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Title: The Response of *Ventenata dubia* to Prescribed Fire and Ungulate Grazing on the Pacific Northwest Bunchgrass Prairie

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Ventenata dubia L. (ventenata) is an introduced, winter annual grass that has recently been raising concerns across the Pacific Northwest Bunchgrass Prairie and the Palouse Prairie. It is well established now in pasturelands, croplands, and a variety of ecosystems including grasslands, sagebrush steppe, ponderosa pine forests and woodlands. Ventenata is quickly raising concerns about impacts on agricultural production, wildlife habitat, plant community composition, and watershed services. Even with this wide range of habitats and long list of concerns for managers, very little of its basic ecology and dynamics are known or just beginning to be studied. Prescribed fire and targeted herbivory are two management tools that are often used to control exotic annual grasses, but may also exacerbate populations. My objective for this thesis was to examine how these two disturbance factors influence and/or exacerbate ventenata invasion in the Pacific Northwest Bunchgrass prairie (PNB) using two different

studies. In the first study, I explored how ventenata responded to prescribed fires, large ungulate herbivory (cattle and elk), and the interactions between them over the last 10 years on the PNB prairie. I used monitoring data (2008, 2016, and 2018) from experimental prescribed fire and grazing study plots established in 2004 and burned in the fall of 2006 and 2016. Using a randomized block repeated measures mixed linear model ANOVA I found ventenata was significantly increasing overtime in all response variables ($p=0.0011$, $p=0.0001$, $p=0.0007$). I found no significant differences ($P<0.05$) in ventenata with cattle grazing alone except for frequency ($p = 0.03$) in 2016, 10 years after the first prescribed fire. However, there was some evidence that grazing (livestock grazing combined with elk herbivory) increased ventenata frequency ($P = 0.11$) across all years, especially if those sites are not also managed with prescribed fire. For my second study, I resurveyed a subset of plots established in 2004 to compare ventenata cover and standing crop between paddocks that were grazed by cattle and elk to those where cattle had been excluded for 12 years. The study design was a randomized complete block design with four blocks and two treatment levels: 1) grazed (1.3-1.6 ha/AUM), and 2) fenced to exclude cattle, but open to elk (excluded). Using a linear mixed model ANOVA I found no significant differences ($P<0.05$) between grazed and excluded treatments. However, three out of the four blocks had much higher cover and standing crop in grazed areas, with, one block demonstrating the opposite pattern. Thus there is some evidence that combined herbivory by cattle and elk may lead to more ventenata, even though the effect was not captured when all blocks were analyzed. My thesis represents some of the first experimental and observational research involving ventenata and prescribed fire and ungulate grazing. Although more work still needs to be done, the findings contained in this research will help add to the much needed science for managing this species.

The Response of *Ventenata dubia* to Prescribed Fire and Ungulate Grazing on the Pacific Northwest Bunchgrass Prairie

by
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Luke W. Ridder, Author

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Chapter 1: Introduction

1.1 Introduction

Ventenata dubia L. (ventenata) is an introduced, winter annual grass that has recently been raising concerns across the Pacific Northwest Bunchgrass Prairie and the Palouse Prairie (Wallace et al. 2015). Although a relatively recent invader, it has already been linked to undesirable impacts on agricultural production, wildlife habitat, plant community composition, and watershed services. Due to the negative impacts of ventenata on hay quality and harvesting equipment, producers of Timothy (*Phelum pretense* L.) have been forced to adjust their harvesting schedules, replant fields, and spend more on herbicides to avoid the losses of up to $145 per ton of hay (Fountain, 2011; Mackey, 2014). Others report declines of up to 75% in forage yields after invasion by ventenata (Wallace and Prather, 2011). Some suggest that native species diversity has been decreasing due to ventenata and that it is able to outcompete and replace other invasive winter annual grasses (Northam and Callihan, 1986; Johnson and Swanson, 2005). Ventenata is a known host for the *barley/cereal yellow dwarf virus*, a pathogen that can infect plants both in native ecosystems as well as cropland systems (Ingwell and Bosque-Pérez, 2014). It has already invaded habitats of numerous federally-listed grassland plants in a variety of plant associations (Bernards and Morris, 2016; Fryer, 2017; Endress et al. In Review). Cascading effects on fitness and survival of Tree Swallows (*Tachycineta bicolor*) are documented to occur among habitats with 50% or greater ventenata cover due to the negative effects this annual grass has on plant diversity, insect communities, and insect abundance (Mackey, 2014). Finally, the shallow rooting depth of this annual grass is also likely to put ventenata-infested rangelands at higher risk for soil erosion, leading to habitat degradation and altered nutrient cycling within grassland ecosystems (Brooks et al. 2004; Mackey, 2014).

Ventenata was first recorded in the United States in Washington in 1952 and has since spread to at least 11 other states and several provinces in southwestern and southeastern Canada (Scheinost et al. 2008). It has a wide elevational gradient, occurring in elevations from 10 m to 1800 m (Pavek et al. 2011). Ventenata grows in slim erect culms that can reach 10 to 46 cm in height and can produce 15-35 seeds per plant on an open panicle (Pavek et al. 2011; Scheinost et al. 2008). These seeds are hydroscopic with the ability to germinate in a wide array of temperatures (Northam and Callihan, 1986). However, these seeds decrease in viability (<1%) when buried under 2 cm of soil for up to 3 years (Wallace et al. 2015). Management considerations often group ventenata with other winter annual grasses such as *Bromus tectorum L. and Taeniatherum caput-medusae (L.) Nevski* even though its seedling emergence and phenology is slightly later and its biomass is relatively lower compared to these other winter annuals (James, 2008; Mckay et al. 2017). Though a more recent invader than these other annual grasses, it is already well established in grasslands, pastures, croplands, sagebrush steppe, ponderosa pine forests and woodlands (Bernards and Morris, 2016; Averett et al. 2016; Jones et al. 2018; Fryer, 2017). Even with this wide range of habitats and long list of concerns for managers, very little of its basic ecology and dynamics are known and only just beginning to be studied (Wallace et al. 2015).

