INVASIVE PLANT INFLUENCE ON THE NATIVE GRASS COMMUNITY
OF THE WHITE LAKE BASIN, BRITISH COLUMBIA

By

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Abstract

Invasive plants can have significant ecological effects. Cheatgrass (*Bromus tectorum*) is of particular concern in North America, where its competitive nature can seriously degrade natural grasslands. This study, conducted in the White Lake Basin region of British Columbia, investigated the impact of cheatgrass on native plant diversity and the relationship between diffuse knapweed (*Centaurea diffusa*) and introduced grass cover. The study also analysed the association of cheatgrass with other grass species to provide insight in selecting grass seed composition for seeding after habitat disturbance. Results indicated higher native grass diversity in plots without cheatgrass and in plots containing bluebunch wheatgrass (*Pseudoregneria spicata*). While diffuse knapweed decreased during the study period, due to biological control, invasive grasses increased. Native grass species positively associated with cheatgrass include needle and thread grass (*Hesperostipa comata*), Sandberg bluegrass (*Poa secunda*), and sixweeks fescue (*Vulpia octoflora*), indicating potential for seeding in disturbed areas prone to cheatgrass.
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Introduction

Invasive Plants and Their Effects

The spread of plants from native to exotic habitats can have significant ecological effects (Myers and Bazely, 2003). Approximately 10% of introduced plants become invasive in the new habitat. While these species often exist at low and patchy densities in their native habitat, without their natural enemies, herbivores and diseases, they become able to out-compete native plant species. The result is that invasive plants can dominate and reduce the value of natural habitats.

Plant invasions can be financially detrimental and have been estimated to cause an annual loss of $27 billion to the United States economy alone (Pimental et al. 2005). From an ecological perspective, invasive plants can change both the structure and function of ecosystems (D’Antonio and Vitousek, 1992). The effect of invasive species on natural ecosystems is especially significant when disturbance regimes, such as natural fire intervals, are altered beyond the range of adaptation of the native species (Brooks et al. 2004).

Cheatgrass, Bromus tectorum, as an invasive species

An introduced plant species of particular concern in North America is an annual cheatgrass, *Bromus tectorum* Linnaeus. Cheatgrass was unintentionally introduced to North America approximately 150 years ago,
likely as a contaminant of grain and hay. It became established in British Columbia in the 1880’s, associated primarily with areas of soil disturbance following overgrazing by livestock (Mack, 1981). Since its arrival, cheatgrass has spread extensively throughout the grasslands of the province, particularly in arid regions. Its life history characteristics including early spring growth, high seed production (Smith et al. 2008) and annual life cycle, enable cheatgrass to effectively out-compete native grass species following soil disturbances. Cheatgrass germinates early in the spring or even in autumn, which allows it to utilize moisture and nutrient resources well before the native plant species (Bradley & Mustard, 2006). It persists following disturbance by germinating from its transient seed bank established in the previous or recent growing seasons. In contrast for example, bluebunch wheatgrass, *Pseudoroegneria spicata* (Pursh) Á. Löve, the dominant native species in this study area, produces far less seed than cheatgrass per unit area and, as with most native grasses in the Intermountain Area of British Columbia it produces very poor seed banks (Young & Clements, 2009).

Cheatgrass is a shallow-rooted plant that extracts moisture from the uppermost soil horizon, making the establishment of native perennial grasses difficult (Upadhyaya *et al.* 1986). The vigorous growth of cheatgrass increases fine fuels, which can increase wildfire intervals in regions where it is dominant (Haubensak, D’Antonio, & Wixon, 2009). This results in increased
fire suppression costs. It can be argued that by encouraging higher wildfire intervals, cheatgrass is able to further promote its own establishment through the creation of greater disturbance. According to Mack (1981), cheatgrass has now become the most ubiquitous, and in many rangelands, the dominant plant species in the shrub-steppe intermountain areas of western North America. On extensively overgrazed rangelands, cheatgrass has been known to form monocultures (Upadhyaya et al. 1986) and can entirely suppress the native vegetation in the area. This is reinforced by Knapp (1996), who states that cheatgrass has replaced many of the native annual and perennial grass species, and decreased the dominant ‘climax’ species in the Great Basin region of the United States. Populations of cheatgrass are often patchy in nature, with higher densities occurring with increased proximity to Ponderosa pine trees (*Pinus ponderosa*) (Deane 2010) and sagebrush shrubs, *Artemisia tridentata* (Griffith 2010). Previous studies have indicated that some native and introduced grass species are able to compete with cheatgrass when mature. Few species, however, can compete with cheatgrass at the seedling stage (Reid, 2008), and cheatgrass can out-compete native perennial species as seedlings, due to their greater seed production (Young and Allen, 1997). Given the competitive nature of cheatgrass in a grassland ecosystem, it would be reasonable to expect a decrease in grass species diversity in areas that have been invaded by cheatgrass, compared to unininvaded areas.
Impacts of cheat grass on land management and species-specific grass associations

Cheatgrass, and other introduced species, are of particular concern on conservation lands, acquired for the purpose of protecting significant habitat values and managed for their continued integrity. This is likewise the case with other land use areas, such as rangelands for livestock, which benefit greatly from the continued presence of an intact, functioning grassland ecosystem. Managing invasive plants, to protect or restore ecological integrity is a serious burden on the finances and staffing capacity of many conservation and range management agencies. Some species of introduced plants are successfully managed through the use of biological control agents, primarily insects, which can provide a financially and scientifically viable treatment option (Myers and Bazely, 2003).

