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Expansion of Feral Cereal Rye (*Secale cereale* L.) on Non-crop Hillsides in Northern Utah

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Feral cereal rye is an aggressive, persistent winter annual grass. Although feral rye has been documented as a weed in Utah cropland for many years, it has only recently been described as a weed of natural areas in Utah. After feral rye was observed on hillside locations where it had not previously been present, research was conducted to evaluate expansion rates in isolated patches and on a landscape scale. Individual patch measurements indicated expansion rates of 17%, 42%, 44%, and 112% in 2009. The landscape expansion rates were 1%, 4%, 8%, 21%, and 50% in the same year. The spread of feral rye appears to have occurred primarily on south- to west-facing slopes where the density and diversity of native species is limited. The expansion of feral rye into natural, undisturbed areas indicates that this species should be closely monitored. The relatively short seed longevity and current small infestations make it a good candidate for early detection/rapid response efforts.

Nomenclature: Cereal rye, *Secale cereale* L, SECE.

Key words: Bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], non-cropland, patch expansion, volunteer rye, weed invasion, weedy rye.

Feral cereal rye is an aggressive, persistent winter annual grass that evolved from cereal rye (Burger et al. 2006). Feral rye differs phenotypically from cereal rye in that it has smaller seeds, thinner culms, delayed flowering (Burger et al. 2007), and a shattering inflorescence. Feral rye survives extreme conditions and can complete its life cycle with as little as 13 cm of precipitation and winter temperatures as low as −35 C without snow cover (Burger and Ellstrand 2005). It has a more extensive root system than cereal grains and has been reported to root to depths of 1.0 to 1.5 m before entering fall dormancy (Nalborczyk and Sowa 2001). These traits make feral rye highly competitive in crop and non-crop settings. In Oklahoma, predicted yield losses due to feral rye in hard red winter wheat (*Triticum aestivum* L.) were reported at much higher values than losses due to wild oats (*Avena fatua* L.), jointed goatgrass (*Aegilops cylindrica* Host), Italian ryegrass [*Lolium perenne* ssp. *multiflorum* (Lam.) Husnot], or cheat (*Bromus secalinus* L.) (Fast et al. 2009), indicating that feral rye is more competitive than these species.

Cereal rye has been cultivated in North America for centuries. Feral rye has been documented in all U.S. states and most Canadian provinces (Anonymous 2016; Bushong 2008; Hitchcock 1922; U.S. Department of Agriculture 2016). In 1876, cereal rye was produced on 180 ha in Utah Territory, and by 1883, cereal rye production had increased to 257 ha in Cache County alone (Sloan 1884), providing ample opportunity for the crop to escape cultivation. For many years feral rye has been recognized as a weed in Utah cropland; however, it was not described as a weed in non-cropland in Utah (Burger and Ellstrand 2005) prior to a preliminary study by Roerig and Ransom (2009). In the fall of 2008, feral rye had expanded across large areas of the upland hillsides near Logan, in Cache County, Utah. The dominant native grass on these hillsides is bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve]. A few small patches low on the foothills were noticeable in photos taken in 1990. By 2008, those patches had expanded and gained considerable elevation. Now each summer through the end of fall, much of the hillside above Cache Valley, Utah, is covered in distinctive yellow patches of the expanding feral rye population. Previous to the current study, analysis of a single photo from

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Management Implications

Feral cereal rye has been a weed of Utah cropland and roadsides for many years. Now, in northern Utah, feral rye has been observed to spread up non-crop foothills and dominate south- to west-facing slopes. Human-related seed dispersal and disturbance has been limited, with the exception of occasional fire, due to steep slopes. Photos from 1990 indicate that the expansion has occurred rapidly. Measurements of patch expansion along the leading edge of the infestation indicate that feral rye continues to spread rapidly at high elevations and at great distances from the original source. The threat of feral rye competition displacing native grasses and forbs on south- to west-facing slopes in natural areas in northern Utah is high. Due to relatively short seed longevity and the small size of current infestations, feral rye may be good candidate for early detection/rapid response management efforts.