There are many uncertainties about the dynamics between ventenata and fire (Fryer, 2017). The only experimental research regarding fire comes from seeded areas in the Conservation Reserve Programs (CRP) (Fryer, 2017; Mackey, 2014). Other than ventenata the most prevalent species on these CRP sites were orchardgrass (*Dactylis glomerata* L.), Japanese brome (*Bromus japonicas* Thunb. Ex Murr.), meadow foxtail (*Alopecurus pratensis* L.) and autumn willowherb (Epilobium brachycarpum) (Mackey, 2014). This research recorded a reduction in ventenata density on CRP fields the year following a fall prescribed fire (Mackey, 2014). However, the reported observations regarding the effects of fire on ventenata abundance are not unanimous. For example, there are reports of increased ventenata density following summer fires in Washington and Oregon (Haferkamp et al. 1984; Wallace et al. 2015). Similarly, landowner survey respondents described fire as an ineffective management tool to control ventenata and reported higher dominance of ventenata following prescribed fire (Pavek et al. 2011). Prescribed burns are hypothesized to aid in ventenata control by reducing the thatch layer it creates and which promotes its own seedling survival (Wallace et al. 2015). Others reported that ventenata was able to establish in trace amounts (<3%) following treatments in the form of prescribed fire and thinning in the forested ecosystems of Oregon's Blue Mountains (Youngblood et al. 2006). As an annual grass that has senesced by late summer and often found in high density, there are concerns about its contribution to highly combustible fuels and fuel connectivity in the Blue Mountain Ecoregion as well (Fryer, 2017). However, since ventenata differs from other invasive winter annual grasses both in phenology and plant traits, it requires a closer study of the dynamics that influence its invasion success, particularly the potential role fire plays in facilitating its spread (Bansal et al. 2014; James, 2008; Rinella et al. 2014; McKay et al. 2017; Fryer, 2017).

Little is also known about the dynamics between large ungulate herbivory and this newer invasive species in the region. Large ungulates have been linked to the spread of invasive plant species in several ways. Cattle (*Bos taurus*) and elk (*Cervus canadensis*) are capable of spreading seeds of invasive plants via passage of seeds through the digestive tract or from attachment to the animal's body (Janzen, 1984). Not only do ungulates have the potential to transport the seeds of invasive plants, they are also known to increase bare ground, erosion and soil compaction, all of which, are disturbances that can facilitate the establishment of invasive plants (Schulz and Leininger, 1990; Sheley and Petroff, 1999). Ventenata contains relatively high levels of silica It is reported that the silica content of ventenata (~2.7%), may make it an undesirable forage species for herbivores (Pavek et al. 2011), however ventenata's silica content is well within the normal range for a grass (Johnston et al. 1967; Mcnaughton et al. 1985). Regardless, livestock producers, land managers, and researchers have observed cattle avoiding grazing on ventenata or spitting it out when they do get a full bite of the grass. Some suggest that the poor palatability of ventenata relates to its texture (McCurdy et al. 2017). However, Pekin et al. (2016) found no significant increase in cover of exotic annuals grasses (including ventenata) in plots grazed by elk or cattle in semi-arid conifer forests. In contrast, others found ventenata increased in areas that are heavily used by elk populations (Johnson et al. 2013; Pavek et al. 2011). More research is needed to understand the interactions between both domestic and wild ungulates with this rapidly increasing exotic annual grass.

In this thesis, my overarching objective was to examine how two disturbance factors (fall prescribed fire and herbivory) influence ventenata invasion in the Blue Mountain Ecoregion. To meet this objective, I completed two studies on the largest remaining intact remnant of the Pacific Northwest Bunchgrass Prairie, the Zumwalt Prairie Preserve. My first study (Chapter 2) used a set of experimental plots that were installed in 2004 to study the long-term impacts of fall prescribed fire and grazing on the prairie. Employing monitoring data (2008, 2016, 2018) collected after two fall prescribed burns (2006 and 2016), I studied the differences in ventenata cover, frequency, and density in relation to grazing, prescribed fire, and their interactions. For my second study (Chapter 3), I compared the response of ventenata cover and standing crop in paddocks that were grazed by cattle and elk to paddocks where cattle had been excluded since 2004. My findings add to our overall understanding of the invasion by this new exotic annual grass and reveal complex relationships with these two disturbances that are discussed in detail in the following chapters.

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Chapter 2: Response of *Ventenata dubia* Abundance to Prescribed Fire and Large Ungulate Herbivory

2.1 Introduction

Exotic and invasive annual grasses pose a threat to multiple ecosystems around the globe (Drake et al. 1989) including temperate grasslands in North America (Fitzpatrick, 2004). Prescribed fire and targeted grazing are both common management tools to control invasive species in grassland systems (Menke, 1992). However, fire can also play an important and highly variable role in the invasion success of a wide variety of exotic plant species (Alba et al. 2015, D'Antonio, 2000; DiTomaso et al. 2006). Fire can promote or inhibit invasion depending upon the traits of the exotic species and the adaptations of the native plant community to fire disturbances (DiTomaso et al. 2006; Porensky and Blummenthal, 2016; Juani et al. 2015; Leffler et al. 2013). For example, the fire-invasion feedback cycle is well known for promoting and maintaining dominance of exotic annual grass invasions in arid and semi-arid ecosystems (D'Antonio, 2000; D'Antonio and Vitousek, 1992; Bradley et al. 2018; Balch et al. 2013). Annual grasses, such as cheatgrass (*Bromus tectorum* L.), can reduce fire return intervals from 30 years to 3 to 5 years, favoring its own lifecycle and putting native plant communities at risk (Chambers et al. 2007; D'Antonio and Vitousek, 1992). Fire can also promote the establishment and spread of exotic plant species by removing or reducing competition from native plant species and providing a nutrient-rich environment for fast growing ruderal species, especially annual grasses (D'Antonio, 2000; Alba et al. 2015).