Cheatgrass, in particular, is an invasive plant that is not readily controlled, due to its extensive distribution and competitive nature. Great efforts are made, therefore, to prevent establishment of cheatgrass in newly disturbed soils for example by seeding disturbed soils with native species to prevent new cheatgrass invasions. Studies, such as that by Clary (1988), suggest that planting of native plant species can be an effective component in cheatgrass suppression efforts after disturbances, such as wildfire. The use of native seed in habitat restoration efforts is a costly undertaking. Supply and demand cycles following periods of higher wildfire intensity in North
America causes seed costs to fluctuate significantly (Waters and Shaw, 2003). In addition, native grasses are regionally specific and not readily farmed for commercial production on a local scale. Many conservation agencies are resistant to using farmed cultivars of native species for genetic reasons and prefer to use seeds collected within their project region. This makes seed production more expensive and further reduces the economic feasibility of using native seeds in restoration efforts. As a result, expending limited resources on native plant seeds, many of which may eventually be outcompeted by cheatgrass, is financially unfeasible, particularly in the case of non-profit conservation initiatives. Knowing which native species were more likely to withstand cheatgrass invasion, could increase the feasibility of using these species in restoration efforts.

**Background studies of cheatgrass in British Columbia**

Deane (2010) studied the co-occurrence between cheatgrass and other grass species over a 4-year period at one site in the White Lake Basin and found that plots containing cheatgrass tended to have a lower diversity of grass species compared to plots without cheatgrass. He also observed that the distributions of several native grass species, including bluebunch wheatgrass, sand dropseed (*Sporobolus cryptandrus*), and needle-and-thread grass (*Hesperostipa comata*), were positively correlated with cheatgrass. This suggests that these native grasses may be more capable than others of persisting in association with cheatgrass, and may be less likely to be
suppressed over time. Further support for these findings at a broader scale, could assist in the choice of native grass species to use in restoration efforts, in the Okanagan region of British Columbia

The effect of long-term diffuse knapweed decline on other invasive plants

A relatively recent ecological change in grasslands in the Southern Interior of British Columbia is the dramatic decrease in diffuse knapweed (*Centaurea diffusa*) densities. Starting in the 1970s, 12 different species of exotic insects were introduced in a biological control program for diffuse knapweed. Several studies have now shown a decline in diffuse knapweed populations beginning in the early 2000’s (Myers *et al.* 2009), Stephens *et al.* 2009; Newman *et al.* 2011; and Gayton & Miller, 2011). Although a number of factors may have influenced knapweed population densities including weather trends, changes to livestock management, and increasing native plant competitiveness, these factors are not considered to have as strong of an influence as biological control (Gayton & Miller, 2011). Particularly important has been the impact of the seed weevil, *Larinus minutus* (Myers *et al.* 2009).

With the decline of such a formerly abundant component of the ecosystem as diffuse knapweed, other plant species in the grasslands are also likely to change. The successors could be either the dominant native vegetation, or other invasive plants. Stephens *et al.* (2009) evaluated the
response of the plant community in the White Lake Basin to reductions in diffuse knapweed using plots monitored by the Canadian Wildlife Service over the years 2001, 2002, 2003, and 2005. Introduced grasses, including cheatgrass appeared to increase to the greatest extent following the knapweed decline, but variation in precipitation may have given the introduced annual grasses a competitive advantage over native grasses. Gayton & Miller (2011) evaluated the knapweed decline throughout the Southern Interior of British Columbia and found that two of the most dominant bunchgrasses, bluebunch wheatgrass and Idaho fescue (*Festuca idahoensis*), either remained unchanged or declined over the period of 1983 to 2010, a period encompassing the knapweed decline in the late 1990s.

**Research overview and objectives**

This study focuses on the effects of cheatgrass on the diversity of other grass species in the White Lake Basin of British Columbia and considers the cover of introduced grass species in relation to diffuse knapweed and cheatgrass in plots established and monitored by The Nature Trust of British Columbia from 2004 to 2008. Deane (2010) showed that bluebunch wheatgrass, sand dropseed, and needle-and-thread grass are positively associated with cheatgrass. Here we test if these associations are observed in other areas and over different time periods. The objectives of this research are:
1. To determine if the relationships between cheatgrass and grass species diversity of earlier studies occur over a broader landscape in the White Lake Basin study area.

2. To investigate the relationship of bluebunch wheatgrass, a dominant native grass species, to the diversity of other grass species.

3. To investigate the implications of the above objectives to the decision-making process for land managers in choosing seed mixtures for post-disturbance rehabilitation efforts.

This research will provide an improved understanding of the relationship between introduced and native plant species in grasslands of the Okanagan region. In particular, it will provide information to conservation and resource land managers to be used as a tool in selecting native plant species best suited for restoration efforts. Greater success in restoration of areas affected by invasive plants, and prevention of invasive plant establishment in new areas of soil disturbance, would be a significant aid in supporting ecological sustainability in the region.

Methods

Study sites

The White Lake Basin (49°16′33N, 119°38′16W) is one of the few remaining relatively non-fragmented grassland communities in the southern
Okanagan region of British Columbia, Canada (Figure 1a). Most of the White Lake Basin is owned by the Government of Canada’s National Research Council, for the operation of the Dominion Radio Astrophysical Observatory. These lands are under a long-term management lease to The Nature Trust of British Columbia and a local ranching family, Clifton Ranch. This arrangement is a component of the White Lake Basin Biodiversity Ranch initiative, undertaken in 2000 and continuing to this time, with the goal of integrating habitat conservation and livestock management practices to the benefit of both industries.
Figure 1: Study area and location of sample sites within the White Lake – Vaseux Lake conservation areas of the Okanagan Valley, British Columbia, Canada.

