Weed Technology 2013 27:171–183

Education/Extension

Herbicide-Resistant Weeds in the Canadian Prairies: 2007 to 2011

Hugh J. Beckie, Chris Lozinski, Scott Shirriff, and Clark. A. Brenzil*

A late-summer survey of herbicide-resistant (HR) weeds was conducted in Alberta in 2007, Manitoba in 2008, and Saskatchewan in 2009, totaling 1,000 randomly selected annually cropped fields. In addition, we screened 1,091 weed seed samples (each sample from one field) submitted by Prairie growers between 2007 and 2011. Of 677 fields where wild oat samples were collected, 298 (44%) had an HR biotype. Group 1 (acetyl CoA carboxylase inhibitor)-HR wild oat was confirmed in 275 fields (41%), up from 15% in previous baseline surveys (2001 to 2003). Group 2 (acetolactate synthase)-HR wild oat was found in 12% of fields (vs. 8% in 2001 to 2003). Group 8 (triallate, difenzoquat)-HR wild oat was identified in only 8% of fields (not tested in 2001 to 2003); the frequency of occurrence of group 1+2-HR wild oat was similar (8%, vs. 3% in 2001 to 2003). Group 1-HR green foxtail was found in 27% of 209 fields sampled for the weed (vs. 6% in 2001 to 2003). Group 2-HR spiny sowthistle was confirmed in all Alberta fields sampled (vs. 67% in 2001); common chickweed was found mainly in Alberta in 40% of fields (vs. 17% in 2001). Group 2-HR weed biotypes not previously detected in the baseline surveys included false cleavers mainly in Alberta (17% of fields) and Saskatchewan (21%), Powell amaranth in Manitoba (16% of fields), wild mustard (three populations in Saskatchewan and Manitoba), and wild buckwheat (one population in Alberta). No sampled weed populations across the Prairies were found to be resistant to herbicides from group 4 (synthetic auxins), group 9 (glyphosate), or group 10 (glufosinate). Based on the proportion of total field area at each site infested with HR weeds, it is estimated that 7.7 million ha (29% of annually cropped land) are infested with HR weeds (eight-fold increase from 2001 to 2003), in a total field area of 9.9 million ha (37%)—over a two-fold increase. Of 816 cases of HR wild oat identified from submitted samples, 69% were group 1-HR, 15% group 2-HR, and 16% group 1+2-HR. Additionally, there were 10 populations of group 1-HR green foxtail in Saskatchewan or Manitoba, and six populations of group 1-HR Persian darnel in southern Alberta and Saskatchewan. Various group 2-HR broadleaf weeds were identified, including 17 wild mustard populations mainly from Saskatchewan and 39 cleavers populations across the three Prairie provinces. Herbicide-use data from 2006 to 2010 indicated continued reliance on group 1 herbicides in cereal crops and group 2 herbicides in pulse crops.

Nomenclature: Common chickweed, *Stellaria media* (L.) Vill. STEME; false cleavers, *Galium spurium* L. GALSP; green foxtail, *Setaria viridis* (L.) Beauv. SETVI; Persian darnel, *Lolium persicum* Boiss. & Hohen. ex Boiss. LOLPS; Powell amaranth, *Amaranthus powellii* S. Wats. AMAPO; spiny sowthistle, *Sonchus asper* (L.) Hill SONAS; wild buckwheat, *Polygonum convolvulus* L. POLCO; wild mustard, *Sinapis arvensis* L. SINAR; wild oat, *Avena fatua* L. AVEFA.

Key words: ACCase inhibitor, ALS inhibitor, herbicide resistance, resistance management, survey.

Un estudio observacional sobre malezas resistentes a herbicidas (HR) se realizó al final del verano en Alberta en 2007, Manitoba en 2008 y Saskatchewan en 2009, para un total de 1,000 muestras aleatoriamente seleccionadas de campos cultivados anualmente. Adicionalmente, evaluamos 1,091 muestras de semillas de malezas (cada muestra proveniente de un campo) remitidas por productores de las Praderas entre 2007 y 2011. De 677 campos donde se colectó muestras de *Avena fatua*, 298 (44%) tuvieron un biotipo HR. Se confirmó *Avena fatua* HR grupo 1(inhibidores de acetyl CoA carboxylase) en 275 campos (41%), lo cual fue un incremento del 15% con base en estudios de referencia previos (2001–2003). Se encontró *A. fatua* HR grupo 2 (acetolactate synthase) en 12% de los campos (vs. 8% en 2001 a 2003). *A. fatua* HR grupo 8 (triallate, difenzoquat) fue identificada en solamente 8% de los campos (no se evaluó en 2001 a 2003). La frecuencia de presencia de *A. fatua* HR grupos 1+2 fue similar (8%, vs. 3% en 2001 a 2003). *Setaria viridis* HR grupo 1 fue encontrada en 27% de 209 campos muestreados por esta maleza (vs. 6% en 2001 al 2003). Se confirmó *Sonchus asper* HR grupo 2 en todos los campos muestreados en Alberta (vs. 67% en 2001); mientras que *Stellaria media* HR se encontró principalmente en Alberta en 40% de los campos (vs. 17% en 2001). Biotipos de malezas HR grupo 2 que no habían sido detectados en los estudios previos incluyeron *Galium spurium* principalmente en Alberta (17% de los campos) y en Saskatchewan (21%), *Amaranthus powellii* en Manitoba (16% de los campos), *Sinapis arvensis* (tres poblaciones en Saskatchewan y Manitoba) y *Polygonum convolvulus* (una población en Alberta). De las poblaciones de malezas muestreadas a lo largo de las Praderas, no se encontró ninguna que fuera resistentes a herbicidas del grupo 4(auxinas sintéticas), grupo 9 (glyphosate) o grupo 10 (glufosinate). Basándose en la proporción del área total de campos infestados con malezas HR en cada sitio, se estimó que 7.7 millones ha (29% de la tierra cultivada anualmente) están infestadas con malezas HR (un incremento de ocho veces desde 2001 a 2003), en un área total de 9.9 millones ha (37%)—más del doble de incremento. De 816 casos de *A. fatua* HR identificados en las muestras remitidas, 69% fueron HR grupo 1, 15% HR grupo 2 y 16% HR grupo 1+2. Adicionalmente, hubo 10 poblaciones de *S. viridis* HR grupo 1 en Saskatchewan o Manitoba, y seis poblaciones de *Lolium persicum* HR grupo 1 en el sur de Alberta y Saskatchewan. Varias malezas de hoja ancha HR grupo 2 fueron identificadas,

DOI: 10.1614/WT-D-12-00095.1

* First, second, and third authors: Weed Scientist, Technician, and Technician, respectively, Agriculture and Agri-Food Canada, Saskatoon Research Centre, 107 Science Place, Saskatoon, Saskatchewan S7N 0X2, Canada; fourth author: Weed Control Specialist, Saskatchewan Ministry of Agriculture, 125-3085 Albert Street, Regina, Saskatchewan S4S 0B1, Canada. Corresponding author's E-mail: hugh.beckie@agr.gc.ca

incluyendo 17 poblaciones de *S. arvensis* predominantemente de Saskatchewan y 39 poblaciones de *G. spurium* a lo largo de tres provincias de las Praderas. Datos de uso de herbicidas de 2006 a 2010 indicaron que ha continuado la dependencia en herbicidas grupo 1 en cultivos de cereales y de herbicidas grupo 2 en cultivos de granos de especies dicotiledóneas.

The principal field annual crops are grown on 27 million ha across the Northern Great Plains of Canada (Prairies), accounting for 88% of national crop area (Statistics Canada 2011) and 86% of herbicide use (Statistics Canada 2007a). Weed resistance monitoring has been routinely conducted across the Prairies since the mid-1990s. A baseline survey of HR weeds was conducted in Alberta in 2001, Manitoba in 2002, and Saskatchewan in 2003, totaling nearly 800 randomly-selected fields; in addition, nearly 1,300 weed seed samples were submitted by growers or industry across the Prairies between 1996 and 2006 for resistance testing (Beckie et al. 2008). Collected or submitted samples were screened for group 1 (acetyl-CoA carboxylase [ACC] inhibitor] or group 2 [acetolactate synthase [ALS] inhibitor) resistance.

Twenty percent of 565 sampled fields had an HR wild oat population. Most populations exhibited broad cross-resistance across various classes of group 1 or group 2 herbicides. In Manitoba, 22% of 59 fields had group 1-HR green foxtail. Group 2-HR populations of common chickweed and spiny sowthistle were documented in Alberta, and green foxtail and redroot pigweed (*Amaranthus retroflexus* L.) in Manitoba. Across the Prairies, HR weeds were estimated to occur in fields with a total area of 4.4 million ha.

Of 1,067 wild oat seed samples submitted by growers or industry for testing between 1996 and 2006, 725 were group 1 HR, 34 group 2 HR, and 55 group 1+2 HR (Beckie et al. 2008). Of 80 submitted green foxtail samples, 26 were confirmed group 1 HR; most populations originated from southern Manitoba where the weed is most abundant. Similar to the field surveys, various group 2-HR weed populations were confirmed among submitted samples, including kochia [*Kochia scoparia* (L.) Schrad.], wild mustard, field pennycress (*Thlaspi arvense* L.), *Galium* spp., common chickweed, and common hempnettle (*Galeopsis tetrahit* L).

