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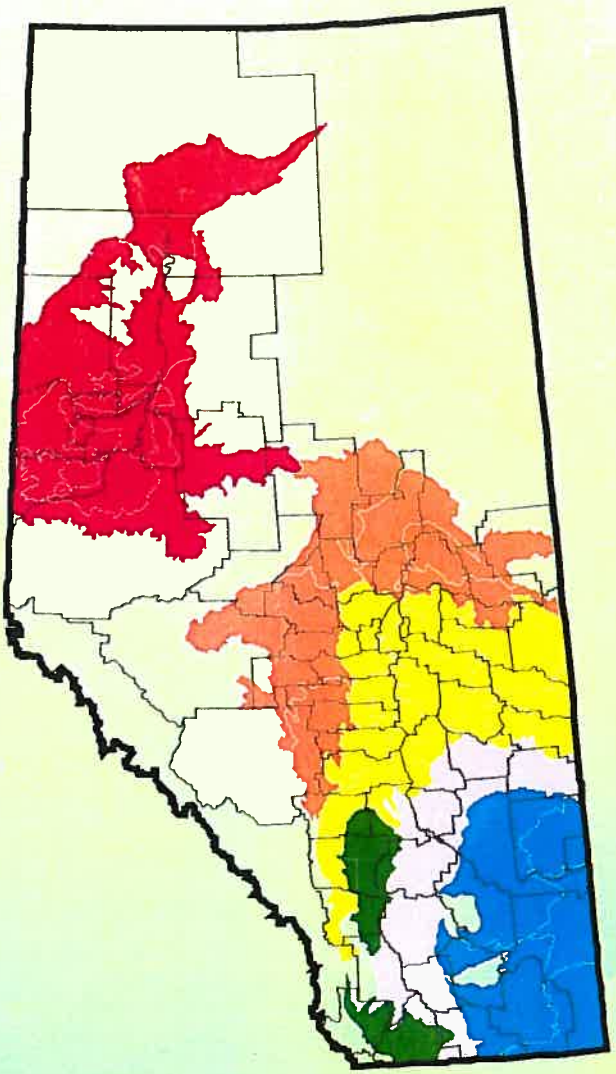
Alberta Weed Survey

Herbicide-Resistant Weeds 2001



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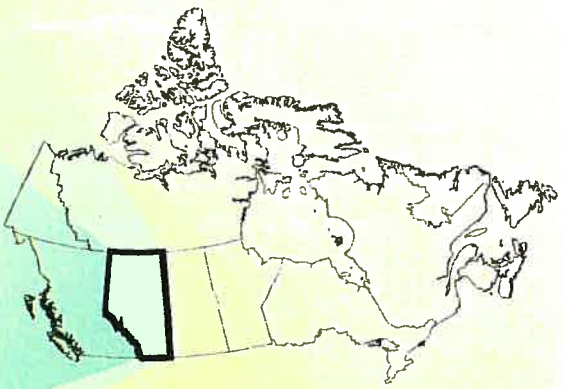

Weed Survey Series

Alberta Agriculture, Food and

Canada

Alberta Weed Survey of Herbicide-Resistant Weeds in 2001

by

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Weed Survey Series
Publication 04-1

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

June 2004

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
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, 1979 and 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 and their competitive effect 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)

(Table continued on next page)

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

Number	Title
87-3	Saskatchewan cereal and oilseed crops weed survey questionnaire (1986)
88-1	Weed survey of cereal and oilseed crops in Manitoba (1986)
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

A major four-year weed survey project entitled "Shifts in the Distribution, Abundance, Resistance, and Management of Weeds in Prairie Ecosystems" was inititated in 2001. The project has three equally important components. The field survey component involves weed counts in 4000 randomly selected sites in Alberta, Saskatchewan, and Manitoba. The second project component includes a management questionnaire that is used to gather details of the farm practices used in the 4000 surveyed fields. Dr. A. Gordon Thomas is the coordinator for these two project components. The third project component, which I coordinate, involves a survey of resistant weeds in 800 fields from the list of surveyed sites.

Previously published reports in the Weed Survey Series on occurrence of herbicide-resistant weeds were: (1) 98-3: Saskatchewan weed survey of herbicide-resistant wild oat and green foxtail in 1996; (2) 98-4: Saskatchewan grain elevator weed survey of herbicide-resistant wild oat and green foxtail in 1997; (3) 98-5: Manitoba weed survey of herbicide-resistant wild oat in 1997; and (4) 99-4: Saskatchewan weed survey of herbicide-resistant wild oat in 1997. Thus, these surveys focused on herbicide resistance in our two most important grass weed species, wild oat and green foxtail.

This report documents the nature, distribution and abundance of herbicide-resistant weeds in Alberta in 2001. The survey is unique in three ways. It is the first comprehensive weed resistance survey in Alberta and therefore serves as a baseline for future surveys. Nearly 250 fields were surveyed across the province. Secondly, the sites in this survey were selected randomly, weighted only according to crop type and ecodistrict similar to that in the general weed survey conducted in the same growing season (see report 02-1). Most previous surveys involved fields that were rated as high risk for occurrence of weed resistance. Thirdly, all weed species with viable seed were sampled, and resistance testing was the most extensive to date.

Succeeding reports will detail weed resistance in Manitoba in 2002 and Saskatchewan in 2003. A fourth report will integrate the results from the three reports to facilitate a comparison of weed resistance across the major prairie ecoregions and provide "the big picture" of weed resistance in the prairies. A final report will describe how management practices of producers, as documented in the management questionnaire, influences the risk of herbicide resistance in weeds using data from the three prairie provinces. This analysis will build upon studies published previously, and help producers to manage for weed resistance.

Hugh J. Beckie
Weed Resistance Survey Project Leader
Agriculture and Agri-Food Canada

Saskatoon, SK
June 2004

ACKNOWLEDGEMENTS

Financial support for this survey was provided by the Matching Investment Initiative (MII) of Agriculture and Agri-Food Canada; Alberta Agriculture, Food and Rural Development Farming for the Future Program; and by the following herbicide manufacturers and distributors:

Aventis Crop Science Canada Co.
BASF Canada
Bayer CropScience
Dow AgroSciences Canada Inc.
DuPont Canada Inc.
Monsanto Canada Inc.
Nufarm Agriculture Inc.
Western Co-operative Fertilizers Limited

We gratefully acknowledge the AAFC technical expertise of Christopher Lozinski, Scott Shirriff, Brent Slobodian, and Mike Robinson in conducting the survey, processing and screening samples for resistance, data entry, or contacting producers. We thank David Giffen for producing the maps and Ralph Underwood for design graphics and printing copies of the report.

Five Crop Specialists arranged for site qualification in their respective regions, and provided regular updates on crop development to aid field survey scheduling. We acknowledge the individual contribution of the following Specialists to the overall success of the project:

John Huffman (Peace)
Trevor Kloeck (North)
Russel Horvey (Central)
Dorothy Stewart (Central)
Rob Dunn (Southern)

Special thanks are extended to the 236 producers who participated in this survey.

Hugh J. Beckie, Linda M. Hall, Julia Y. Leeson, and A. Gordon Thomas

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

A survey of weeds resistant to herbicides in 236 randomly selected fields was conducted across the major ecoregions of Alberta in 2001. This baseline survey determined the incidence of herbicide resistance, and will serve as a reference for future surveys. 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 questionnaire.

Nearly 20% of surveyed fields had a herbicide-resistant weed biotype. Of 190 fields where wild oat samples were collected, 11% had Group 1-resistant wild oat (9% of all fields surveyed) and 13% had Group 2-resistant wild oat (10% of all fields surveyed). Half of the fields with either resistant biotype originated in the Aspen Parkland ecoregion, which was attributed to historically high frequency of use of products from these groups. Most Group 1-resistant wild oat populations exhibited resistance to both aryloxyphenoxyproprionate and cyclohexanedione herbicides. Group 2-resistant 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 (four fields in the Aspen Parkland ecoregion) and spiny annual sow-thistle (four 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) suggests that rotations practiced by a significant number of these producers are less than effective in delaying resistance to these herbicides. Use of these herbicides for grass weed control in cereal crops is expected to increase with the loss of older chemistries or decline in preemergence application.

Only 5% of producers with resistant 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 resistant 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% producers expected herbicide resistance to pose a moderate or high impact on their farm.

Herbicide Use in Alberta: 1992 to 2001

Questionnaires completed by 428 producers (63% response rate) in the 1997 Alberta weed survey (Thomas et al. 1998) and 780 producers (68% response rate) in the 2001 Alberta weed survey (Leeson et al. 2002a) enabled an assessment of herbicide-use patterns in the surveyed fields (one field per producer) from 1992 to 2001 (Thomas et al. 2003). The number of fields surveyed in each ecodistrict (area of similar landform, relief, surficial material, soil, vegetation, and land use; Ecological Stratification Working Group 1995) was proportional to the seeded area of the main crops that included spring wheat (*Triticum aestivum* L.), durum wheat [*Triticum turgidum* L. subsp. *durum* (Desf) Husn.], barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), canola (*Brassica napus* L. or *B. rapa* L.), and field pea (*Pisum sativum* L.) (field pea in 2001 only). A total of 684 fields were surveyed in 1997 and 1,153 fields in 2001.

Although herbicides can be applied pre-harvest, post-harvest, pre-seeding, or in-crop, most fields (91%) in 2001 received at least an in-crop herbicide application (Thomas et al. 2003). Reducing herbicide rates has been suggested as a strategy for delaying the development of target site resistance in wild oat (*Avena fatua* L.) (Beckie and Kirkland 2003). In 2001, 25% of the herbicides were applied at lower-than-recommended rates (Leeson et al. 2002b).

Although herbicide resistance has been emphasized in extension programs, Group 1 herbicides (ACCase inhibitors) and Group 2 herbicides (ALS inhibitors) were consistently applied to 45 and 40% of the surveyed area, respectively, between 1996 and 2001 (Figure 1; pulse crops excluded). The use of preemergence herbicides, the dinitroanilines (Group 3) and triallate (Group 8), had declined to about 4% (2% each) of the surveyed area by 2001. Application of synthetic auxins (Group 4) was consistently high (>50%) from 1992 to 2001.

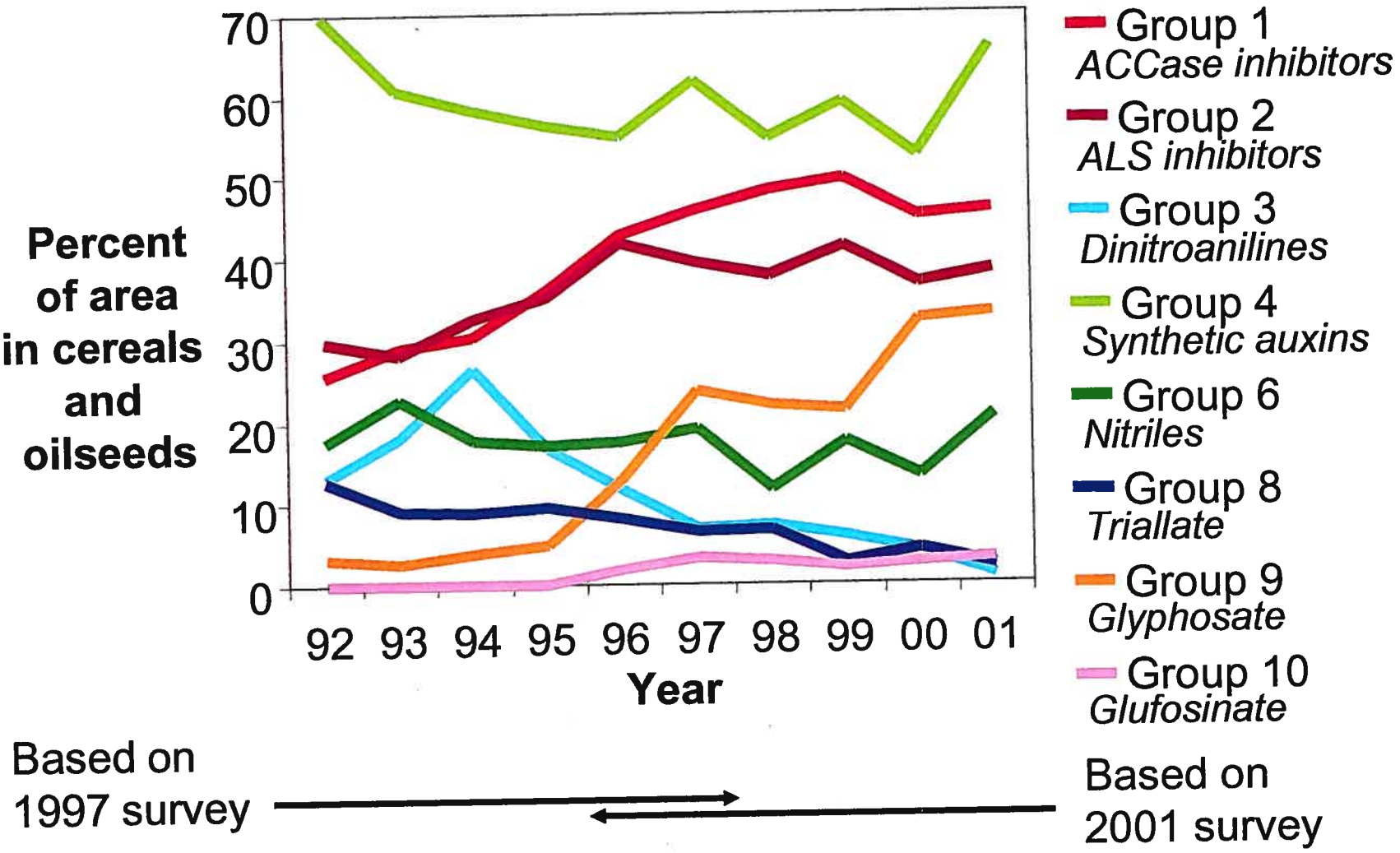


Figure 1. Herbicide group use in cereal and oilseed crops in Alberta (Source: Thomas et al. 2003)

Table 1. Herbicide (in-crop) group use across the major ecoregions of Alberta in 2001 (Source: Leeson et al. 2002b)

Group	Mixed Grassland	Moist Mixed Grassland	Fescue Grassland	Aspen Parkland	Boreal Transition	Peace Lowland
	% of area					
None	20	9	4	4	18	8
1	49	45	55	47	47	42
2	23	19	42	40	38	50
4	70	76	78	54	47	44
6	33	41	39	14	9	2
8	-	-	-	-	2	-
9	-	6	-	20	8	13
10	-	1	1	4	6	3

Group 6 herbicide (nitriles) use averaged only about 20% of the area during this 10-year period. The use of glyphosate (Group 9) had increased to 34% by 2001, in part because of the cultivation of glyphosate-resistant canola, reduced use of tillage, and the falling cost of glyphosate. Glufosinate (Group 10) use, primarily in glufosinate-resistant canola, remained below 5% of the survey area during this 10-year period.

Further examination of herbicide group use across the six major ecoregions (Figure 2; major ecoregions listed in legend), defined on the basis of climate, natural vegetation, and soils, (Ecological Stratification Working Group 1995) in 2001 indicated uniformly high (> 40%) frequency of Group 1 herbicide use (Table 1). Most Group 2 herbicides were applied primarily for broadleaf weed control in 2001. Group 2 herbicide use ranged from about 20% of the survey area in the Mixed and Moist Mixed Grassland ecoregions, to 40% in the Fescue Grassland, Aspen Parkland, and Boreal Transition ecoregions, to 50% in the Peace Lowland ecoregion.

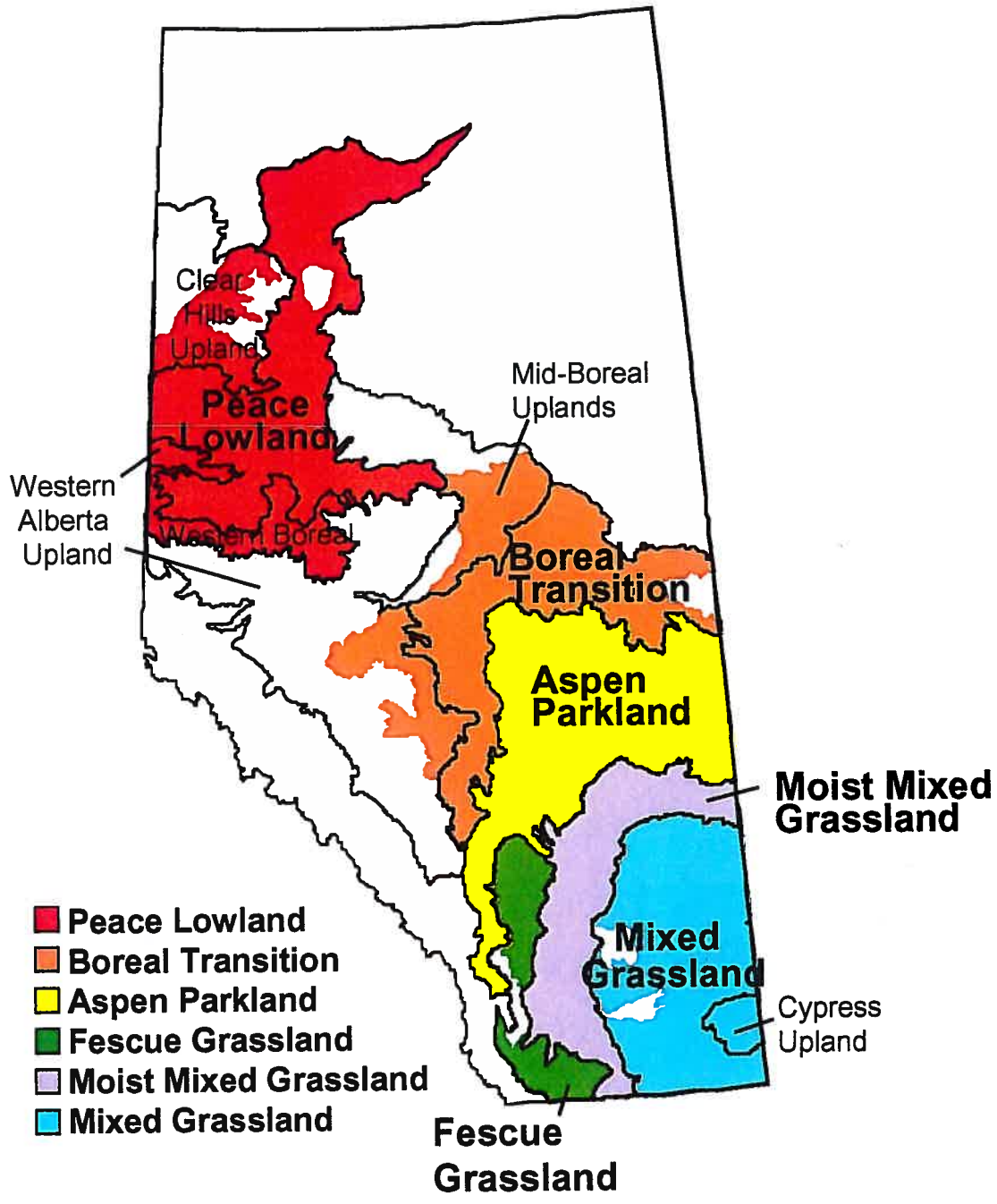


Figure 2. Ecoregions of Alberta (map derived from Agriculture and Agri-Food Canada (2003)).

Group 4 and 6 herbicide use were lowest in the Parkland ecoregions (Peace Lowland, Boreal Transition, Aspen Parkland) and highest in the Grassland ecoregions. In contrast, glyphosate (Group 9) and glufosinate (Group 10) use were highest in the Parkland region.

Herbicide Group Rotation

The majority of producers (82% of 579 respondents) in 2001 reported rotating herbicide groups to manage (proactively or reactively) resistant weeds (Table A1 –see Appendix; Leeson et al., in preparation). The adoption rate of this important weed resistance management practice, by ecoregion, was the following: Mixed Grassland, 69%; Moist Mixed Grassland, 78%; Fescue Grassland, 90%; Aspen Parkland and Boreal Transition, 86%; Peace Lowland, 82%. Herbicide group rotation was practiced between 1 and 5 years in nearly 50% of the survey area, and between 6 and 10 years in 40% of the area (Figure 3). The greatest percentage of producers (30%) rotating herbicide groups more than 10 years were from the Mixed Grassland ecoregion; this percentage was at least twice that of the other ecoregions (Table A2). Averaged across all ecoregions, a majority of producers (54%) did not follow a set rotation (e.g., one in three years), whereas one-quarter of producers indicated that frequency of herbicide group rotation varied among the groups used (Table A3).