1990 and a photo from 2008 showed that within the photographed area, feral rye had expanded 304% in 18 yr, or about 17% each year (Roerig and Ransom 2009). This study seeks to document the rate of feral rye expansion on non-crop hillsides in northern Utah at the patch and landscape scale.

Materials and Methods

Expansion of feral rye populations on the foothills east of Logan, Utah, was measured using individual patch- and landscape-scale approaches. The patch data and landscape photos were taken in the same geographical area on the western flank of the Bear River Range, starting near Logan Canyon and going north 7.5 km to Hyde Park Canyon. Monthly weather data from the 2008 to 2009 growing season at the Logan–Cache Airport, approximately 6.5 km west of the infestation, are presented in Table 1.

Patch-Scale Expansion. Patch-scale expansion was evaluated at four locations. Selected patches were at the leading edge of the infestation, with distinct borders and enough distance from other patches that merging would be unlikely. Location, approximate elevation, approximate slope, and aspect of the patches are shown in Table 2. These four sites were marked by corner stakes and by GPS in 2008 to ensure they could be relocated and measured the following year. The sites were mapped using a 0.09-m^2 grid system established in the fall of 2008. If one or more plants were observed within a given 0.09 m^2, that area was recorded as infested. Measurements were taken each year until an area free of feral rye was reached. Each patch had a minimum separation of approximately 10 m from the nearest neighboring patch to ensure that measurements would only reflect the expansion of a single patch. In general, this approach was successful, and patches did not merge. However, due to greater than anticipated expansion at site four in 2009, the lower edge did not have a distinct border. As a result, a midpoint between downward expansion of the patch of interest and the upward expansion of a lower infestation was estimated. The midpoint was estimated as the point where the population of the measured patch stopped decreasing and the population of the neighboring patch began increasing. All measurements were taken in late summer when plants had completed their life cycle.

The presence or absence of feral rye at each patch was recorded as X, Y, Z data. X and Y provided grid coordinates for each sample point, while Z indicated the infestation value (0 = noninfested, 1 = infested). Data were imported into ArcGIS 10 as point features for further analysis. A final infestation value for each point was determined by overlaying data from 2008 and 2009. The value 0 represented a point that was not infested in either year, the value 1 represented an infested point in 2008 that was no longer infested in 2009, the value 2 represented a point with a new infestation in 2009, and the value 3 represented a point that was infested in both years. Changes in the number of infested cells from 2008 to 2009 were used to calculate expansion at each patch. A visual representation of patch expansion was created using a

Table 1. Monthly weather data for the 2008–2009 growing season from the Logan–Cache Airport, approximately 6 km west of the feral rye infestation.

Measurement	September 2008	October 2008	November 2008	December 2008	January 2009	February 2009	March 2009	April 2009	May 2009	June 2009	July 2009	August 2009
Maximum temperature (C)	29	29	21	12	9	8	21	24	31	34	37	36
Mean temperature (C)	15	9	4	–4	–6	–6	1	7	13	16	22	19
Minimum temperature (C)	1	–6	–8	–21	–22	–19	–18	–3	–1	6	7	4
Growing degree days (base 5 C)	321	133	22	0	0	0	23	89	248	337	514	454
Precipitation (mm)	8.1	36.6	41.7	27.9	46.5	25.9	48.0	53.8	39.6	91.4	0.0	30.5

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Table 2. Location and elevation of four hillside feral rye patches evaluated to determine annual expansion rates.

Patch	Elevation	Location	Approximate slope	Aspect
	——m——		——Degrees——	
1	1,664	41.81159°N, 111.78069°W	32	South
2	1,725	41.77634°N, 111.77265°W	28	West-southwest
3	1,676	41.76273°N, 111.77888°W	25	West
4	1,753	41.75027°N, 111.77778°W	32	West-southwest

conversion tool that converted point data into a raster data set with a cell size of 30 by 30 cm.

