	19	41	28	4	9	6
Saskatchewan	*97*	*32*	*24*	*22*	*7*	*6*

[a]Tested: fields where seeds were collected (n=300); 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.

The Group 1 cross-resistance pattern of the wild oat populations did not show a significant difference in resistance frequency among the three classes of Group 1 herbicides (data not shown). However, resistance incidence among Group 1-HR populations to APP herbicides tended to be greater than that of CHD herbicides or pinoxoden. Resistance frequency among Group 1-HR populations to clethodim tended to be lowest, consistent with results of the 2003 Saskatchewan survey (Beckie et al. 2006, 2008).

Group 2 resistance was confirmed in 22 wild oat populations (7% of fields where seeds were collected or 6% of all fields surveyed (Table 4, Map 3). This frequency of resistance in 2009 compares with 4% of sampled fields in 2003, i.e., a slight increase over this period. The lower incidence of Group 2- vs. Group 1-HR wild oat reflects the past relative usage of wild oat herbicides with these modes of action (Beckie, unpubl. data). Similar to 2003, most fields with resistance were located in the Parkland region (Aspen Parkland and Boreal Transition ecoregions) where Group 2 herbicide use has historically been the greatest (Beckie et al. 2008). Broad cross-resistance was evident among populations to the Group 2 herbicides tested, imidazolinones and flucarbazone, similar to that observed in the 2003 survey (data not shown). The incidence of Group 2-HR wild oat in Saskatchewan in 2009 was lower than than of Alberta (12% of fields) and Manitoba (18% of fields) (Beckie et al. 2009, 2010).

The incidence of Group 8-HR wild oat was only 3% of fields where wild oat was sampled, compared with 11% of fields in Manitoba in 2008 and 15% of fields in Alberta in 2007 (Map 4; Beckie et al. 2009, 2010). Three of the 10 fields with Group 8-HR wild oat were located in the Boreal Transition ecoregion, five fields in the Aspen Parkland ecoregion, and one field each in the Mixed and Moist Mixed Grassland ecoregion. There were 15 Group 1+2-HR wild oat populations (5% of fields sampled) (Map 5), compared with three fields in 2003 (1%): one field

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

Ecoregion	No.	%	Surveyed[a]
Mixed Grassland[b]	0	0	0
Moist Mixed Grassland	3	10	4
Aspen Parkland	11	22	8
Boreal Transition	0	0	0
Saskatchewan	*14*	*14*	*4*

[a]Tested: fields where seeds were collected (n=103); 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.

in the Mixed Grassland ecoregion, two fields in the Boreal Transition ecoregion, and 12 fields in the Apen Parkland ecoregion. Other intergroup-HR populations also were found: Group 1+8 (five fields), 2+8 (one field), and 1+2+8 (one field) (Maps 6 to 8, respectively).

Group 1-HR green foxtail was found in 14% of 103 fields (Table 5) where seeds were collected (Map 9). No fields of Group 1-HR green foxtail were found in the 2003 survey (Beckie et al. 2006, 2008). Over three-quarters of the fields were located in the Aspen Parkland ecoregion, similar to results of a previous survey (Beckie et al. 1999a). In submission sample testing from 1996 to 2010, 16 cases of Group 1-HR green foxtail from Saskatchewan were confirmed. In comparison to Saskatchewan, Group 1-HR green foxtail was found in two fields in Alberta in 2007, and 44% of fields in Manitoba in 2008 (Beckie et al. 2009, 2010). Group 2 resistance in this weed was not detected. Group 1-HR Persian darnel was found in one field in

the Moist Mixed Grassland ecoregion (Map 10). This biotype was reported previously at two sites in southwestern Saskatchewan in 2004 (Beckie et al. 2007).

Broadleaf Weed Resistance

In contrast to the results from the Alberta survey in 2007, there were relatively fewer cases of broadleaf weed resistance (Beckie et al. 2009); all cases were Group 2 resistance. In the 2003 Saskatchewan survey, only Group 2-HR kochia was found, although this biotype was not sampled in this survey because seed viability is poor at preharvest (Beckie et al. 2006). Previous surveys have documented widespread Group 2-HR kochia in Saskatchewan (Beckie et al. 2011).

Two of eight fields (25%) had Group 2-HR wild mustard, located in the Grassland region (Map 11). From 1996 to 2010, 23 wild mustard biotypes from Saskatchewan submitted for testing were Group 2-HR (Beckie et al. 2007, unpubl. data). Eleven of 52 fields (21%) had Group 2-HR false cleavers: two fields in the Aspen Parkland ecoregion and nine fields in the Boreal Transition ecoregion (Map 12). From 1996 to 2010, 18 cleavers biotypes from the province submitted for testing were Group 2-HR (Beckie et al. 2007, unpubl. data). Group 2 resistance in these two weed species in Saskatchewan was documented by Warwick et al. (2005) and Beckie et al. (2012). 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 400 fields is extrapolated to the total annual-cropped land in Saskatchewan (15,325,910 ha or 37,855,000 ac

Table 6. Estimated annual· pacted by herbicide-resistant (HR) weeds in 2009

Biotype	Infestation area (ac/ha)	Field area (ac/ha)
Gp 1-HR wild oat	5,317,790/2,152,950	6,375,000/2,580,970
Gp 2-HR wild oat	568,030/229,970	568,030/229,970
Gp 8-HR wild oat	289,850/117,350	426,030/172,480
Gp 1+2-HR wild oat	1,141,960/462,330	1,236,560/500,630
Gp 1+8-HR wild oat	201,180/81,450	278,020/112,560
Gp 1+2+8-HR wild oat	82,790/33,520	82,790/33,520
Gp 1-HR green foxtail	953,420/386,000	1,046,490/423,680
Gp 1-HR Persian darnel	150/60	94,530/38,270
Gp 2-HR broadleafs	1,171,250/474,190	1,171,250/474,190
Total	**9,726,420/3,937,820**	**11,278,700/4,566,270**

in 2009) (Statistics Canada 2009), it is estimated that 3.9 million ha (26%) are infested with HR weeds, in a total field area of 4.6 million ha (30%) (Table 6). In comparison, 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 with HR weeds has increased 13-fold, while the total field area affected has increased by 3-fold over this intervening 6-year period.