More than one-third of the producers were using high risk herbicides in Groups 1 or 2 at a frequency greater than once every three years (i.e., twice in six years) from 1996 to 2001 (Figures 4 and 5). Consecutive annual applications of Group 1 herbicides (six applications in six years) declined slightly during 1996 to 2001 compared with 1992 to 1997. However, the area sprayed with three, four, or five applications in six years increased from 35% between 1992 and 1997 to 45% between 1996 and 2001 (Figure 4). Frequency of use rose from about 25% in 1992

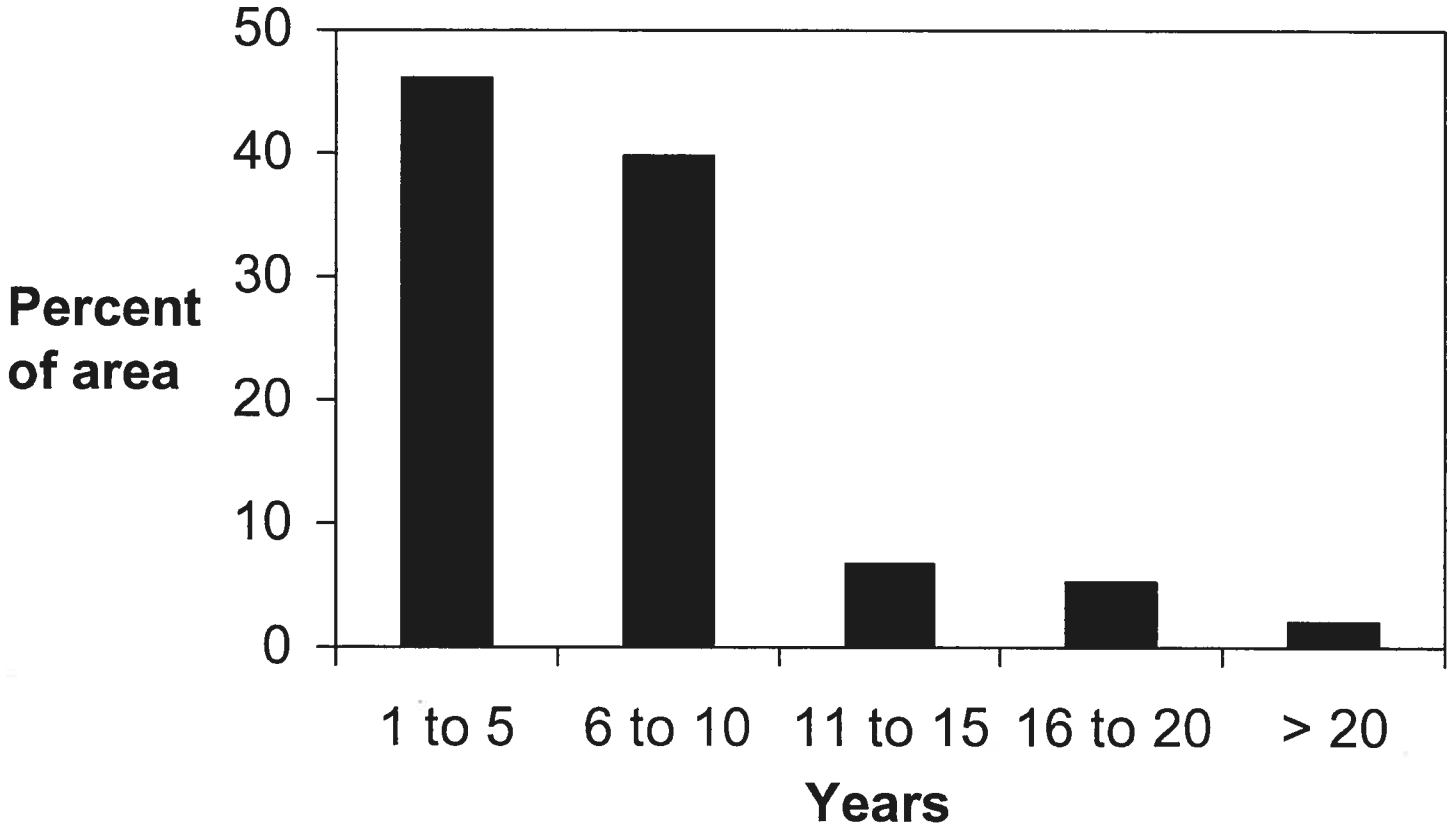


Figure 3. Length of time that herbicide group rotations were practiced by Alberta producers in 2001 (Source: Thomas et al. 2003)

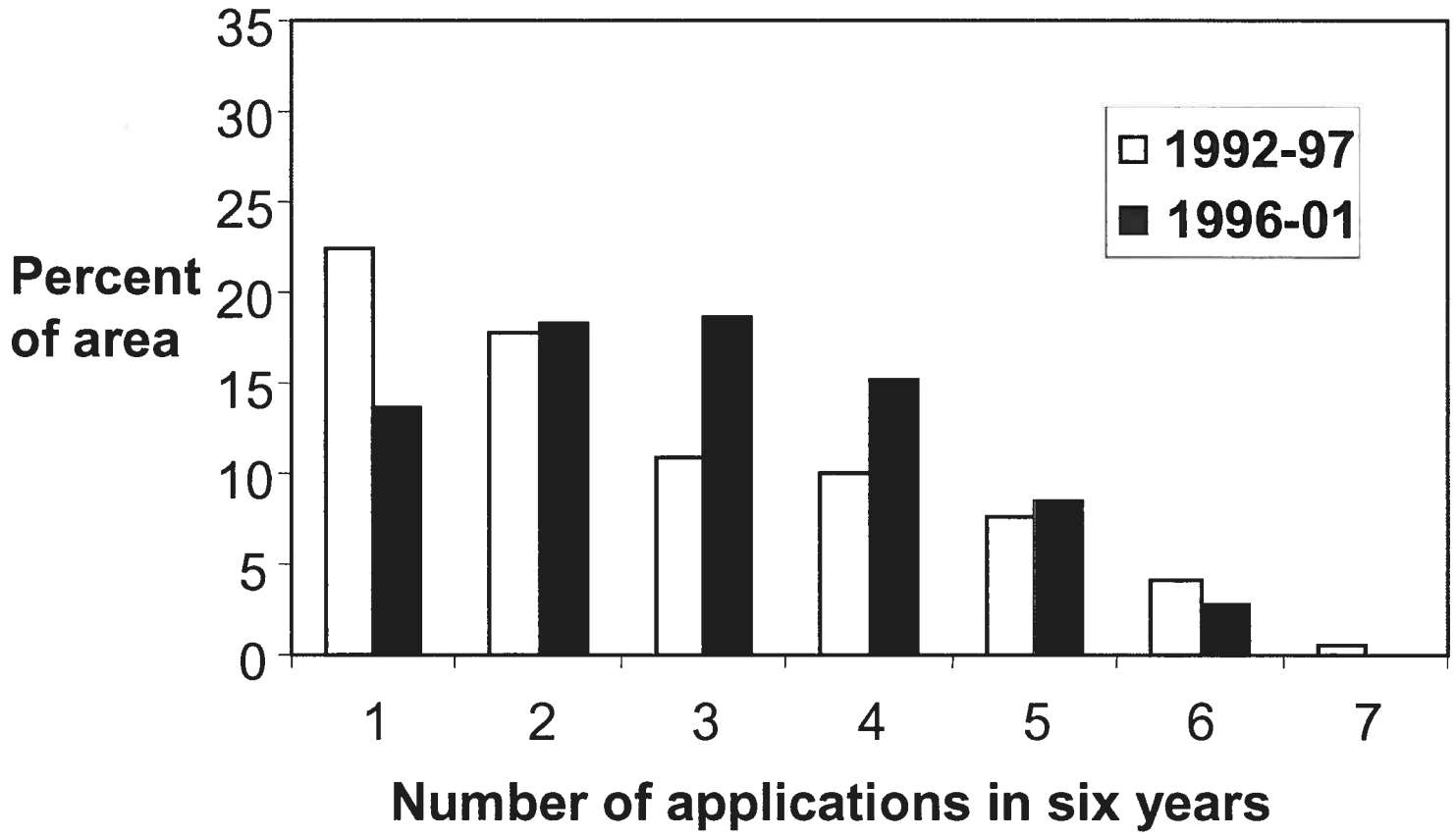


Figure 4. Group 1 herbicide use in the surveyed area of Alberta (Source: Thomas et al. 2003)

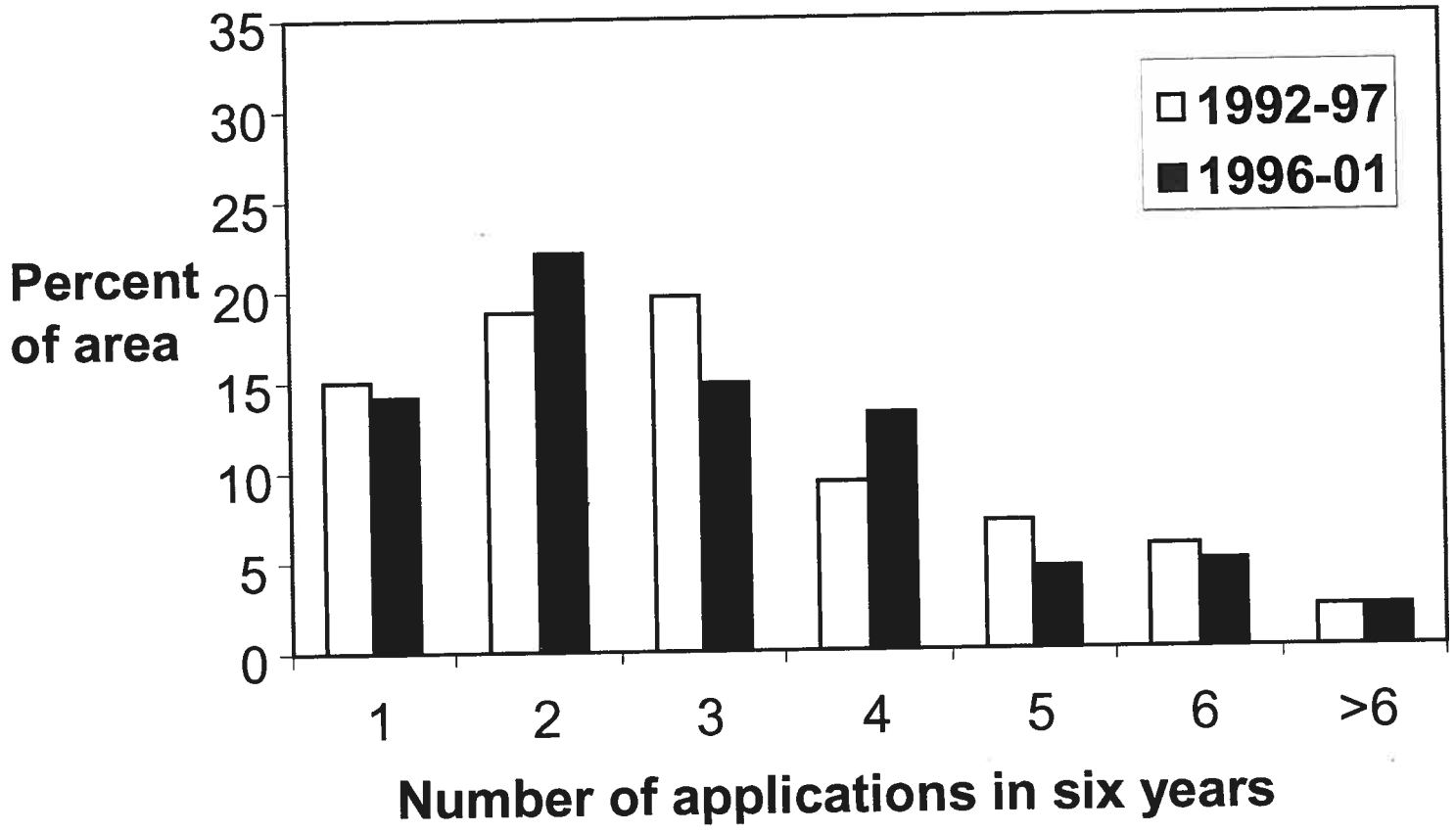


Figure 5. Group 2 herbicide use in the surveyed area of Alberta (Source: Thomas et al. 2003)

to 45% of land cropped to cereals and oilseeds in 2001 (Figure 1). The area treated with three or more applications of Group 2 herbicides in a six-year period declined slightly from 45% between 1992 and 1997 to 40% between 1996 and 2001 (Figure 5). Overall, frequency of use increased from 30% of fields cropped to cereals and oilseeds in 1992 to 40% of fields in 1996, and remained near that level through to 2001 (Figure 1).

A recommendation in the 1990s to limit frequency of herbicide group use in a field to once every three years was based on anecdotal evidence for time required for selection of Group 1 resistance in wild oat. A subsequent recommendation recognized the different propensity of herbicides from different groups to select for resistant weeds (Beckie et al. 2001). Herbicide groups were classified as high risk (Groups 1 and 2), moderate risk (e.g., Group 3 – green foxtail, *Setaria viridis* (L.) Beauv.; Group 8 – wild oat) or low risk (Groups 4, 6, 9, and 10). Thus, frequency of herbicide group use should be inversely proportional to the relative risk. For example, glyphosate or Group 4 herbicides applied once annually in a field would not pose a greater risk for selecting for herbicide-resistant weeds than Group 1 or 2 herbicides used once every three or four years. Nonetheless, diversifying use of herbicides from different groups is the best management practice.

Past Weed Resistance Surveys in Alberta

Field surveys of specific resistant-weed biotypes have been conducted in Alberta since 1990. They focused on wild oat 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-resistant wild oat (O'Donovan et al. 1994). In 1996, 38 fields where a Group 1 herbicide had been applied

that year were surveyed for Group 1-resistant wild oat (O'Donovan et al. 1998). Nine of those fields (25%) had Group 1-resistant wild oat. Most of the populations originated in the southern (Grassland) region of Alberta, which was attributed to greater Group 1 herbicide use (O'Donovan et al. 1998). In Wheatland County, Alberta located in the Fescue Grassland ecoregion, 95 fields were surveyed for herbicide-resistant wild oat from 1997 to 1999 (Beckie et al. 1999, 2004). These fields had been treated repeatedly with the same herbicide mode of action 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 Agriculture, Food and Rural Revitalization and AAFC, Saskatoon. Results from the 1996 to 2001 crop years were recently published (Beckie et al. 2003). In Alberta, many wild oat samples confirmed as Group 1-resistant originated from the Aspen Parkland ecoregion, although a significant number were from the Grassland region. Group 2- or 8-resistant wild oat or multiple group (1 and 2) -resistant wild oat were most abundant in the Aspen Parkland ecoregion. There were no cases of Group 1-resistant green foxtail from 1996 to 2001. Cases of Group 2-resistant kochia [*Kochia scoparia* (L.) Schrad.] were all from the Grassland region near Lethbridge.

Objectives

A comprehensive field survey of herbicide-resistant weeds had not been conducted in Alberta. A baseline survey was needed to determine the incidence of herbicide resistance and serve as a reference for future surveys to identify trends. Therefore in 2001, 236 of the 1,153 fields

surveyed earlier that year for residual weed populations (Leeson et al. 2002a) 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 high-risk herbicides, namely Groups 1 and 2, to determine the cross-resistance patterns within groups. In addition to weed resistance incidence, herbicide resistance awareness among participating producers in this survey and perceived present or future impact of resistance were assessed by means of a management questionnaire.

Sites

A total of 236 fields were surveyed for herbicide-resistant weeds (Map 1). The general weed survey (Leeson et al. 2002a) utilized a stratified-randomized design. The number of field sites surveyed in each ecodistrict for herbicide-resistant weeds was directly proportional (about 20%) to the number selected in the general weed survey. In addition, the proportional allocation of fields among the major crops grown in each ecodistrict was the same as that of the general weed survey. Each sampling unit comprised a 64-ha area that contained the field surveyed in the general weed survey. The field allocation by crop in the six major ecoregions is shown in Table 2. Most of the fields (85%) were cropped to cereals. Wheat occupied 55% of the 201 survey fields cropped to cereals, barley 40%, and oat 5%. Canola and field pea comprised 80 and 20%, respectively, of the 35 survey fields cropped to broadleaf crops.

Table 2. Field allocation by crop in the major ecoregions

Crop	Mixed Grassland	Moist Mixed Grassland	Fescue Grassland	Aspen Parkland	Boreal Transition	Peace Lowland	*All areas*
	No. of fields						
Spring wheat	10	18	8	36	5	17	*94*
Durum wheat	11	5	0	0	0	0	*16*
Barley	3	19	8	32	10	7	*79*
Oat	1	1	0	4	3	3	*12*
Canola	1	2	1	15	1	8	*28*
Field pea	1	1	0	4	1	0	*7*
Total	*27*	*46*	*17*	*91*	*20*	*35*	***236***

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 3.

The majority of the 20 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance in fields surveyed in 2001 (Leeson et al. 2002a) or only in the 236 fields included in this survey (Table 3). Six species tested ranked lower than 20th based on relative abundance in the 236 fields. Some species whose seeds had been collected were not tested because of limited seed, no known response to Group 1 or 2 herbicides, 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. Weed samples were screened for Group 1 and Group 2 resistance.

Grass weed species were tested for resistance to a maximum of six Group 1 herbicides: three

Table 3. Weed species tested for resistance to Group 1 or 2 herbicides

Weed species	Samples tested	Fields where collected	Rank[a]	
			All fields	236 fields
Grass:	No.			
Wild oat, *Avena fatua* L.	505	190	2	2
Green foxtail, *Setaria viridis* (L.) Beauv.	22	14	9	17
Quack grass, *Elytrigia repens* (L.) Desv. ex B. D. Jacks	3	3	14	12
Broadleaf:				
Ball mustard, *Neslia paniculata* (L.) Desv.	3	3	45	56
Chickweed, *Stellaria media* (L.) Vill.	32	24	3	3
Cleavers, *Galium aparine* L.	29	26	6	11
Corn spurry, *Spergula arvensis* L.	1	1	26	42
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	8	8	29	32
Hemp-nettle, *Galeopsis tetrahit* L.	13	13	8	7
Lamb's-quarters, *Chenopodium album* L.	31	29	7	6
Narrow-leaved hawk's-beard, *Crepis tectorum* L.	7	7	17	15
Redroot pigweed, *Amaranthus retroflexus* L.	5	5	22	19
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	19	18	13	8
Annual smartweed species, *Polygonum* spp.	18	16	11[a]	9
Spiny annual sow-thistle, *Sonchus asper* (L.) Hill	6	6	41	31
Perennial sow-thistle, *Sonchus arvensis* L.	5	5	18	16
Stinkweed, *Thlaspi arvense* L.	61	55	5	4
Stork's-bill, *Erodium cicutarium* (L.) L'Hér.ex Aiton	4	4	28	24
Wild buckwheat, *Polygonum convolvulus* L.	47	44	1	1
Wild mustard, *Sinapis arvensis* L.	5	5	37	30

[a]Relative abundance rank of species in in all 1,153 fields surveyed (Leeson et al. 2002a) and in the 236 fields surveyed for weed resistance; rank of annual smartweed species is that of pale smartweed.

aryloxyphenoxypropionate (APP) herbicides and three cyclohexanedione (CHD) herbicides. The three APP herbicides were fenoxaprop (without safener) at 150 g/ha (wild oat) or 40 g/ha (green foxtail); clodinafop at 70 g/ha; and quizalofop at 35 g/ha; the three CHD herbicides were sethoxydim at 110 g/ha; tralkoxydim at 200 g/ha; and clethodim at 45 (recommended rate) or 6.25 g/ha. In a preliminary experiment, 6.25 g/ha clethodim was the lowest rate that controlled the known herbicide-susceptible biotype, but not the known herbicide-resistant biotype, UM1. 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 imidazolinones (imazamethabenz,

imazethapyr, imazapyr), two sulfonylureas (sulfosulfuron, sulfometuron), and flucarbazone, a sulfonylaminocarbonyltriazolinone herbicide. Imazamethabenz was applied at 500 g/ha; imazethapyr at 50 g/ha; imazapyr at 0.85 g/ha; sulfosulfuron at 20 g/ha; sulfometuron at 155 g/ha; and flucarbazone at 30 g/ha (wild oat) or 15 g/ha (green foxtail). Imazapyr and sulfometuron are not registered for use in Canada; these herbicides were included to provide clues to the mechanism of resistance. Species with metabolic resistance are normally controlled by one or both herbicides. Broadleaf weed species were treated with a maximum of five Group 2 herbicides: one imidazolinone (imazethapyr), three sulfonylureas (thifensulfuron/tribenuron mixture, metsulfuron, sulfosulfuron), and florasulam, a triazolopyrimidine herbicide. Imazethapyr was applied at 100 g/ha; thifensulfuron/tribenuron at 30 g/ha; metsulfuron at 9 g/ha; sulfosulfuron at 40 g/ha, and florasulam at 10 g/ha. 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 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).

Herbicide Resistance Awareness and Impact: Producer Management Questionnaire

In the management questionnaire (Leeson et al., in preparation), two questions focused on herbicide resistance awareness: (1) Are you aware or do you suspect that you have a herbicide-

resistant weed in the surveyed field; and (2) if so, herbicide groups and weeds that you are aware as being resistant or suspect resistance. Two additional questions examined producers' belief of the present (2001) and future (next 5 years) impact of weed resistance on their farm. Results are reported only for the producers participating in the weed resistance survey.