The initial point data for each patch and year were used to calculate distance and direction statistics in ArcGIS 10. All calculations were based upon proximity of each newly infested cell to the nearest previously infested cell. Point data were rasterized, and the Spatial Analyst Euclidean Distance Tool was used to create distance and direction rasters for the first year's data. The cells in these rasters overlaying infested cells in the second year were saved, while others were set to null. The direction statistics are simply the attribute table from the final direction raster and provide a count of the number of grid cells that moved in a given direction. A comparison of patch movement upslope versus downslope was then calculated by removing all patch numbers at 90° and 270° from the final count, because they were stable in those directions. Similarly, expansion to the left versus the right was determined by removing all patch numbers recorded at 360° and 180°. For each comparison, the percent expansion in either direction was then calculated. To generate distance statistics, a zonal raster was created based on computed distances in the final distance raster, and statistics were computed using the Spatial Analyst Zonal Statistics as Table tool.

Landscape-Scale Expansion. To determine feral rye expansion on a landscape scale, a series of photographs were taken at several locations in 2008. Photographs were taken with a digital camera mounted on a tripod using an 80- to 200-mm lens and encompassed an area of approximately 0.33 to 1 km^2. The photographs were taken from the same location and cropped to the same area each year. Images from five locations were analyzed using image analysis software (VegMeasurement, v. 1.6.0, Oregon State University, Corvallis, OR) that identified feral rye based on its distinctive color. The analysis used a brightness algorithm (Johnson et al. 2003), and thresholds were individually adjusted for each image to accurately depict feral rye infestations. The software then calculated the percent of pixels in each image comprised of feral rye. While sets of images differed in the distance from the camera to the infestation, and in the total area encompassed by the image, the relative change between photos taken from the same locations in 2008 and 2009 provided an indication of expansion.

Results and Discussion

Patch-Scale Expansion. Expansion at the four patches ranged from 17% to 113% with an average of 60% between 2008 and 2009 (Table 3). Expansion at each patch is shown in Figure 1. Most of the newly infested grid cells occurred within 1 m of the original patch (Figure 2). Expansion occurring around the original infestation suggests incremental expansion from an initial point of introduction. The greatest expansion occurred at patch 4, which was the highest elevation in this infestation, suggesting that elevation may not yet be a limiting factor for this feral rye expansion. At patch 1, few, if any, perennial grasses or other native plants were observed. Some portions of this patch were so rocky that soil was not visible or easily uncovered, yet feral rye was able to occupy areas apparently uninhabitable by other plant species. Expansion of these patches occurred in all directions, up- and downslope and right and left (Table 4).

Landscape-Scale Expansion. Analysis of changes between 2008 and 2009 photographs (Figure 3) showed feral rye expansion of 1%, 4%, 8%, 12%, and 50%, with an average for the five photographs of 15% (Table 5). Generally lower estimates in expansion, as measured by the

Table 3. Expansion rates of feral rye patches 1 yr after initial measurement using a grid system.

Patch	Area infested 2008	Area infested 2009	Expansion	
	——m²——			——%——
1	43.85	62.99	19.14	43.6
2	60.66	85.84	25.18	41.5
3	88.44	103.68	15.24	17.2
4	107.39	228.16	120.77	112.5
Average	75.09	120.67	45.08	60.0