Ventenata dubia L. (ventenata) is a relatively new exotic invasive annual grass raising concerns across grasslands in the Pacific Northwest Bunchgrass (PNB) and the

Palouse Prairies (DiTomaso, et al. 2013; Beck, 2014). Since ventenata is a relatively recent invader, there are many uncertainties about its potential dynamics with fire (Fryer, 2017). Studies from reseeded pastures, part of the Conservation Reserve Programs (CRP), are currently the only published experimental research looking into the relationships between ventenata and fire (Fryer, 2017; Mackey, 2014). However, there are some conflicting reports about the effect fire can have on ventenata abundance. For example, some report an increase in ventenata density after summer fires in Washington and Oregon (Haferkamp et al. 1984). Mackey (2014), however, recorded a reduction in ventenata density on CRP fields the year following a fire that occurred in the fall. Landowner survey respondents suggest fire is an ineffective management tool to control ventenata and describe higher dominance of ventenata following fire (Pavek et al. 2011). Prescribed burns are hypothesized to reduce the thatch layer created by ventenata, which may promote its own seedling survival (Wallace et al. 2015). Youngblood et al. (2006) found ventenata established in trace amounts (<3%) following thinning and prescribed fire treatments in the forested ecosystems of Oregon's Blue Mountains. As a winter annual grass, ventenata control and management considerations are often grouped with cheatgrass and other invasive winter annuals (Nyamai et al. 2011). Ventenata differs enough from other invasive winter annual grasses both in phenology and plant traits, that it requires a closer study of the dynamics that influence its invasion success, particularly the role fire plays in facilitating or controlling its spread (Bansal et al. 2014; James, 2008; Rinella et al. 2014; McKay et al. 2017; Fryer, 2017). Timing of prescribed fire can have variable effects on the vegetation. For example, spring fire is thought to be more damaging to vegetation due to young plant tissues being more vulnerable to heat (Bond and van Wilgen 1996), where later season fires have been found to not be as harmful to bunchgrass species (Wright and Klemmedson 1965). In the only study to examine ventenata and fall prescribed fire in rangelands, ventenata increased regardless of historical fires in the Pacific Northwest Bunchgrass Prairie (Ridder et al. *In Revision*). However, this was a retrospective approach and there are no studies that examine this question in an experimental design.

There is also little known about the dynamics between large ungulate herbivory and the response of ventenata in the region. Cattle (*Bos taurus*) and elk (*Cervus canadensis*) are capable of spreading seeds of invasive plants in two different ways including endozoochory, which is the passage of seeds through the digestive tract, and epizoochory, which occurs when the seeds are attached to the animal's body (Janzen, 1984). Not only do ungulates have the potential to transport the seeds of invasive plants, they are also known to increase bare ground, erosion and soil compaction, all of which, are disturbances that can facilitate the establishment of invasive plants (Schulz and Leininger, 1990; Sheley and Petroff, 1999). Grazing in general can impact plant communities through selective removal of the more palatable species, resulting in an increase in the less palatable species (Dyksterhuis, 1958; Parsons and Dumont, 2003). Livestock producers, land managers, and researchers report anecdotally that cattle avoid eating ventenata and spit it out in clumps when they do take a bite of the grass for reasons that are still unknown. Some speculate the level of silica (~2.7%) in ventenata make it an undesirable forage species (Pavek et al. 2011), although this silica content is relatively low for a grass (Johnston et al. 1967; Mcnaughton et al. 1985). Feeding tests suggest the poor palatability may relate to texture (McCurdy et al. 2017). Livestock grazing in the Snake River Plains region is tied to the proliferation of cheatgrass but grazing in early spring is sometimes used to control it (Young et al. 1987). In the PNB prairie, early spring is when native grasses are the most vulnerable to disturbance, such as grazing (Young et al. 1987; Young and Clements, 2007) and the later phenological growth of ventenata means it is short enough to avoid grazing by cattle at this time (Wallace et al. 2015). Even though the overall diet composition for elk is approximately 60% grasses (Skovlin and Vavra 1979), studies find no significant increase in cover of exotic annual grasses (including ventenata) in plots grazed by elk or grazed by cattle in semi-arid conifer forests (Pekin et al. 2016). In contrast, others have reported ventenata increases in areas that are heavily used by elk populations, even when cattle grazing has been excluded for decades (Johnson et al. 2013; Pavek et al. 2011). More work is needed to understand the interactions between both domestic and wild ungulates with this rapidly increasing exotic annual grass, particularly in the highly threatened and economically important grasslands of the Pacific Northwest Bunchgrass Prairie (Fitzpatrick, 2003).

Although it is widely accepted that grasslands evolved with both fire and ungulate grazing disturbances (Kanpp et al. 1999 Risser et al. 1981; Collins 1987), the majority of research historically focuses on their main effects and less upon their interactions (Fulehndorf and Engle 2004). More attention is given now to understanding the interactions between fire and grazing in numerous ecosystem types including the tallgrass prairie (Collins, 1987; Hobbs et al. 1991; Fuhlendorf and Engle, 2004; Collins and Smith, 2006), annual grasslands in California (Harrison et al. 2003), ponderosa pine forests (Kerns et al. 2011), savannas (Van Langevelde et al. 2003; Staver et al. 2009), and the Great Basin (Diamond et al. 2009; Diamond et al. 2012). While interactions between fire and grazing are variable by ecosystem type, their contribution to the development of grasslands makes them important tools for management of invasive species (Collins, 1987; Fuhlendorf and Engle 2004). The Pacific Northwest Bunchgrass prairie did not evolve with strong grazing pressure as was found in the Great Plains (Mancuso and Mosley, 1994). Prior to modern fire suppression efforts, this grassland would have low to moderate severity fires every 10-20 years due to the climate and fuel conditions (Black et al. 1998; Bartuszevige et al. 2012; and Hall, 1976). As stated previously, there is only one study that examines fire dynamics and ventenata in this system (Ridder et al. In Review) but there is currently no published research that examines interactions between prescribed fire and grazing on the native or exotic species responses on the Pacific Northwest Bunchgrass Prairie.

In this study, I explored how ventenata responded to prescribed fires, large ungulate herbivory (cattle and elk), and the interactions between them over the last 10 years on the PNB. I used monitoring data (2008, 2016, & 2018) from experimental prescribed fire and grazing study plots established in 2004 and burned in the fall of 2006 and 2016. The PNB plant communities are considered to be fire adapted and, therefore, ventenata invasion may not be favored by fire as in other ecosystems with longer fire-return intervals like those in the Great Basin (Ridder et al. *In Revision*). Although there is scant literature from which to hypothesize its response to prescribed fire and ungulate herbivory, ventenata appears to be capable of spreading regardless of either disturbance (Taylor and Schmalz, 2012; Ridder et al., in Review; Johnson et al. 2013; Pekin et al. 2016). Therefore, I hypothesize that prescribed fire, livestock grazing, and the interactions between them will have little to no effect on the increase of cover, frequency, and density of ventenata.