Grass Weed Resistance

Of the 190 fields where wild oat samples were collected, 20 (11%) had Group 1-resistant wild oat (Table 4, Map 2). Therefore, 9% of all fields surveyed (236) had resistant wild oat. Half of these fields were located in the Aspen Parkland ecoregion, followed by 20% of sites in the Peace Lowland, 15% in the Moist Mixed Grassland, 10% in the Mixed Grassland, and 5% in the Boreal Transition ecoregion. Resistance occurrence was proportionally greatest in the Aspen Parkland and Peace Lowland ecoregions (13 and 17% of fields, respectively, where seeds were collected). Most cases of Group 1 resistance in wild oat, based on samples submitted by producers between 1996 and 2001, originated in the Aspen Parkland ecoregion (Beckie et al. 2003). Group 1 herbicide use was consistently high among ecoregions in 2001 (Table 1). However, in 1997, frequency of application was greatest in the Aspen Parkland ecoregion (49% of fields; J. Leeson, pers. comm.). Use of Group 1 herbicides in 1997 was least in the Mixed Grassland ecoregion (13%). Occurrence of Group 1 resistance was generally greatest where Group 1 herbicides had been applied four or more years between 1996 and 2001 (Table 5).

Table 4. Fields with resistance 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	2	8	7	2	8	7
Moist Mixed Grassland	3	8	7	5	13	11
Fescue Grassland	0	0	0	2	17	12
Aspen Parkland	10	13	11	12	16	13
Boreal Transition	1	6	5	0	0	0
Peace Lowland	4	17	11	3	13	9
Alberta	20	11	9	24	13	10

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

Table 5. Number of years of Group 1 herbicide use from 1996 to 2001 in fields with Group 1-resistant and -susceptible wild oat[a]

Years	Seeds not collected		Susceptible		Resistant	
	No.	%	No.	%	No.	%
None	1	5	17	27	1	8
One	5	23	12	19	1	8
Two	4	18	9	15	2	15
Three	4	18	13	21	1	8
Four	6	27	5	8	3	23
Five	2	9	4	6	4	31
Six	-	-	2	3	1	8
Total	22		62		13	

[a]Fields of producers who completed a management questionnaire.

Three of these fields had APP (only)-resistant wild oat (Map 3), and only one field had CHD (only)-resistant wild oat (Map 4); 16 fields had APP+CHD-resistant populations (Map 5). Therefore a total of 19 fields had APP-resistant wild oat and 17 fields had CHD-resistant wild oat. Thus, most fields had wild oat populations resistant to both APP and CHD herbicides. Greater frequency of APP- than CHD-resistant wild oat had consistently been shown in previous surveys conducted across the prairies in the 1990s; previously, fenoxaprop was used to screen for APP resistance and sethoxydim for CHD resistance. Based on resistance to these two herbicides only, the same number of fields (19) would have APP-resistant wild oat, but 9 fields (not 17) would have CHD-resistant wild oat.

The cross-resistance pattern in Group 1-resistant wild oat populations is shown in Table 6. The percentage of fields with wild oat resistant to the APP herbicides, fenoxaprop, clodinafop, and quizalofop was 95, 79, and 77%, respectively. These results suggest broad cross resistance among populations to these APP herbicides. In contrast, the percentage of fields with wild oat resistant to the CHD herbicides, sethoxydim, tralkoxydim, and clethodim was 45, 57, and 0%, respectively. Clethodim applied at the field-recommended rate effectively controlled Group 1-

Table 6. Group 1 herbicide cross-resistance patterns in wild oat in 20 fields in Alberta in 2001

	APP			CHD		
Field-sample	Fenoxaprop	Clodinafop	Quizalofop	Sethoxydim	Tralkoxydim	Clethodim**
	% resistant seedlings					
1-1	100	100	100	0	0	0/92
1-2	100	100	100	0	83	0/83
1-3	100	100	86	0	0	0/100
1-4	100	100	100	0	0	0/LS
2-1	100	100	44	100	0	0/92
3-1	28	LS*	LS	19	LS	LS
4-1	100	100	100	100	100	0/100
5-1	100	100	100	100	91	0/100
5-2	100	100	100	100	86	0/100
5-3	100	100	100	100	100	0/100
6-1	100	35	100	0	0	0/8
7-1	100	LS	LS	0	LS	LS
8-1	100	0	100	0	0	0/8
8-2	100	LS	LS	0	LS	LS
9-1	100	100	100	100	100	0/75
10-1	100	0	100	0	0	0/LS
11-1	100	100	100	100	100	0/100
12-1	28	LS	LS	0	LS	LS
12-2	100	LS	LS	0	LS	LS
12-3	27	LS	LS	0	LS	LS
12-4	100	LS	LS	100	LS	LS
13-1	100	LS	LS	100	LS	LS
14-1	100	LS	LS	0	LS	LS
15-1	19	36	LS	0	78	LS
16-1	60	8	0	0	42	0/28
17-1	0	LS	LS	100	LS	LS
18-1	100	0	0	0	0	0/35
19-1	17	100	0	0	0	0/67
19-2	11	22	LS	0	29	LS
20-1	100	100	42	0	0	0/100
No. fields	*20*	*14*	*13*	*20*	*14*	*13/12*
Resistance frequency	***95***	***79***	***77***	***45***	***57***	***0/100***

*LS – limited viable seed supply.
**Results for clethodim applied at 45 g ai/ha / 6.25 g ai/ha.

resistant populations, which has also been documented in other species in other countries (e.g., Bradley and Hagood 2001). However, when applied at 6.25 g/ha (about 15% of field rate), all tested populations exhibited resistance to the herbicide whereas the susceptible check population was controlled. The resistant check, UM1, was controlled at the high rate but not at the low rate; the GR_{50} R/S ratio for response of UM1 to clethodim is 4 (Heap et al. 1993). It is unclear if these populations would be controlled in the field by clethodim applied at the recommended rate.

Further research is warranted to correlate greenhouse efficacy with field efficacy; Group 1 herbicides are generally more efficaceous in the greenhouse than in the field. Clethodim-resistant wild oat populations have been documented previously in Manitoba (Bourgeois et al. 1997; Beckie, unpubl. data).

Group 2 resistance was confirmed in 24 wild oat populations (13% of fields where seeds were collected or 10% of all fields surveyed) (Table 4, Map 6). This is the first survey in western Canada to show similar incidence of Group 2 compared with Group 1 resistance. Similar to Group 1 resistance, half of the fields with Group 2-resistant wild oat were located in the Aspen Parkland ecoregion. Most cases of Group 2 resistance in wild oat, based on samples submitted by producers between 1996 and 2001, also originated in the Aspen Parkland ecoregion (Beckie et al. 2003). Similar to Group 1 herbicide use, Group 2 herbicide use in this ecoregion was relatively high in 2001 (40% of the area, Table 1), and the highest among ecoregions in 1997 (49%) (J. Leeson, pers. comm.). Five fields (21%) were located in the Moist Mixed Grassland, 13% in the Peace Lowland, and 8% in each of the Mixed and Fescue Grassland ecoregions. As a percentage of fields where seeds were collected, resistance occurrence was greatest in the Aspen Parkland and Fescue Grassland ecoregions (16 and 17% of fields, respectively) (Table 4). Similar to occurrence of Group 1 resistance, Group 2-resistant wild oat was most prevalent and Group 2-susceptible wild oat least frequent in fields where Group 2 products were applied four or more years from 1996 to 2001 (Table 7).

Broad cross resistance was evident among populations to the Group 2 herbicides, imazamethabenz, imazethapyr, sulfosulfuron, and flucarbazone (Table 8). Susceptibility to imazapyr and sulfometuron suggests, but does not confirm, altered metabolism as the basis for resistance. Group 1- and 2-resistant wild oat were found in six fields: two in each of the Moist

Table 7. Number of years of Group 2 herbicide use from 1996 to 2001 in fields with Group 2-resistant and -susceptible wild oat[a]

Years	Seeds not collected		Susceptible		Resistant	
	No.	%	No.	%	No.	%
None	6	18	30	29	3	17
One	8	24	23	22	4	22
Two	8	24	30	29	4	22
Three	9	26	12	11	1	6
Four	1	3	8	8	3	17
Five	2	6	2	2	3	17
Total	34		105		18	

[a]Fields of producers who completed a management questionnaire.

Mixed Grassland, Aspen Parkland, and Peace Lowland ecoregions (Map 7).

Group 1 herbicide use in the survey year favored detection of Group 1-resistant wild oat (Table 9). Resistance in wild oat was detected in 21% of fields where a Group 1 product had been applied that year compared with only 3% of fields where such products had not been applied. Similarly, Group 2 resistance in wild oat was detected in 20% of fields where a Group 2 herbicide had been applied that year compared with only 6% of fields where such herbicides were not applied.

Resistance to Group 1 or 2 herbicides was not found in green foxtail in 14 fields (Map 8) or in quack grass from three fields (Map 9). Herbicide resistance in quack grass in Canada has not been reported. No green foxtail samples were submitted by Alberta growers from 1996 to 2001 for resistance testing (Beckie et al. 2003). Although Group 1-resistant green foxtail has been reported in Alberta since 1996 (Heap 2004), the incidence is likely low.

Table 8. Group 2 herbicide cross-resistance patterns in wild oat in 24 fields in Alberta in 2001

	Imidazolinone			Sulfonylurea		Sulfonylamino-carbonyltriazolinone
Field-sample	Imazamethabenz	Imazethapyr	Imazapyr	Sulfosulfuron	Sulfometuron	Flucarbazone
	% resistant seedlings					
1-1	72	100	0	100	0	100
2-1	89	100	0	94	0	81
2-2	100	100	0	100	0	100
2-3	100	100	0	100	0	100
2-4	100	100	0	92	0	100
3-1	69	LS	LS	LS	LS	LS
4-1	83	100	0	28	0	78
5-1	100	39	0	100	0	100
5-2	89	LS	LS	LS	LS	LS
6-1	83	LS	LS	LS	LS	LS
6-2	100	67	0	100	0	100
7-1	100	100	0	100	0	100
7-2	100	83	0	100	0	100
7-3	83	LS	LS	LS	LS	LS
7-4	100	100	0	100	0	100
8-1	67	79	0	83	0	62
9-1	92	94	0	22	0	81
10-1	100	100	0	100	0	100
10-2	94	100	0	100	0	97
11-1	100	100	0	83	0	67
12-1	100	LS	LS	LS	LS	LS
12-2	100	LS	LS	LS	LS	LS
13-1	21	34	0	17	0	22
14-1	100	LS	LS	LS	LS	LS
14-2	100	100	0	100	0	100
15-1	100	100	0	36	0	0
15-2	22	28	0	42	0	47
16-1	9	LS	LS	LS	LS	LS
16-2	94	LS	LS	LS	LS	LS
17-1	100	100	0	LS	0	44
18-1	14	30	0	44	0	28
19-1	100	LS	LS	LS	LS	LS
20-1	8	17	0	22	0	6
21-1	100	LS	LS	LS	LS	LS
22-1	100	100	0	100	0	100
23-1	19	43	0	39	0	33
24-1	89	LS	LS	LS	LS	LS
No. fields	*24*	*18*	*18*	*17*	*18*	*18*
Resistance frequency	***100***	***100***	***0***	***100***	***0***	***100***

*LS – limited viable seed supply.

Table 9. Influence of herbicide group use in the survey year on detection rate of herbicide resistance in wild oat (number and percentage of fields)[a]

Group use in survey year	Group 1-resistant wild oat				Group 2-resistant wild oat			
	Yes		No		Yes		No	
	No.	%	No.	%	No.	%	No.	%
Resistant	16	21	2	3	12	20	5	6
Susceptible	47	61	49	73	36	60	61	73
Not tested	14	18	16	24	12	20	18	21
Total	77		67		60		84	

[a]Fields of producers who completed a management questionnaire.

Broadleaf Weed Resistance

Four of 24 fields (17%) had Group 2-resistant chickweed; these fields were located in the Aspen Parkland ecoregion (Map 10). The cross-resistance patterns among the four populations (Table 10) indicate broad resistance across the three chemical classes, similar to that of wild oat. Frequency of resistance to imazethapyr and florasulam was slightly lower than the sulfonylureas. Group 2-resistant chickweed in central Alberta has been reported since 1988 (Beckie et al. 2001; Heap 2004; Morrison and Devine 1994).

Four of six fields (67%) had Group 2 (metsulfuron)-resistant spiny annual sow-thistle; these fields were located in the Moist Mixed Grassland, Fescue Grassland, or Aspen Parkland ecoregions (Map 11). Two resistant biotypes from the Aspen Parkland ecoregion of Alberta in

Table 10. Group 2 herbicide cross-resistance patterns in chickweed in 4 fields in Alberta in 2001

	Imidazolinone	Sulfonylurea			Triazolopyrimidine
Field-sample	Imazethapyr	Thifensulfuron/tribenuron	Metsulfuron	Sulfosulfuron	Florasulam
	% resistant seedlings				
1-1	97	94	LS	LS	100
1-2	0	39	LS	LS	0
2-1	0	56	9	100	0
3-1	83	78	LS	LS	67
4-1	6	6	14	100	9
Resistance frequency	***75***	***100***	***100***	***100***	***75***

*LS – limited viable seed supply.

1996 were reported previously (Rashid et al. 2003).

Resistance to Group 2 herbicides in 15 other broadleaf weed species was not detected (Maps 12-26). Group 2-resistant cleavers, kochia, ball mustard, wild mustard, and stinkweed in Alberta have been reported previously (Beckie et al. 2001; Heap 2004). Group 2-resistant kochia was found in the Grassland region, based on samples submitted by producers between 1996 and 2001 (Beckie et al. 2003). Two producers in this survey reported confirmed Group 2-resistant kochia. Surprisingly, only four kochia samples were collected in the Mixed or Moist Mixed Grassland ecoregions; seeds from these samples were non-viable.

The timing of the field survey favors weed species whose maturity is similar to that of the crop; species that mature before the crop and shed seed or that are immature and non-viable near crop harvest are biased against for seed collection. Ideally, seed collection in a field planted to a spring-seeded crop would occur over multiple dates from July to crop harvest.

Herbicide Resistance Awareness and Impact

Of 153 respondents, 12% suspected or were aware of a herbicide-resistant weed in their field in 2001 (Table 11). Thus, most producers (88%) did not believe they had a herbicide-resistant weed in their field. The greatest percentage of producers with suspected or confirmed resistance was in

Table 11. Are you aware or do you suspect that you have a herbicide-resistant weed in the surveyed field in Alberta's six major ecoregions

Resistance?	Mixed Grassland		Moist Mixed Grassland		Fescue Grassland		Aspen Parkland		Boreal Transition		Peace Lowland		All areas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
No	17	94	21	81	11	61	49	86	6	67	30	97	134	88
Suspected	1	6	3	12	0	0	8	14	3	33	1	3	16	10
Confirmed	0	0	2	8	1	6	0	0	0	0	0	0	3	2
Total	18		26		18		57		9		31		153	

Table 12. Herbicide groups and weeds that farmers are aware or suspect resistance

Group	Weed	Fields	
		No.	%
1	Wild oat	6	32
8	Wild oat	5	26
2	Chickweed	4	21
2	Wild oat	2	11
2	Kochia	2	11
9	Canola	1	5
4	Wild buckwheat	1	5
---	Wild buckwheat	1	5
---	Canada thistle	1	5

Note: When herbicide products were reported, the weed was considered resistant to all relevant component herbicide groups. Weeds for which the herbicide or herbicide group was not reported are listed at the end of the table. The percentage adds up to more than 100% as some fields may have weeds exhibiting resistance to more than one herbicide group

the Boreal Transition ecoregion (33%); the lowest percentage was in the Peace Lowland ecoregion (3%). The top five herbicide-resistant weeds reported on the questionnaire were the following (19 respondents): wild oat, Group 1 (32%); wild oat, Group 8 (26%); chickweed, Group 2 (21%); kochia, Group 2 (11%); wild oat, Group 2 (11%) (Table 12).

Only 1 of the 20 producers (5%) with fields having Group 1-resistant wild oat suspected resistance (17 did not and 2 did not provide a response) (Table 13). Similarly, only 1 of the 24 producers (4%) with fields with Group 2-resistant wild oat suspected resistance (16 did not and 7 did not provide a response). None of the producers with fields having Group 2-resistant chickweed or spiny annual sow-thistle suspected resistance.

This low awareness of herbicide resistance is consistent with results from previous surveys conducted in Saskatchewan (Beckie et al. 1999). One factor that may explain this low awareness of resistance is the infestation area of biotypes within a field. For Group 1-resistant wild oat, the average infestation area in a field was only 0.12 ha (14 of 20 fields with patches). Four fields

Table 13. Confirmation of producer's suspicions of weed resistance

Suspected	Group 1-resistant wild oat			Group 2-resistant wild oat		
	Yes	No	No response[a]	Yes	No	No response
Resistant	1	17	2	1	16	8
Susceptible	4	97	65	1	103	63
Seeds not collected	1	33	12	0	34	12

[a]Fields of producers who did not complete a management questionnaire.

were infested throughout (average of 59 ha per field) (no information for two fields). The total infestation area of Group 1-resistant wild oat was estimated at 240 ha. Similarly, the average infestation area of Group 2-resistant wild oat in a field was 0.10 ha (17 of 24 fields with patches). Seven fields were infested throughout (average of 45 ha per field). The total infestation area of Group 2-resistant wild oat was estimated at 320 ha. Group 2-resistant chickweed covered an average area per field (n=3) of only 7 m^2; one field (61 ha) was infested throughout. Spiny annual sow-thistle occurred in a 100-m^2 patch in one field; in the remaining three fields where the weed occurred throughout, the average infestation area was 31 ha. Therefore, the infestation of herbicide-resistant biotypes generally comprised a small fraction of a field area and could be missed depending upon the intensity of weed scouting after herbicide application.

Averaged across all ecoregions, 56 and 32% of 144 respondents indicated that herbicide resistance had no impact or slight impact, respectively, on their farm (Table 14). Therefore, most

Table 14. Present impact of weed resistance on farms in Alberta's six major ecoregions

Impact	Mixed Grassland		Moist Mixed Grassland		Fescue Grassland		Aspen Parkland		Boreal Transition		Peace Lowland		All areas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
None	13	76	11	46	6	50	27	50	2	25	22	76	81	56
Slight	2	12	12	50	3	25	21	39	4	50	4	14	46	32
Moderate	1	6	0	0	2	17	6	11	2	25	3	10	14	10
Large	1	6	1	4	1	8	0	0	0	0	0	0	3	2
Total	17		24		12		54		8		29		144	

Table 15. Future impact of weed resistance on farms in Alberta's six major ecoregions

Impact	Mixed Grassland		Moist Mixed Grassland		Fescue Grassland		Aspen Parkland		Boreal Transition		Peace Lowland		All areas	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
None	8	47	6	26	1	8	10	19	0	0	11	39	36	25
Slight	7	41	14	61	8	67	33	61	4	50	14	50	80	56
Moderate	1	6	2	9	2	17	8	15	4	50	3	11	20	14
Large	1	6	1	4	1	8	3	6	0	0	0	0	6	4
Total	17		23		12		54		8		28		142	

producers do not perceive herbicide resistance to pose a significant problem on their farm. Only 12% of producers believed resistance was having a moderate or large impact; unexpectedly, the highest percentage of producers (25%) who indicated this level of impact lived in the Fescue Grassland and Boreal Transition ecoregions where the incidence of resistance was relatively low. In the future (next five years), 18% of 142 producers indicated that resistance could have a moderate or large impact (Table 15).

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 [25 November 2003].

Beckie, H. J., C. Brenzil, and G. Holzgang. 2003. Herbicide-resistant kochia, green foxtail, and wild oat in the prairie provinces: 1996-2001 results from samples submitted to the Crop Protection Lab, SAFRR. Saskatoon, SK: Agriculture and Agri-Food Canada. 23 p.

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

Beckie, H. J., L. M. Hall, and F. J. Tardif. 2001. Herbicide resistance in Canada - where are we today? Pages 1-36 *In* R. E. Blackshaw and L. M. Hall, eds. Integrated Weed Management: Explore the Potential. Sainte-Anne-de-Bellevue, QC: Expert Committee on Weeds.

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. and K. J. Kirkland. 2003. Implication of reduced herbicide rates on resistance enrichment in wild oat (*Avena fatua*). Weed Technol. 17:138-148.

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.

Bourgeois, L., N. C. Kenkel, and I. N. Morrison. 1997. Characterization of cross-resistance patterns in acetyl-CoA carboxylase inhibitor resistant wild oat (*Avena fatua*). Weed Sci. 45:750-755.

Bradley, K. W. and E. S. Hagood, Jr. 2001. Identification of a johnsongrass (*Sorghum halepense*) biotype resistant to aryloxyphenoxypropionate and cyclohexanedione herbicides in Virginia. Weed Technol. 15:623-627.

Ecological Stratification Working Group. 1995. A national ecological framework for Canada. Ottawa, ON and Hull, QC: Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research, and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch. 125 p.

Heap, I. M. 2004. International Survey of Herbicide-Resistant Weeds. [Online]: http://www.weedscience.com.