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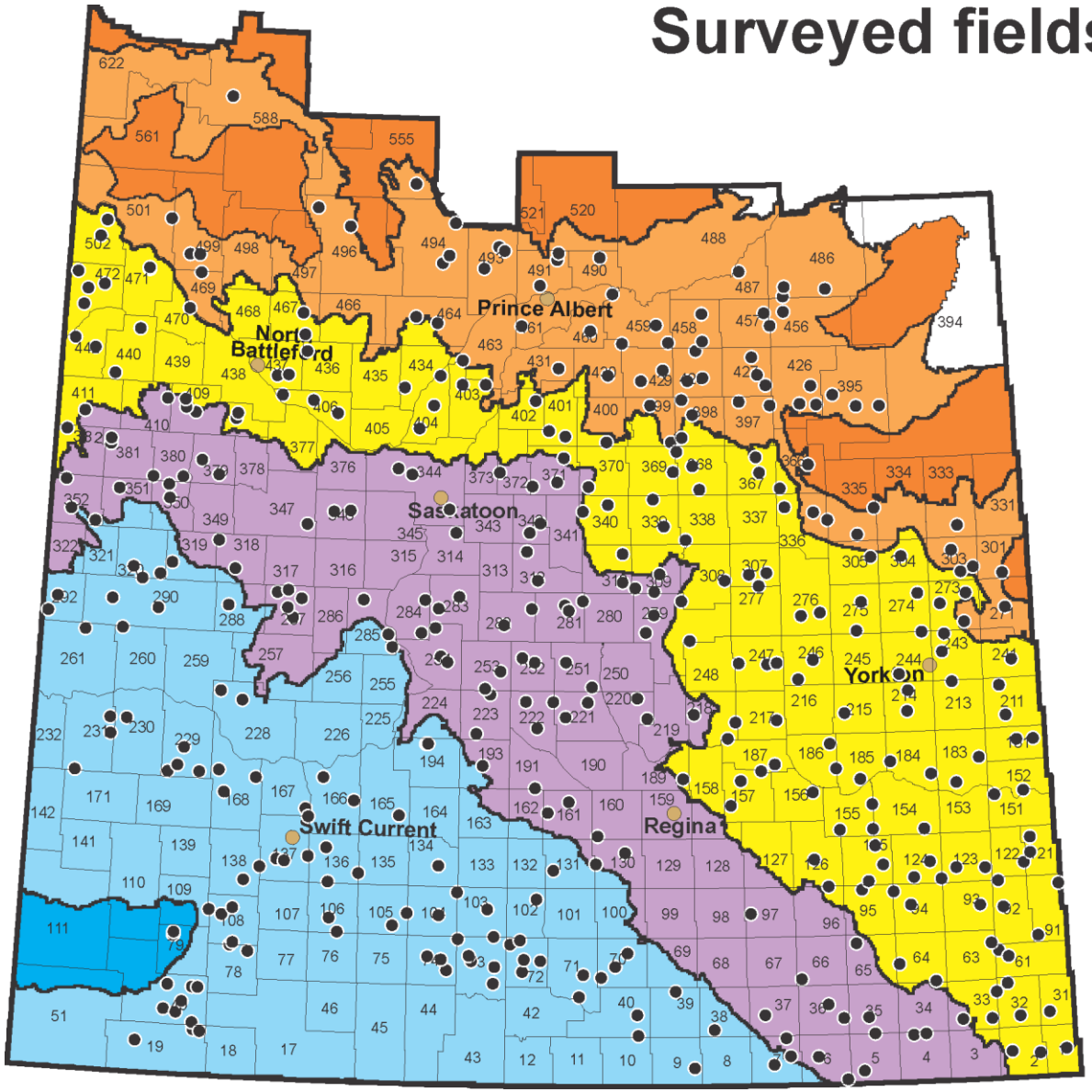
LIST OF MAPS