2.2 Methods

2.2.1 Study Site

This study was conducted on the Zumwalt Prairie Preserve (ZPP), owned and managed by The Nature Conservancy. The ZPP is located in northeastern Oregon (45° 34’ N, 116° 58’ W) and is a 13,300 ha remnant of the Pacific Northwest Bunchgrass prairie (PNB). This grassland system once encompassed eight million hectares of the Pacific Northwest, including several states and portions of British Colombia in Canada (Tisdale, 1982). The ZPP plant community is dominated by native perennial bunchgrass species including *Pseudoroegnaria spicata, Festuca idahoensis* Elmer, *Poa secunda* J. Presl, and *Koeleria macrantha* (Ledeb.) Schult. (Kennedy et al. 2009). The ZPP also hosts a high diversity of native forbs. The soils are categorized as Xerolls, that consist of colluvium and loess over Basalt (Schmalz et al. 2013). The Zumwalt Weather Station located on site (elevation of 1,335 m) recorded average winter (Dec-Feb) temperature at -2.7° C over the 2006-2015 period, and average summer (July-Aug) temperature was

15° C (Taylor, 2016). This system is categorized by cold moist winters and warm, dry summers. Total annual precipitation in the same 2006-2015 timeframe averaged 34.9 cm with 14.7 cm falling between April 1st and July 31st which is considered the main growing season (Taylor, 2016). The majority of the precipitation on this site falls during the winter with an average of only 2.7 cm falling during the summer each year over the same timeframe (Taylor, 2016) (Figure 2.3).

Approximately 90% of the historical extent of the PNB has been converted to agriculture (Tisdale, 1982), making the ZPP the largest remaining remnant of this grassland type. Through the Homestead Acts of 1862 and 1909, Euro-American settlers acquired land on what is now the ZPP (Bartuszevige et al. 2012). The large herds of livestock that accompanied settlement likely consumed much of the fine fuels for fire (Bartuszevige et al. 2012). Large herds of ungulates are a relatively recent addition to the PNB therefore the plant associations on the prairie have not evolved with strong grazing pressure (Mancuso and Mosley, 1994). This could result in more severe grazing impacts on the native plant association on the PNB compared to systems that have a longer history of supporting herds of large ungulates. Although there is no complete fire history for the ZPP, it is believed to have low to moderate severity fires every 10-20 years due to the climate and fuel conditions (Black et al. 1998; Bartuszevige et al. 2012). Prior to 2005, when The Nature Conservancy initiated a prescribed burning program, fires on the ZPP and surrounding grasslands were very infrequent (Morgan et al. 1996; The Nature Conservancy, unpublished data).

2.2.2 Study Design

In 2004, the Fire/Grazing plots (FG) were established on the ZPP with the intention of studying the effects of prescribed fire, grazing and their interaction (Figure 2.1). The study is a randomized complete block two-way factorial design with two levels of grazing (grazed and excluded) and two levels of prescribed burn (burned every ten years and unburned) (Taylor and Schmalz, 2012). Each block was split into four experimental units and randomly assigned to one of two grazing levels and one of two prescribed fire treatment levels. Thus, each treatment combination was replicated four times, once in each block (n=4). Each experimental unit is 100 x 300 m. The experimental units that were randomly assigned to control for the grazing treatment were fenced to exclude cattle. The grazed experimental units have been grazed by cattle every year from late July through August with a stocking rate ranging from 1.3-1.6 Hectares/AUM depending on available forage (Grazing Schedule, unpublished). Livestock were removed after no more than seven days. Experimental units assigned the burn treatment were burned in the fall of 2006 and 2016 (Grazing Schedule, unpublished). The burned treatments were implemented by USFS personnel in accordance to their prescribed burning procedure.

2.2.3 Sampling

The original monitoring data were collected two years after the first burns in 2008 within each 100 x 300 m experimental unit using six, 100-meter transects that ran parallel to the 100-m side and were spaced 50 m apart (Figure 2.2). Foliar cover data were collected using the line-point intercept (LPI) method with foliar hits recorded by species every three meters along each transect (Taylor and Schmalz, 2012). These points were then mathematically converted to percent cover. Ventenata nested frequency data were collected every six meters on the same six transects using frame sizes of 10 x 10 cm, 30 x 30 cm, and 100 x 100 cm. Ventenata was recorded in the smallest frame in which it was present and the counts were mathematically converted to percent frequency by experimental unit. In 2016 the monitoring protocol was adjusted and foliar cover data were collected using LPI every meter along 9, 50-meter transects that were 30 m apart within each experimental unit (Figure 2.2). Nested frequency data were collected every 2 m along 6 of the 9 transects (150 measurements per experimental unit) collecting data on the same species as listed in 2008. In addition, density of ventenata was collected in 10 x 10 cm quadrats every 2 m along the same 6 transects as were used to collect nested frequency data. Monitoring in 2018, two years after the second burn, followed the protocol for cover, frequency, and density as outlined for 2016. Change in ventenata frequency would be better detected in the 10 X 10 cm frame, thus this was the frame sized used to analyze frequency. The data representing ventenata cover, frequency, and density were summarized by experimental unit within years. Annual precipitation data have been recorded at a weather station on the Zumwalt Prairie Preserve for over a decade. I downloaded precipitation data from the ZPP website and summarized it for the sampling years in this study, 2008, 2016, 2018 (The Conservation Gateway, 2018).