Heap, I. M., B. G. Murray, H. A. Loeppky, and I. N. Morrison. 1993. Resistance to aryloxyphenoxypropionate and cyclohexanedione herbicides in wild oat (*Avena fatua*). Weed Sci. 41:232-238.

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

Leeson, J. Y., A. G. Thomas, L. M. Hall, and H. J. Beckie. 2002b. Do Alberta producers reduce in-crop herbicide rates? Proc. 2002 National Meeting, Can. Weed Sci. Soc. [available at www.cwss-scm.ca].

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. Vegreville, AB: Alberta Research Council. 134 p.

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

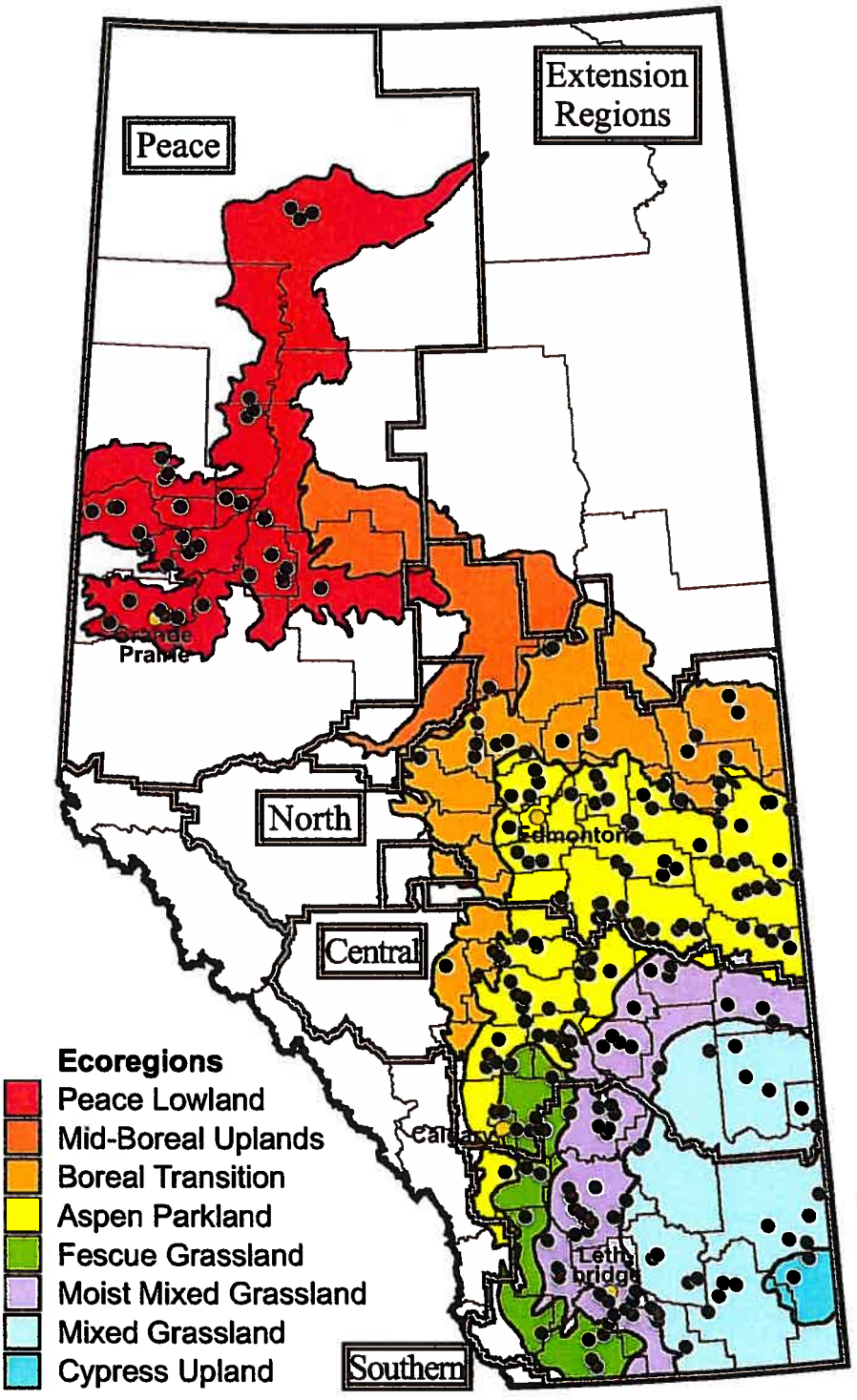
Rashid, A., J. C. Newman, J. T. O'Donovan, D. Robinson, D. Maurice, D. Poisson, and L. M. Hall. 2003. Sulfonylurea herbicide resistance in *Sonchus asper* biotypes in Alberta, Canada. Weed Res. 43:214-220.

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

Thomas, A. G., B. L. Frick, and L. M. Hall. 1998. Alberta weed survey of cereal and oilseed crops in 1997. Weed Survey Ser. Publ. 98-2. Saskatoon, SK: Agriculture and Agri-Food Canada. 283 p.

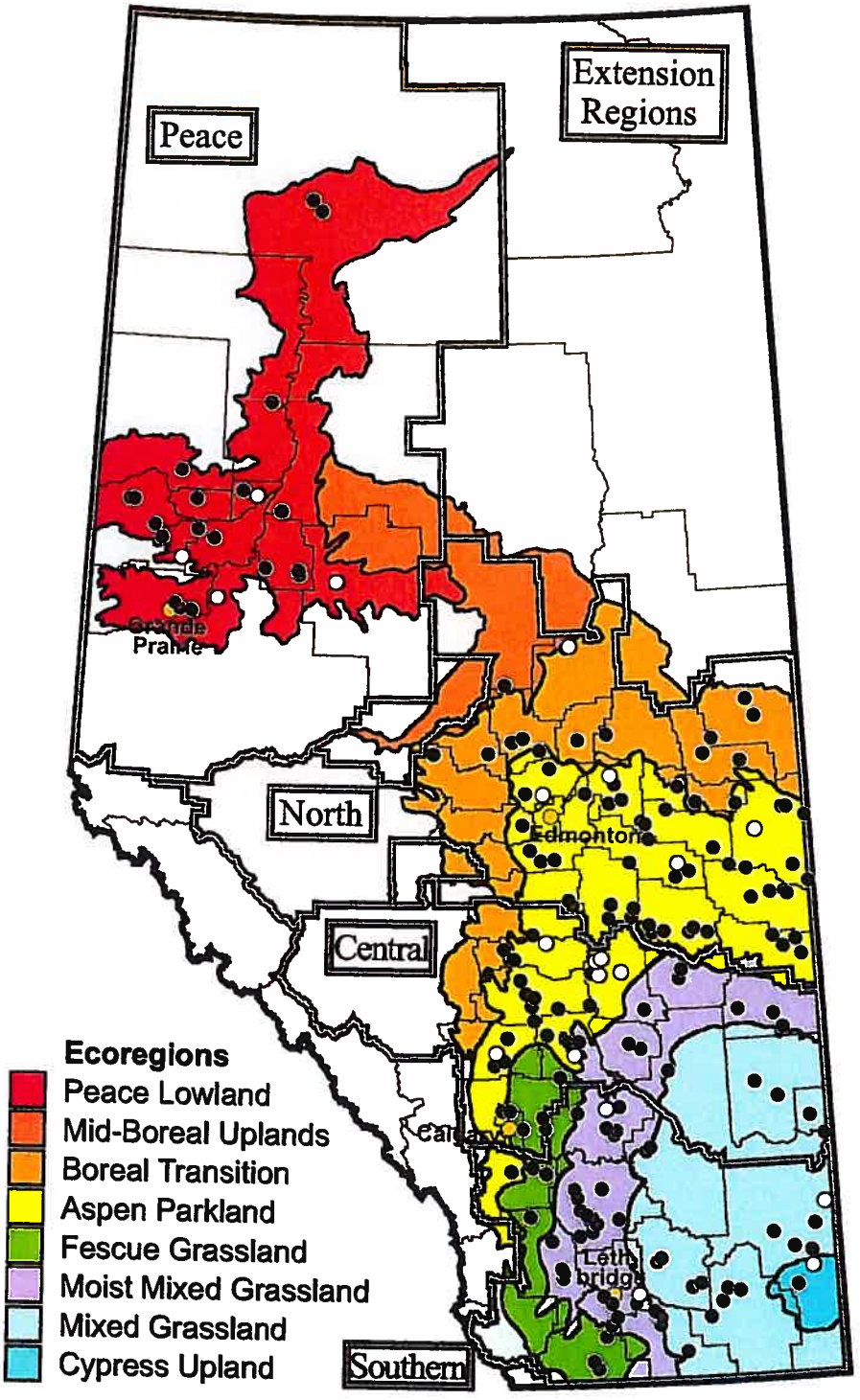
Thomas, A. G., J. Y. Leeson, H. J. Beckie, and L. M. Hall. 2003. Herbicide use patterns and herbicide-resistant weed awareness: results from grower surveys in Alberta, Canada. Weed Sci. Soc. Am. Abstr. 43:66.