**Abbreviations: CWS = Canadian Wildlife Service transects; TNT = The Nature Trust of British Columbia transects.

Broad habitat communities in the White Lake Basin include sagebrush (*Artemisia tridentata* and *Artemisia tripartita*) shrub-steppe; open grassland; open Ponderosa pine forest; and Interior Douglas-fir (*Pseudotsuga menziesii*) forest. The elevation of the White Lake Basin ranges from 500 m to 1400 m, with the majority of the study area being at approximately 550 m. The average annual total precipitation for this semi-arid region, from 1998 to 2010, was 331 mm. The average precipitation for the growing season (May 1
– August 30) over this same time period was 133 mm based on data from the Penticton A weather station, WMO ID 71889 (Environment Canada, 2011). Spring rainfall (March – May) varied little over the period 1998–2010, with the exception of 2006, which was well above average, and 2000, 2007, 2008, and 2009, which were somewhat below average. Summer rainfall (June – August) was more variable with below average rainfall occurring during the summers of 2002 and 2003 and above average rainfall in 2001, 2004, and 2008. For the period of 1998–2010, total annual precipitation was well below average in 2002, and well above average in 2004 and 2006 (Figure 2).

**Figure 2: Precipitation 1998-2010 for Penticton A weather station.**

Sites used in previous work of Deane (2010) and Stephens *et al.* (2009) were monitored by the Canadian Wildlife Service in 2001, 2002, 2003, and 2005 and are described in those publications. The full data set consists of 400
plots at 6 sites in the White Lake Basin. In the Stephens et al. (2009) study, all 400 plots were analysed while Deane (2010) analysed vegetation data from 90 plots at one site, the Park Rill North pasture unit. The Nature Trust of British Columbia collected data annually between 2002 and 2011, from 22 sites at White Lake and Vaseux Lake, consisting of another 220 vegetation plots using the same sampling methodology as the Canadian Wildlife Service. Of these, 11 sites (110 plots), monitored from 2003 through 2008, were analyzed, based on geographical characteristics and sampling consistency (Appendix 1).

**Site Selection**

Sites for transects were related to the livestock pasture units established by the White Lake Basin Biodiversity Ranch Management Plan (The Nature Trust of British Columbia, 2000). Following the establishment of the White Lake Basin Biodiversity Ranch operation, the Canadian Wildlife Service and The Nature Trust of British Columbia each installed a series of permanent vegetation monitoring plots. The objective of the plots was to establish benchmark data from which changes in vegetation over time could be observed with the implementation of the White Lake Basin Biodiversity Ranch Management Plan. These monitoring transects were situated in six separate ranch pastures where land management activities, such as fence construction, invasive plant management, and cattle grazing, are prescribed (Figure 3, Figure 4).
Figure 3: Pasture units and associated transects in the White Lake Basin, Okanagan Valley, British Columbia, Canada.
The geographic range and temporal extent of this study is greater than previous studies (Stephens et al. 2009) but is still limited to the White Lake and Vaseux Lake areas of the Okanagan region and the years of 2001 to 2008. Data were collected from a broad range of habitat types, including riparian, grassland, and mixed forest, within the BBxh1 (Bunchgrass, very hot, very dry) and PPxh1 (Ponderosa pine, very hot, very dry) biogeoclimatic zones. Biogeoclimatic zones are a system of ecosystem classification, whereby the province is divided into a series of ecosystem zones where a combination of biological, geographical, and climatic features make particular areas distinctive (Meidinger & Pojar, 1991).
**Data Collection**

Sampling of plots installed by The Nature Trust of British Columbia consisted of permanent transects, as described by Duralia (2003). Within pasture units a starting point was selected from which a random direction was travelled for a random distance, to establish a 0 m mark for each transect. Another random number was used to determine the direction of the transect from that point outward.

Transects of 100 m length were laid out with the use of a tape measure, along which 10 Daubenmire quadrats of 0.2 m by 0.5 m were established, providing a benchmark from which vegetation changes can be measured with land management practices (Duralia, 2003).

Quadrats were installed using a 0.2m X 0.5m frame, positioned adjacent to the transect tape, starting at 0 m, and every 10 m after, up to 90 m (10 quadrats per 100 m transect). Painted 10-inch spikes were inserted into the ground to mark each corner of the frame. For future reference, the painted nails were oriented such that a blue nail was positioned next to the transect tape at 0 m, and each successive 10 m interval. The yellow nail was positioned 0.5 m away from the blue nail, also alongside the transect tape, and the white and red nail were positioned 0.2 m across from the blue and yellow nails, respectively (Figure 5).
In each 0.1m² Daubenmire quadrat, the density and percent cover of each plant species rooted within the quadrat were recorded (Figure 6). Although plants that hung over the quadrat but were not rooted within the quadrat were not counted, they were included in the estimate of the percent cover for that species.

A similar methodology was used in establishing the Canadian Wildlife Service plots, where a series of 39 permanent transects were installed, each with a series of Daubenmire plots, ranging from 5 to 45 plots per transect (Appendix 1).
Figure 6: Daubenmire quadrat sample plot.