Surveyed fields

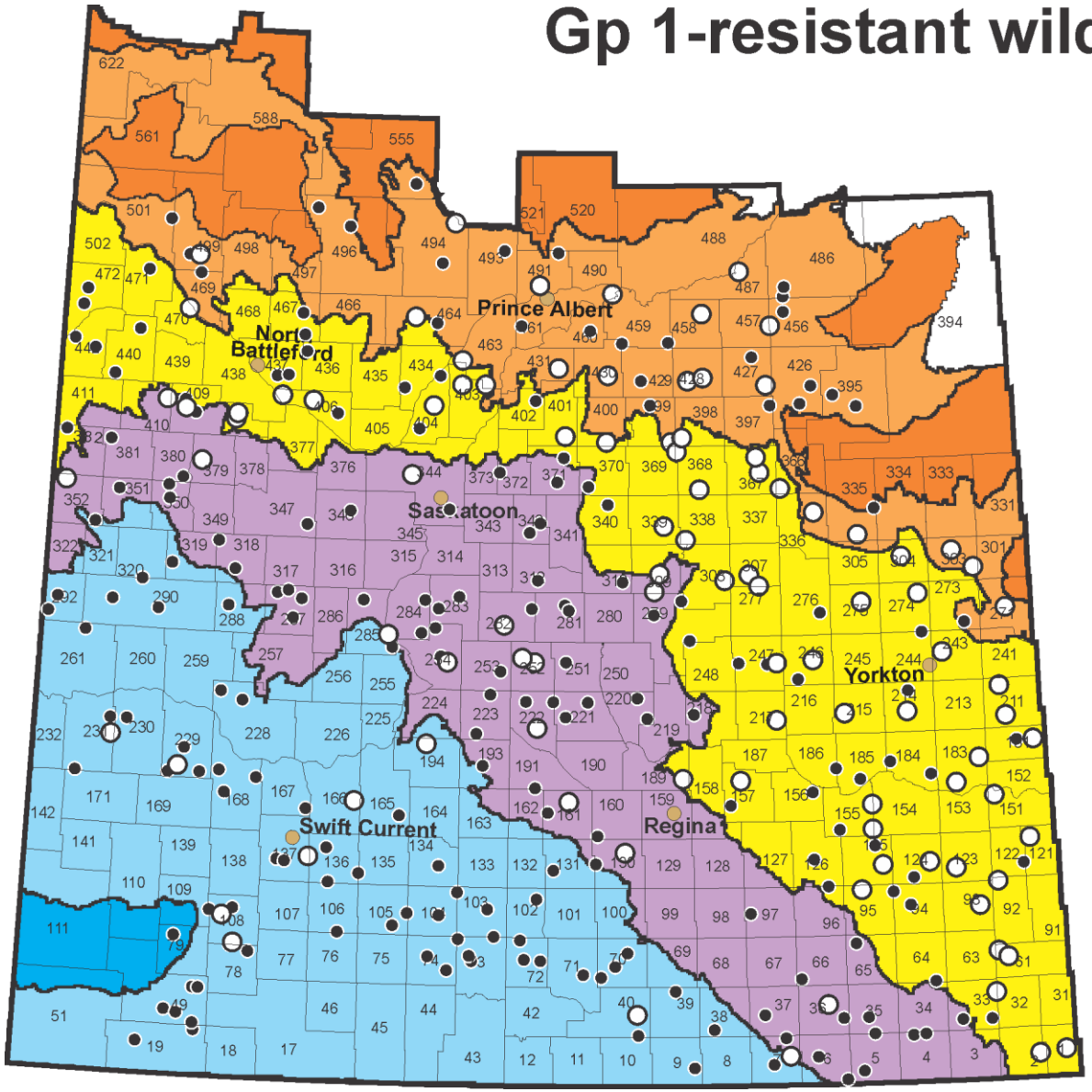


Field locations •

Ecoregions

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

Gp 1-resistant wild oat



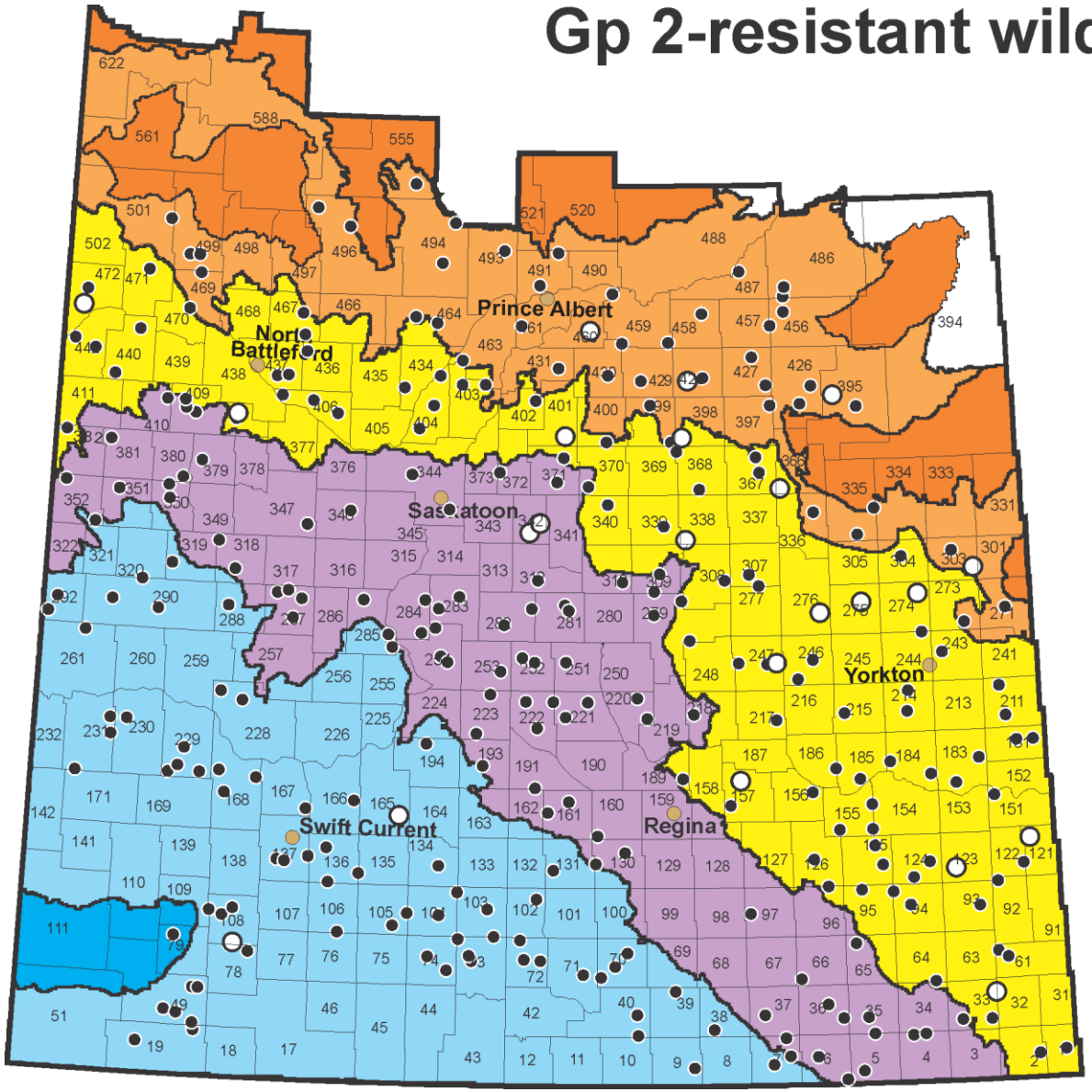
Resistant ○

Not resistant •

Ecoregions

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

Gp 2-resistant wild oat



Resistant ○

Not resistant •

Ecoregions

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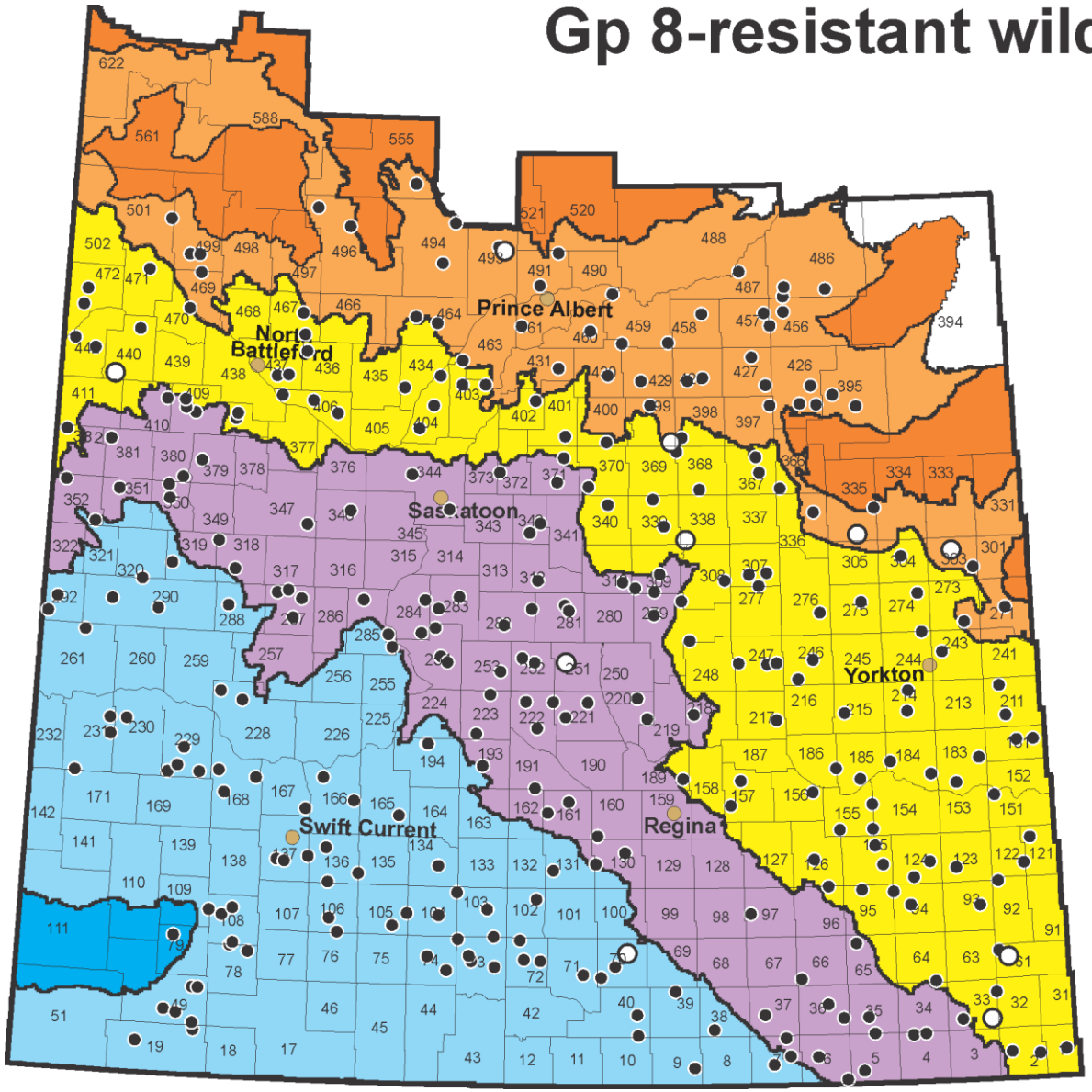
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