Information from grower questionnaires indicated that patterns of herbicide usage were related to location, changing with cropping system (Beckie et al. 2008). Two herbicide sites of action most prone to select resistance, group 1 (ACC inhibitor) and 2 (ALS inhibitor), continued to be widely and repeatedly used. There was little evidence that growers were aware of the level of resistance within their fields, but a majority had adopted herbicide rotations to proactively or reactively manage HR weeds.

Six years after the baseline weed resistance survey in each of the three Prairie provinces, a survey of 1,000 fields using the same methodology was conducted to determine the change in abundance of HR weeds. Collected samples of 39 weed species were screened in the greenhouse with herbicides belonging to six sites of action or groups. In addition, we screened 1,091 samples of nine weed species submitted by Prairie growers or industry between 2007 and 2011.

Materials and Methods

Survey Sites. A total of 1,000 fields across the major Prairie agricultural ecoregions (area of similar climate, natural vegetation, soils, and land use; Agriculture and Agri-Food Canada 2003) were surveyed for HR weeds from 2007 to 2009 (Table 1): 300 fields in Alberta in 2007, 300 fields in Manitoba in 2008, and 400 fields in Saskatchewan in 2009. Each field was farmed by a different grower. Similar to the general weed survey (Leeson et al. 2005), 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

Table 1. Fields surveyed across Prairie ecoregions[a] by crop.

Crop	Mixed Grassland	Moist Mixed Grassland	Fescue Grassland	Aspen Parkland	Boreal Transition	Lake Manitoba Plain	Interlake Plain	Peace Lowland	All areas
	No. of fields								
Wheat	72	57	5	157	34	38	13	8	384
Barley	13	25	10	62	15	7	2	12	146
Oat	4	4	0	30	7	11	1	4	61
Canary seed	1	0	0	2	0	0	0	0	3
Corn	0	0	0	1	0	2	0	0	3
Canola	10	25	4	113	52	37	11	21	273
Flax	4	7	0	22	4	4	2	0	43
Mustard	2	5	1	0	0	0	0	0	8
Soybean	0	0	0	0	0	5	0	0	5
Sunflower	0	0	0	2	0	0	0	0	2
Field pea	10	9	0	18	3	0	0	0	40
Lentil	12	20	0	0	0	0	0	0	32
Subtotal	128	152	20	407	115	104	29	45	1,000
% of total	12.8	15.2	2.0	40.7	11.5	10.4	2.9	4.5	100

[a] The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Aspen Parkland ecoregion includes the Southwest Manitoba Uplands ecoregion; the Boreal Transition ecoregion includes the Mid-Boreal Uplands ecoregion; and the Interlake Plain ecoregion includes Lake of the Woods ecoregion. The semiarid Grassland region includes the Mixed Grassland, Moist Mixed Grassland, and Fescue Grassland ecoregions; the subhumid Parkland region includes the remaining ecoregions (Agriculture and Agri-Food Canada 2003).

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

Table 2. Weed species tested for resistance.

Weed species	Samples tested	Fields	Rank[a]
	No.		
Grass:			
Barnyardgrass, *Echinochloa crus-galli* (L.) Beauv.	18	18	15
Downy brome, *Bromus tectorum* L.	1	1	70
Foxtail barley, *Hordeum jubatum* L.	16	16	32
Green foxtail, *Setaria viridis* (L.) Beauv.	219	210	1
Persian darnel, *Lolium persicum* Boiss. & Hohen. ex Boiss.	1	1	40
Quackgrass, *Elymus repens* (L.) Gould	2	2	21
Wild oat, *Avena fatua* L.	775	677	2
Yellow foxtail, *Setaria pumila* (Poir.) Roem. & J.A. Schult.	37	37	60
Broadleaf:			
Horseweed, *Conyza canadensis* (L.) Cronq.	7	7	69
Canada thistle, *Cirsium arvense* (L.) Scop.	2	2	4
Common chickweed, *Stellaria media* (L.) Vill.	70	67	6
Common groundsel, *Senecio vulgaris* L.	5	5	30
Common hempnettle, *Galeopsis tetrahit* L.	21	21	17
Common lambsquarters, *Chenopodium album* L.	88	86	5
Common mallow, *Malva neglecta* Wallr.	4	4	27
Corn spurry, *Spergula arvensis* L.	3	3	41
Cowcockle, *Vaccaria hispanica* (Mill.) Rauschert	11	11	36
Dandelion, *Taraxacum officinale* G. H. Weber ex Wiggers	3	3	11
Field pennycress, *Thlaspi arvense* L.	114	111	7
Flixweed, *Descurainia sophia* (L.) Webb ex Prantl	20	20	28
Galium spp.	109	105	9
Greenflower pepperweed, *Lepidium densiflorum* Schrad.	1	1	58
Knotweed spp., *Polygonum* spp.	1	1	39
Narrowleaf hawksbeard, *Crepis tectorum* L.	14	14	23
Nightflowering catchfly, *Silene noctiflora* L.	40	40	33
Powell amaranth, *Amaranthus powellii* S. Wats.	39	39	8
Prickly lettuce, *Lactuca serriola* L.	6	6	51
Redroot pigweed, *Amaranthus retroflexus* L.	32	32	8
Redstem filaree, *Erodium cicutarium* (L.) L'Hér.ex Ait.	6	6	38
Russian pigweed, *Axyris amaranthoides* L.	2	2	101
Shepherd's-purse, *Capsella bursa-pastoris* (L.) Medik.	34	34	20
Smartweed (annual) species, *Polygonum* spp.	32	32	13
Sowthistle (annual, perennial), *Sonchus* spp.	26	26	19
Spiny sowthistle, *Sonchus asper* (L.) Hill	11	11	22
Tumble pigweed, *Amaranthus albus* L.	2	2	63
Western salsify, *Tragopogon dubius* Scop.	1	1	75
Wild buckwheat, *Polygonum convolvulus* L.	93	90	3
Wild mustard, *Sinapis arvensis* L.	25	24	24
Yellow toadflax, *Linaria vulgaris* P. Mill.	1	1	—

[a] Relative abundance rank of species in 3,806 fields surveyed from 2001 to 2003 (Leeson et al. 2005).

similar in landform, relief, surficial material, soil, vegetation, and land use) was based on data from Statistics Canada (2006, 2007b, 2008). Fields were randomly selected from the Agricore United database. Each field comprised 65 ha. The crop allocation in the major agricultural ecoregions of the Prairies is shown in Table 1.

A majority of the fields (60%) were cropped to cereals. This proportion was lower than that of the 2001 to 2003 weed resistance surveys (75%) (Beckie et al. 2008). Wheat (*Triticum aestivum* L.) occupied 64% of the 597 survey fields cropped to cereals, barley (*Hordeum vulgare* L.) 24%, oat (*Avena sativa* L.) 10%, canary seed (*Phalaris canariensis* L.) 1%, and corn (*Zea mays* L.) 1%; in the 2001 to 2003 surveys, wheat comprised 60%, barley 30%, oat 9% , and canary seed 1% of cereal fields. Oilseeds comprised 33% of surveyed fields (vs. 22% in 2001 to 2003): canola (*Brassica napus* L.) 82% of that, flax (*Linum usitatissimum* L.) 13%, mustard [*Brassica juncea* (L.) Czern. or *Sinapis alba* L.] 2%, soybean [*Glycine max* (L.) Merr.] 2%, and sunflower (*Helianthus annuus* L.) 1%. The proportion of oilseed fields cropped to canola, flax, and mustard was similar as that of the 2001 to 2003 surveys. Pulse crops comprised 7% of surveyed fields (vs. 3% in 2001 to 2003), with field pea (*Pisum sativum* L.) at 56% and lentil (*Lens culinaris* Medik.) at 44% of pulse crop area.

Field Survey. Fields were surveyed using a W-transect pattern (adapted from Thomas 1985) in August or September before crop harvest. About 1,000 mature seeds of a weed species were collected, when available, from plants occurring in a patch (each patch sampled separately) and placed in an unsealed paper bag (Beckie et al. 2000). Any patch visible from a transect was sampled. If the weed population was widely disseminated across a 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 infestation area of a suspected HR weed species in a field was estimated with a tape measure or calculated with GPS coordinates. Samples were air dried and stored at room temperature (ca. 20 C) before conducting the resistance tests.

The number of weed samples tested is shown in Table 2. About 40% of the 39 weed species tested for resistance were ranked in the top 20 on the basis of relative abundance (composite index of the field frequency, field uniformity, and density values for a species) in fields surveyed from 2001 to 2003 (Leeson et al. 2005). Some species whose seeds had been collected were not tested because of limited amount of seed, no known response to herbicides used in screening, or nonviable seed.

Resistance Tests. Resistance tests were initiated 4 mo after seeds were collected with the expectation that levels of innate dormancy would be reduced by this storage period. All tests were conducted with the use of whole-plant assays in the greenhouse. Weed species were sprayed at early growth stages (usually two to four leaves) to optimize herbicide efficacy. Weed samples were screened for resistance to various herbicides (commercial formulations) from six groups (Table 3).