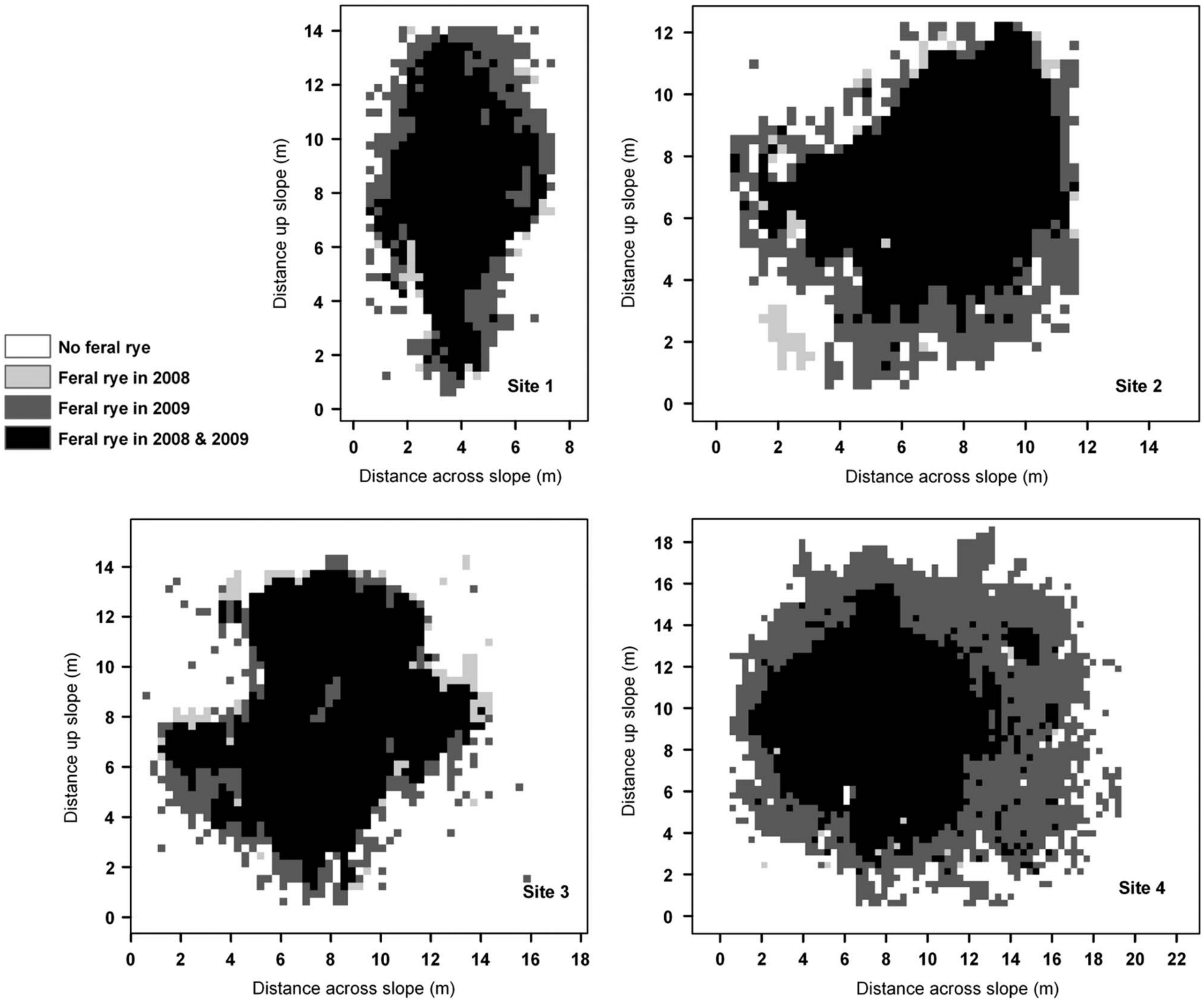

Figure 1. Illustration of feral rye expansion from 2008 to 2009 at each site.

landscape photo method compared with the patch method, may have been for two reasons. First, the photo method was focused on extensive infestations where much of the photo was already occupied by feral rye or beyond the distance feral rye would be likely to travel in 1 yr, whereas the patch-scale measurements were made on isolated patches surrounded by unoccupied area that could potentially be invaded. Second, there is a potential for distortion caused by the relative distance of patches from the camera within the same photo and the angles associated with ground-based photos of steep hillsides. Areas closer to the camera appear larger, and changes in the foreground have a disproportionally large influence on the rate of expansion. Distortion of land-based photos of steep slopes would be similar to that associated with aerial photos, where increasing slope angles result in underestimates of total land area; as much as 17% to 31% for slopes from 30° to 40° (Anderson 1972). While these data do not indicate a percent expansion in terms of land area, they do serve to confirm expansion is occurring and that it is occurring on a landscape level.