Gp 8-resistant wild oat



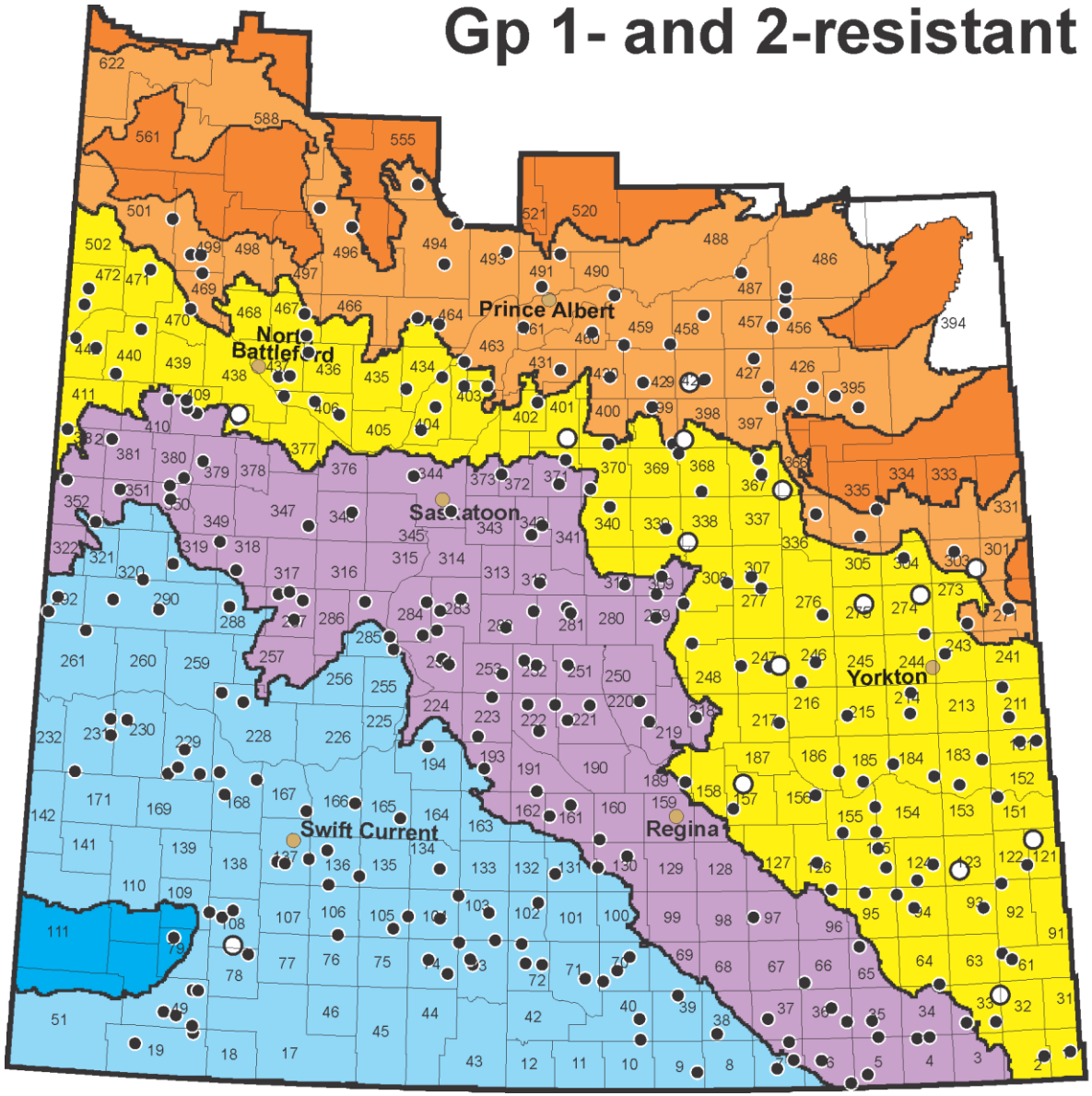
Resistant ○

Not resistant •

Ecoregions

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

Gp 1- and 2-resistant wild oat



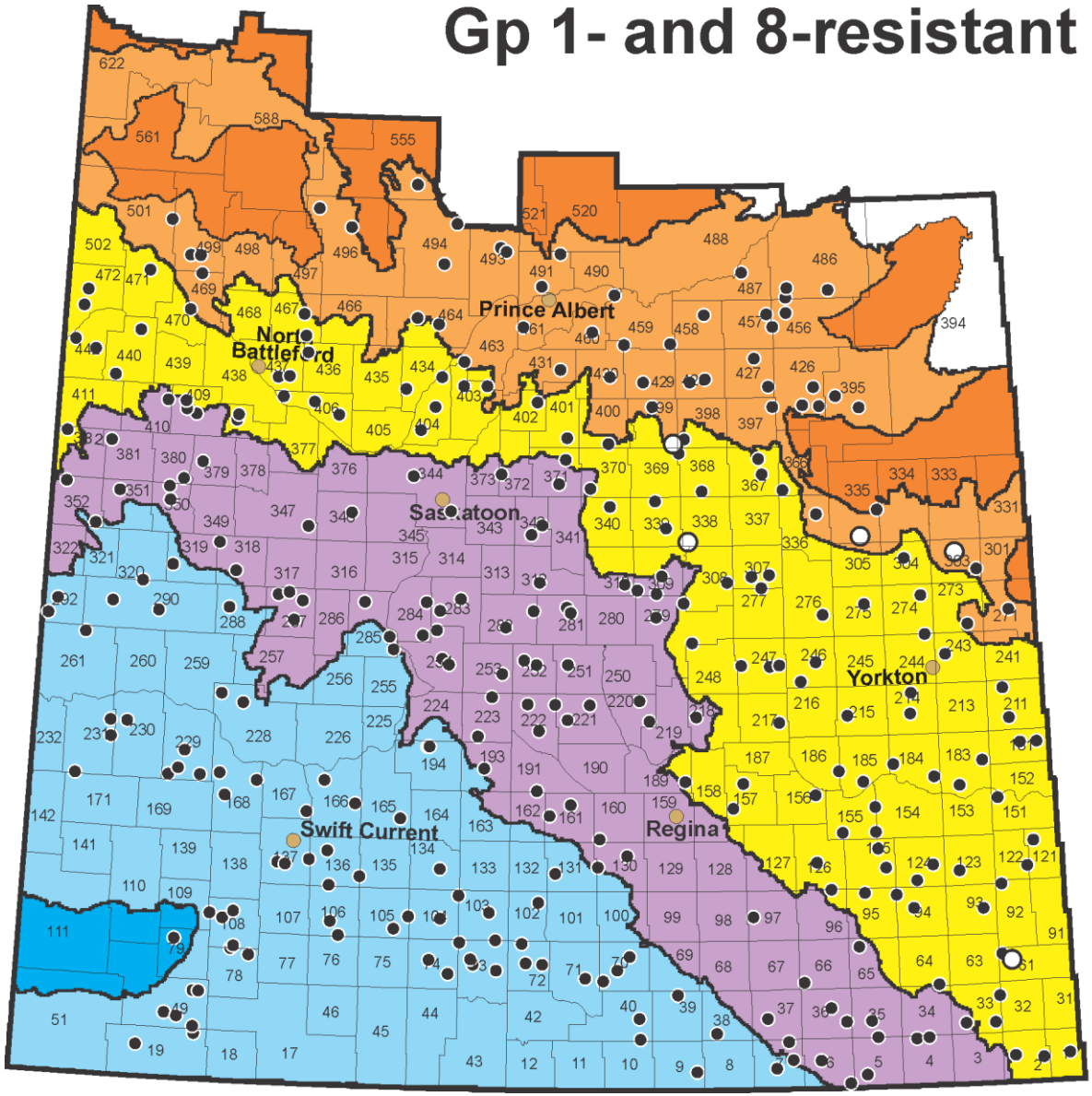
Resistant ○

Not resistant •

Ecoregions

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