Data Analysis

Statistical methods were based on the previous work of Deane (2010) as follows:

1. Measurement of grass diversity – The effect of cheatgrass on grass species diversity was analysed by calculating the mean number of native grass species within each vegetation plot, in each year. These mean numbers were then separated into plots that contained cheatgrass and plots in which cheatgrass was absent. A similar analysis was conducted to measure the mean number of native grass
species in plots that contained bluebunch wheatgrass versus plots that were devoid of bluebunch wheatgrass. Comparisons were made for each year by conducting a t-test on the mean values for all of the quadrats in the transects of each of the study sites using the VassarStats website for statistical computation (http://faculty.vassar.edu/lowry/VassarStats.html).

2. Co-occurrence analysis – An analysis of co-occurrence between cheatgrass and other species was conducted by separating plots that contain cheatgrass (“invaded”) from plots without cheatgrass (“intact”), and then calculating the proportion of plots occupied by each grass species by pasture unit and by year. To determine differences in the occurrence of each species in intact and invaded plots, data were pooled across all sites and years and were tested by calculating the Z ratio for the difference between the proportions. A one tailed probability was used based on the prediction that species would be less common in invaded plots. This was done using the VassarStats website for statistical computation (http://faculty.vassar.edu/lowry/VassarStats.html).

3. Precipitation data – Precipitation data were compiled for all years in which plant data were collected.
Results

*Grass Diversity related to the presence of Bromus tectorum*

Deane (2010) analysed 90 plots in one pasture unit of the Canadian Wildlife Service data set to determine the effect of cheatgrass on grass species diversity using both native and introduced species (Table 1).

**Table 1: List of grasses (native and introduced) compiled by Deane (2010).**

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Common name</th>
<th>Status</th>
<th>Life form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achnatherum nelsonii</td>
<td>Columbia</td>
<td>native</td>
<td>perennial</td>
</tr>
<tr>
<td>Agropyron cristatum</td>
<td>crested wheatgrass</td>
<td>non-native</td>
<td>perennial</td>
</tr>
<tr>
<td>Apera interrupta</td>
<td>dense silkybent</td>
<td>non-native</td>
<td>annual</td>
</tr>
<tr>
<td>Agrostis stolonifera</td>
<td>creeping bentgrass</td>
<td>non-native</td>
<td>perennial</td>
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<tr>
<td>Bromus hordeaceus</td>
<td>soft brome</td>
<td>non-native</td>
<td>annual</td>
</tr>
<tr>
<td>Bromus tectorum</td>
<td>cheatgrass</td>
<td>non-native</td>
<td>annual</td>
</tr>
<tr>
<td>Bromus commutatus</td>
<td>smooth brome</td>
<td>non-native</td>
<td>annual</td>
</tr>
<tr>
<td>Bromus racemosus</td>
<td>hairy brome</td>
<td>non-native</td>
<td>annual</td>
</tr>
<tr>
<td>Bromus anomalus</td>
<td>nodding brome</td>
<td>native</td>
<td>perennial</td>
</tr>
<tr>
<td>Calamagrostis rubescens</td>
<td>pinegrass</td>
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<td>Distichlis spp.</td>
<td>saltgrass species</td>
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</tr>
<tr>
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<td>Heller's rosette</td>
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<td>Junegrass</td>
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<td>native</td>
<td>perennial</td>
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<td>Italian ryegrass</td>
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</tr>
<tr>
<td>Species</td>
<td>Common Name</td>
<td>Status</td>
<td>Life Form</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>---------------------</td>
<td>------------</td>
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<td>mat muhly</td>
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</tr>
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<td>Kentucky bluegrass</td>
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<td>perennial</td>
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<tr>
<td>Poa secunda</td>
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<td>perennial</td>
</tr>
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<td>perennial</td>
</tr>
<tr>
<td>Poa spp.</td>
<td>bluegrass species</td>
<td>-</td>
<td>perennial</td>
</tr>
<tr>
<td>Pseudoroegneria spicata</td>
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<td>perennial</td>
</tr>
<tr>
<td>Sporobolus cryptandrus</td>
<td>sand dropseed</td>
<td>native</td>
<td>perennial</td>
</tr>
<tr>
<td>Vulpia octoflora</td>
<td>sixweeks fescue</td>
<td>native</td>
<td>annual</td>
</tr>
</tbody>
</table>

In the current analysis only the native grass species diversity is considered and thus cheatgrass presence is only a factor in identifying invaded plots. Analyzing native grass diversity on the full complement of Canadian Wildlife Service plots (400 total), by comparing the mean number of native grasses in the plots, generally corroborates Deane (2010) showing higher native grass diversity in plots without cheatgrass, versus those with cheatgrass for all years studied (Figure 7). The number of species in uninvaded plots was almost statistically significant in 2002 and was significant in 2003 (Figure 7 caption) although the pattern for higher diversity in uninvaded plots is consistent over the study period.
Figure 7: Mean (SEM) native grass diversity (number of species) in CWS plots, with and without cheatgrass.

In a two-tailed t-test for significance, values are as follows (t/P): 2001 (0.42/0.68), 2002 (2.07/0.06), *2003 (3.24/0.001), 2005 (0.76/0.46). Degrees of freedom = 5. Standard error bars apply to the mean number of grass species within each pasture.

The data from plots monitored by The Nature Trust of British Columbia, 110 total from 11 sites, were also analyzed. These data extended the period of observation from 2003 to 2008 and the trend was for native grass diversity to be higher in plots not containing cheatgrass, for all years analyzed (Figure 8). Similar to the CWS data diversity scores peak in 2005 and show the greatest difference between intact and invaded plots in 2003. None of the results in the Nature Trust plots were statistically significant, but the trend of higher native grass diversity in plots without cheatgrass was consistent. The number of species was slightly lower in the TNT plots compared to the CWS plots.
Figure 8: Mean (SEM) native grass diversity (number of species) in a total of 110 TNT plots with and without cheatgrass at 11 different sites.