Grass weed species were tested for resistance to a maximum of seven group 1 herbicides: three aryloxyphenoxypropionate (APP) herbicides, three cyclohexanedione (CHD) herbicides, and pinoxaden, a phenylpyrazolin (PPZ) herbicide. The three APP herbicides were fenoxaprop (without safener) at 150 g ha^{-1} (wild oat) or 40 g ha^{-1} (green foxtail and other annual grasses), clodinafop at 35 g ha^{-1}, and quizalofop at 35 g ha^{-1} (70 g ha^{-1} for perennial grasses); the three CHD herbicides were sethoxydim at 110 g ha^{-1} (wild oat), 50 g ha^{-1} [green or yellow foxtail, *Setaria pumila* (Poir.) Roemer & J. A. Schultes], 145 g ha^{-1} (other annual grasses), or 250 g ha^{-1} (perennial

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

Table 3. Herbicides used in resistance screening.[a,b,c,d]

Herbicide	Group	Weed species	Rate
			g ai or g ae ha^{-1}
Fenoxaprop-P	1 (APP)	Wild oat, green foxtail, other annual grass	150, 40, 40
Clodinafop	1 (APP)	Wild oat, green foxtail, yellow foxtail	35, 35, 35
Quizalofop	1 (APP)	Wild oat, green foxtail, perennial grass	35, 35, 70
Sethoxydim	1 (CHD)	Wild oat, green foxtail, other annual grass, perennial grass	110, 50, 145, 250
Tralkoxydim	1 (CHD)	Wild oat, green foxtail	25, 25
Clethodim	1 (CHD)	Wild oat, green foxtail	15, 15
Pinoxaden	1 (PPZ)	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
Thifensulfuron : tribenuron	2 (SU)	Broadleaf	15
Flucarbazone	2 (SCT)	Wild oat	15
Pyroxsulam	2 (TP)	Wild oat	11
Florasulam	2 (TP)	Broadleaf	5
2,4-D	4 (Auxin)	Broadleaf	560–930
Dicamba	4 (BA)	Broadleaf	140–600
Fluroxypyr	4 (CA)	Broadleaf	80
Triallate	8	Wild oat	1,180
Difenzoquat	8	Wild oat	700
Glyphosate	9	Grass and broadleaf	450–900
Glufosinate	10	Grass and broadleaf	500

[a] For each herbicide, only weed species listed on the label as being controlled were screened.

[b] Abbreviations: APP, aryloxyphenoxypropionate; BA, benzoic acid; CA, carboxylic acid; CHD, cyclohexanedione; IMI, imidazolinone; PPZ, phenylpyrazolin; SCT, sulfonylaminocarbonyltriazolinone; SU, sulfonylurea; TP, triazolopyrimidine.

[c] Manufacturers (trade name in parenthesis): Arysta LifeScience Canada, Edmonton, Alberta, Canada: clethodim (Select), flucarbazone (Everest); BASF Canada, Mississauga, Ontario, Canada: dicamba (Banvel II), imazamox (Solo), imazethapyr (Pursuit), sethoxydim (Poast Ultra); Bayer CropScience Canada, Calgary, Alberta, Canada: fenoxaprop-P (Tundra component 1), glufosinate (Liberty 200 SN); Dow AgroSciences Canada, Calgary, Alberta, Canada: florasulam (Frontline), fluroxypyr (Attain XC component A), pyroxsulam (Simplicity), tralkoxydim (Achieve); E. I. duPont Canada, Mississauga, Ontario, Canada: metsulfuron (Ally), quizalofop (Assure II), thifensulfuron:tribenuron (Refine SG); Gowan Canada, Calgary, Alberta, Canada: triallate (Avadex Extra Strength BW); Monsanto Canada, Winnipeg, Manitoba, Canada: glyphosate (Roundup WeatherMax); Nufarm Agriculture, Calgary, Alberta, Canada: 2,4-D Ester 700, imazamethabenz (Assert); Syngenta Crop Protection Canada, Regina, Saskatchewan, Canada: clodinafop (Horizon 240EC), difenzoquat (Avenge 200C), pinoxaden (Axial).

[d] Adjuvants: Achieve: Turbocharge (oil-based); Ally: Agral 90 (nonionic); Assure: Sure-mix (oil-based); Axial: Adigor (oil-based); Everest: Agral 90; Poast: Merge (oil-based); Pursuit: Agral 90; Select: Amigo (oil-based); Simplicity: Agral 90; Solo: Merge.

grasses), tralkoxydim at 25 g ha^{-1}, and clethodim at 15 g ha^{-1}. Pinoxaden was applied at 15 g ha^{-1}. 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^{-1}, imazamox at 35 g ha^{-1}, and flucarbazone at 15 g ha^{-1}. 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^{-1}, imazamox at 35 g ha^{-1}, metsulfuron at 4.5 g ha^{-1}, thifensulfuron : tribenuron at 15 g ha^{-1}, and florasulam at 5 g ha^{-1}.

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

Table 4. Fields with herbicide-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]	17	18	14	4	4	3
Moist Mixed Grassland	29	25	19	4	3	3
Fescue Grassland	4	36	20	3	27	15
Aspen Parkland	145	52	36	39	14	10
Lake Manitoba Plain	30	46	29	8	12	8
Boreal Transition	25	40	21	8	13	7
Interlake Plain	13	68	45	10	53	35
Peace Lowland	12	44	27	2	7	4
Prairie provinces	*275*	*41*	*28*	*78*	*12*	*8*

[a] Tested: fields where seeds were collected ($n = 677$); surveyed: all fields surveyed ($n = 1,000$).

[b] The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Aspen Parkland ecoregion includes the Southwest Manitoba Uplands ecoregion; the Boreal Transition ecoregion includes the Mid-Boreal Uplands ecoregion; and the Interlake Plain ecoregion includes Lake of the Woods ecoregion.

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

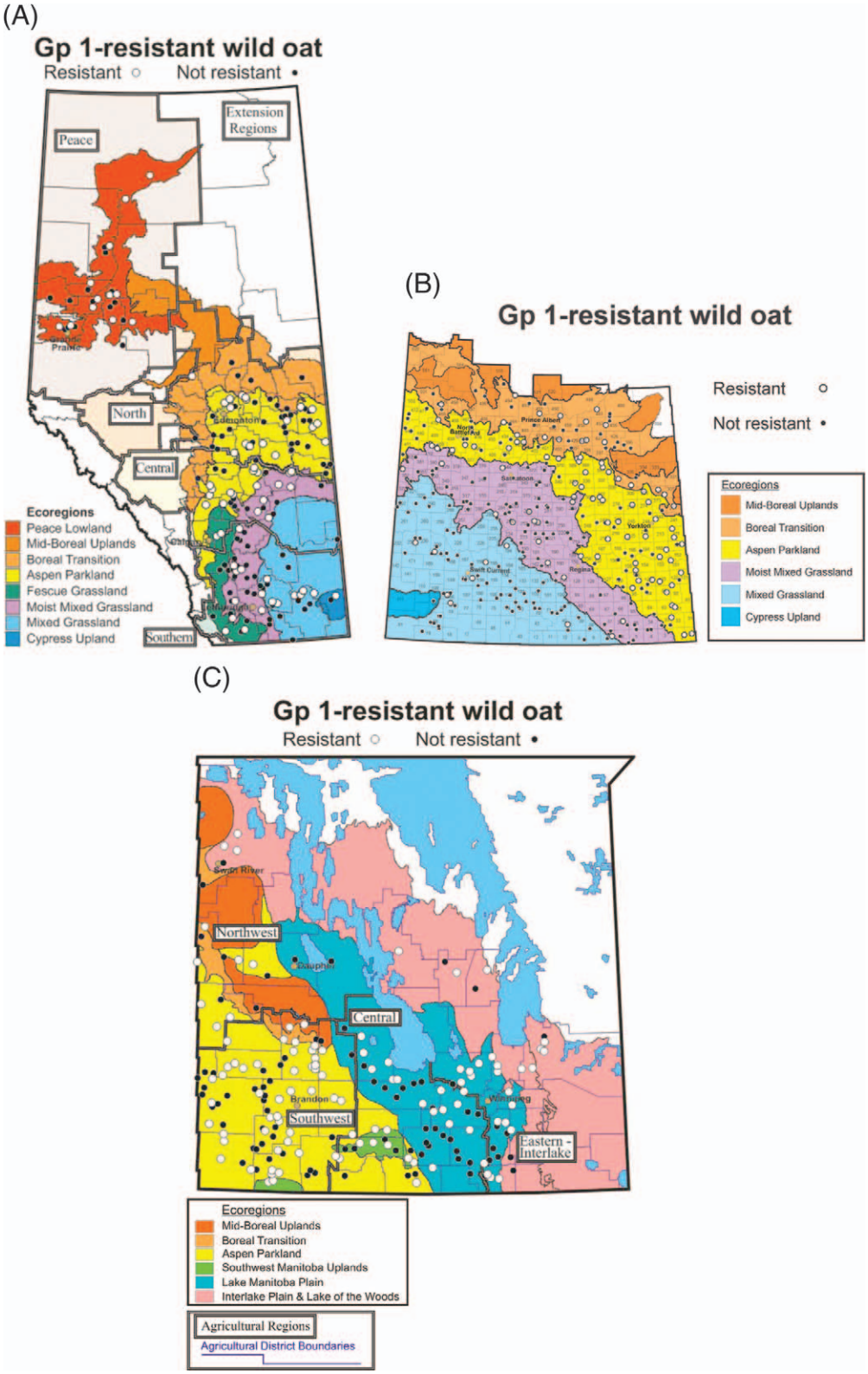

Figure 1. Field surveys: group 1 (acetyl CoA carboxylase inhibitor)-resistant wild oat across the Prairie provinces, 2007 to 2009; (A) Alberta (B) Saskatchewan, and (C) Manitoba.