Gp 1- and 8-resistant wild oat



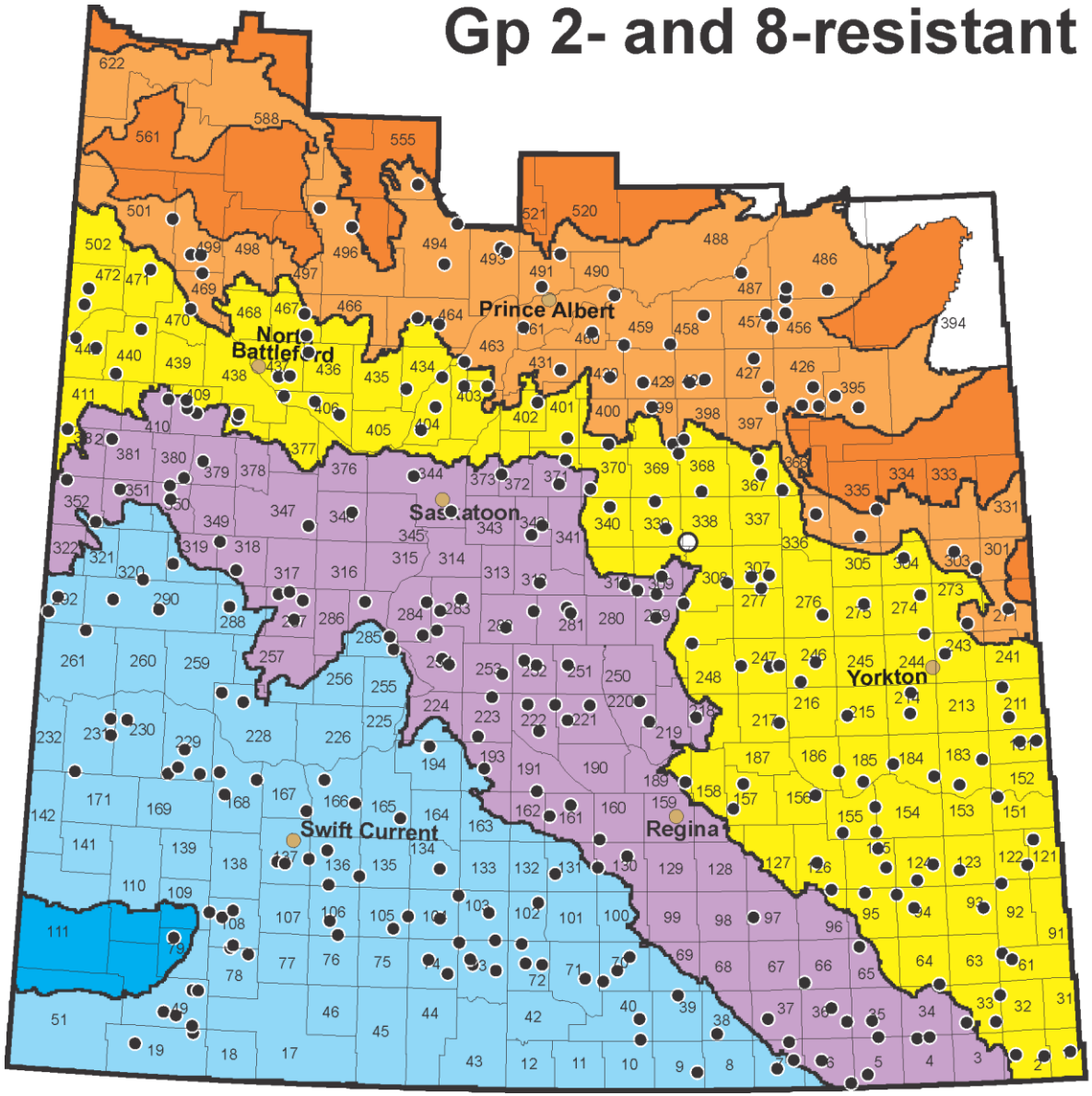
Resistant ○

Not resistant •

Ecoregions

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

Gp 2- and 8-resistant wild oat



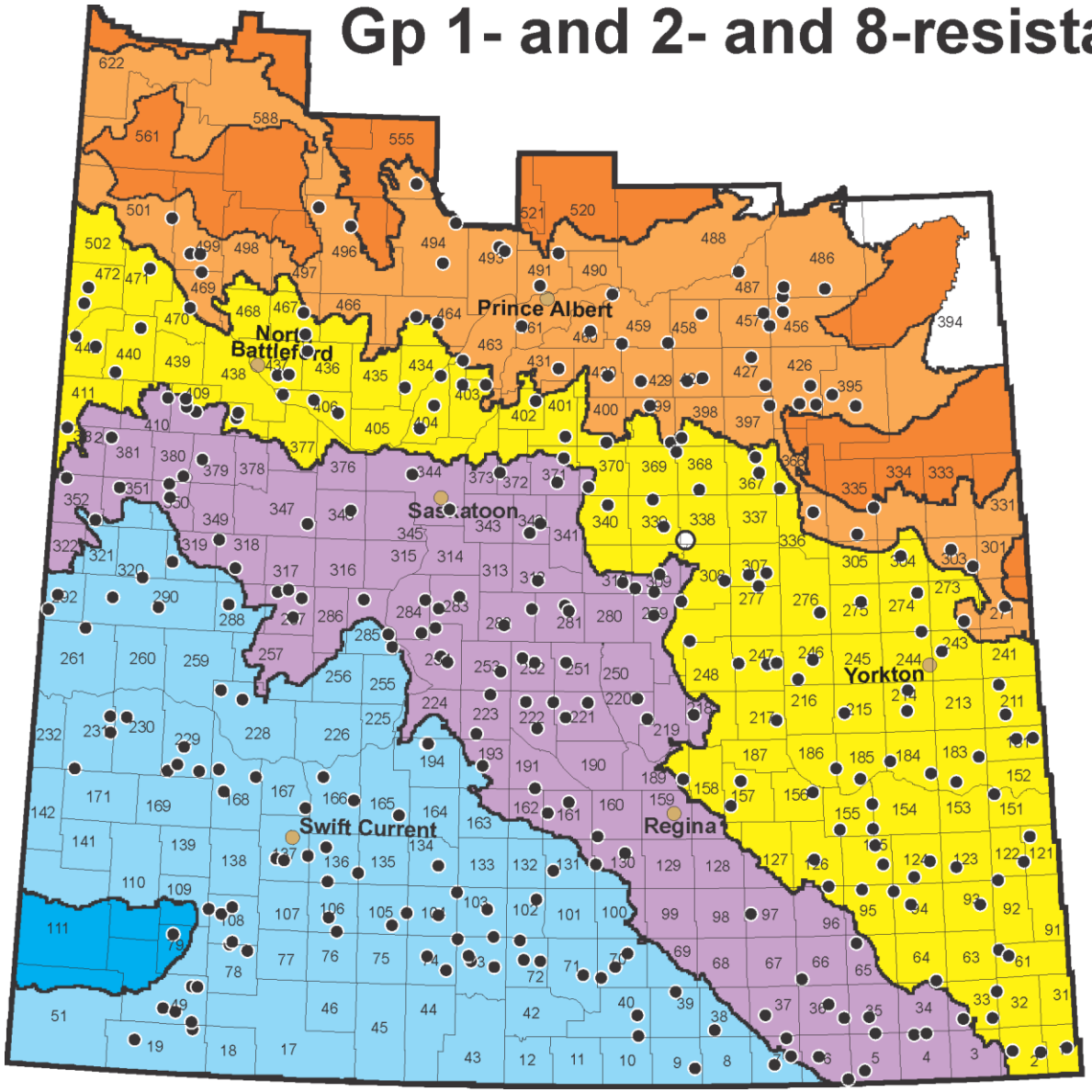
Resistant ○

Not resistant •

Ecoregions