In a two-tailed t-test for significance, values are as follows (t/P): 2003 (1.86/0.08), 2004 (1.12/0.28), 2005 (1.26/0.22), 2006 (0.68/0.50), 2007 (0.94/0.36), 2008 (0.45/0.66). Degrees of freedom = 10. Standard error bars apply to the mean number of grass species within each pasture unit.

**Grass Diversity – in response to the presence of Pseudoregneria spicata**

To evaluate the effect of a dominant native grass species on native grass diversity, as compared to that of the introduced cheatgrass, native grass diversity was calculated in plots with and without bluebunch wheatgrass (Figure 9).

Whereas cheatgrass appears to be negatively associated with native grass diversity, bluebunch wheatgrass tended to be positively correlated with native grass diversity. In an analysis of the Canadian Wildlife Service data from 2001 through 2005, native grass diversity tended to be higher in plots
containing bluebunch wheatgrass for all years, although this was not statistically significant.

Figure 9: Mean (SEM) number of native grass species in 400 CWS plots, with and without bluebunch wheatgrass.

In a two-tailed t-test for significance, values are as follows (t/P): 2001 (0.73/0.48), 2002 (0.42/0.68), 2003 (0.91/0.38), 2005 (0.66/0.52). Degrees of freedom = 10. Standard error bars apply to the mean number of grass species within each pasture.

Similar trends occur in the Nature Trust data over the longer study period (2003 – 2008), with native grass diversity being higher in plots containing bluebunch wheatgrass, for all years analyzed (Figure 10), and a peak diversity in 2005 although differences were not statistically significant.
Figure 10: Mean number of native grass species in TNT plots, with and without bluebunch wheatgrass.

In a two-tailed t-test for significance, values are as follows (t/P): 2003 (1.79/0.09), 2004 (1.53/0.14), 2005 (2/0.059), 2006 (-1.09/0.29), 2007 (1.27/0.22), 2008 (1.67/0.11). Degrees of freedom = 10. Standard error bars apply to the mean number of grass species within each pasture.

**Diffuse Knapweed vs. Introduced Grasses**

The studies of Myers *et al.* (2009) at Vaseux Lake and of Stephens *et al.* (2009) in the White Lake Basin, as well as those of Gayton & Miller (2011) and Newman *et al.* (2011) on a provincial level, indicated that diffuse knapweed declined before and during the study period of 2001 to 2005. Stephens *et al.* (2009) also found that invasive grasses overall increased during the study period.

Analysis of the 110 TNT plots indicates that diffuse knapweed generally remained low from 2003 through 2008. The invasive grasses also
remained similar over the study an increased nonsignificantly in 2008 (Figure 11).

**Figure 11:** Mean (SEM) percent cover of introduced grasses and diffuse knapweed by year for 110 plots from 5 sites in the Okanagan Valley. Standard error bars apply to the mean of the average percent cover for each pasture.

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**Species-specific associations**

A total of 33 grass species occurred within the vegetation plots, of which 22 were native species and 11 were introduced species (Table 1).

Comparing the proportion of intact plots and the proportion of plots invaded by cheatgrass containing each particular grass species indicated degree of association with cheatgrass. Grasses occurring in higher proportions in plots with cheatgrass could indicate that a species might be more able to withstand competition from cheatgrass, or have similar habitat requirements.
An analysis of frequency by Deane (2010) of 90 plots within the Canadian Wildlife Service data sets for only years 2001 and 2005 indicated that species showing higher association with cheatgrass included the introduced species, crested wheatgrass, and four native species; western needlegrass, bluebunch wheatgrass, sand dropseed, and needle and thread grass. All of these species were perennial species.

The analysis here of the full Canadian Wildlife Service data set (400 plots) from 2001, 2002, 2003, and 2005 tends not to support Deane (2010). Of the 16 grass species tested, ten occurred proportionally more in plots that did not contain cheatgrass. Of these, six were significant, including Columbia needlegrass, saltgrass, Idaho fescue, junegrass, bluebunch wheatgrass, and Kentucky bluegrass (Table 2). Western needlegrass (*Stipa occidentalis*), examined in the Deane study, was determined in this study to actually be Columbia needlegrass. Columbia needlegrass, bluebunch wheatgrass, and sand dropseed, all indicated by Deane (2010) as being positively associated with cheatgrass, were conversely found to be proportionally less in the presence of cheatgrass in this study. On the other hand, Deane’s finding that needle and thread grass was positively associated with cheatgrass was corroborated by this study.

Of particular interest to this study are those species that occur proportionally more in the presence of cheatgrass (Table 2). These include six
species, four of which were significantly more frequent with cheatgrass.

These significant species include one introduced grass, dense silkybent, and three native grasses: needle and thread grass, Sandberg bluegrass, and sixweeks fescue.

It should be noted that for a particular grass species to be included in Table 2, it must have been found both in plots containing cheatgrass, and in plots devoid of cheatgrass. If this were not the case for particular grass species, the species was not considered. Species that were found over a transect in either invaded or intact plots, but not both, tended to be limited to very few plots, so it could be argued that they are not a significant component of the vegetation community in the study area. Examples include hairy brome (*Bromus racemosus*), slender wheatgrass (*Elymus trachycaulus*), quackgrass (*Elymus repens*), foxtail barley (*Hordeum jubatum*), scratchgrass (*Muhlenbergia asperifolia*), mat muhly (*Muhlenbergia richardsonis*), and Cusick's bluegrass (*Poa cusickii*).