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

(group 10) (Table 3). POST herbicides were applied using a moving-nozzle cabinet sprayer equipped with a flat-fan spray tip (TeeJet 8002VS, Spraying Systems Co., Wheaton, IL) calibrated to deliver 200 L ha^{-1} of spray solution at 275 kPa in a single pass over the foliage. Triallate was applied PRE as described by O'Donovan et al. (1994) to an Udic Haploboroll loam soil with 4% organic matter content and pH 7.0.

Thirty-six plants were grown in flats measuring 52 by 26 by 5 cm that were filled with a mixture of soil, peat, vermiculite, and sand (3 : 2 : 2 : 2 by volume) plus a controlled-release fertilizer (15-9-12, 150 g 75 L^{-1}; Scotts Osmocote PLUS, Mississauga, Ontario, Canada). Plants were visually assessed as HR (2, some injury but new growth or 3, no injury) or herbicide-susceptible (HS) (0 =dead or 1 = nearly dead) at 21 to 28 d after treatment. A minimum of 100 seedlings per sample were screened in each resistance test. Treatments (and untreated controls) were replicated three times and the tests were repeated. Known HR and HS biotypes, when available, were included in all tests (Beckie et al. 2000). Samples either collected in fields or submitted for testing were assumed to consist of populations potentially containing both HS individuals and HR individuals having one or multiple herbicide resistance mechanisms. A population was considered HR when at least one individual in each test scored 2 or 3.

Samples Submitted by Growers: 2007 to 2011. In Petri-dish assays, wild oat and green foxtail seedlings were screened for group 1 resistance using the APP herbicides fenoxaprop (green foxtail) or clodinafop (wild oat), and the CHD herbicide sethoxydim (Beckie et al. 2008). In whole-plant assays, pinoxaden was used to screen wild oat for group 1 resistance (only when requested), imazamethabenz was typically used to screen wild oat for group 2 resistance (also pyroxsulam at 11 g ha^{-1} for samples from the 2011 crop year), and tribenuron : thifensulfuron mixture to screen various broadleaf weeds for group 2 resistance, according to the procedures described previously.

Results and Discussion

Grass Weed Resistance. Of the 677 fields where wild oat samples were collected, 298 (44%) had an HR biotype. Group 1-HR wild oat was confirmed in 275 fields (41%) (Table 4, Figure 1). In comparison, in the previous Prairie surveys during 2001 to 2003, 15% of fields with wild oat had a group 1-HR biotype (Beckie et al. 2008). Therefore, 28% of all fields surveyed (1,000) had group 1-HR wild oat. This field frequency of resistance is significantly greater than that documented in the 2001 to 2003 surveys (11%) (Beckie et al. 2008). Over half of all fields with group 1-HR wild oat were located in the Aspen Parkland ecoregion, although resistance was proportionally greatest in the Interlake Plain ecoregion of Manitoba (68% of fields with wild oat; Table 4). In general, incidence of group 1-HR wild oat was greater in the Parkland than Grassland ecoregions. Similar trends were observed in the 2001 to 2003 surveys, although the frequency of fields with group 1-HR wild oat had increased in all ecoregions in the 2007 to 2009 surveys. The greater incidence of group 1-HR wild oat in the subhumid Parkland vs. semiarid 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). Across the Prairie provinces, group 1-HR wild oat was found in 32% of fields in Saskatchewan, 39% of fields in Alberta, and 55% of fields in Manitoba.

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 2001 to 2003 surveys (Beckie et al. 2008).

Group 2 resistance was confirmed in 78 wild oat populations (12% of fields where seeds were collected or 8% of all fields surveyed; Table 4, maps not shown). This frequency of resistance in 2007 to 2009 compares with 8% of sampled fields in 2001 to 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 herbicides that control wild oat with these sites of action (H. J. Beckie, unpublished data). Similar to the 2001 to 2003 surveys, most fields with resistance were located in the Parkland region (Aspen Parkland, Boreal Transition, Lake Manitoba Plain, Interlake Plain ecoregions; Table 4) where group 2 herbicide use has historically been the greatest (Beckie et al. 2008). Frequent cross-resistance was evident in HR populations to the group 2 herbicides tested, imidazolinones and flucarbazone (data not shown), similar to that observed in the 2001 to 2003 surveys. The incidence of group 2-HR wild oat was lowest in Saskatchewan (7% of fields), compared with Alberta (12%) and Manitoba (18%).

The incidence of group 8-HR wild oat (56 fields) across the Prairies averaged only 8% of fields where wild oat was sampled: 3% of fields in Saskatchewan (most in the Parkland region), 11% in Manitoba (most in the Aspen Parkland and Lake Manitoba Plain ecoregions), and 15% in Alberta (equally distributed between Grassland and Parkland ecoregions) (maps not shown). Wild oat samples from the 2001 to 2003 surveys were not screened for group 8 resistance.

There were 55 fields with group 1+2-HR wild oat populations (8% of fields sampled) (Figure 2), compared with 16 fields in the 2001 to 2003 surveys (3%): five fields (9%) in the Grassland region and 50 fields (91%) in the Parkland region (Aspen Parkland, 28; Lake Manitoba Plain, eight; Interlake Plain, seven; Boreal Transition, five; and Peace Lowland, two). Resistance in these intergroup-HR wild oat populations is primarily target-site (ACC inhibitor) or metabolism-based (ALS inhibitor) (Beckie et al. 2012a). Other intergroup-HR biotypes also were found: Group 1+8 (34 fields, 5%), 2+8 (10 fields, 2%), and 1+2+8 (17 fields, 3%).

The proportion of HR wild oat samples with a frequency of HR individuals < 20% (often defined by other researchers as "developing resistance") varied by biotype and province. For example, the proportion for group 1-HR wild oat varied from 18 to 20% in Manitoba and Saskatchewan to 37% in Alberta.