Factors Explaining Feral Rye Expansion. No direct observations have been made to determine the factors contributing to the steady expansion of feral rye patches and their movement up hillsides. However, at a patch scale, measurements showed that the majority of new infestations occurred within only 0.91 m of a previously infested area, and expansion was roughly equal up- and downslope and left and right (Figure 2). This expansion suggests the shattering seed head of feral rye plays an important role in the steady rate of expansion. Although occasionally disturbed by fire, human impact has been generally limited due to the extreme slope of these sites. Thus, it is likely the main factors contributing to long-distance seed dispersal are

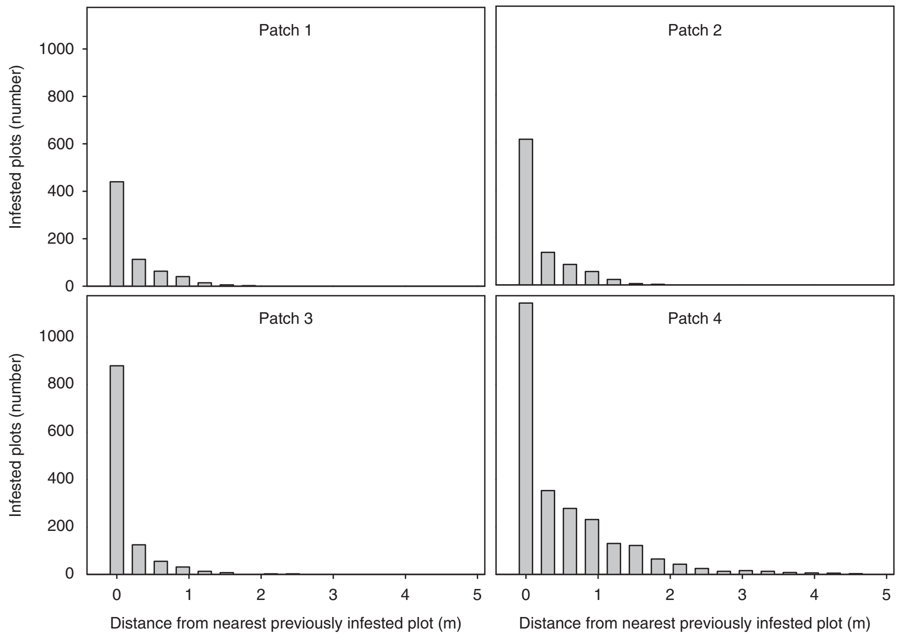

Figure 2. Histogram of distance of cells infested with feral rye in 2009 from cells infested in 2008.

related to animals or other nonhuman factors. Sowell (1981) noted the winter diet of mule deer (*Odocoileus hemionus*) in the Texas Panhandle consisted of 27% cereal grains when deer populations were located near grainfields. This suggests endozoochorous or epizoochory movement as a possible mechanism for seed dispersal.

The greatest expansion and patch movement was observed on steep, southern aspects, where limited desirable vegetation was present. Feral rye is not present on north-facing slopes. Northern slopes accumulate greater amounts of snow over the winter and are subject to less heat in the spring and summer, which increases the available water compared with south-facing slopes. South-facing slopes are also subject to colder winter temperatures due to more frequent snowmelt. These conditions favor a plant like feral rye, which can access deep soil moisture, uses little water, and survives extremely cold temperatures. In many places, a distinct line was observed between aspects suitable and unsuitable for feral rye invasion. The observation of a distinct line is consistent with the findings that the harshness or other unique attributes of an environment can significantly reduce its ability to be invaded by weeds (Williamson and Harrison 2002); however, in the case of feral rye, a harsh environment seems to favor infestation. Much greater native species diversity and density were observed on northern slopes, and this may play a role in the exclusion of feral rye. Downy brome (*Bromus tectorum* L.) was unable to establish in forest sites in northern Idaho and eastern Washington after repeated introduction, while other areas in the region are infested (Pierson and Mack 1990). Likewise, the greater biodiversity of north-facing slops

Table 4. Comparison of the direction of spread for new cells infested with feral rye in 2009 at each site.