Table 2: Species-specific associations with cheatgrass based on grass species frequency ratio between intact quadrats and invaded quadrats.

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Common name</th>
<th>Status</th>
<th>Life form</th>
<th>Intact quadrats prop.</th>
<th>Invaded quadrats prop.</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Achnatherum nelsonii</em></td>
<td>Columbia needlegrass</td>
<td>native</td>
<td>perennial</td>
<td>0.14  628</td>
<td>0.01  510</td>
<td>&lt;0.0001</td>
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<tr>
<td><em>Agropyron cristatum</em></td>
<td>crested wheatgrass</td>
<td>non-native</td>
<td>perennial</td>
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<td>0.21  244</td>
<td>0.18</td>
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<tr>
<td><em>Apera interrupta</em></td>
<td>dense silkybent</td>
<td>non-native</td>
<td>annual</td>
<td>0.19  734</td>
<td>0.28  569</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Species</td>
<td>Description</td>
<td>Type</td>
<td>US%</td>
<td>CA%</td>
<td>Mo%</td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------</td>
<td>---------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td></td>
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<tr>
<td>Bromus hordeaceus</td>
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<td>0.19</td>
<td>0.13</td>
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<tr>
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<td>0.1</td>
<td>0.3</td>
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<td>0.08</td>
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<td>Hesperostipa comata</td>
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<td>0.21</td>
<td>0.54</td>
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<td>Wildrye bluegrass</td>
<td>native</td>
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<td>0.02</td>
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<td>Poa bulbosa</td>
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<td>0.02</td>
<td>0.03</td>
<td>0.38</td>
<td></td>
</tr>
<tr>
<td>Poa pratensis</td>
<td>Bluegrass Sandberg</td>
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<td>0.22</td>
<td>0.11</td>
<td>0.72</td>
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<tr>
<td>Poa secunda</td>
<td>Bluegrass wheatbunch</td>
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<td>0.37</td>
<td>0.72</td>
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<tr>
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<td>0.38</td>
<td>0.26</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Sporobolus cryptandrus</td>
<td>Dropseed sixweeks</td>
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<td>0.1</td>
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<td></td>
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<tr>
<td>Vulpia octoflora</td>
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<td>0.18</td>
<td>0.27</td>
<td>0.66</td>
<td></td>
</tr>
</tbody>
</table>

Significant positive associations with cheatgrass are shown in green. Significant negative associations with cheatgrass are shown in yellow.

**Discussion**

**Native Grass Diversity**

Although the trend was for native grass diversity to be lower in the presence of cheatgrass high variation among quadrats and sites caused the variation to be nonsignificant. In the Great Basin desert region, cheatgrass dominance has resulted in changes to species richness and evenness, with fewer native bunchgrasses in a given area (Knapp, 1996). The characteristics that make cheatgrass such a strong competitor with native plants begin at
the seedling stage, and include early germination, superior cold-temperature growth capability, prolific root production, and a high specific leaf area (Ray-Mukherjee et al. 2011).

In all years of the Deane (2010) study, 2001 to 2005, the mean number of grass species was less in plots invaded by cheatgrass. It should be noted, however, that in the Deane study cheatgrass was not included as one of the species for the total diversity value. If cheatgrass were included in the Deane analysis, the resulting grass diversity scores would be increased by one in plots invaded by cheatgrass.

It is unlikely that the increased native grass diversity of plots with bluebunch wheatgrass is due to a characteristic that promotes other grasses. It is more likely that bluebunch wheatgrass is an indicator of healthier grassland ecosystems, which would naturally contain a fuller complement of native grass species. Portions of the study area that do not contain bluebunch wheatgrass, in spite of the fact that this species is a natural dominant for the ecosystem, may indicate reduced ecosystem integrity. These less than optimal habitat conditions would potentially support a greater prevalence of introduced grasses, resulting in lower native grass diversity.

It is interesting to note the trend in overall native grass diversity in the White Lake Basin appears to peak in 2005 and 2006, with a gradual
decrease through to 2008 (Figure 8). On the other hand, invasive grasses were lowest point in 2006, and increased in cover in 2007 and 2008 (Figure 11). This may be linked to annual fluctuations in precipitation levels in the study area.

Above average precipitation throughout the growing season in 2004, followed by average precipitation in 2005 (Figure 2), may have improved conditions for native grass species, resulting in a greater number of these species during the growing season of 2005. In contrast, the above average precipitation during the spring (March through May) of 2006 may have aided introduced grasses, such as cheatgrass, which could take advantage of the spring precipitation with their early germination capabilities. This boost to introduced grass species populations might then have contributed, along with subsequently decreased precipitation levels, to the gradual decline in native grass species diversity through 2008.

**Diffuse Knapweed and introduced grass cover**

As discussed by Stephens *et al.* (2009), the ongoing decline of diffuse knapweed in the White Lake Basin, during their study period of 2001 through 2005, was accompanied by an overall increase in invasive grass cover. This increase in invasive grasses was most prevalent between 2003 and 2005. It was noted that native grass species remained fairly constant while the invasive grasses increased. The underlying question is whether the
increase in invasive grass cover was a direct response to habitat availability occurring with declining diffuse knapweed cover, or whether there were other significant ecological factors.