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

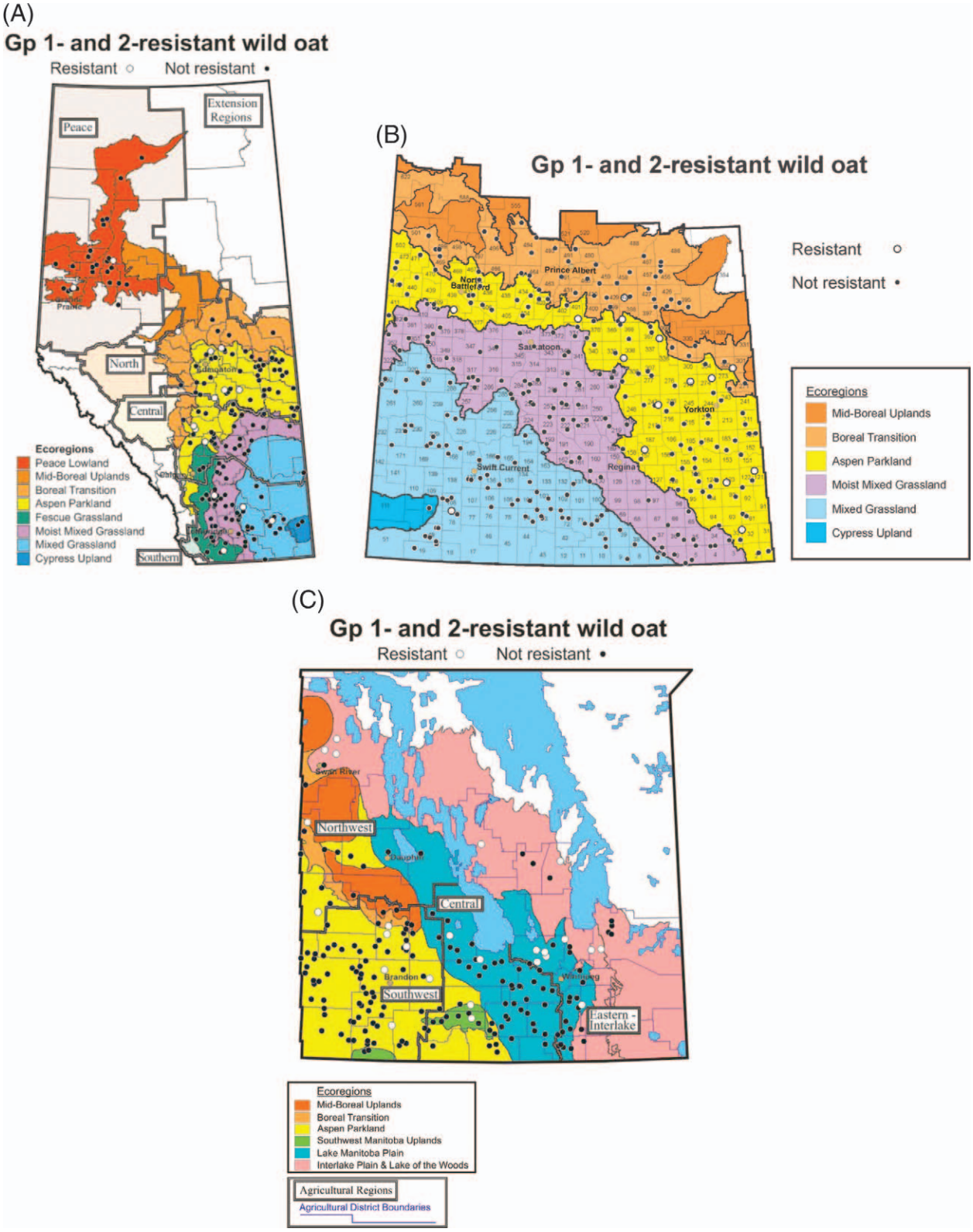

Figure 2. Field surveys: group 1+2 (acetyl CoA carboxylase and acetolactate synthase inhibitor)-resistant wild oat across the Prairie provinces; (A) Alberta, (B) Saskatchewan, and (C) Manitoba.

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

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

Ecoregion	Resistant	Tested[a]	Surveyed[a]
	No.	%	
Mixed Grassland[b]	0	0	0
Moist Mixed Grassland	4	11	3
Fescue Grassland	0	0	0
Aspen Parkland	37	37	9
Lake Manitoba Plain	14	35	14
Boreal Transition	0	0	0
Interlake Plain	1	20	3
Peace Lowland	0	0	0
Prairie provinces	*56*	*27*	*6*

[a] Tested: fields where seeds were collected ($n = 209$); surveyed: all fields surveyed ($n = 1{,}000$).

[b] The Mixed Grassland ecoregion includes the Cypress Upland ecoregion; the Aspen Parkland ecoregion includes the Southwest Manitoba Uplands ecoregion; the Boreal Transition ecoregion includes the Mid-Boreal Uplands ecoregion; and the Interlake Plain ecoregion includes Lake of the Woods ecoregion.

In contrast, the proportion for group 2-HR wild oat varied from only 4% of samples in Alberta to 15% in Manitoba to 40% in Saskatchewan. This variation generally corresponded with the history of group 1 or 2 herbicide selection pressure. Overall, the majority of HR samples had a frequency of resistance > 20%.

Herbicide resistance in wild oat has been reported in 13 other countries (Heap 2012). In a 2005 survey in Western Australia, 71% of 150 *Avena* spp. populations were resistant to diclofop, an ACC-inhibiting herbicide, but no population was resistant to an ALS-inhibiting herbicide (Owen and Powles 2009). A 2007 survey in New South Wales, Australia found 38% of 113 *Avena* spp. populations resistant to an ACC-inhibiting herbicide, but none to an ALS-inhibiting herbicide (Broster et al. 2011). In a 2009 survey in Greece, 89% of 104 sterile wild oat (*Avena sterilis* L.) populations were resistant to diclofop, but only 3% resistant to an ALS-inhibiting herbicide (Travlos et al. 2011). Therefore, a common finding of these surveys (and similar to that described herein) was the relatively high incidence of ACC-inhibitor resistance but low incidence of ALS-inhibitor resistance.

Group 1-HR green foxtail was found in 27% of 209 fields where seeds were collected (Table 5, Figure 3). Group 1-HR green foxtail was found in 14% of fields in Saskatchewan and 44% of fields in Manitoba (vs. 22% in Manitoba in 2002; Beckie et al. 2008), with only two sites in Alberta (map not shown). Only 10% of samples had a frequency of resistance < 20%. Two-thirds of the fields were located in the Aspen Parkland ecoregion, similar to results of a previous survey (Beckie et al. 1999a). Incidence of resistance was also proportionally high in the Lake Manitoba Plain ecoregion (Table 5). Group 2 resistance in this weed was not detected (one site in Manitoba in 2002; Beckie et al. 2008). Group 1-HR Persian darnel was found in one field in the Moist Mixed Grassland ecoregion of Saskatchewan (not detected in the 2001 to 2003 surveys).

Broadleaf Weed Resistance. A spring survey of 109 Prairie fields in 2007 had documented widespread (ca. 90%) group 2-HR kochia across the Prairies; however, group 2-HR Russian-thistle (*Salsola tragus* L.) was found in only two

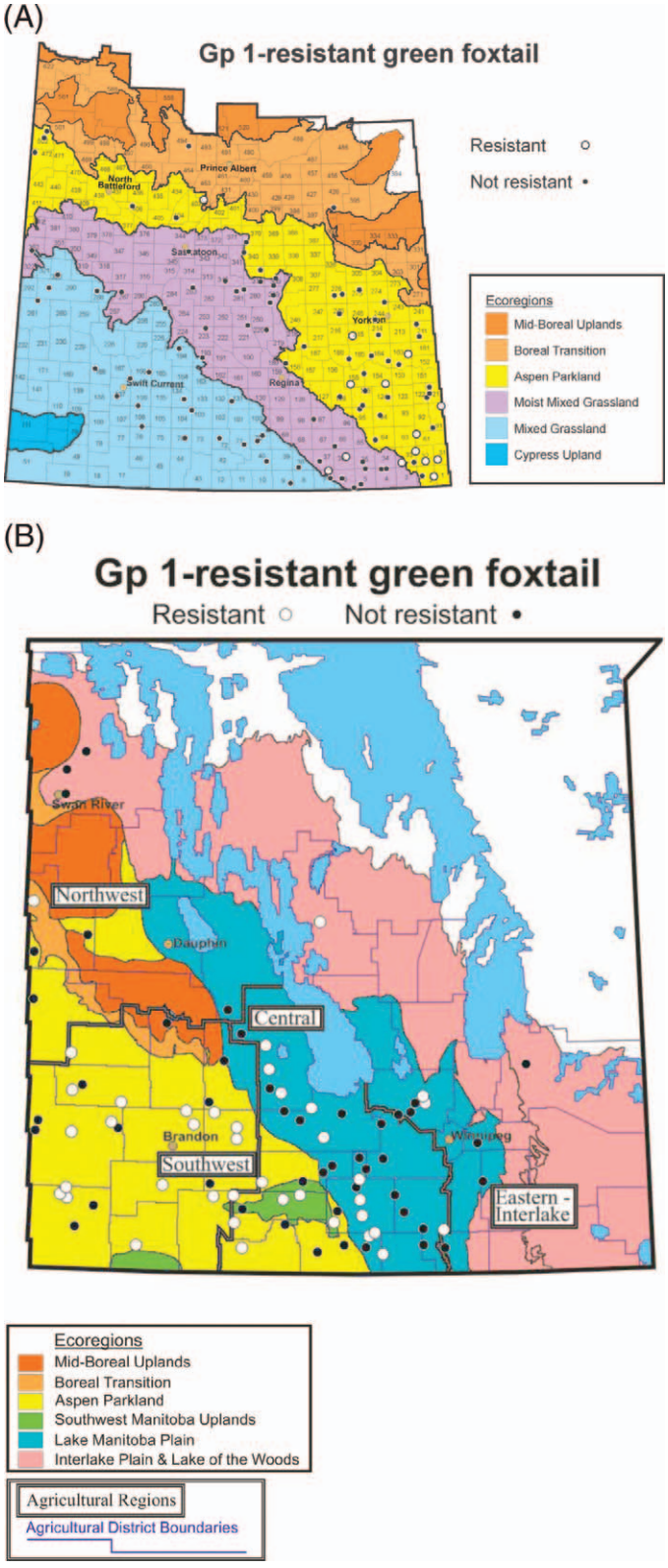

Figure 3. Field surveys: group 1 (acetyl CoA carboxylase inhibitor)-resistant green foxtail in (A) Saskatchewan and (B) Manitoba (Alberta map not shown).