2.2.4 Data analysis

To account for the repeated measures and blocked design of this study, I used a randomized block repeat measures mixed linear model ANOVA using Proc MIXED in SAS 9.4. Year, burn, graze and their interactions were treated as fixed effects. Block and the nested burn by grazing within block were treated as random effects. Year was the repeated measure with nested burn by grazing within block as the subject effect and the Kenward-Rogers degree of freedom method. I considered the covariance structures: compound symmetry, heterogeneous compound symmetry, antidependance, unstructured, and spatial power for the analysis and settled upon the antedependance covariance structure based on Akaike information criterion. To examine the differences within years and among treatment combinations as well as possible interactions I ran pairwise comparisons. I focused on comparisons with combinations of both levels of grazing and burning within each sampling year, as well as how the individual treatment combinations changed over time. Residuals were examined to ensure the assumptions of the mixed linear model were met. None were violated therefore no transformations were necessary. Interpretation of all analysis was conducted with an *a priori* alpha value of 0.05. However, given the growing acceptance that only presenting p values less than 0.05 does not provide full context, p values from all comparisons are reported. We also discuss the evidence that means are different when p values are low, or approximately near or less than 0.10 and effect size is biologically relevant (Wasserstein and Lazar 2016).

2.3 Results

The main effect of time (year) was a significant main effect for cover, frequency and density using a traditional alpha approach (P = 0.05, Table 2.1). There is some evidence that combined grazing reduced the frequency of ventenata across all sample years (p = 0.11, Table 2.1). Our other treatment effects and their interactions were negligible (Burn*Graze, Graze*Year, Burn*Year, and Burn*Graze*Year) for cover and density (Table 2.1). Comparisons by year between treatments revealed no significant (P < 0.05) differences between burned and unburned plots in cover (Figure 2.4; Table 2.2), frequency (Figure 2.5; Table 2.3) or density (Figure 2.6; Table 2.4). The only significant interaction was for frequency of ventenata in Graze*Year (Table 2.1). Comparisons of grazed treatments revealed significantly higher ventenata frequency in 2016 (Figure 2.5; Table 2.3). Further comparisons between the unburned grazed and burned excluded treatments revealed a difference of -39.66% frequency (p-value= 0.0255) and between the grazed and excluded treatments of 40.33% frequency (p-value = 0.0236) in the 2016 sampling year only (Figure 2.5; Table 2.3). There were no statistically significant treatment effects for density (Figure 2.6; Table 2.4). However, when comparing the burned, grazed and the unburned, grazed treatment, there was an estimated 527 plants/m^2 difference with burning in 2018, as well as a difference of 831 plants/m^2 when comparing the treatment combinations unburned grazed, and burned excluded, though neither are statistically significant (Figure 2.6; Table 2.4).

2.4 Discussion

The results from this study show that ventenata is consistently and significantly increasing in cover, frequency, and density over time on the Zumwalt Prairie Preserve. As expected, I found no differences in ventenata cover, frequency, or density in response to prescribed fire. These findings add support to previous studies suggesting that managers may be able to reintroduce prescribed fire to this system without high risk of conversion to ventenata and where the native system is still intact (Mackey, 2014; Taylor and Schmalz, 2012; Ridder et al. In Review). While I did not find consistently significant interactions between prescribed fire and livestock grazing on ventenata, livestock grazing without prescribed fire appears to promote a significant increase in ventenata frequency in at least one year, 2016. This could be a result of precipitation differences in 2016 but Bansal et al. (2014) suggest that cumulative soil moisture may be more important than the frequency and pulse size of precipitation events. The precipitation for the sampling year in 2016 had more spring moisture than that of the other sampling years (Figure 2.3). Further, the overall pattern of higher ventenata cover, frequency, and density where livestock are grazed without prescribed fire (Figure 2.4; 2.5; 2.6) suggests prescribed fire could be a factor but that my study did not have the statistical power to detect it. If so, it could be an effective management tool to reduce ventenata where livestock grazing occurs. For example, there was 17-25% estimated difference in ventenata frequency in 2018 and 2016 respectively (Table 2.3), a 7-15% difference in ventenata cover in 2016 and 2018 respectively (Table 2.2), and a 527 plants/m^2 difference in ventenata density in 2018 between pastures with livestock grazing and livestock grazing with prescribed fire (Table 2.4). Taken together, my results suggest that fall prescribed fire does not exacerbate ventenata invasion by increasing its cover, frequency, and density like has been found with cheatgrass in the Great Basin (Young and Evans, 1978). Fall prescribed fire does not appear to effectively contain the spread of ventenata either. However, it is possible that fall prescribed fire may help reduce ventenata where livestock are grazed in this system. Further, my results suggest that livestock grazing in combination with elk, but without prescribed fire, may contribute to a higher abundance of ventenata in the PNB.

Alternatively, the significant increase in ventenata frequency in grazed only experimental units in year 2016 without similar significant responses in cover and density could be related to other factors. One possible reason for this is the differences in timing since burns between sampling years. Both 2008 and 2018 were two years after the last fall prescribed fire. The sampling done in 2016 was ten years after the last which, could have resulted in varying results between the sampling years. Another possible explanation, is the potential for livestock to spread seeds through epizoochory distributing the seeds of ventenata within the grazed experimental units, causing an increase in the frequency of ventenata, to which cover and density are not as sensitive. In combination with the differences in invasion dynamics that are possibly being observed in the system, the 2018 sampling year may not have shown as strong of a difference in treatment due to ventenata being more prevalent in the system overall. Taken together, given the high frequency values for the sampling years 2016 and 2018, it could be that cattle and elk are distributing ventenata across the site resulting in somewhat of a ventenata saturated system, which may suggest ungulate grazing could vary in impact depending on what stage of invasion the site is experiencing. Another potential reason for this observed significance is the possibility for higher recorder error in cover, and density measurements than frequency measurements. Still, the pattern is consistent enough to suggest that livestock grazing without the use of prescribed fire may have undesirable impacts in terms of ventenata abundance.

My findings are consistent with a number of other studies examining the response of ventenata in the PNB grasslands as well as annual grasses in other grassland systems. For example, Taylor and Schmalz (2012) reported that ventenata frequency was increasing on the Zumwalt Prairie Preserve regardless of fire. These findings are also consistent with a previous retrospective study on the Zumwalt that showed historical prescribed fire did not appear to effect ventenata cover or frequency (Ridder et al. In Review). A similar increase in ventenata over time has also been recorded in this region on forested systems (Averett et al. 2016) as well as the canyon grasslands near my study site (Bernards and Morris, 2016; Johnson et al. 2013). Finally, my findings are consistent with a study on a tallgrass prairie system in Oklahoma where *Bromus tectorum* cover was significantly lower in burned and grazed plots than in plots that were just grazed (Collins, 1987). Collins (1987) attributed his finding to grazing reducing the dominant species allowing the less dominant species to proliferate. My study did not examine the effects on the surrounding vegetation, however, it is possible that there is a competitive dynamic that is shifting depending on disturbance.