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

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



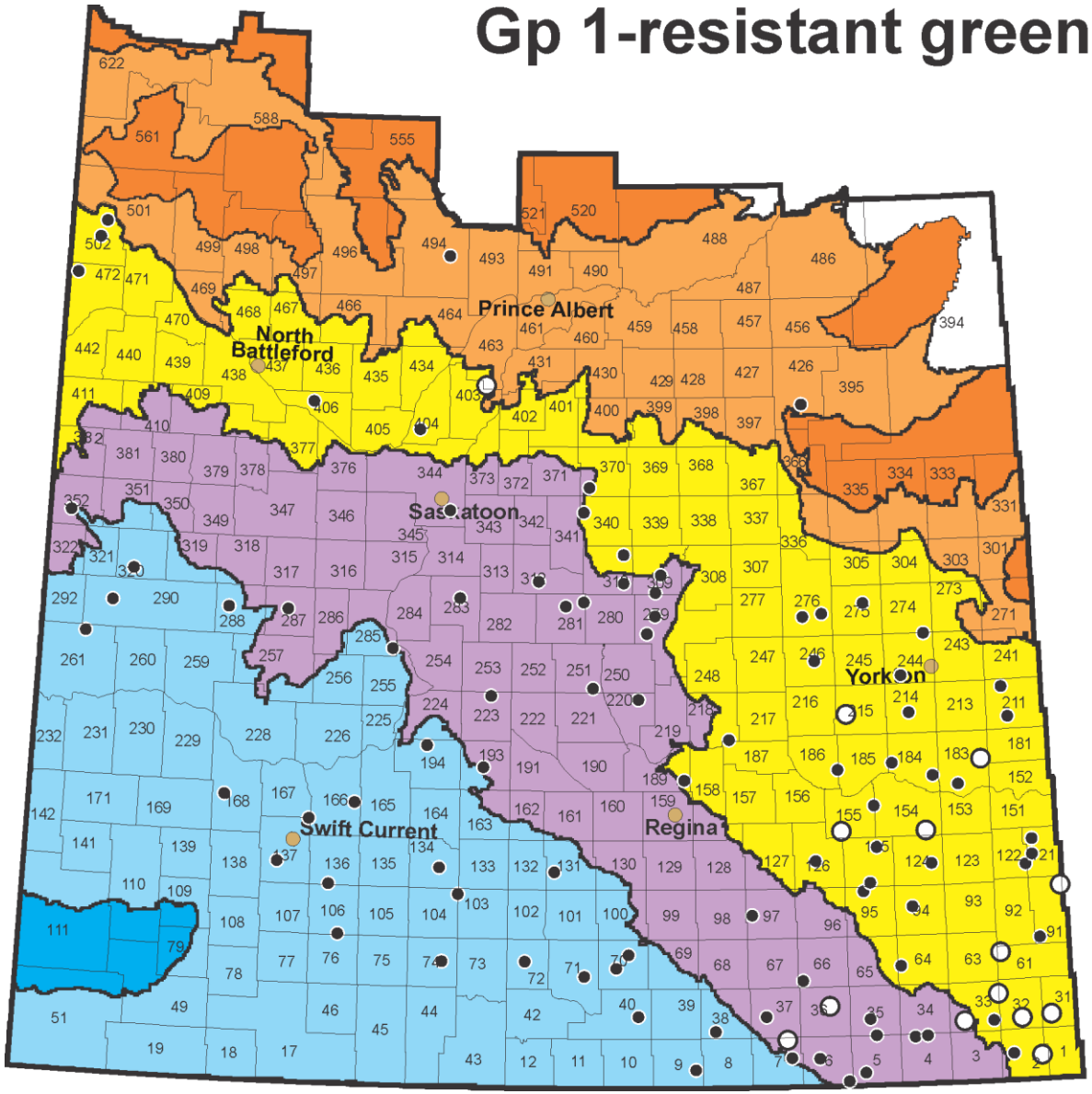
Resistant ○

Not resistant •

Ecoregions

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

Gp 1-resistant green foxtail



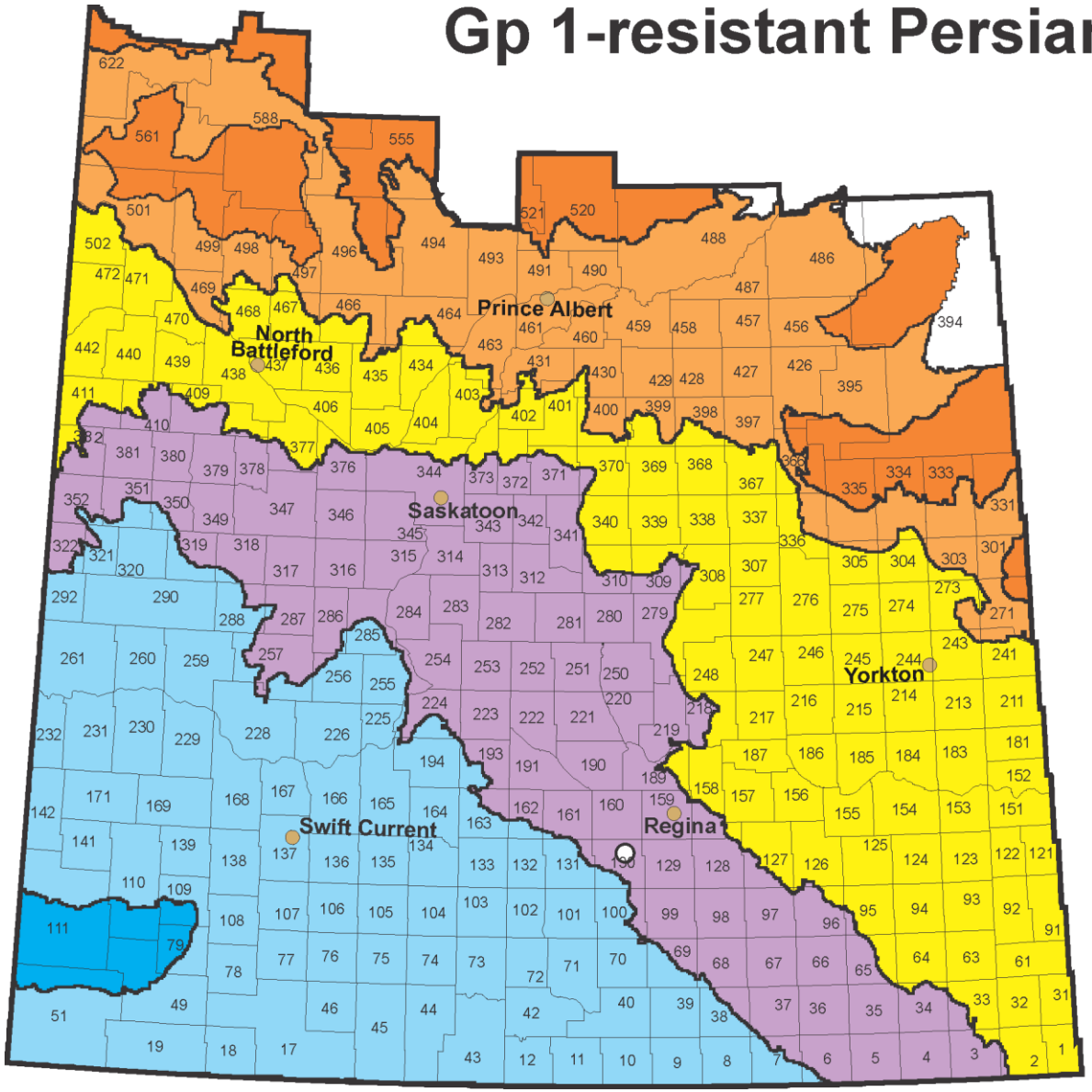