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

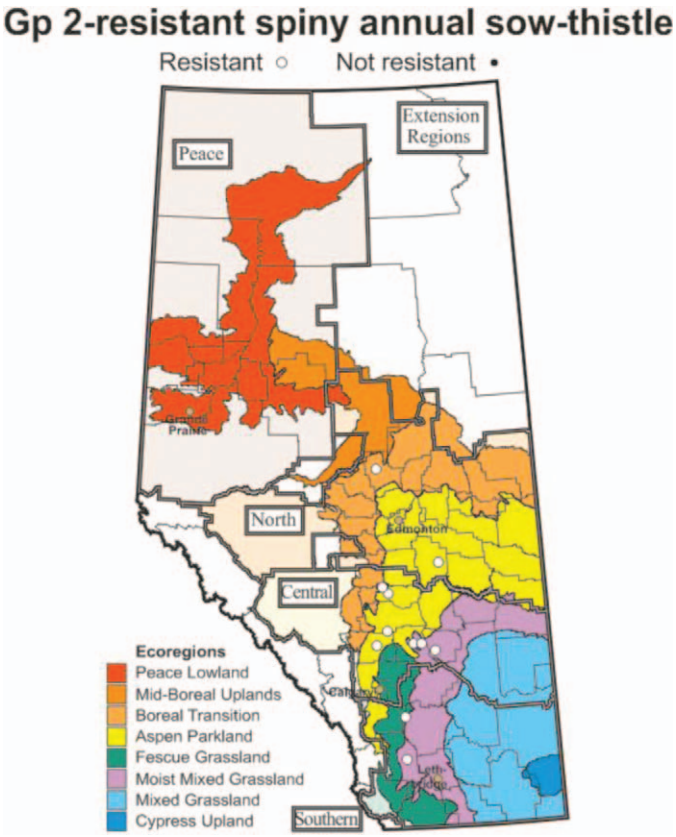

Figure 4. Field surveys: group 2 (acetolactate synthase)-resistant spiny sowthistle in Alberta.

surveyed fields (Beckie et al. 2011b; Warwick et al. 2010). All Alberta fields sampled for spiny sowthistle had group 2-HR populations (Figure 4), compared with 67% of sampled fields in 2001. Even with the small sample size, growers with this weed species should assume their populations are group 2-HR; wind readily disperses the light-weight seed. Group 2-HR common chickweed was found mainly in Alberta (40% of sampled fields; map not shown), with only one confirmed site in the Boreal Transition ecoregion of Manitoba. In 2001, this HR biotype was found in 17% of fields in the Aspen Parkland ecoregion of Alberta (Beckie et al. 2008). Therefore, incidence of group 2 resistance in this weed has increased relatively rapidly over the 6-yr period.

Group 2-HR false cleavers was found in one site in the Interlake Plain ecoregion of Manitoba, 17% of sites in the Aspen Parkland ecoregion of Alberta, and 21% of sites in the Parkland region of Saskatchewan (Figure 5). Resistance in this weed was not detected in the 2001 to 2003 field surveys. Because *Galium* spp. are increasing in abundance at the fastest rate among all weeds (Leeson et al. 2005), the expected rapid increase in occurrence of this HR biotype

→

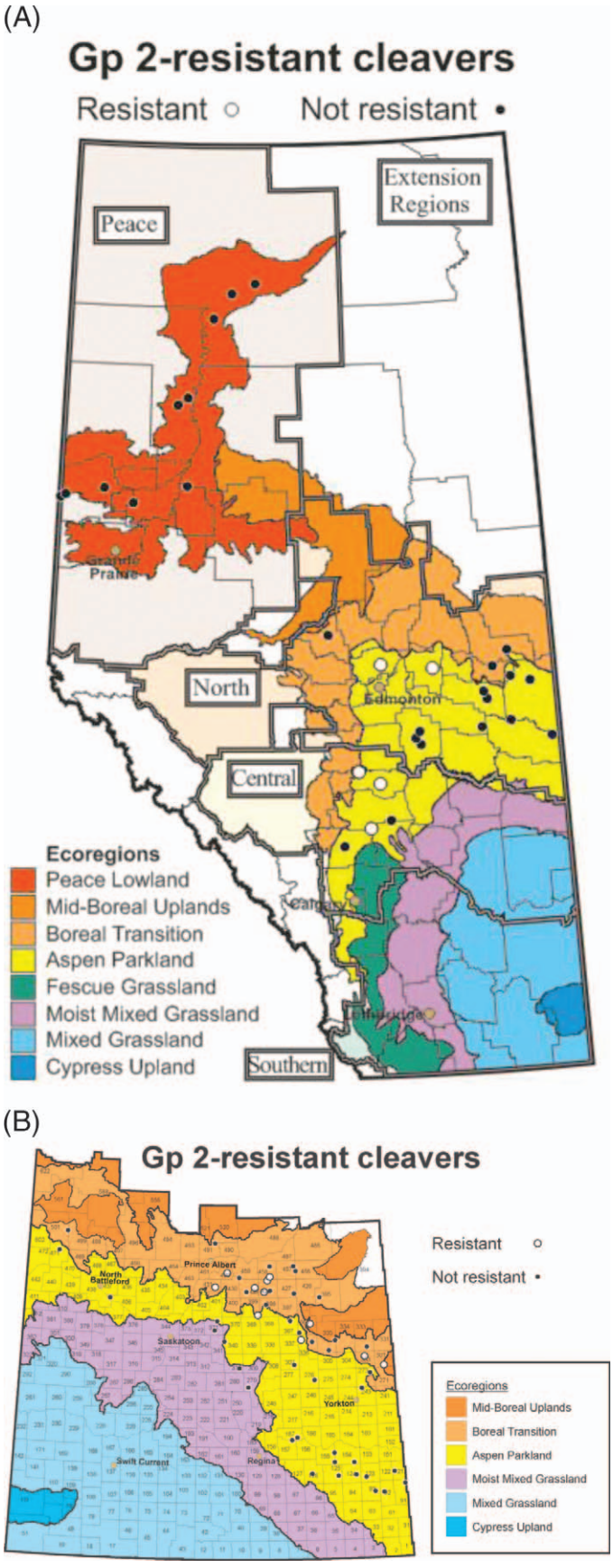

Figure 5. Field surveys: group 2 (acetolactate synthase)-resistant false cleavers in (A) Alberta and (B) Saskatchewan (Manitoba map not shown).

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

Table 6. Estimated annually-cropped land area across the Prairies impacted by herbicide-resistant (HR) weeds: 2007 to 2009.[a]

Biotype	Infestation area	Field area
	ha	
Group 1-HR wild oat	3,616,180	4,970,540
Group 2-HR wild oat	488,360	513,540
Group 8-HR wild oat	300,840	550,810
Group 1+2-HR wild oat	932,990	1,108,850
Group 1+8-HR wild oat	137,800	200,670
Group 2+8-HR wild oat	5,810	12,590
Group 1+2+8-HR wild oat	134,210	134,210
Group 1-HR green foxtail	827,640	979,710
Group 1-HR Persian darnel	60	38,270
Group 2-HR broadleafs	1,275,700	1,374,860
Total	*7,719,600*	*9,884,050*

[a] Infestation area = actual area occupied by HR weeds; field area = total field area with an HR weed infestation.

(characterized in Beckie et al. 2012c) will cause future challenges for pulse crop production because of lack of alternative herbicides.

In Manitoba, 16% of fields sampled for Powell amaranth had a group 2-HR population, all located in the Lake Manitoba Plain ecoregion (map not shown). Group 2-HR wild mustard was found in two of eight sampled sites in the Grassland region of Saskatchewan and one site in Manitoba (Lake Manitoba Plain) (no sites confirmed for either HR biotype in 2001 to 2003 surveys). One field in the Aspen Parkland ecoregion of Alberta had group 2-HR wild buckwheat, the first global report of resistance in this weed species (Beckie et al. 2012b). For all group 2-HR biotypes, most samples had a frequency of resistance > 20% (data not shown).

No sampled weed populations (grass or broadleaf species) across the Prairies were found to be resistant to herbicides from group 4 (synthetic auxins), 9 (glyphosate), or 10 (glufosinate). The lack of group 4 resistance in broadleaf weeds was somewhat surprising, given the generally long history of selection pressure with herbicides of this site of action and their widespread use (Beckie et al. 2008). Possible factors contributing to the absence of glyphosate resistance in weeds in western Canada were postulated in Beckie et al. (2011a). However, in 2012, glyphosate- and ALS inhibitor-resistant kochia was confirmed in 11 fields in southern Alberta (H. J. Beckie et al., unpublished data).

Land Area Impacted by Herbicide-Resistant Weeds. When the frequency of fields with weed resistance in this random survey of 1,000 fields is extrapolated to the total annually-cropped land in the Prairies (26,973,910 ha) (Statistics Canada 2007b, 2008, 2009), it is estimated that 7.7 million ha (29%) are infested with HR weeds, in a total field area of 9.9 million ha (37%) (Table 6). In comparison, the baseline weed resistance surveys from 2001 to 2003 indicated that 1.0 million ha was infested with HR weeds, in a total field area of 4.4 million ha. Therefore, the actual area infested with HR weeds has increased eight-fold, while the total field area affected has increased by over two-fold over this intervening 6-yr period.