Conversely, my findings are different from other research in the region and in other grasslands in several ways. For example, Haferkamp et al. (1984) reported an increase in ventenata density following summer fire. Other studies found ventenata established in trace amounts following forest thinning and prescribed fire treatments in Oregon's Blue Mountain forest systems (Youngblood et al. 2006). My study did not find any significant differences in ventenata density between burned and unburned treatments rather, the opposite trend was observed in experimental units that were grazed though not statistically significant (Figure 2.6). This observed difference could be a result of differences in timing of burn. Responders from a landowner survey suggested that fire was an ineffective tool to control ventenata, reporting higher dominance of ventenata following prescribed fire (Pavek et al. 2011). Prescribed fire did not significantly affect ventenata abundance, however on sites that were grazed prescribed fire may help maintain ventenata closer to levels as seen in the excluded paddocks.

Although my findings suggest that livestock grazing, in combination with extant elk herbivory, without fall prescribed fire can increase the overall abundance of ventenata in the PNB, there are several limitations to the inference of this study. For example, I did not experimentally manipulate cattle stocking rates throughout time or between plots in any way. Increasing stocking rates on the PNB have been show to increase soil compaction (Schmalz et al. 2013), alter vegetation structure (Johnson et al. 2011), and impact utilization and grazing preferences (Wyfells, 2009). Therefore, the results may vary in other sites depending upon the stocking rates and utilization. In addition, I did not have a full exclosures for elk herbivory so I could not test for the effects of elk independently. It is also possible that differences in abundance of ventenata, soils, and plant community play a confounding role in our results. For example, Endress et al. (in review) found that ventenata distribution and increase can be related to its location in either xeric, mesic, or a reseeded old-field. In addition, Bryant et al. (2013) reported interactions between livestock grazing, soil parent material, and topography influenced the abundance of ventenata. We did not map old fields, analyze our data using plant community, or collect soil data for this study. Future research should be done to examine the impacts of these factors on ventenata abundance.

Likewise, the findings in this study only relate to fall prescribed fire in this grassland type. Ventenata may have different fire dynamics across different ecosystems (Ridder et al. In Review). In the forested systems of the Blue Mountains in northeastern Oregon, for example, there is also concern that infilling of ventenata will provide more fine fuels that alter fire dynamics in open sites where native species ground cover is typically low (Fryer, 2017; Oliver, 2016). It is still unknown if ventenata will influence fine fuels in a way that initiates a positive feedback cycle promoting its own invasion, like the annual cheatgrass (Balch et al. 2013). In addition, I did not experimentally manipulate fire intensity, which could lead to different responses by ventenata. The timing of the burn and use of pretreatments that reduce the fuel load can also impact fire severity (D'Antonio et al. 2003). It is uncommon for seeds near the surface to be damaged by grassland fires (Daubenmire, 1968; Vogl, 1974). Burn severity indices on my experimental units never reached a heavily burned category for substrate, the only class that may have affected ventenata seeds at this time of year (Movich and Schmalz, 2016). Season of burn could impact fire severity, but even more so, a spring or summer burn could have more impact on ventenata seed prior to seed shattering. Further research should be done to determine the effect of timing of prescribed fire on ventenata abundance.

2.5 Conclusion

The results of my study add to the growing evidence that ventenata will not increase or decrease with fall prescribed fire in the Pacific Northwest Bunchgrass Prairie. I did not find significant differences in ventenata with livestock grazing alone except in one sampling year. However, the overall pattern of ventenata frequency, cover, and density across sampling years suggests that livestock grazing combined with elk herbivory may lead to more ventenata if those sites are not also managed with fall prescribed fire. It is important to keep these findings in ecological context since prescribed fire, grazing, and their interactions can have variable impacts across many different ecosystems, even when considering the same invasive species. Therefore, my inference is limited to the PNB system on a site that supports elk in large numbers, moderate livestock grazing, and fall prescribed burns. Even with these limitations, my results will add to the limited amount of research that has been conducted on this relatively new invasive annual grass. Further, my study demonstrates the importance of and a need for better understanding about these common grassland disturbances with respect to invasion on other grassland systems.