Survey fields



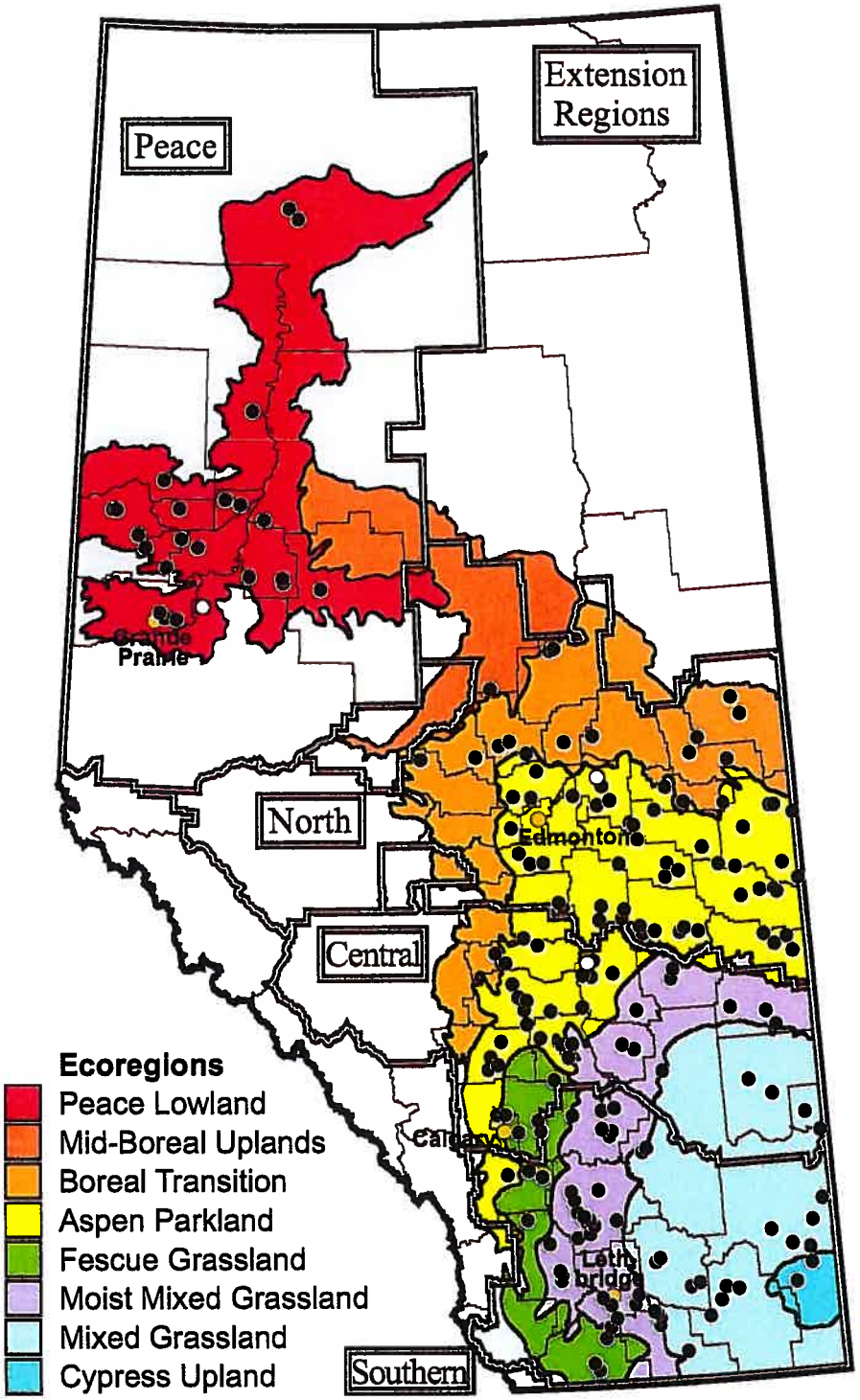
Gp 1-resistant wild oat

Resistant ○ Not resistant •



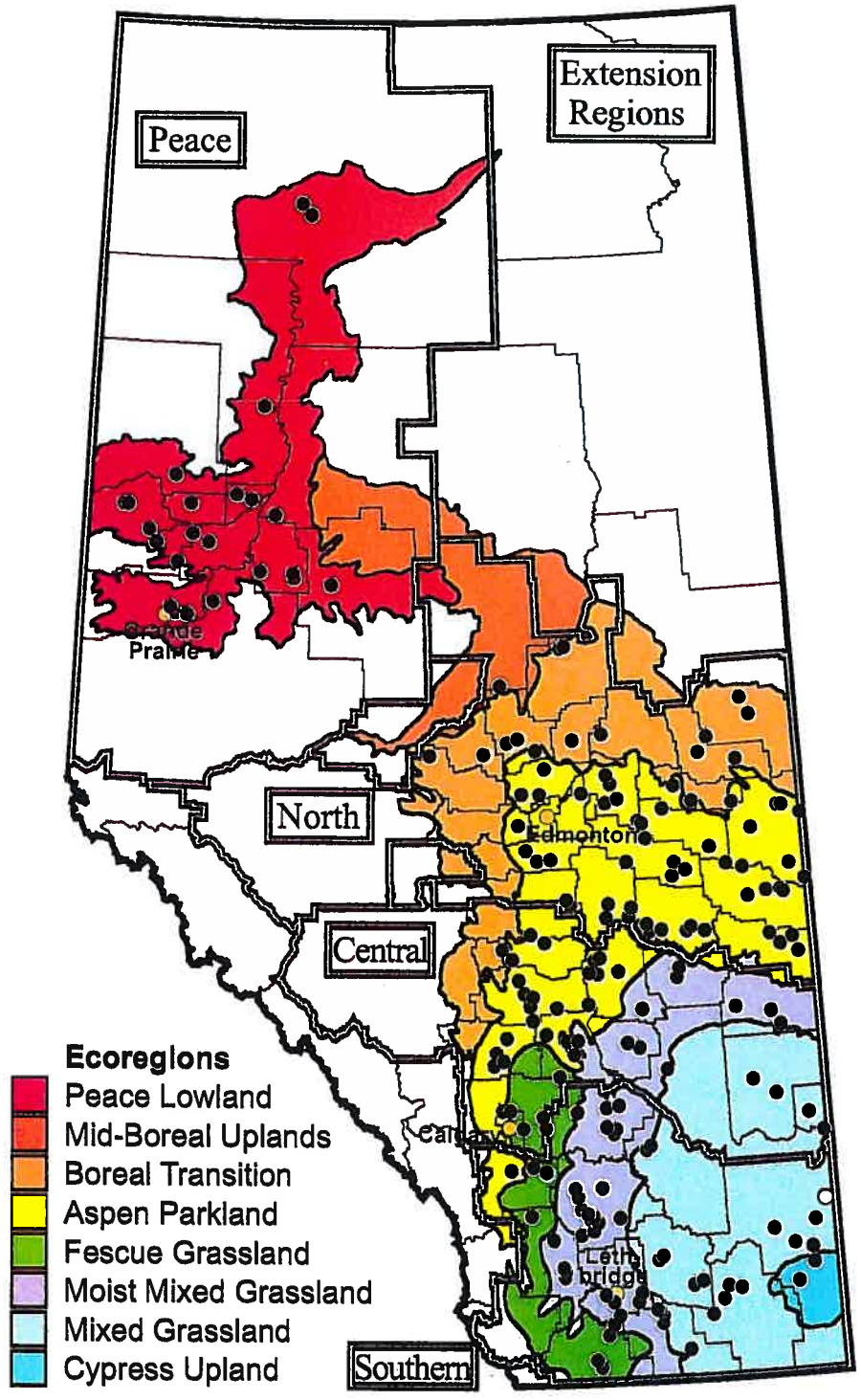
Gp 1 (APP)-resistant wild oat

Resistant ○ Not resistant •



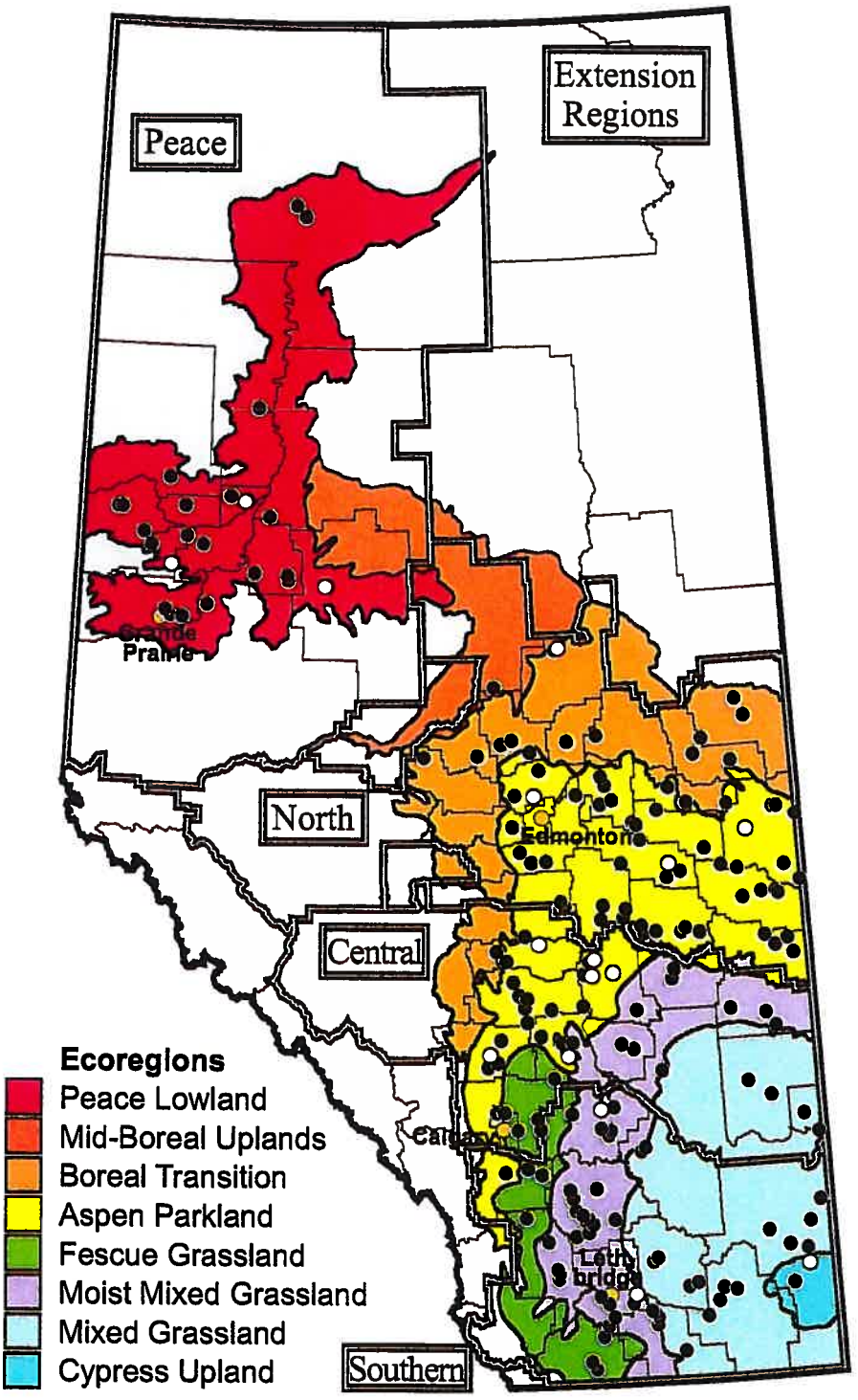
Gp 1 (CHD)-resistant wild oat

Resistant ○ Not resistant •



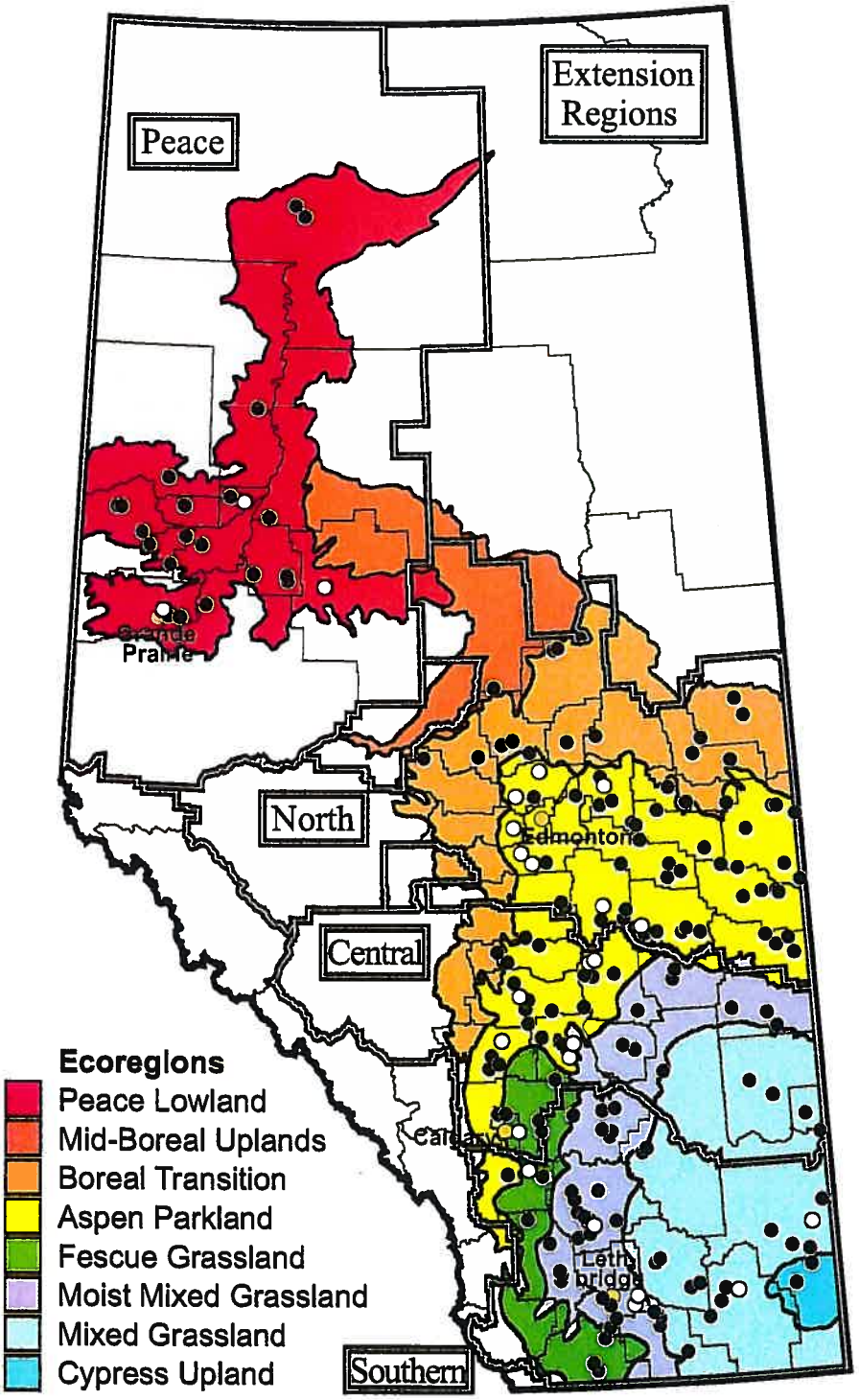
Gp 1 (APP+CHD)-resistant wild oat

Resistant ○ Not resistant •



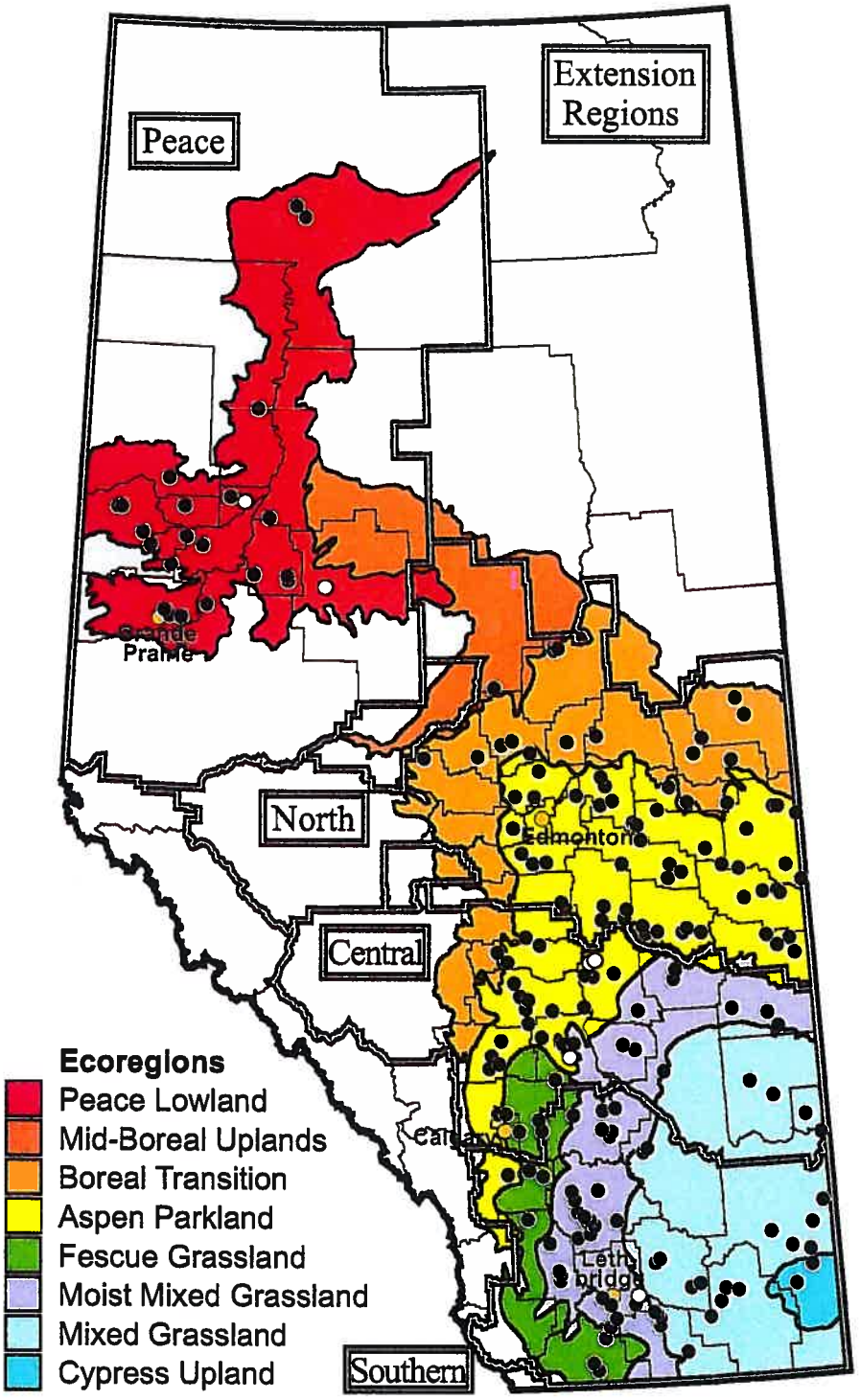
Gp 2-resistant wild oat

Resistant ○ Not resistant •

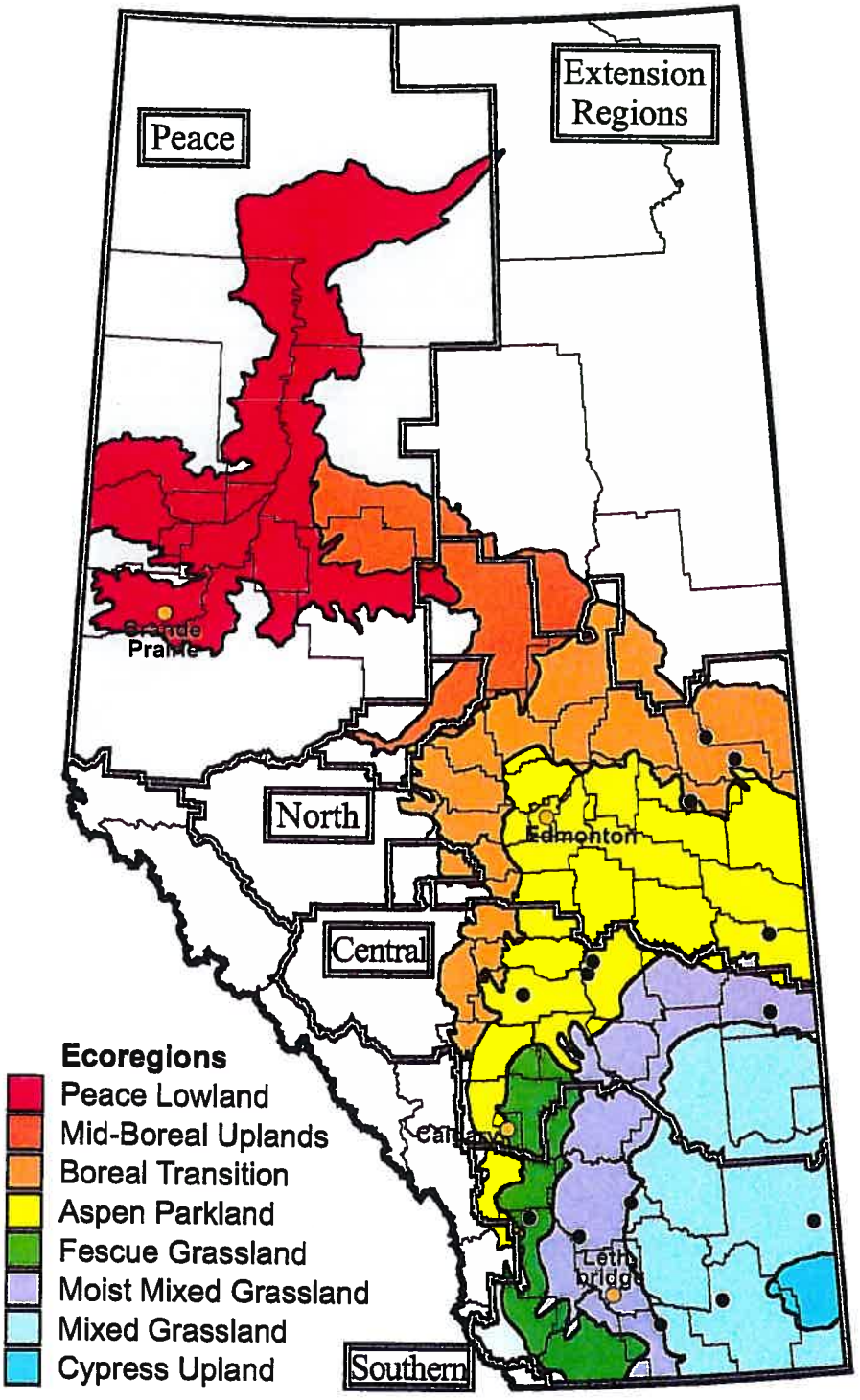


Gp 1- and 2-resistant wild oat

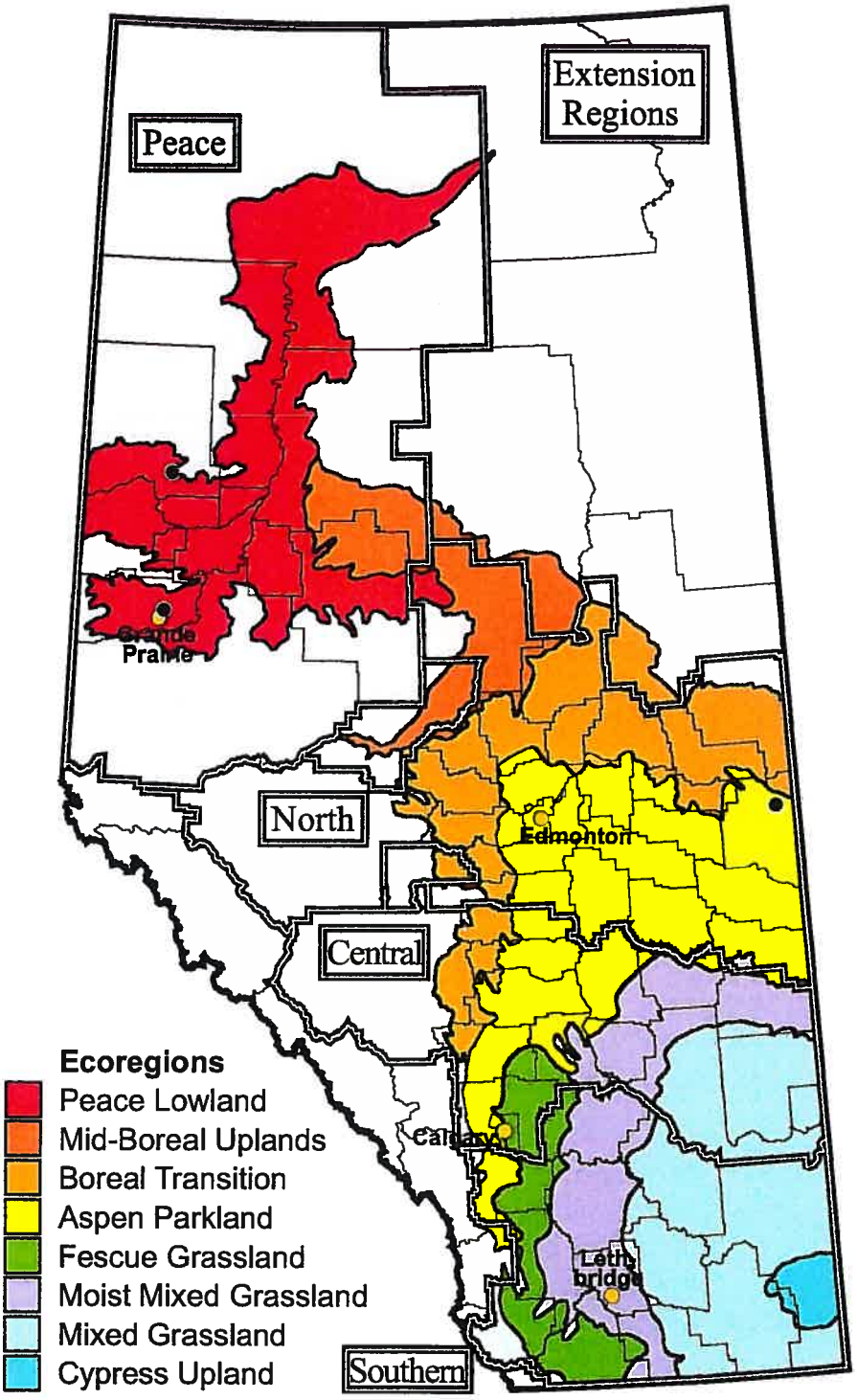
Resistant ○ Not resistant •



Green foxtail



Quack grass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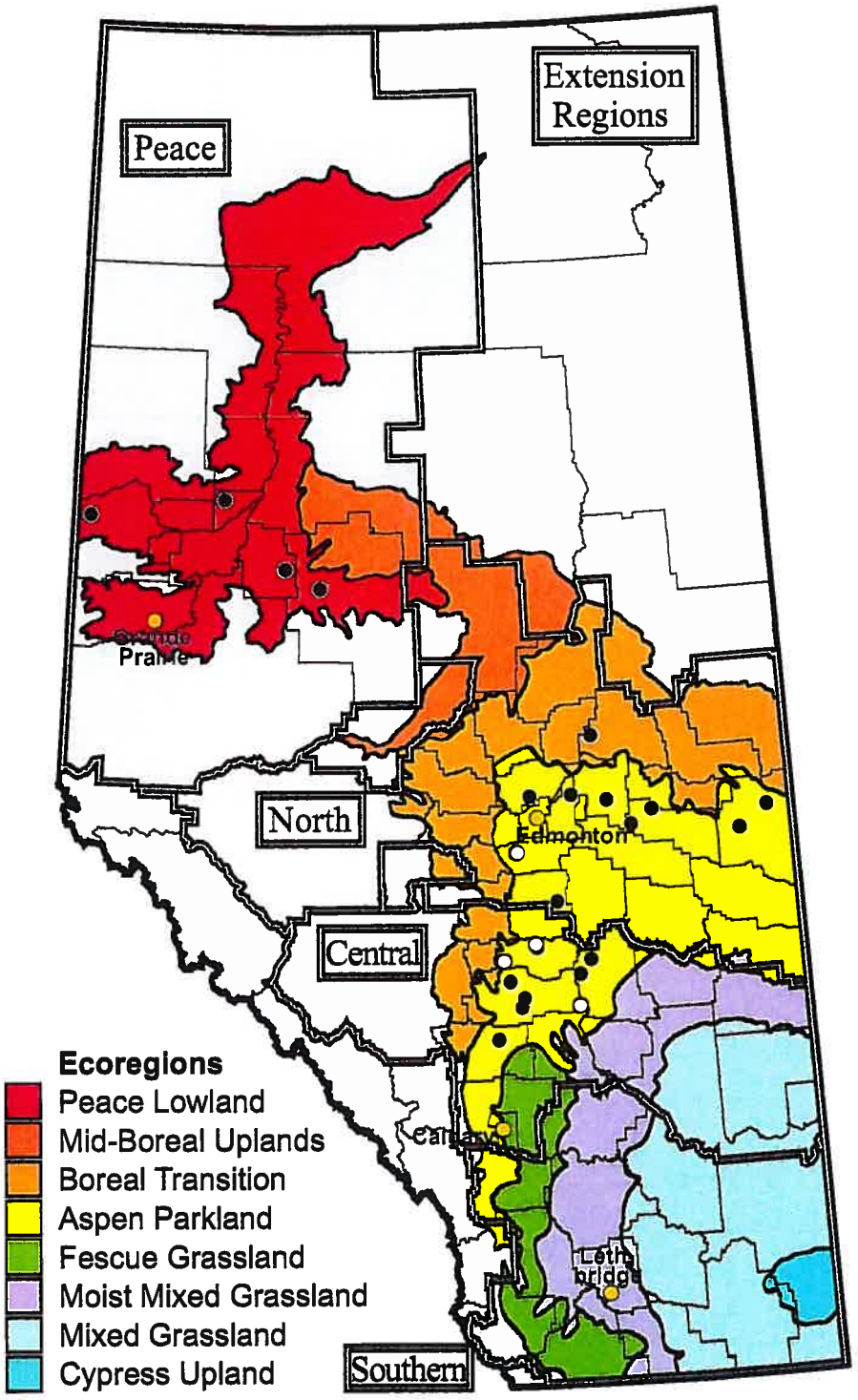
Calgary
Lethbridge
Southern
Ecoregions
Peace Lowland
Mid-Boreal Uplands
Boreal Transition
Aspen Parkland
Fescue Grassland
Moist Mixed Grassland
Mixed Grassland
Cypress Upland