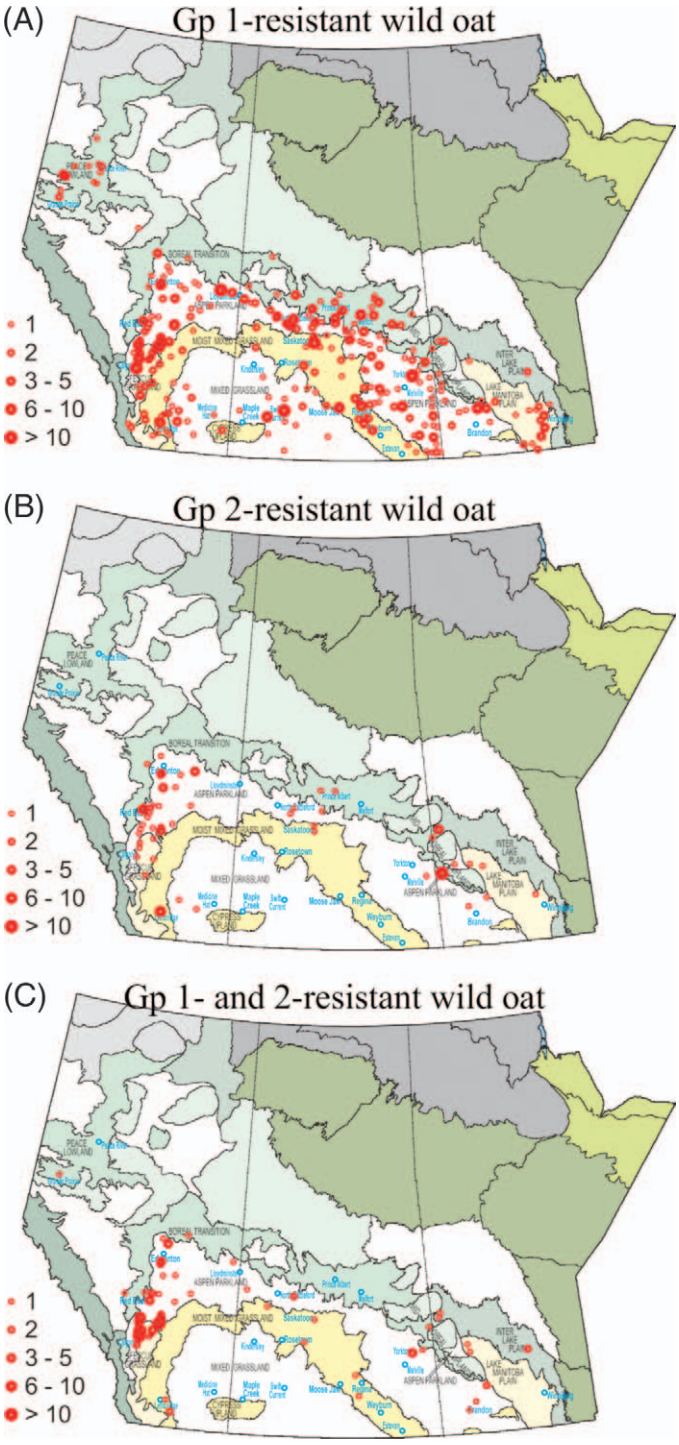

Figure 6. Submitted samples: (A) group 1 (acetyl CoA carboxylase inhibitor)-resistant wild oat across the Prairie provinces (left to right: Alberta, Saskatchewan, Manitoba); (B) group 2 (acetolactate synthase)-resistant wild oat; and (C) group 1+2-resistant wild oat. Legend: number of resistance cases—nearest urban location.

Sample Submissions. A total of 1,091 samples were submitted for HR testing between the 2007 and 2011 crop years, i.e., 5-yr period. This number compares with nearly 1,300 samples submitted during the 11-yr period, 1996 to

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

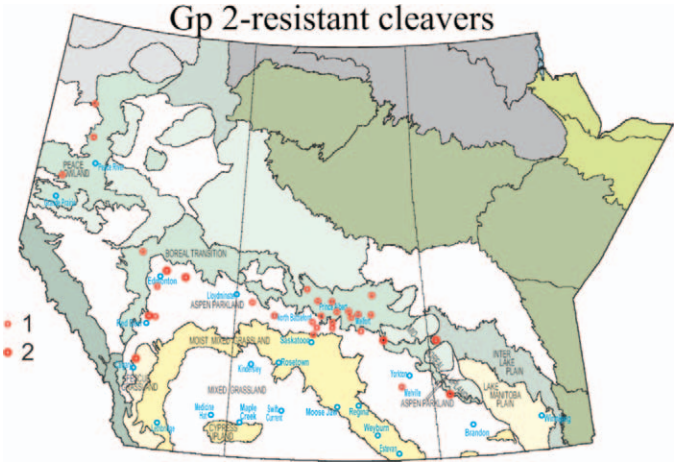

Figure 7. Submitted samples: group 2 (acetolactate synthase)-resistant cleavers (*Galium* spp.) across the Prairie provinces (left to right: Alberta, Saskatchewan, Manitoba). Legend: number of resistance cases—nearest urban location.

2006 (Beckie et al. 2008). A record number of samples (268) were submitted for the 2008 crop year (vs. 167 in 2006; Beckie et 2008). The number of samples varied by year, with the lowest number in 2007 (126 samples). However, over 200 samples have been submitted annually since 2008. The number of samples from Saskatchewan, Alberta, and Manitoba has also fluctuated over the years. The greatest number of samples originated from Alberta (479, ranging from 54 in 2007 to 147 in 2008), followed closely by Saskatchewan (473, ranging from 55 in 2007 to 143 in 2009), and then Manitoba (139, ranging from 12 in 2010 to 55 in 2011).

Ninety-one percent of submitted weed samples (1,091) were wild oat (988). Of these wild oat submissions, 816 (83%) were resistant to group 1 or group 2 herbicides (vs. 814 cases from 1,067 samples (76%) submitted during 1996 and 2006). A significant number of seed samples (99 or 10%) were not viable. When those samples are excluded, most submitted wild oat samples were confirmed as HR. Of these, 563 (69%) were group 1-HR (vs. 725 cases from 1996 to 2006), 121 (15%) group 2-HR (vs. 34 cases from 1996 to 2006), and 132 (16%) group 1+2-HR (vs. 55 cases from 1996–2006). The greatest number of cases of HR wild oat originated from Alberta (395), followed by Saskatchewan (311), then Manitoba (110).

The greatest number of group 1-HR samples originated from Saskatchewan (287; vs. 192 from 1996 to 2006), followed by Alberta (224; vs. 289 from 1996 to 2006), then Manitoba (52; vs. 244 from 1996 to 2006) (Figure 6A). Group 2-HR wild oat populations were mainly from Alberta (64 samples) and Manitoba (48 samples), with only nine samples from Saskatchewan (Figure 6B). A similar trend was observed from 1996 to 2006 (Beckie et al. 2008). The greatest number of group 1+2-HR wild oat samples originated from Alberta (107), followed distantly by Saskatchewan (15), then Manitoba (10) (Figure 6C). Only eight samples were confirmed as group 8-HR. Similar to the previous report (Beckie et al. 2008), the majority of HR wild oat populations originated in the subhumid Parkland region.

Table 7. In-crop herbicides used in the principal field crops in western Canada: 2006 to 2010.[a]

Herbicide	Wheat	Barley	Canola	Flax	Field pea	Lentil
			%			
Group 1	*76*	*86*	*6*	*100*	*24*	*44*
APP	61	16	2	10	0	11
CHD	6	49	3	86	23	33
PPZ	8	18	0	0	0	0
Not specified	1	3	1	4	1	0
Group 2	*23*	*12*	*15*	*0*	*76*	*48*
SU	1	1	0	0	0	0
IMI	2	11	11	0	76	48
TP	3	0	0	0	0	0
SCT	17	0	0	0	0	0
Not specified	0	0	4	0	0	0
Group 3	*0*	*0*	*0*	*0*	*0*	*8*
Group 8	*1*	*2*	*0*	*0*	*0*	*0*
Group 9 total	—	—	*42*	—	—	—
Single			20			
Sequential			22			
Group 10 total	—	—	*37*	—	—	—
Alone			10			
Plus group 1			27			
Total responses (n)	*775*	*280*	*345*	*49*	*129*	*49*

[a] Abbreviations: APP, aryloxyphenoxypropionate; CHD, cyclohexanedione; IMI, imidazolinone; PPZ, phenylpyrazolin; SCT, sulfonylaminocarbonyltriazolinone; SU, sulfonylurea; TP, triazolopyrimidine. Group 1 = acetyl-CoA carboxylase inhibitors; group 2 = acetolactate synthase inhibitors; group 3 = dinitroanilines; group 8 = triallate, difenzoquat, group 9 = glyphosate; group 10 = glufosinate.

Therefore, total cases of group 2-HR wild oat have increased significantly since the last reporting period (253 vs. 89, respectively). One-third of these 253 cases occurred in the 2011 crop year. Given that a number of group 1 wild oat herbicides are off-patent and therefore generally less expensive than group 2 herbicides, the increased incidence of group 2-HR wild oat is attributed to increased group 2 herbicide use over time (H. J. Beckie, unpublished data) as a probable consequence of the prevalence of group 1-HR wild oat. The rise in the number of cases of group 1+2-HR wild oat (132 vs. 55 from 1996 to 2006) will present weed control challenges for those affected growers.

The cross-resistance pattern with the greatest number of cases was resistance to both APP plus CHD herbicides (314 cases). The next largest group was APP only (239 cases). These cross-resistance patterns are similar to those observed in recent field surveys of HR weeds (Beckie et al. 2008). Testing for PPZ (pinoxaden) resistance was only performed when requested (114 cases total).