My research was modeled after the Stephens et al. (2009) study, but examined the 110 plots monitored by The Nature Trust of British Columbia (Figure 11). Over the period 2003 through 2008, a slight decline in invasive grass cover occurred from 2003 to 2005, which overlapped the previous study, and a non-significant increase in 2008 following the above-average growing season precipitation for the years 2004 through 2008.

**Species-specific associations with cheatgrass**

Several grass species occurred in significantly higher proportions in the presence of cheatgrass, suggesting that these species may be better able to withstand the competitive characteristics of cheatgrass. Native grass species having a significant positive association with cheatgrass included needle and thread grass, Sandberg bluegrass, and sixweeks fescue. Another native grass, sand dropseed, had a nonsignificant positive association with cheatgrass. Why these native grasses were found to be associated with cheatgrass remains a question. It is possible that they benefit from the same types of habitat and conditions as cheatgrass, resulting in higher occurrence in these plots.

While it might be expected that other introduced grasses would benefit
from the disturbance factors such as livestock grazing and precipitation cycles that benefit cheatgrass, dense silkybent was the only introduced species to be associated with \textit{B. tectorum}. Both of these species are annuals and lack natural controls in North America.

Native grass species showing a significant negative association with cheatgrass included saltgrass, Idaho fescue, Junegrass, giant wildrye, bluebunch wheatgrass, Columbia needlegrass, and Kentucky bluegrass. No introduced grasses had a significant negative association with cheatgrass. Negative associations with cheatgrass could indicate a lack of tolerance to cheatgrass or the disturbance factors that favor it, a tendency to occupy habitat conditions that are not as well suited for cheatgrass, or a strong competitiveness that prevents local cheatgrass invasion. As shown by Deane (2010) and Griffith (2010) the distribution of cheatgrass can be patchy and influenced by the presence of other species such as ponderosa pine and sagebrush. The number of quadrats containing cheatgrass varied among sites and years and thus to opportunity for co-occurrence would vary as well.

\textbf{Management implications}

Relating these species-specific association results is most relevant to land management in the field of conservation, as managers attempt to choose the best possible seed mix for use in post-disturbance grassland seeding activities in areas prone to cheatgrass invasion. The results of this study
would indicate that of the native grasses, needle and thread grass, Sandberg bluegrass, sixweeks fescue, and to a lesser degree sand dropseed, would be most appropriate as seed mix components, given their perceived ability to endure in the presence of cheatgrass.

The use of native grasses in restoration efforts is a costly effort. As discussed by Ray-Mukherjee et al (2011), invasive grasses, such as cheatgrass, are often better able to compete at the seedling stage than native grasses. This could make seeding with only native grasses an inefficient use of limited resources. Cheatgrass has been shown (Hardegree et al. 2010) to have a higher germination success rate than native grasses, such as bluebunch wheatgrass, particularly in colder weather conditions of late fall through early spring. This would generally cause native grasses to establish on a longer time frame than cheatgrass in most restoration efforts, so including a short-lived agronomic species in the restoration seed mix may be a prudent decision. A short-lived agronomic grass, such as an annual rye grass, seeded in sufficient quantities on disturbed sites, may be successful in tying up bare soils prior to cheatgrass establishment, and possibly in facilitating native species germination. A strategy for higher success in small-scale restoration efforts would be the supplemental planting of mature grass plants of a dominant species that takes well to planting, such as bluebunch wheatgrass. This will help bypass the highly competitive seedling
stage and provide a continual seed source for establishment of native grass over time although would be very expensive and labour intensive.

Making appropriate choices for native grasses to include in a post-disturbance seed mix also requires an investigation of the feasibility of using particular native grass seeds, from the point of practicality. Kay et al (1981), describe studies of the seeding potential for many grass species, including those that appeared to be more competitive in the species-specific associations. They found that the seed characteristics of the needle and thread grass, such as geniculate twisted awns and sharp-pointed callus made harvesting, processing, and planting very difficult with conventional seeding equipment.

Bluebunch wheatgrass, although it is the dominant native grass species in the Intermountain Area, was found in this study to be negatively associated with cheatgrass, and is regarded as having limited success in seeding activities, due to its somewhat poor seedling vigor (Kitchen & Monsen, 1994, Jones et al. 1991). On the other hand this negative association could indicate that where established, bluebunch wheatgrass can suppress cheatgrass establishment.

Sand dropseed, on the other hand, is quite adept at establishing and is one of the first native perennial grasses to do so after disturbances (Quinn and Ward, 1969). Characteristics that allow for the successful establishment
of sand dropseed include prolific seed production and a persistent seed bank. When using sand dropseed in seed mixtures, particular care should be taken in ensuring that seeds are sourced locally. Although this is likely the case with many native plants, Quinn and Ward found that sand dropseed exhibits a particularly strong similarity between the parent plant and its seedlings in morphology and phenological development, so success of establishment from seed may be geographically limited.

Like sand dropseed, Sandberg’s bluegrass is an early colonizer of disturbed sites, commonly used in seed mixes and noted for its prolific seed production. Sandberg’s bluegrass is a known “increaser species” which is able to withstand heavy grazing (McLean & Tisdale, 1972). Therefore it may be very appropriate as a seed mix component in areas that land managers might expect to experience some degree of disturbance over time.

Sixweeks fescue is an annual native grass, and thus propagates entirely by seed, with a great dependence on its seed bank in the soil for long-term persistence (Howard, 2006). It’s reputation as that of an early colonizing ‘weedy’ species could indicate that sixweeks fescue is a good candidate for restoration of disturbed sites.