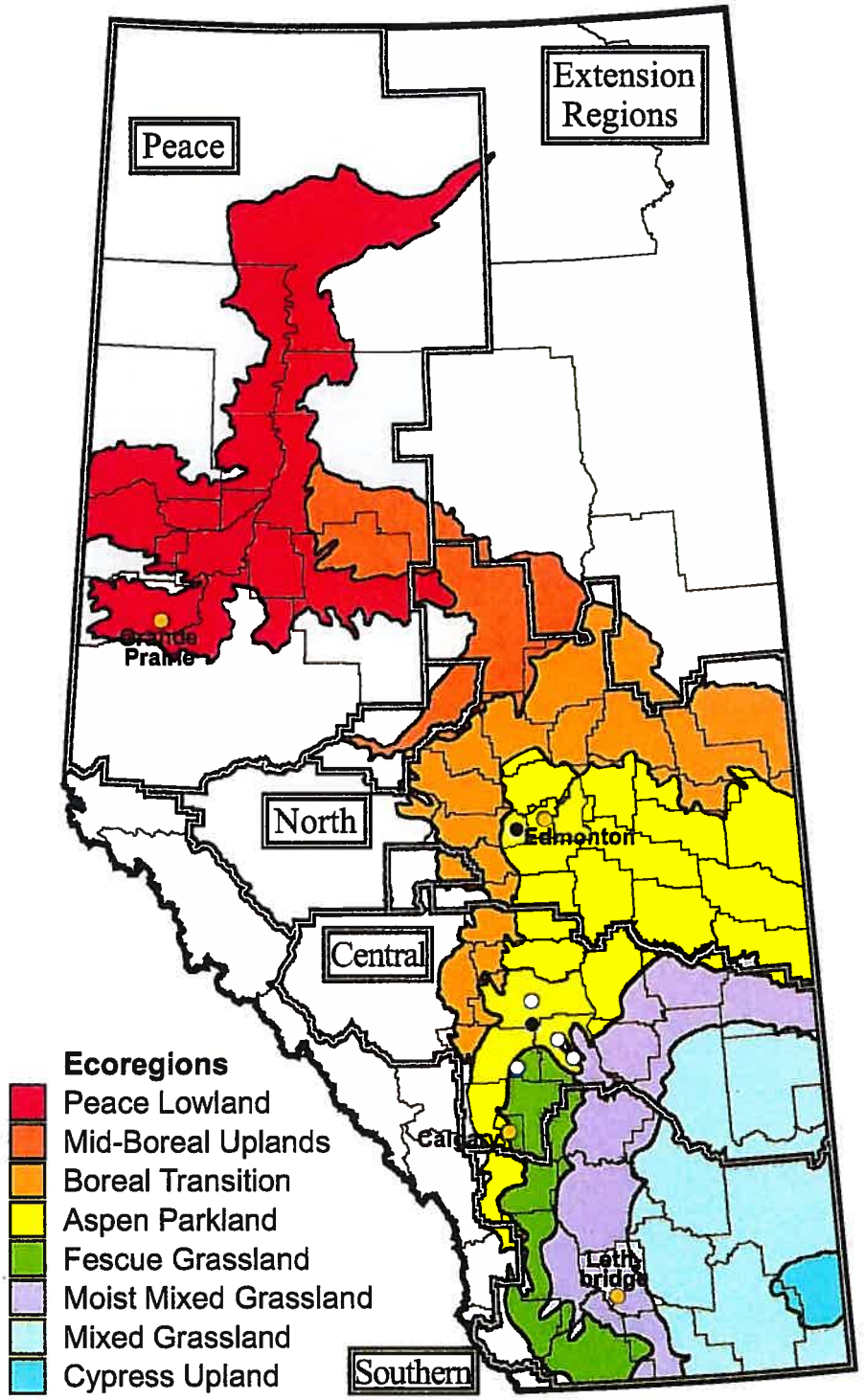
Gp 2-resistant chickweed

Resistant ○ Not resistant •

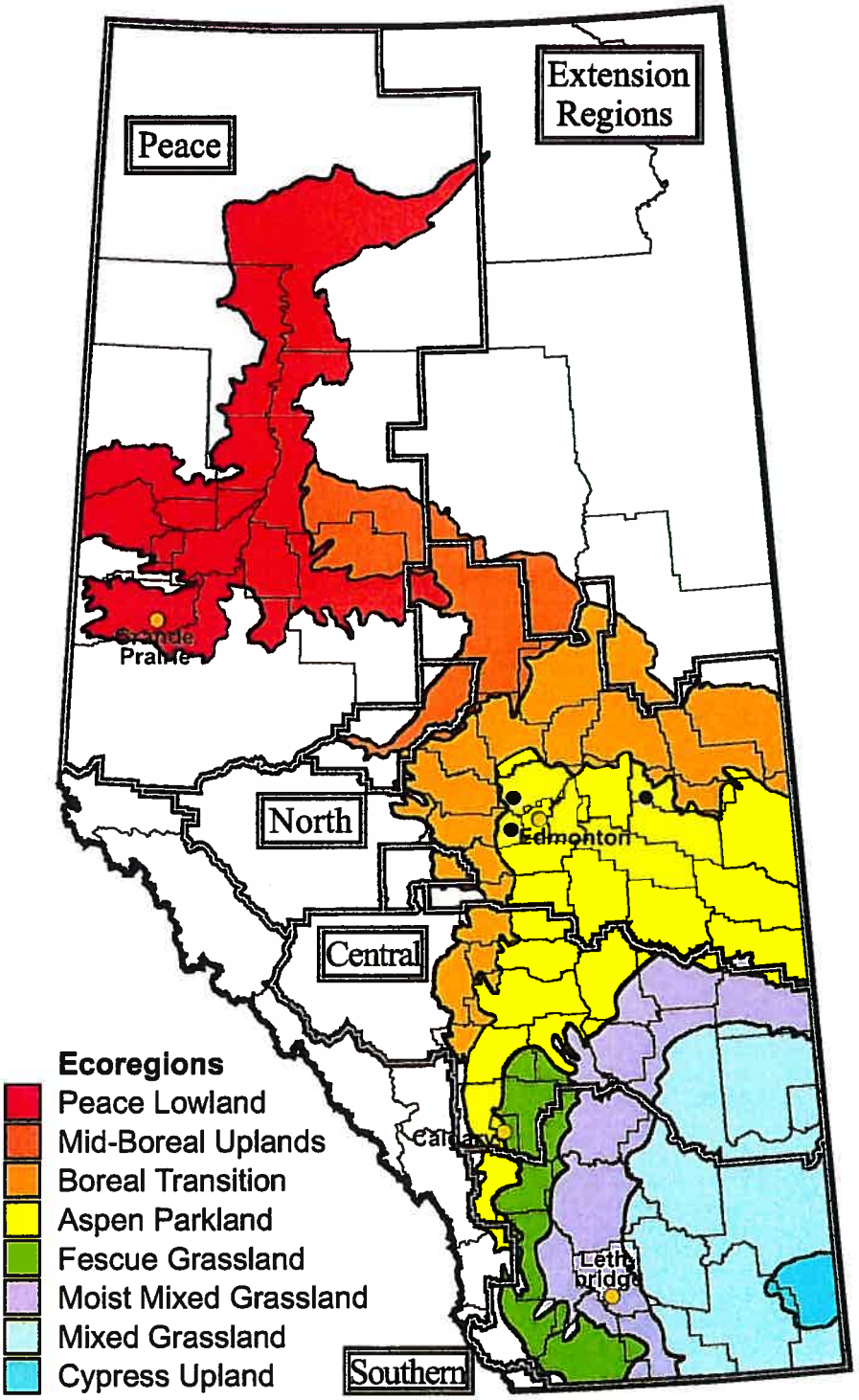


Gp 2-resistant spiny annual sow-thistle

Resistant ○ Not resistant •



Ball mustard



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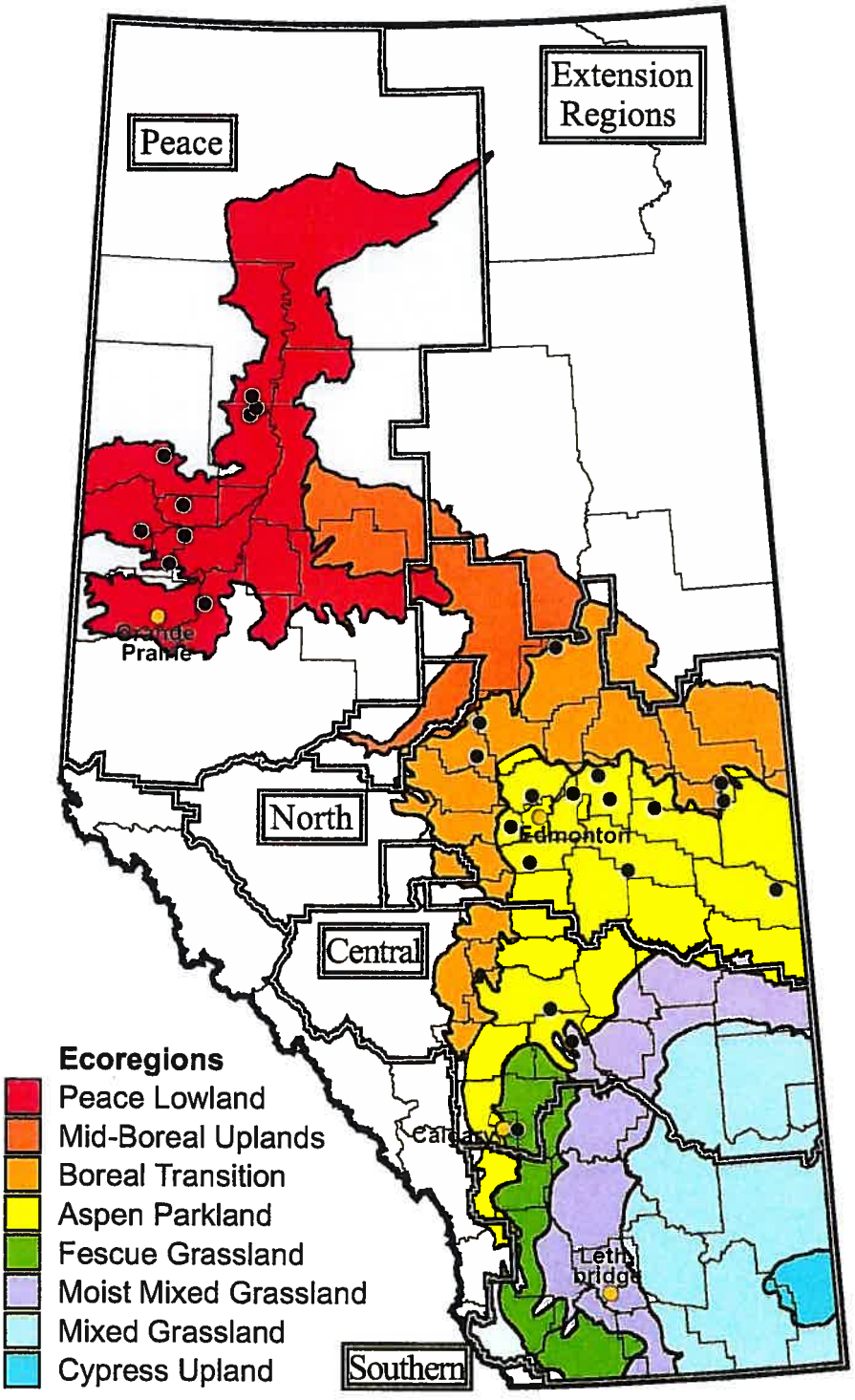
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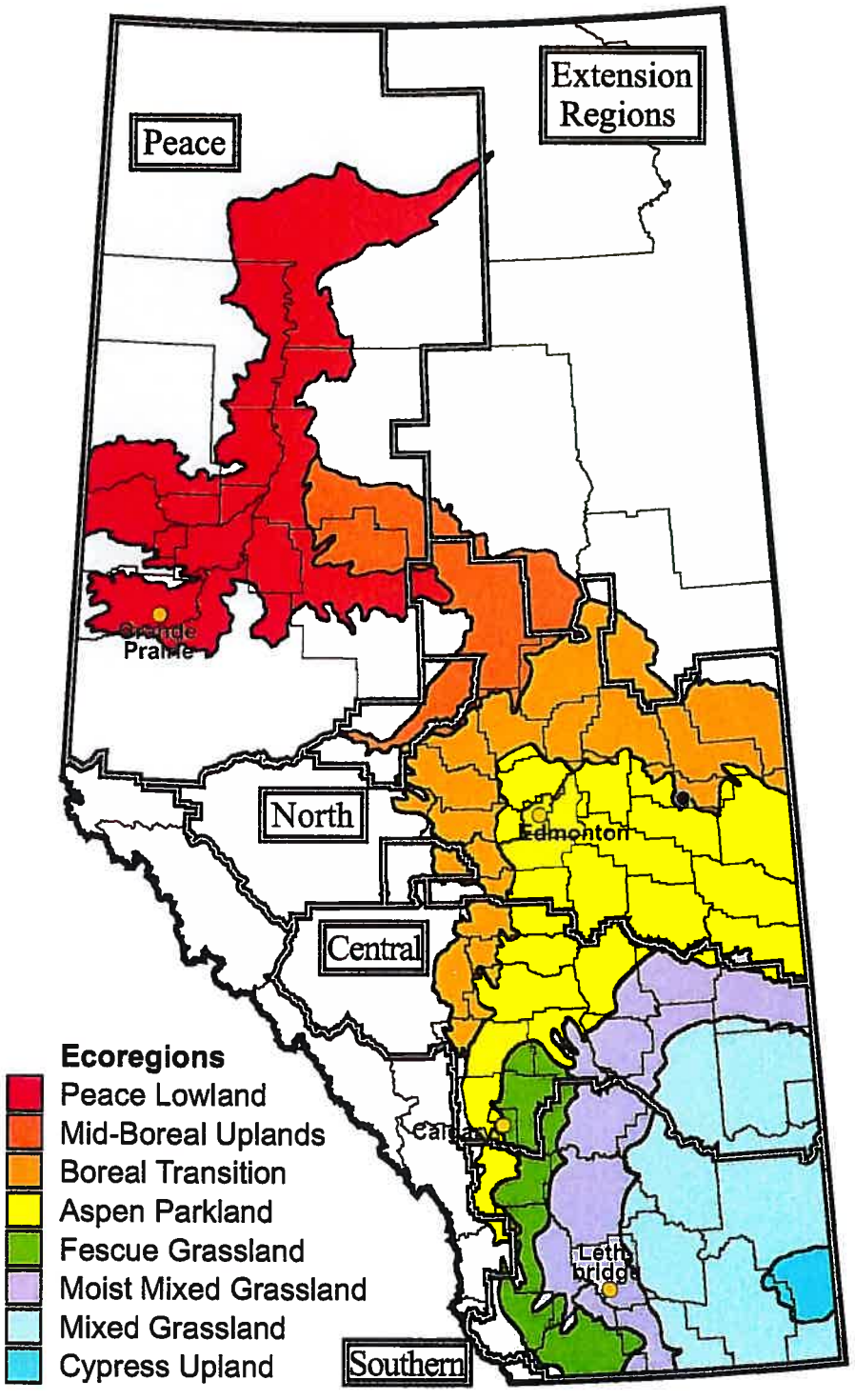
Mixed Grassland
Cypress Upland

Corn spurry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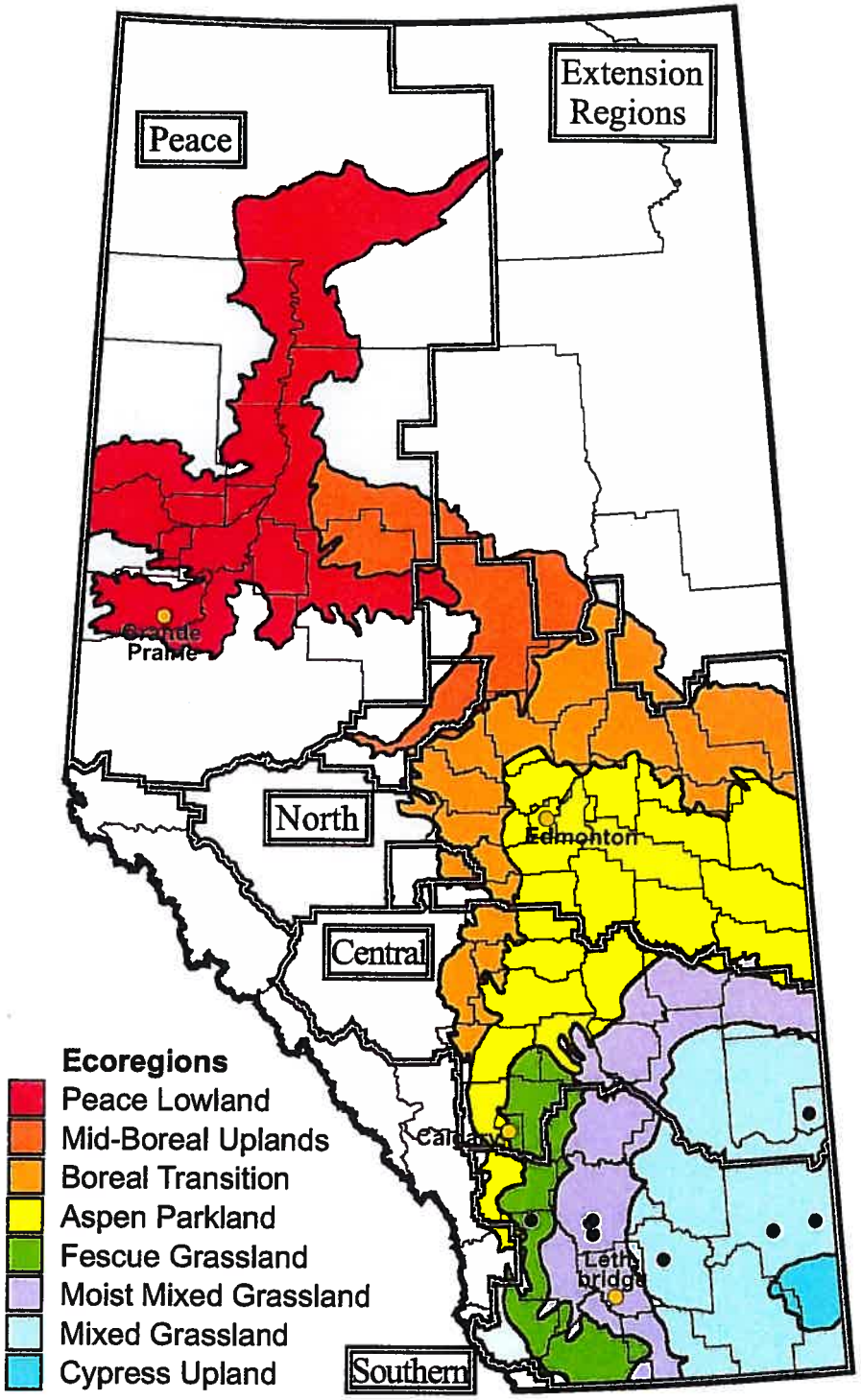
Cypress Upland