Direction	Site 1		Site 2		Site 3		Site 4	
	n	%	*n*	%	*n*	%	*n*	%
Upslope[a]	81	55	72	35	28	18	576	56
Downslope[a]	67	45	135	65	125	82	451	44
Right[b]	87	49	115	49	49	32	588	58
Left[b]	92	51	109	51	106	68	433	42

[a] All infested cells located at 90° and 270° removed from calculations.

[b] All infested cells located at 180° and 360° removed from calculations.

Table 5. Changes in the percent of the landscape infested by feral rye calculated from photographs taken in 2008 and 2009.

	Infestation					
Year	A	B	C	D	E	Average
	%					
2008	12.51	9.71	19.84	37.38	4.98	16.89
2009	14.01	10.49	20.56	37.78	7.49	18.07
Change	12.00	7.99	3.62	1.08	50.20	14.98

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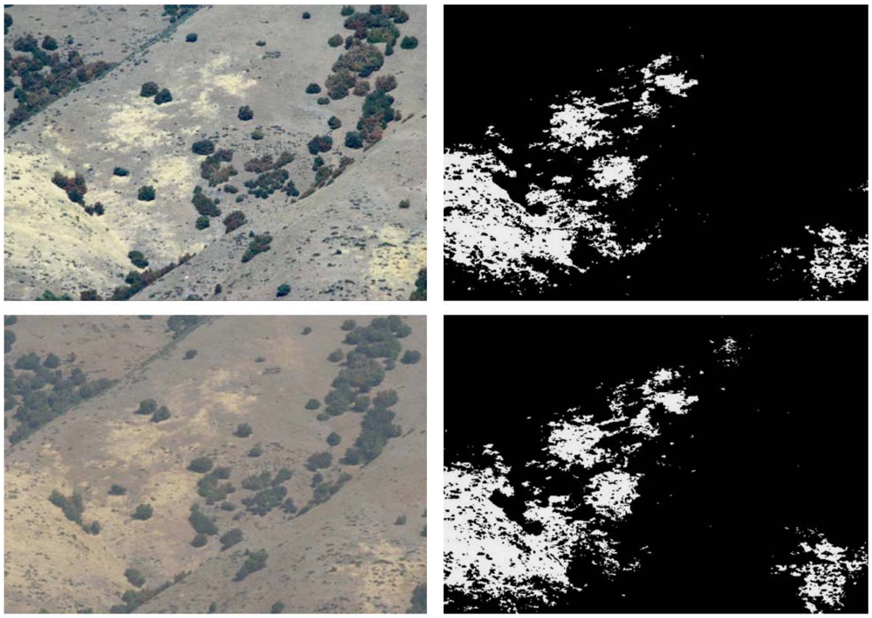

Figure 3. Example of photos (left) and corresponding processed images (right) taken in 2008 (top) and 2009 (bottom) and used to calculate percent change in infested area ("A" in Table 5).

may be preventing invasion, even though introduction is presumably occurring.

In areas where feral rye has expanded and become established, few other plants were observed. This could be due, in part, to allelopathy. The allelopathic properties of feral rye were first identified by Barns and Putnam (1986). It is likely other species are affected by the toxins released as feral rye shoots decompose, further excluding competition and contributing to the formation of a monoculture. High rates of rye residue could also reduce the emergence of other species (Mohler and Teasdale 1993).