The study component that addresses the increase in introduced grass cover over the same time period as reductions in diffuse knapweed
populations has management implications. As biological controls for diffuse knapweed, and other invasive plants such as Dalmatian toadflax, continue to reduce the population levels of these introduced herbaceous plants, other introduced plant species will continue to be dynamic in response to changing availability of space in the ecosystem. Composition and diligent application of effective seed mixes in restoration efforts will allow land managers to better reduce invasive plant infestations through prevention of new source sites.

**Chapter 4. Conclusions**

**General conclusions**

This study indicates, further to previous analysis in the White Lake Basin (Deane, 2010), that cheatgrass invasion is a factor in decreased native grass diversity, in contrast to a dominant native grass species, such as bluebunch wheatgrass, whose presence is associated with higher native grass diversity.

Trends in grass diversity and cover over the study period appear to be linked to annual fluctuations in precipitation levels, with above average rainfall being associated with increased cover by native and introduced grasses alike. This is likely due to improved conditions for germination from the seed bank and increased vigour of established plants. With continuing low diffuse knapweed populations over the study period following declines in
the previous decade, the introduced grass species appear to be filling the
vacant niche in this grassland ecosystem (Stephens et al. 2009).

Management implications

The primary goal of this study, in terms of implications to land
management, is to provide further assistance to land managers in making
informed decisions when choosing post-disturbance seed mixes for native
grasslands in the Okanagan Valley. From this study, several native grass
species were indicated to be positively associated with cheatgrass, and might
be better able to compete in invaded grassland ecosystems. Of these, sand
dropseed, Sandberg’s bluegrass, and sixweeks fescue appear to have the
greatest potential for success, due to their early colonising characteristics and
past success in previous restoration projects. Needle and thread grass does
not appear to be a practical option for larger scale restoration projects, due to
their difficult handling procedures, but could be an important seed mix
component in small-scale restoration efforts. Bluebunch wheatgrass does not
appear to be a highly successful colonizer in disturbed areas, due to
competition at the seedling stage. It is, however, a very important
component of the Intermountain Area grassland ecology, so an alternative to
seeding might be to plant bluebunch wheatgrass plugs, which could then
provide a long-term seed source for the surrounding area.
Overall, native grass seeds are not likely to perform as well as conventional agronomic species from a practicality point of view, but in some situations native species are desired or required.

Above all, after disturbance, establishing plant cover as quickly as possible is critical (Kay *et al.* 1981). This will help to prevent erosion, and decrease available habitat for invasive plants. This promotes the cause for including a quickly established agronomic species, such as annual ryegrass, in the seed mix, as a ‘placeholder’ for in-growth of native species as they establish over time.

**Assumptions and limitations**

A number of limitations and/or potential biases are inherent in this study, as follows:

1. The small size of vegetation plots utilised in the study limits the amount of data that is collected for each site. Although data may suggest that there is no cheatgrass in a particular site, this may not be the case, as they do not provide comprehensive information on the area. The large number of quadrats could, however, compensate for this potential bias.

2. The study area is limited in scope, from a geographic perspective, but given the high density of conservation lands in the immediate vicinity with similar geography and ecology, the results will be valuable to land
managers.

3. The data sets provided by Canadian Wildlife Service and The Nature Trust of British Columbia occupy different time periods (2001 through 2005 versus 2003 through 2008), although there is overlap, which is helpful to the analysis.

4. The data set provided by Canadian Wildlife Service is limited in temporal scope to the period of 2001 through 2005 with data for 2004 missing. Re-measurement of these plots would be a useful exercise for further studies.

5. Plots established by The Nature Trust of British Columbia provide good observational data in portions of the White Lake Basin that were not previously monitored, but the number of plots established in each pasture unit is highly limited, reducing their applicability in species-specific association analysis.

Further research needs

1. The study reported here is based on associations of species and can be interpreted in conflicting ways; if a species is less common with cheatgrass it could be a good competitor and prevent cheatgrass establishment in the local area or it could be a poor competitor with cheatgrass and thus it does not persist in cheatgrass patches. The only
way to distinguish these two interpretations is through experiments. These should include both measuring the success of cheatgrass in established bluebunch wheatgrass plots and planting mixtures of seeds from both plant species in plots. Prior to land managers expending limited resources on costly native seed mixes for use in restoration efforts, further experimental work would be a wise precaution. In addition, further investigation of the seeding methodology requirements for select native grass species is warranted.

2. Increasing the number of plots established in the White Lake Basin would be beneficial. If increasing the number of plots in all pastures is cost-prohibitive, reducing the number of pastures measured, but increasing the number of transects and plots in each, may suffice to produce stronger data.

3. Further analysis of the available data could be done to explore differences among areas in the composition of the grasses. This could be particularly valuable if this information could be related to management tactics being applied to the different pastures.
Works Cited


http://www.for.gov.bc.ca/hfd/pubs/Docs/Srs/Srs06.htm

Conservation Series, Cambridge University Press.


## Appendices

### Appendix 1: Study site transects and locations

<table>
<thead>
<tr>
<th>Transect</th>
<th>Data Source</th>
<th>Pasture Name</th>
<th>Number of Plots</th>
<th>Start UTME</th>
<th>Start UTMN</th>
<th>Years Monitored</th>
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<tr>
<td>1</td>
<td>CWS</td>
<td>White Ranch South</td>
<td>10</td>
<td>305179</td>
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**Note that all location UTM coordinates are NAD83 Zone 11.