Flixweed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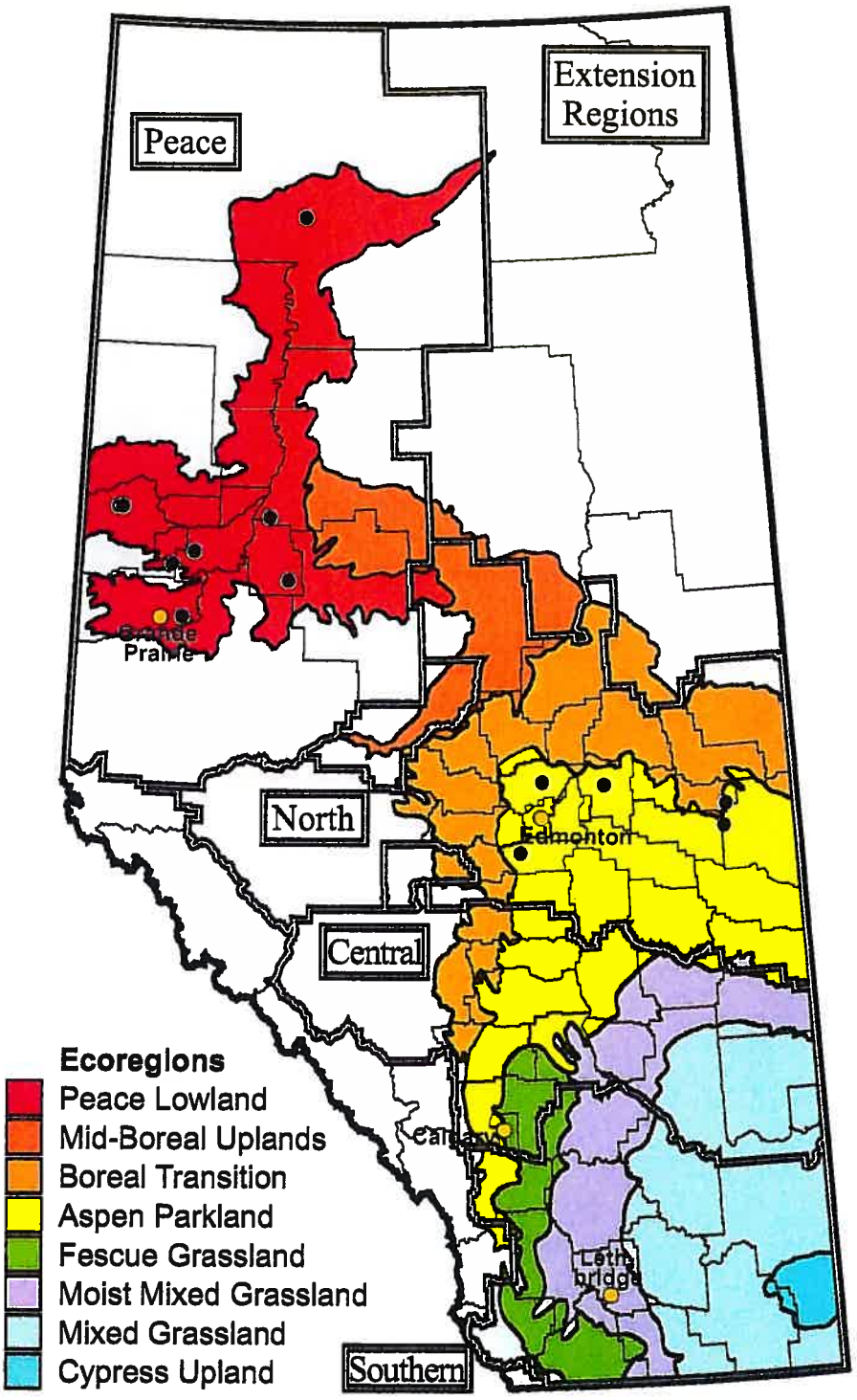
Hemp-nettle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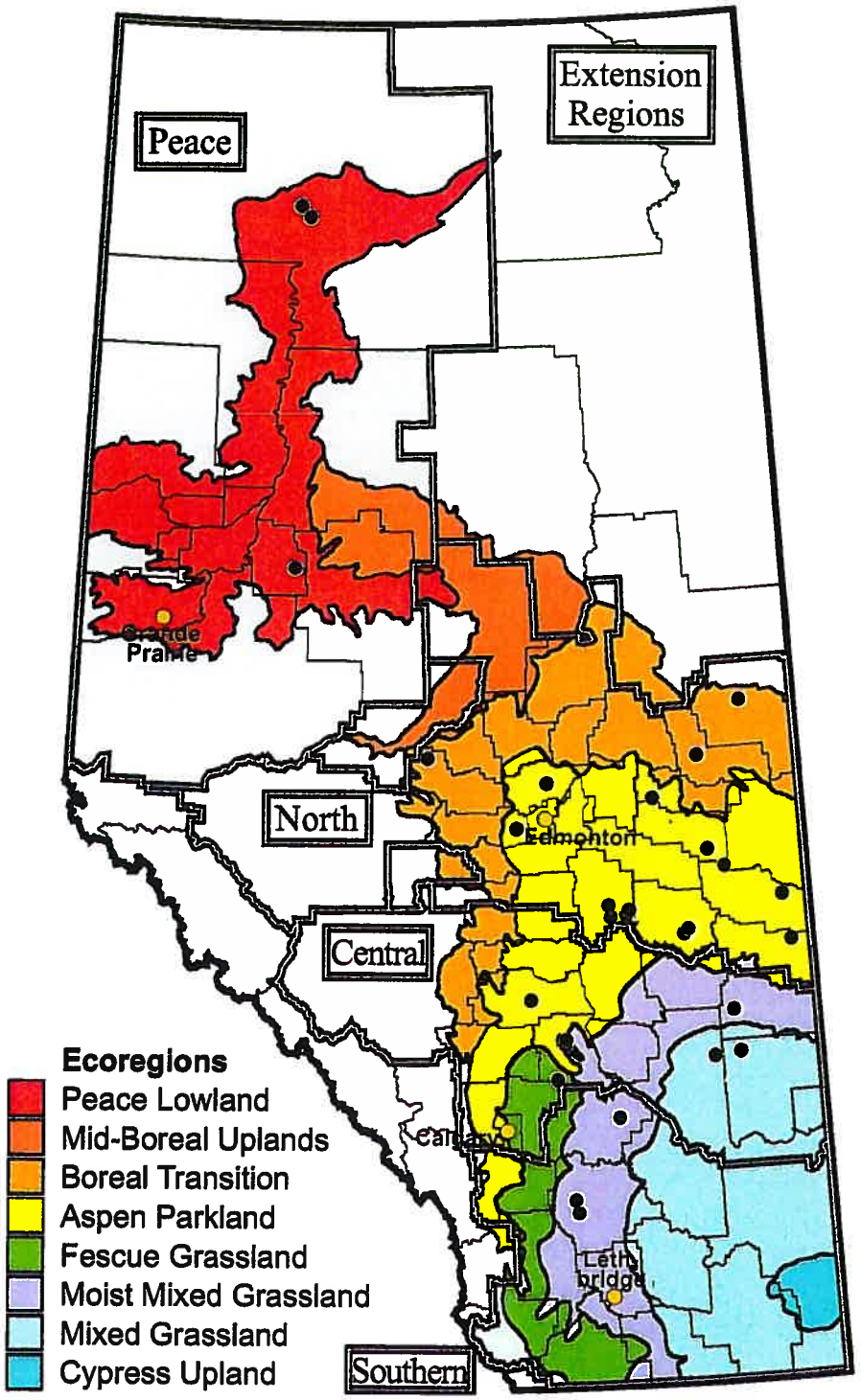
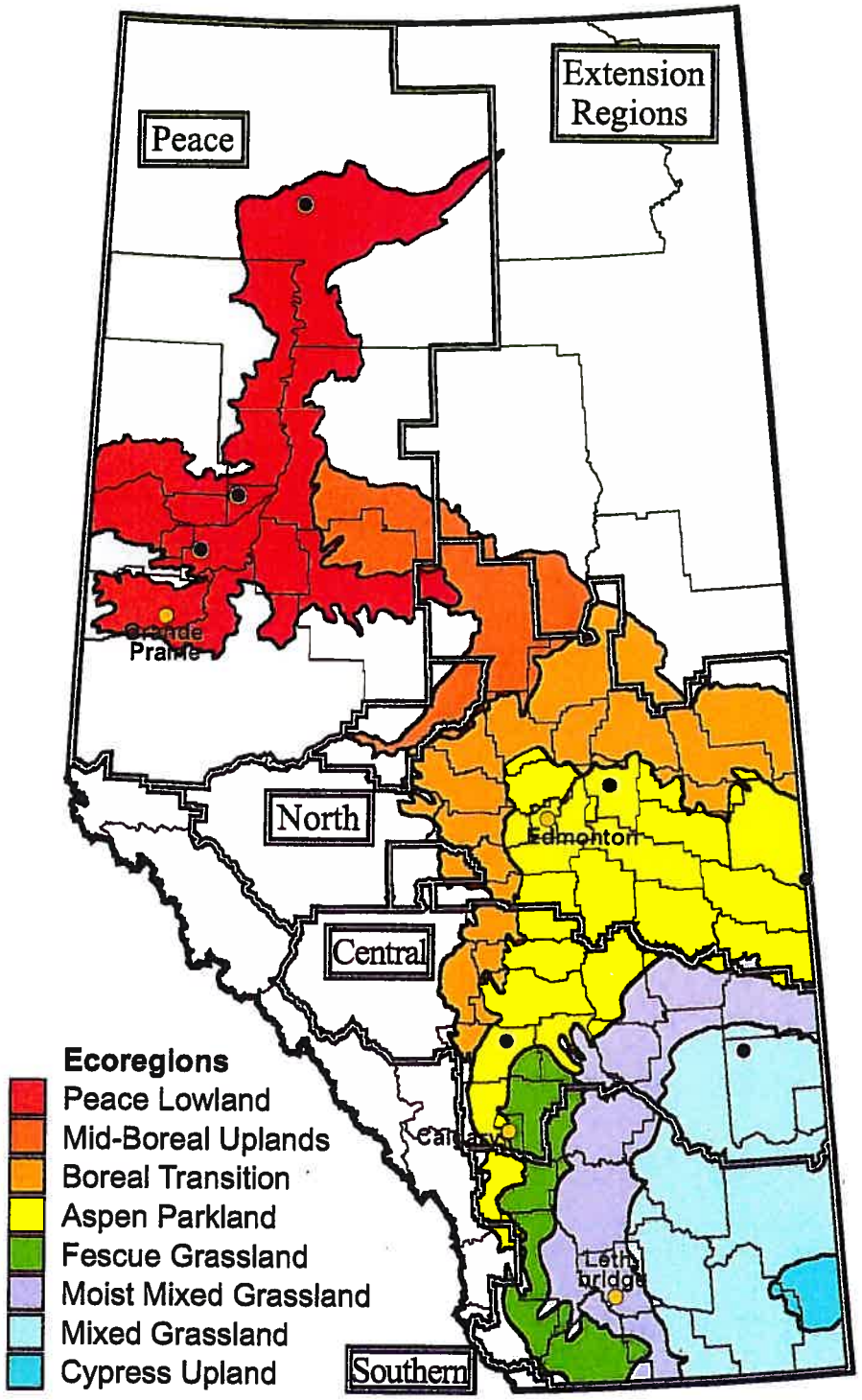
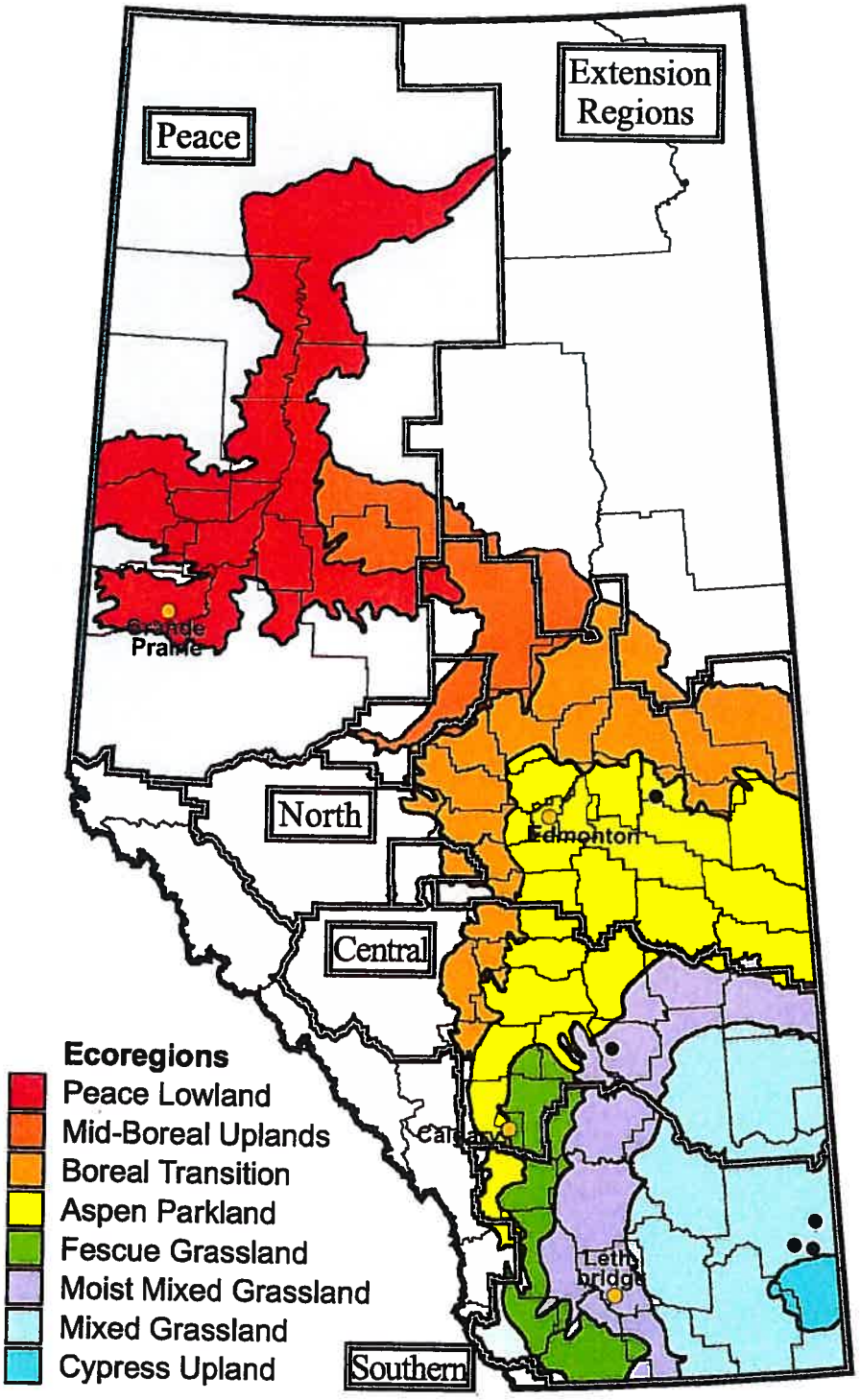
Lamb's-quarters