Feral rye is expanding at a rate detectable within a single growing season. Further, its occupation of high elevations up to 372 m above the 1,382 m elevation of the valley and of undisturbed natural areas and the potential loss in plant diversity are causes for concern. In one study, less than 1% of seed in the soil was viable after 45 mo; however, after 5 yr feral rye was still observed to germinate (Stump and Westra 2000). The relatively short seed longevity of feral rye and current small infestations in some areas make it a good candidate for early detection/rapid response measures. Moody and Mack (1988) found weed control efforts centered on satellite patches to be more effective than trying to control larger patches. Management of feral rye should start with smaller patches located along the perimeter of the infested area. Through aggressive control measures and careful monitoring, managers can reduce the size of existing infestations and limit further uphill expansion that would displace native plants in the Cache National Forest and other similar areas.

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Literature Cited

Anderson EW (1972) Acreage increase due to slope. J Range Manag 25:316–317

Anonymous (2016) Digital Atlas of the Virginia Flora. http://vaplantatlas.org/index.php?do=plant&plant=1696. Accessed: September 10, 2016

Barns JP, Putnam AR (1986) Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Sci 34:384–390

Burger JC, Ellstrand NC (2005) Feral rye—evolutionary origins of a weed. Pages 175–192 *in* Gressel J, ed. Crop Ferality and Volunteerism. Boca Raton, FL: Taylor and Francis

Burger JC, Holt JM, Ellstrand NC (2007) Rapid phenotypic divergence of feral rye from domesticated cereal rye. Weed Sci 55:204–211

Burger JC, Sky L, Ellstrand NC (2006) Origin and genetic structure of feral rye in the western United States. Mol Ecol 15: 2527–2539

Bushong JA (2008) Winter crop rotation with herbicides to control feral rye (*Secale cereale*) and Italian ryegrass (*Lolium perenne* ssp. *multiflorum*). M.S. thesis. Stillwater, OK: Oklahoma State University. 47 p

Fast BJ, Case RM, Murray DS (2009) Five cool-season annual grass weeds reduce hard red winter wheat grain yield and price. Weed Technol 23:206–213

Hitchcock AS (1922) The Grasses of Hawaii. Memoirs of the Bernice Pauahi Bishop Museum, Volume 8, Number 3. Honolulu, HI: Bishop Museum Press. 139 p

Johnson DE, Vulfson M, Louhaichi M, Harris NR (2003) VegMeasure, v. 1.6 User's Manual. Corvallis, OR: Department of Rangeland Resources, Oregon State University

Mohler CL, Teasdale JR (1993) Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Res 33:487–499

Moody ME, Mack RN (1988) Controlling the spread of plant invasions: the importance of nascent foci. J Appl Ecol 25:1009–1021

Nalborczyk E, Sowa A (2001) Physiology of rye. Pages 53–68 *in* Bushuk, W, ed. Rye: Production, Chemistry, and Technology. St. Paul, MN: American Association of Cereal Chemists

Pierson EA, Mack RN (1990) The population biology of *Bromus tectorum* in forests: distinguishing the opportunity for dispersal from environmental restriction. Oecologia 84:519–525

Roerig KC, Ransom CV (2009) Photo analysis of feral rye (*Secale cereale* L.) invasion of non-crop hillsides in Northern Utah. Page 28 *in* Western Society of Weed Science 2009 Research Progress Report

Sloan RW (1884) Utah Gazetteer and Directory of Logan, Ogden, Provo, and Salt Lake Cities 1884. Salt Lake City, UT. Pp 46, 297

Sowell B (1981) Nutritional quality of mule deer diets in the Texas Panhandle. M.S. thesis. Lubbock, TX: Texas Tech University. 62 p

Stump WL, Westra P (2000) The seedbank dynamics of feral rye. Weed Technol 14:7–14

[USDA] U.S. Department of Agriculture. (2016) Introduced, Invasive, and Noxious Plants. http://plants.usda.gov/core/profile?symbol=SECE#. Accessed: September 10, 2016

Williamson J, Harrison S (2002) Biotic and abiotic limits to the spread of exotic revegetation species. Ecol Appl 12:40–51

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