The number of cases of group 1-HR green foxtail (10, 2007 to 2010) is less than that from the previous reporting period (26 cases; Beckie et al. 2008). Six cases were from southern Manitoba and four from south-central Saskatchewan. Most populations were resistant to APP plus CHD herbicides. Two populations from Manitoba were also resistant to dinitroanilines (group 3).

Two cases of group 1-HR Persian darnel were found in southern Alberta in 2009 and four cases in southern Saskatchewan (one in 2009, three in 2011). In 2004, a submitted population of Persian darnel in southwestern

https://doi.org/10.1614/WT-D-12-00095.1 Published online by Cambridge University Press

Saskatchewan was confirmed as group 1-HR (Beckie et al. 2008).

Group 2-HR common chickweed was confirmed in three populations from central to northern Alberta and northwestern Manitoba. From 1996 to 2006, five populations from central to northern Alberta and Saskatchewan were tested as group 2-HR (Beckie et al. 2008). Only two group 2-HR kochia populations were identified, both from central Saskatchewan. Most growers assume that their kochia populations are group 2-HR (Beckie et al. 2011b); consequently, few growers submit samples for testing. Four populations of group 2-HR shepherd's-purse [*Capsella bursa-pastoris* (L.) Medik.] were documented in northwestern Saskatchewan in 2008. There were no previous Prairie reports of group 2 resistance in this weed. Similarly, four populations of group 2-resistant field pennycress were confirmed; three populations from central or northern Saskatchewan in 2008 and one population from southern Saskatchewan in 2011. One population from Alberta was confirmed group 2-HR during 1996 to 2006 (Beckie et al. 2008); no Prairie surveys previously documented this biotype.

Group 2-HR wild mustard was identified from the 2007 to 2009 crop years in 17 populations: one from Alberta and 16 from Saskatchewan. In the previous reporting period, 12 populations were found to be group 2-HR, the majority from Saskatchewan (Beckie et al. 2008). Group 2-HR cleavers (*Galium* spp.) were confirmed in 39 populations: four from Manitoba, 14 from Alberta, and 21 from Saskatchewan (Figure 7). The majority of cases were identified in 2010 and 2011. In the previous reporting period (1996 to 2006), only three populations from central Alberta or northeastern Saskatchewan were identified (Beckie et al. 2008). Overall, the HR weed trends discerned from testing of submission and survey samples are similar, complementing one another in monitoring HR weed distribution and abundance.

Herbicide Use Trends: 2006 to 2010. Based on in-crop herbicide usage documented on submission forms from 2006 to 2010 (2011 data not available), group 1 herbicides were predominantly applied in cereal crops and flax, glyphosate or glufosinate in canola, and group 2 herbicides in pulse crops (Table 7). In wheat, group 1 and 2 herbicides were applied at a frequency of 76 and 23%, respectively. Similarly in barley, group 1 and 2 herbicides were applied at a frequency of 86 and 12%, respectively. A slight majority of canola growers applied glyphosate sequentially in-crop (vs. single application); glufosinate was usually tank-mixed with a group 1 herbicide to enhance grass weed control. In field pea, group 1 and 2 herbicides were applied at a frequency of 24 and 76%, respectively; in lentil, group 1 and 2 herbicides were applied at 43 and 48%, respectively. The number of responses is relatively low for flax and lentil; additionally, most responses are related to wild oat sample submissions.

A new round of weed resistance surveys covering the major agricultural ecoregions of the three Prairie provinces is not planned in the future. Instead, smaller, more targeted surveys will be conducted in the future for monitoring emerging weed resistance problems. For example, a glyphosate-resistant kochia survey was conducted in the southern region of Alberta in the fall of 2012, with a similar survey planned for Saskatchewan and Manitoba in 2013.

Acknowledgments

Financial support for these surveys was provided by the following herbicide manufacturers and distributors: Agricore United (In-kind), Arysta LifeScience Canada Inc., BASF Canada Inc., Bayer CropScience Canada, Dow AgroSciences Canada Inc., E. I. duPont Canada Co., Gowan Canada, Monsanto Canada Inc., Nufarm Agriculture Inc., and Syngenta Crop Protection Canada, Inc. We thank David Giffen, AAFC Saskatoon, for producing the maps. Special thanks are extended to the 1,000 producers who participated in this survey project. Finally, we acknowledge all former and current staff of the Crop Protection Lab, Saskatchewan Ministry of Agriculture involved in herbicide resistance testing, including Dr. Philip Northover, Grant Holzgang, Carla Weitzel, Jaclyne Shiplack, and Tony Stoppa.

Literature Cited

Agriculture and Agri-Food Canada. 2003. A National Ecological Framework for Canada: GIS Data. http://sis.agr.gc.ca/cansis/nsdb/ecostrat/gis_data.html. Accessed: February, 2012.

Beckie, H. J., K. N. Harker, L. M. Hall, F. A. Holm, and R. H. Gulden. 2011a. Risk assessment of glyphosate resistance in western Canada. Weed Technol. 25:159–164.

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

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

Beckie, H. J., A. G. Thomas, and A. Légère. 1999a. Nature, occurrence, and cost of herbicide-resistant green foxtail (*Setaria viridis*) across Saskatchewan ecoregions. Weed Technol. 13:626–631.

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

Beckie, H. J., S. I. Warwick, and C. A. Sauder. 2012a. Basis for herbicide resistance in Canadian populations of wild oat (*Avena fatua*). Weed Sci. 60:10–18.

Beckie, H. J., S. I. Warwick, and C. A. Sauder. 2012b. Acetolactate synthase (ALS) inhibitor-resistant wild buckwheat (*Polygonum convolvulus*) in Alberta. Weed Technol. 26:151–155.

Beckie, H. J., S. I. Warwick, C. A. Sauder, G. M. Kelln, and C. Lozinski. 2012c. Acetolactate synthase inhibitor-resistant false cleavers (*Galium spurium*) in western Canada. Weed Technol. 26:151–155.

Beckie, H. J., S. I. Warwick, C. A. Sauder, C. Lozinski, and S. Shirriff. 2011b. Occurrence and molecular characterization of acetolactate synthase (ALS) inhibitor-resistant kochia (*Kochia scoparia*) in western Canada. Weed Technol. 25:170–175.

Broster, J. C., E. A. Koetz, and H. Wu. 2011. Herbicide resistance in wild oats (*Avena* spp.) in southern New South Wales. Plant Prot. Q. 26:106–107.

Heap, I. M. 2012. International Survey of Herbicide Resistant Weeds. http://www.weedscience.org. Accessed: September 2012.

Leeson, J. Y., A. G. Thomas, L. M. Hall, C. A. Brenzil, T. Andrews, K. R. Brown, and R. C. Van Acker. 2005. Prairie weed surveys of cereal, oilseed and pulse crops from the 1970s to the 2000s. Weed Survey Series Publ. 05–1. Saskatoon, Saskatchewan, Canada: Agriculture and Agri-Food Canada. 395 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.

Owen, M. J. and S. B. Powles. 2009. Distribution and frequency of herbicide-resistant wild oat (*Avena* spp.) across the Western Australian grain belt. Crop Pasture Sci. 60:25–31.

Statistics Canada. 2006. November estimate of production of principal field crops, Canada, 2006. Field Crop Reporting Series, Vol. 85, No. 8. Catalogue No. 22-002-XIB, Ottawa, Ontario, Canada. 31 p.
Statistics Canada. 2007a. Area of Commercial Fertilizer, Herbicides, Insecticides and Fungicides Applied by Province. Census of Agriculture 2006. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/agrc05i-eng.htm. Accessed: June, 2012.
Statistics Canada. 2007b. November estimate of production of principal field crops, Canada, 2007. Field Crop Reporting Series, Vol. 86, No. 8. Catalogue No. 22-002-XIE. Ottawa, Ontario, Canada: 30 p.
Statistics Canada. 2008. November estimate of production of principal field crops, Canada, 2008. Field Crop Reporting Series, Vol. 87, No. 8. Catalogue No. 22-002-XIE, Ottawa, Ontario, Canada. 31 p.
Statistics Canada. 2009. November estimate of production of principal field crops, Canada, 2009. Field Crop Reporting Series, Vol. 88, No. 8. Catalogue No. 22-002-XIE, Ottawa, Ontario, Canada: 71 p.
Statistics Canada. 2011. November estimate of production of principal field crops, Canada, 2011. Field Crop Reporting Series, Vol. 90, No. 8. Catalogue No. 22-002-XIE, Ottawa, Ontario, Canada. 46 p.
Thomas, A. G. 1985. Weed survey system used in Saskatchewan for cereal and oilseed crops. Weed Sci. 33:34–43.
Travlos, I. S., C. N. Giannopolitis, and G. Economou. 2011. Diclofop resistance in sterile wild oat (*Avena sterilis* L.) in wheat fields in Greece and its management by other post-emergence herbicides. Crop Prot. 30:1449–1454.
Warwick, S. I., C. A. Sauder, and H. J. Beckie. 2010. Acetolactate synthase (*ALS*) target-site mutations in ALS inhibitor-resistant Russian thistle (*Salsola tragus*). Weed Sci. 58:244–251.

Received June 15, 2012, and approved September 28, 2012.