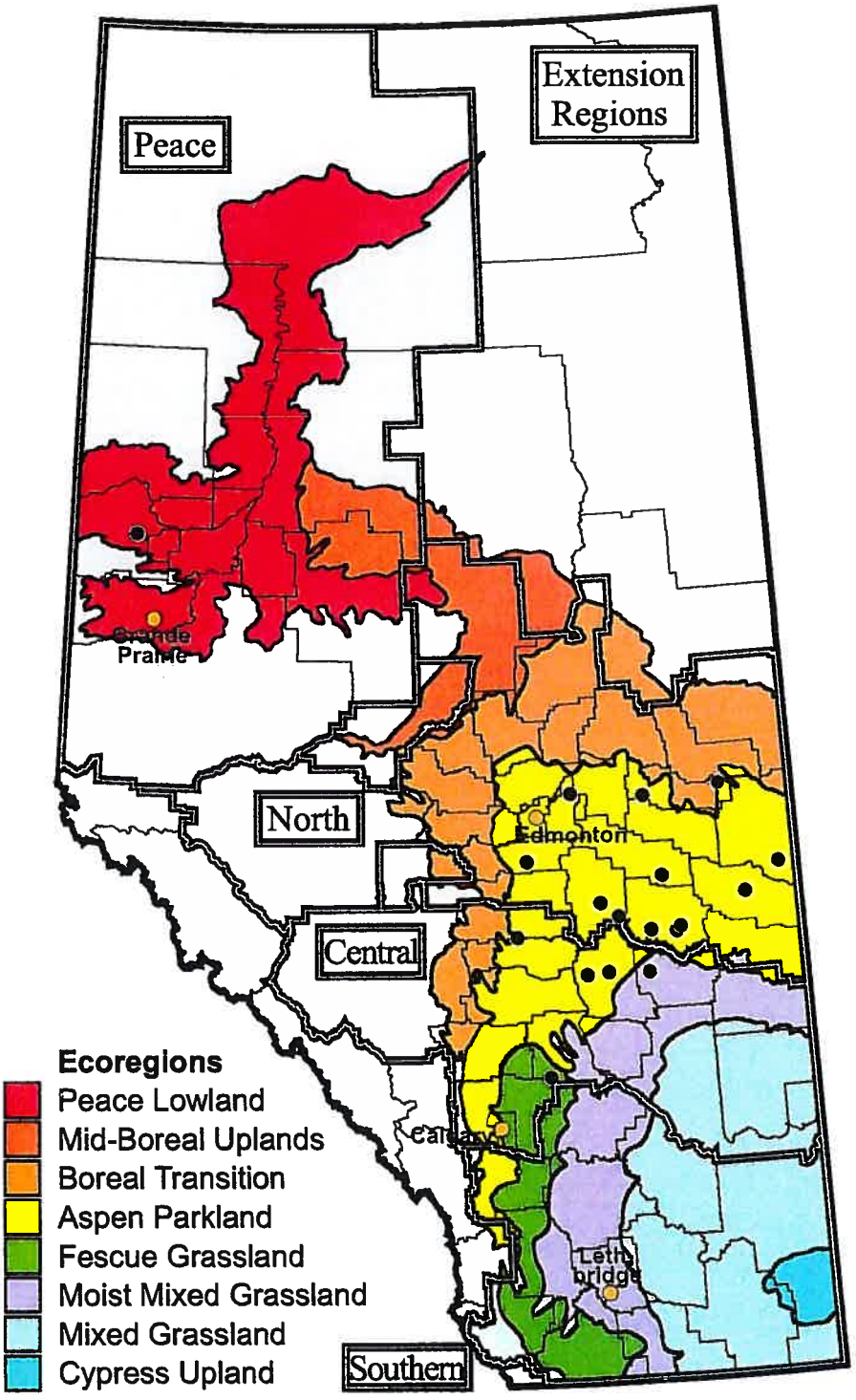
Narrow-leaved hawk's-beard



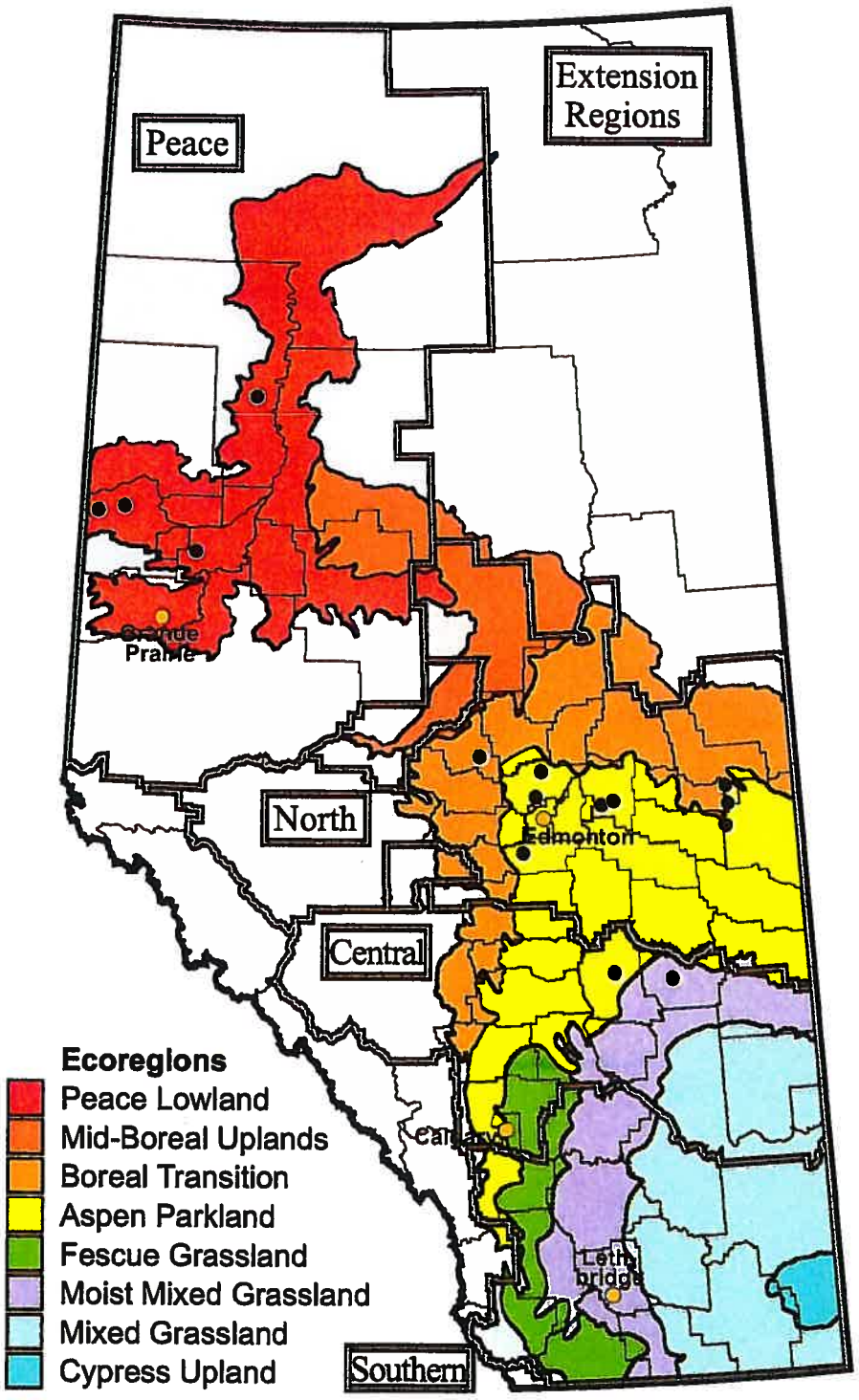
Redroot pigweed



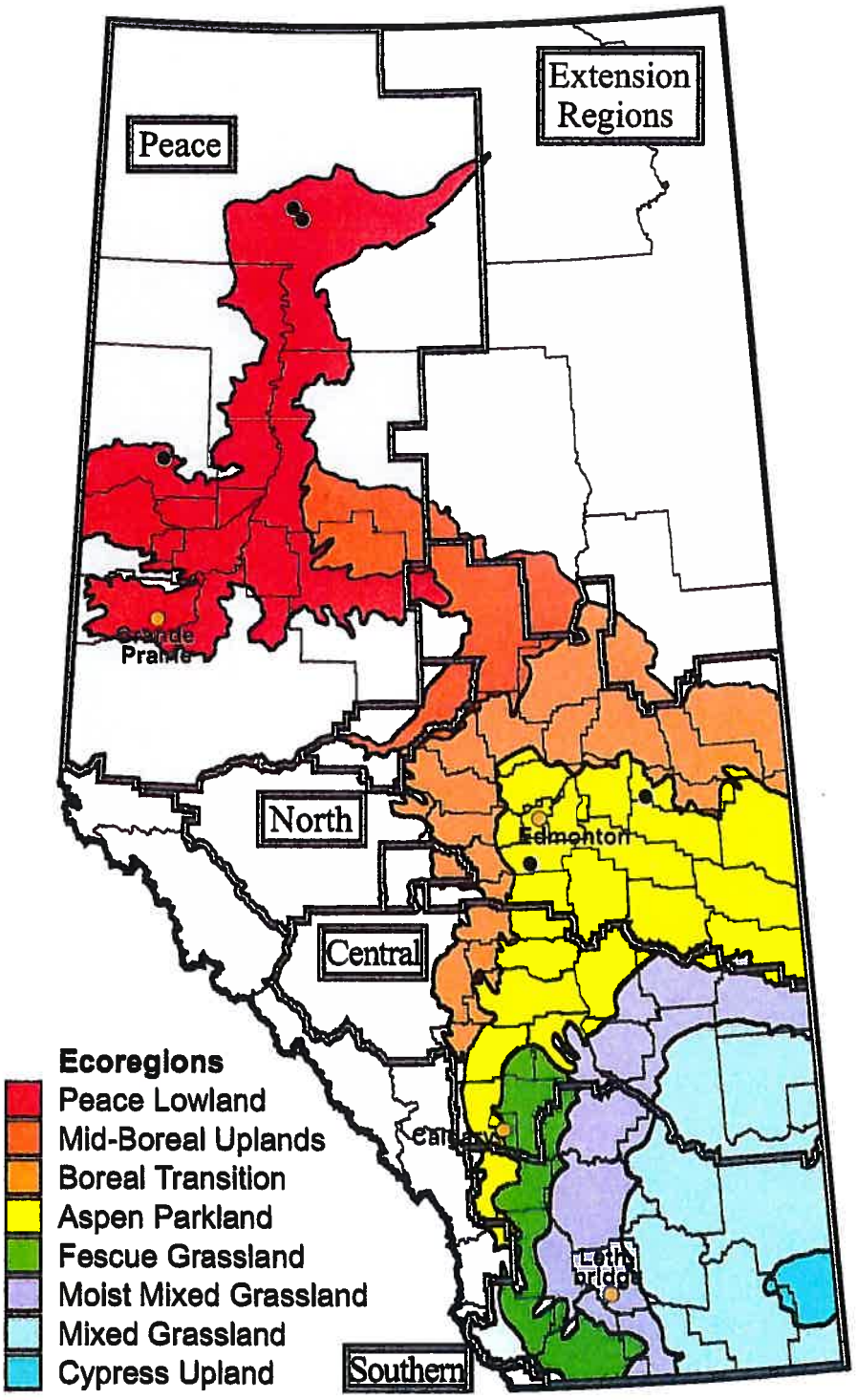
Shepherd's-purse



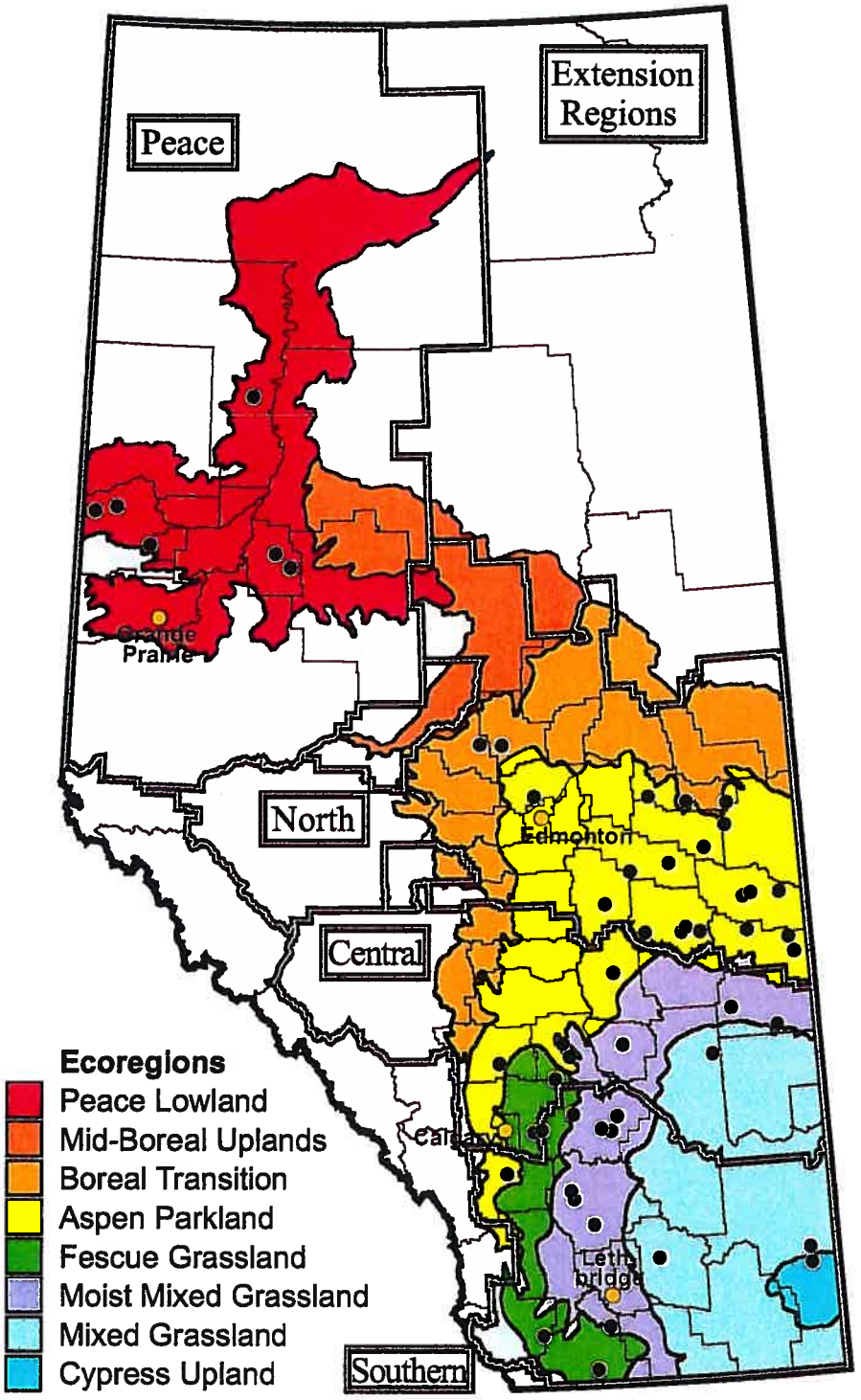
Annual smartweed species



Perennial sow-thistle



Stinkweed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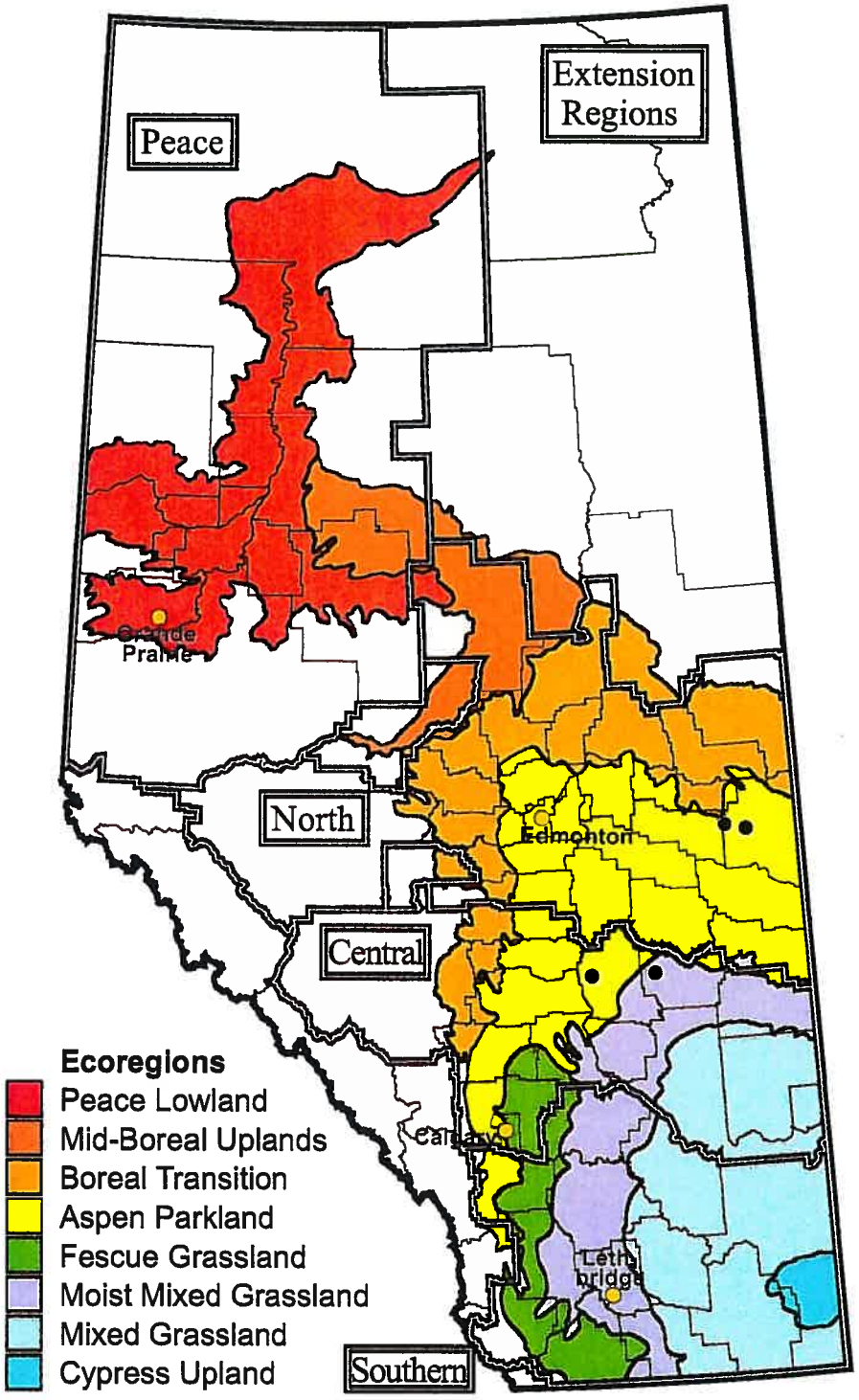
Mixed Grassland
Cypress Upland

Stork's-bill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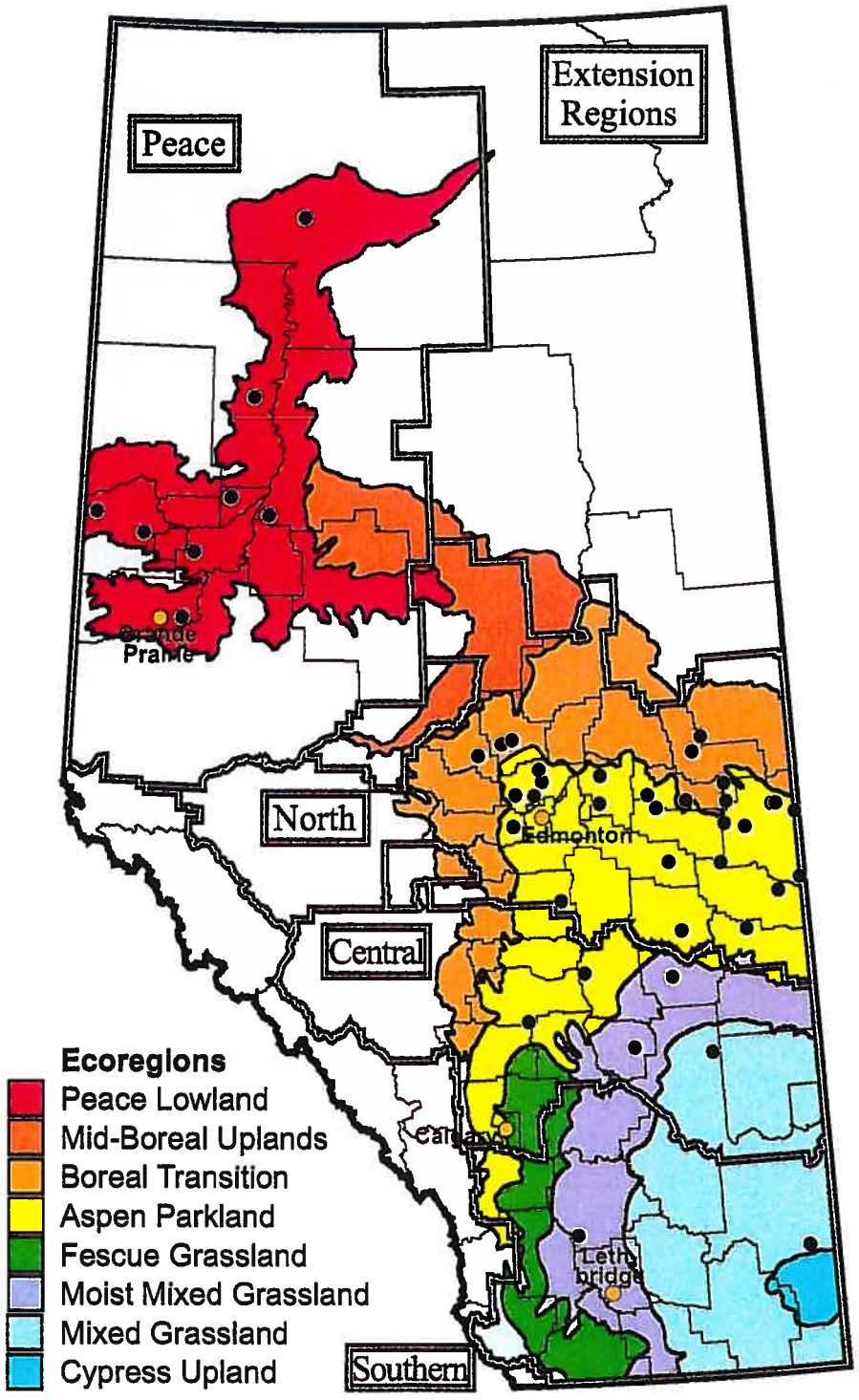
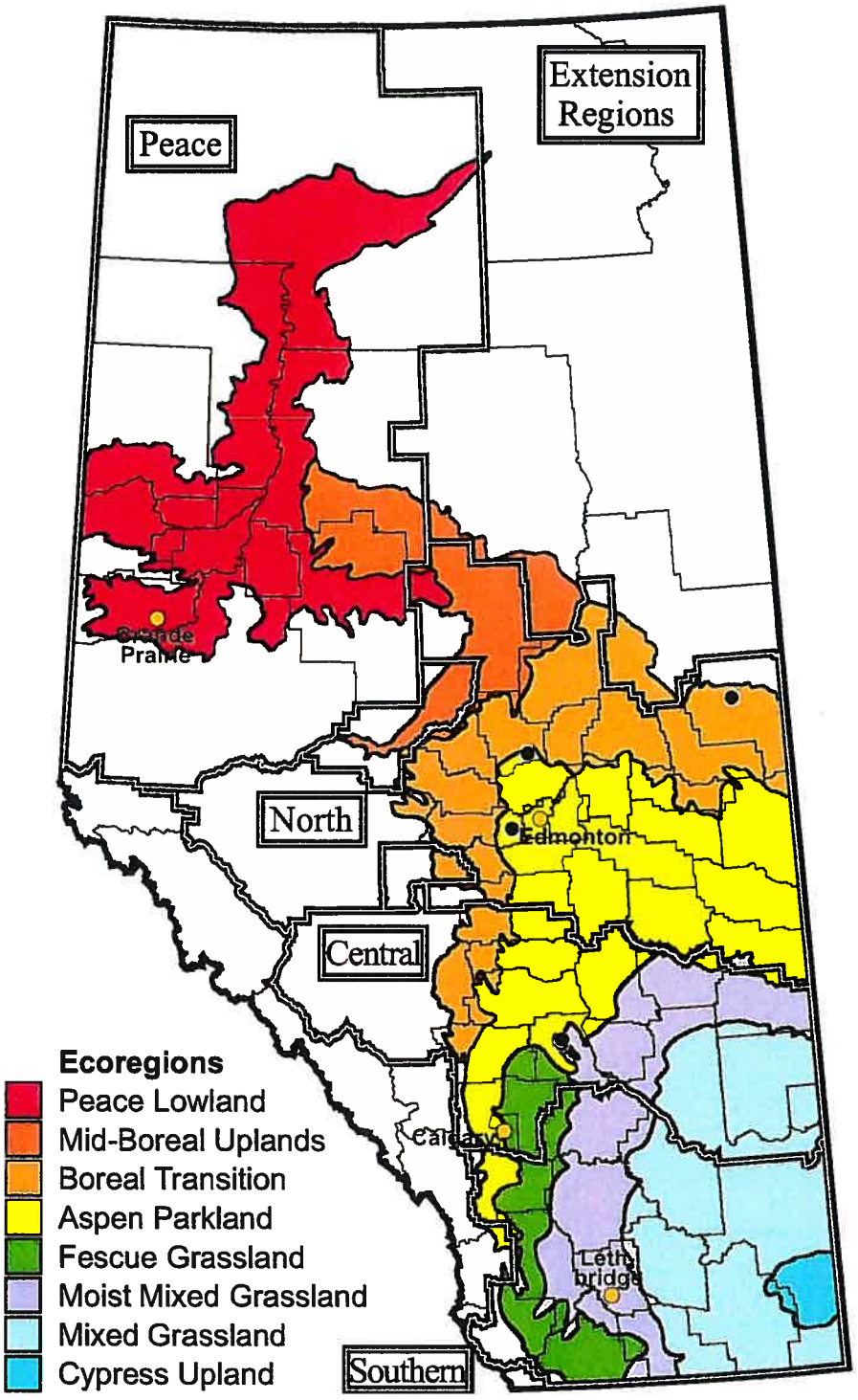
Cypress Upland

Wild buckwheat



Wild mustard



[Source: J. Y. Leeson et al. (in preparation)]

2001 Producer Management Questionnaire Results : Herbicide Resistance Section (Tables A1-A7)

Herbicide group rotation in 2001

The tables list the following:

1) the number of questionnaires with a given response (#)
2) the percentage of acres represented by the positive response (%)
3) the standard error (SE) of the proportion of acres represented by the positive response

The total numbers of responses to each question are also presented.

Standard error is represented by the following rating system:

SE	*Rating*
0.00% - 2.49%	A - very good
2.50% - 4.99%	B - good
5.00% - 7.49%	C – acceptable, but use with caution
7.50% +	D - unreliable

Table A1: Use of herbicide group rotation in 2001 to delay the development or manage resistant weeds in Alberta's six major ecoregions (Part One)

Rotation?	Mixed Grassland			Moist Mixed Grassland			Fescue Grassland		
	#	%	SE	#	%	SE	#	%	SE
Yes	37	69.2	C	79	77.9	B	38	90.4	B
No	28	30.8	C	29	22.1	B	7	9.6	B
Total	65			108			45		

Table A1: Use of herbicide group rotation in 2001 to delay the development or manage resistant weeds in Alberta's six major ecoregions (Part Two)

Rotation?	Aspen Parkland			Boreal Transition			Peace Lowland			All Areas		
	#	%	SE	#	%	SE	#	%	SE	#	%	SE
Yes	165	85.5	A	43	86.0	B	83	82.0	B	445	81.8	A
No	37	14.5	A	12	14.0	B	22	18.0	B	135	18.2	A
Total	202			55			105			580		

Table A2: Length of time herbicide group rotation has been practiced to delay the development or manage resistant weeds in the Mixed Grassland, south-western Alberta and the three northern ecoregions (Part One)

Years	Mixed Grassland			Moist Mixed & Fescue Grassland			Aspen Parkland		
	#	%	SE	#	%	SE	#	%	SE
1 to 5	15	37.3	D	58	57.7	B	68	42.3	B
6 to 10	8	31.3	D	34	34.5	B	49	43.5	B
11 to 15	3	10.4	C	8	6.6	A	8	6.7	A
16 to 20	2	14.2	C	2	1.0	A	10	6.1	A
More than 20	2	6.9	B	1	0.2	A	3	1.3	A
Total	30			103			138		

Table A2: Length of time herbicide group rotation has been practiced to delay the development or manage resistant weeds in the Mixed Grassland, south-western Alberta and the three northern ecoregions (Part Two)

Years	Boreal Transition			Peace Lowland			All Areas		
	#	%	SE	#	%	SE	#	%	SE
1 to 5	16	47.2	C	29	45.6	C	186	46.0	A
6 to 10	14	43.3	D	27	43.2	C	132	39.7	A
11 to 15	2	3.6	B	3	5.4	B	24	6.6	A
16 to 20	1	1.1	A	5	4.3	A	20	5.3	A
More than 20	1	4.8	B	2	1.5	A	9	2.3	A
Total	34			66			371		

Table A3: Use of a set herbicide group rotation in 2001 in Alberta's six major ecoregions (Part One)

Rotation	Mixed Grassland			Moist Mixed Grassland			Fescue Grassland		
	#	%	SE	#	%	SE	#	%	SE
No set rotation	26	71.1	C	49	44.1	B	22	55.2	D
Varies with group	13	22.4	C	23	29.0	B	11	34.9	D
Once every 2 years	4	6.0	B	5	7.9	B	2	5.4	B
Once every 3 years	1	0.3	A	3	1.7	A	1	2.5	B
Once every 4 years	--	--	--	4	16.8	B	1	2.0	A
Once every 5 years	1	0.2	A	--	--	--	--	--	--
Once every 6 years	--	--	--	1	0.5	A	--	--	--
Total	45			85			37		

Table A3: Use of a set herbicide group rotation in 2001 in Alberta's six major ecoregions (Part Two)

Rotation	Aspen Parkland			Boreal Transition			Peace Lowland			All Areas		
	#	%	SE	#	%	SE	#	%	SE	#	%	SE
No set rotation	96	54.1	B	24	45.9	C	41	50.2	C	258	52.6	A
Varies with group	42	22.3	B	12	27.8	C	19	22.6	B	120	25.1	A
Once every 2 years	11	7.3	A	3	9.1	B	10	13.7	B	35	8.3	A
Once every 3 years	16	8.3	A	5	11.1	B	10	12.2	B	36	6.8	A
Once every 4 years	8	7.3	A	1	3.3	B	2	1.4	A	16	6.5	A
Once every 5 years	2	0.7	A	1	2.9	B	--	--	--	4	0.6	A
Once every 6 years	--	--	--	--	--	--	--	--	--	1	0.1	A
Total	175			46			82			470		