Resistant ○

Not resistant •

Ecoregions

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

Gp 1-resistant Persian darnel



Resistant ○

Ecoregions

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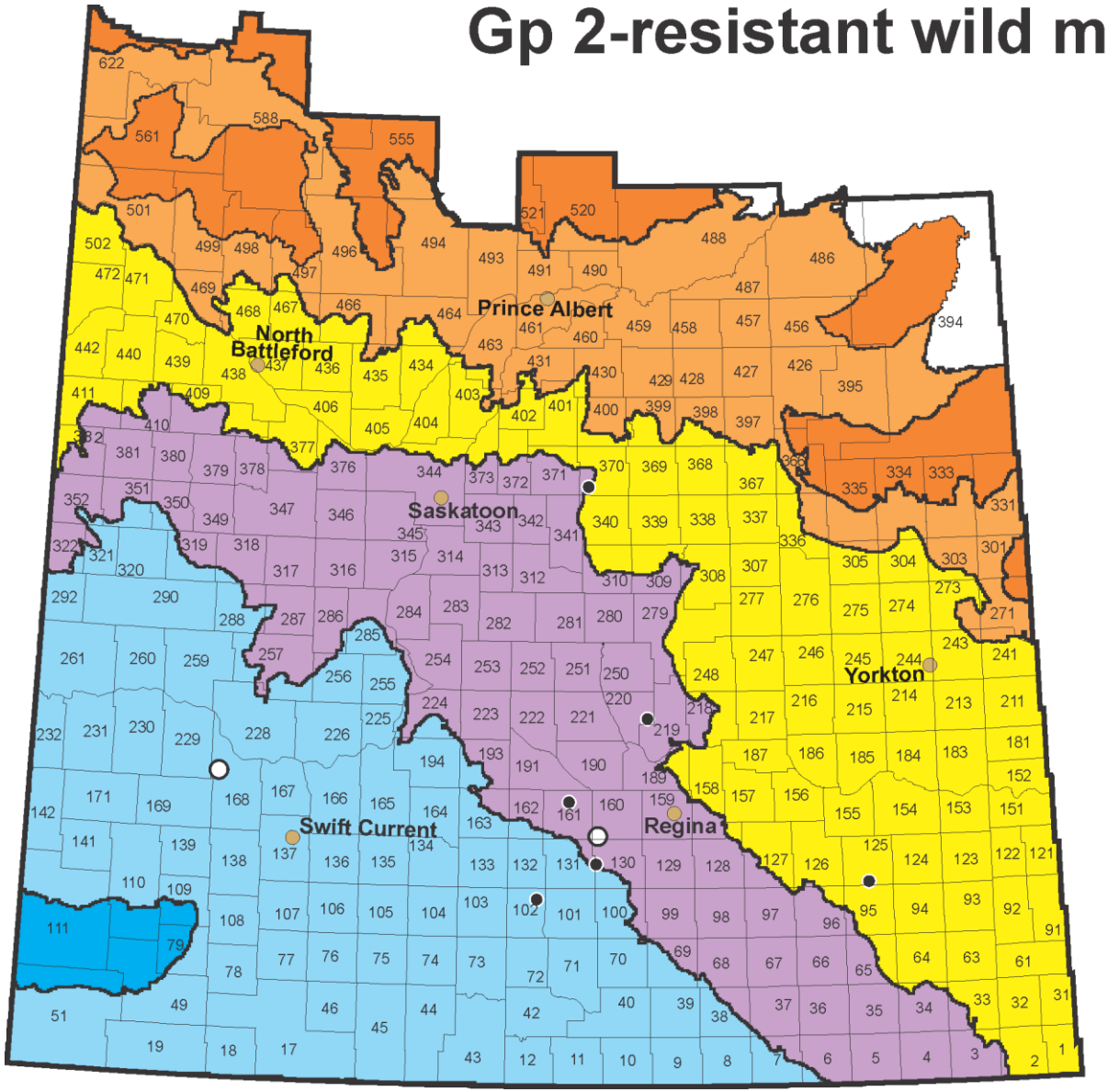
- Boreal Transition
- Aspen Parkland
- Moist Mixed Grassland
- Mixed Grassland