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Chapter 2: Figures

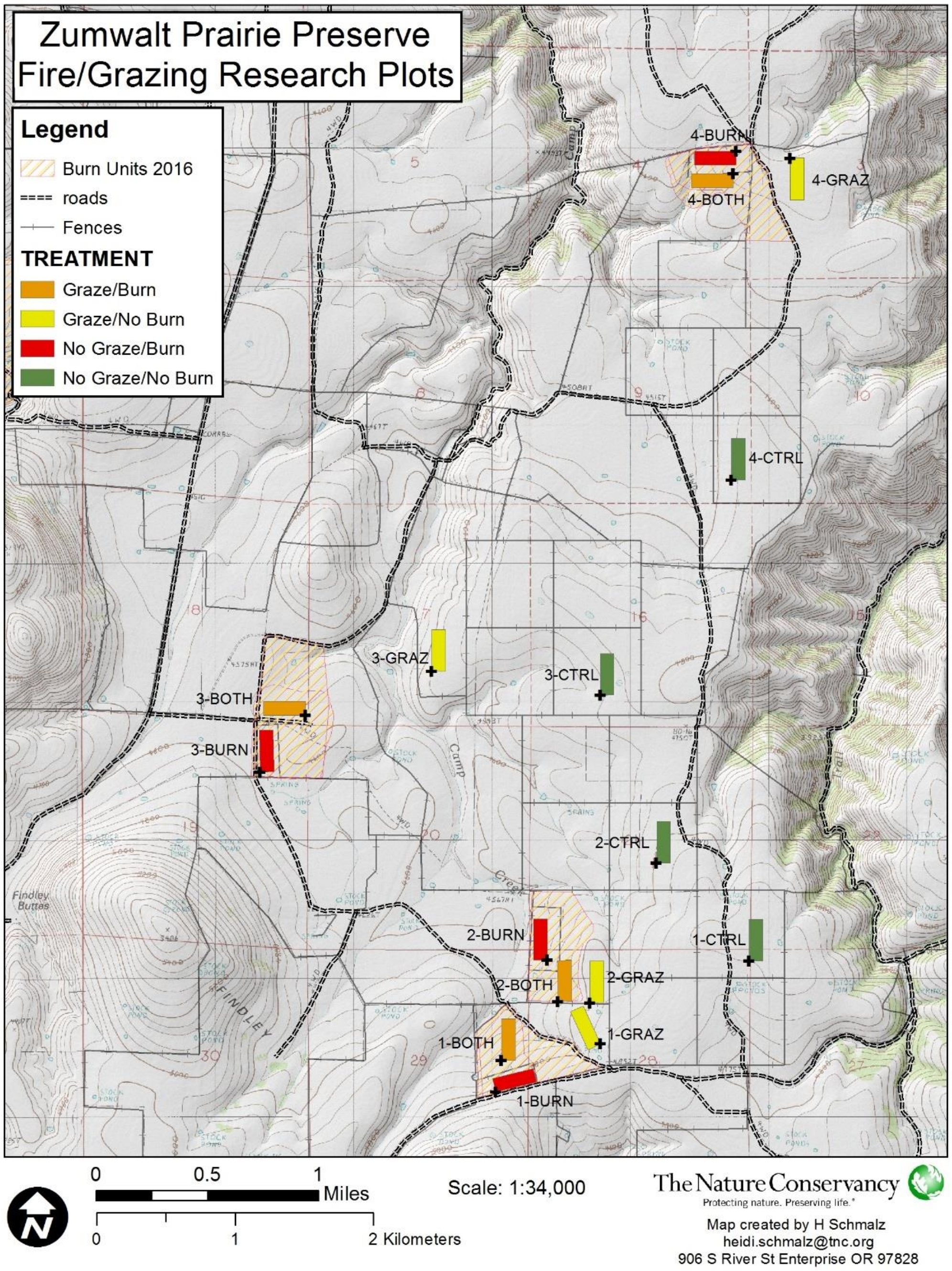

Figure 2.1 Map of Fire/Grazing plots with 2016 prescribed burn outline. Numbers represent Block, GRAZ represents the grazed*unburned treatment combination, BURN represents the excluded*burned treatment combination, BOTH represents grazed*burned treatment combination and CTRL represents the excluded*unburned treatment combination. (Map provided by Heidi Schmalz, The Nature Conservancy).

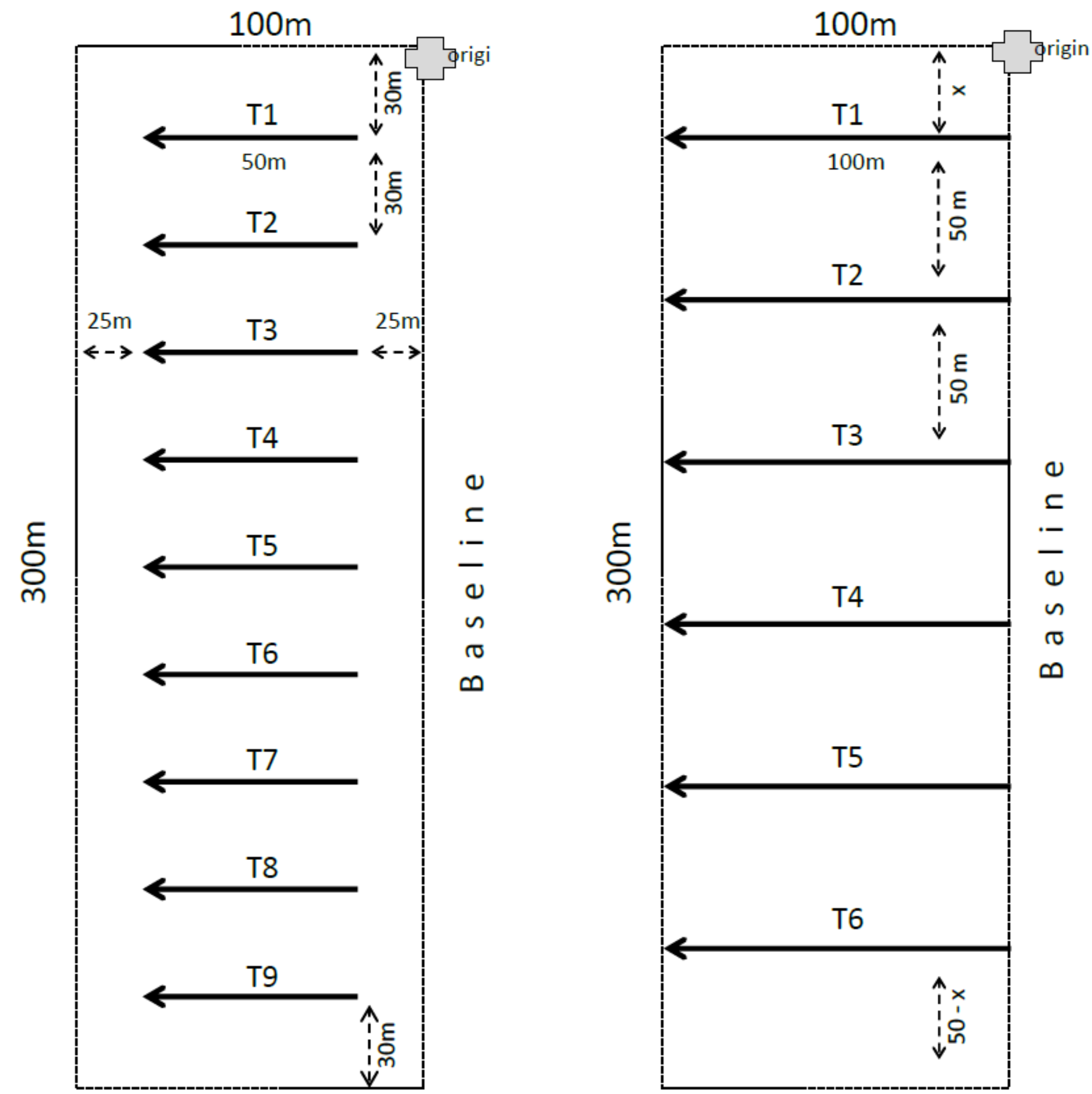

Figure 2.2 Plot layout for the sampling year 2008 (right) and the sampling years 2016 and 2018 (left).