- Cypress Upland

Gp 2-resistant wild mustard



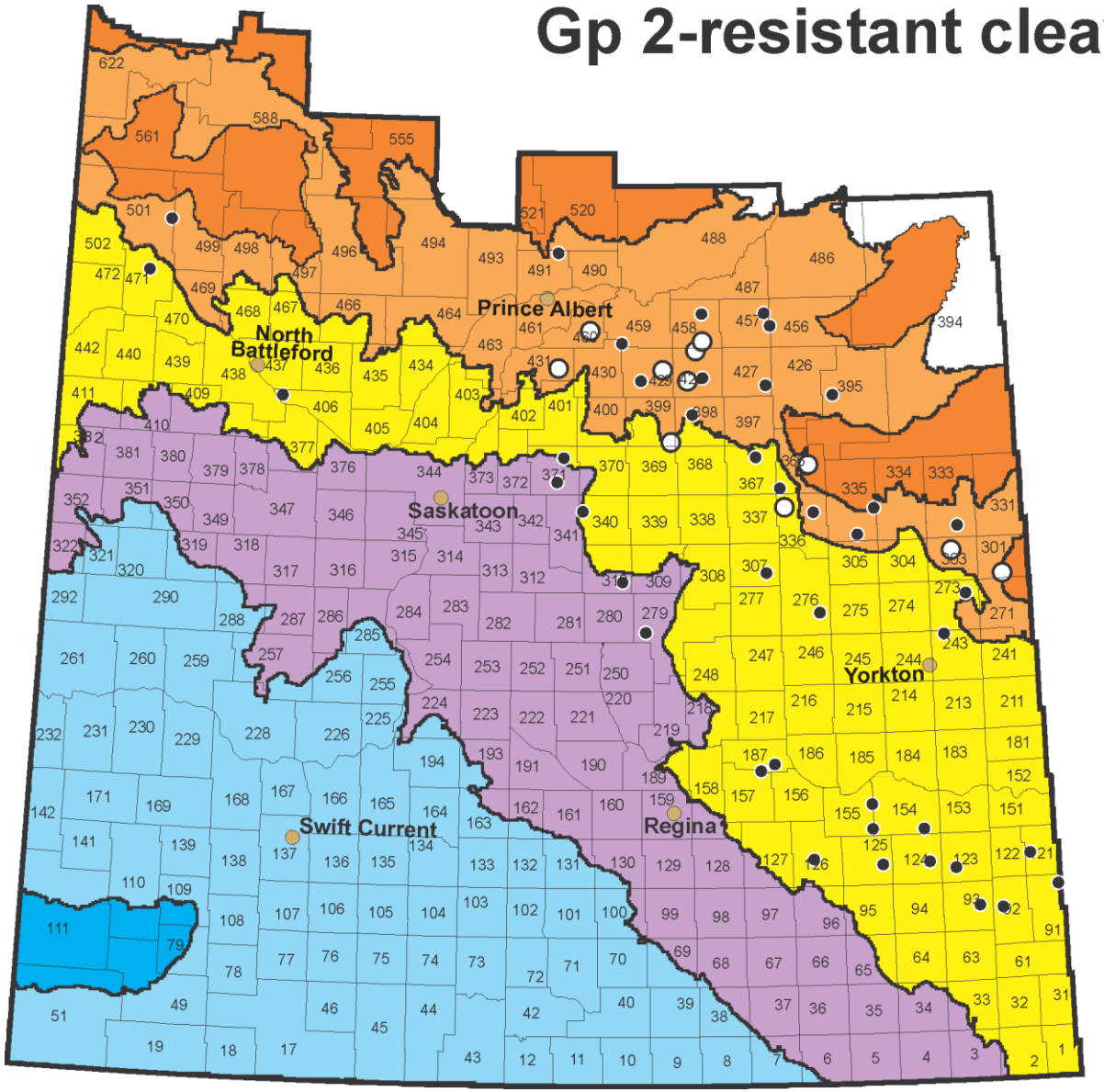
Resistant ○

Not resistant •

Ecoregions

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

Gp 2-resistant cleavers



Resistant ○

Not resistant •

Ecoregions

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