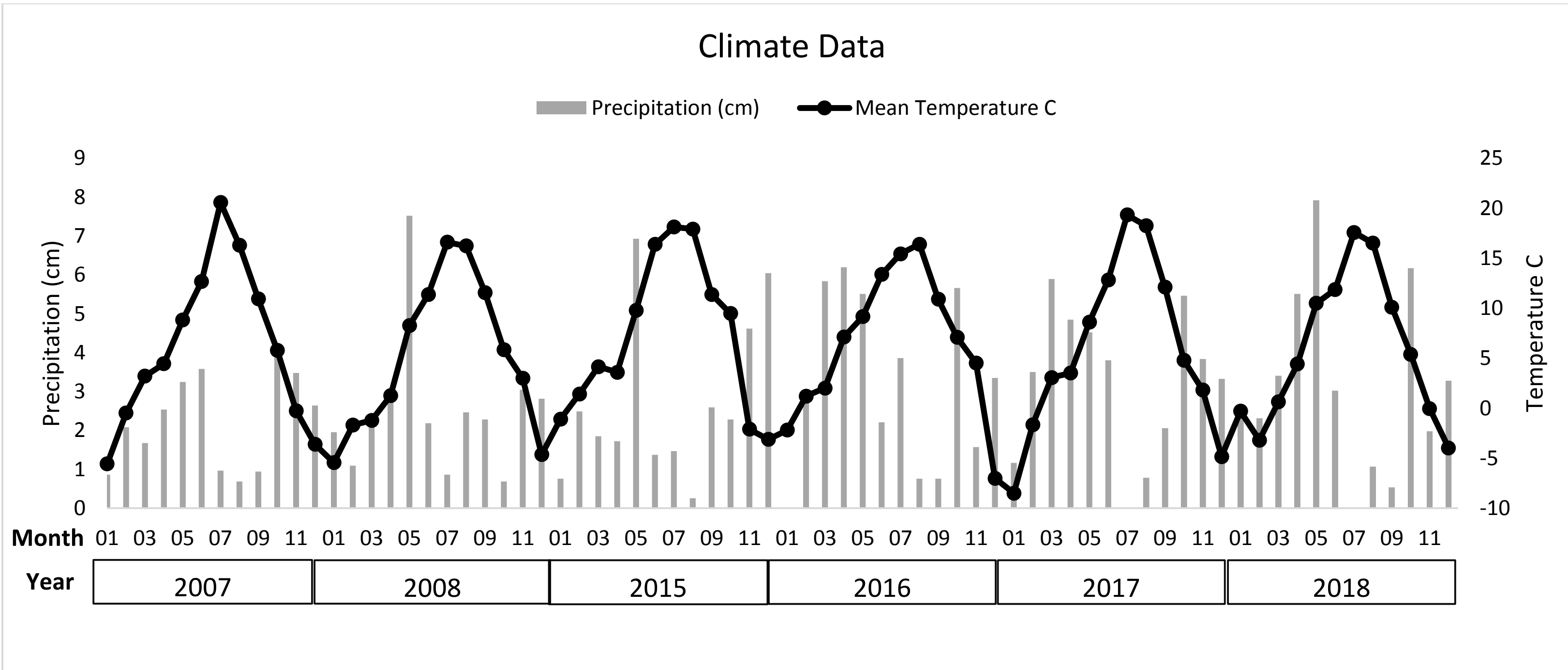

Figure 2.3 Monthly total precipitation and mean temperature for each sampling year as well as the years prior given the fall germination of ventenata on the Zumwalt Prairie Preserve, collected from an onsite weather station (The Nature Conservancy Unpublished data

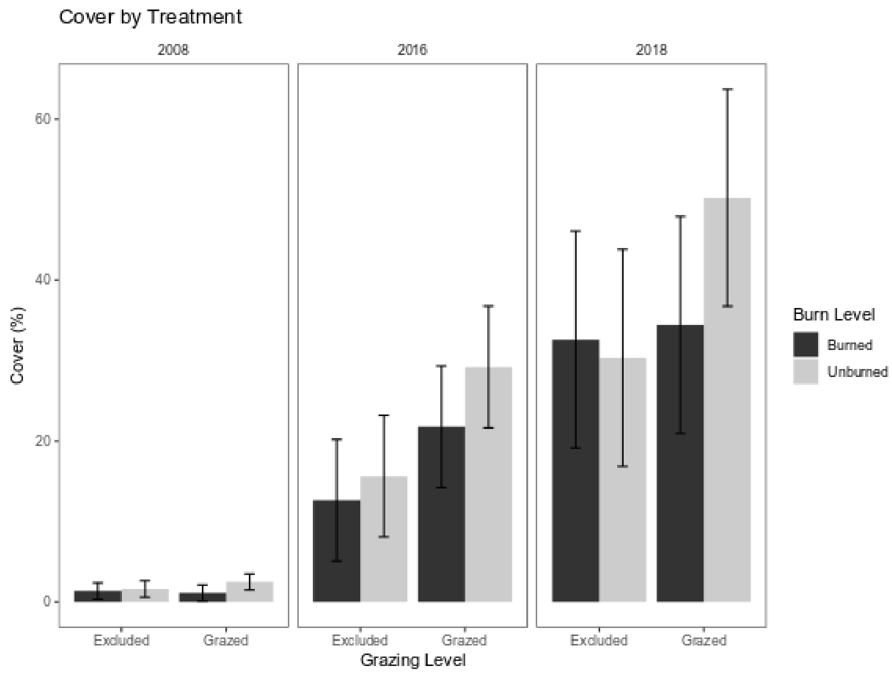

Figure 2.4 Percent cover of ventenata by treatment combinations within sampling year. No significance between treatment combinations within years. Error bars represent Standard Error.

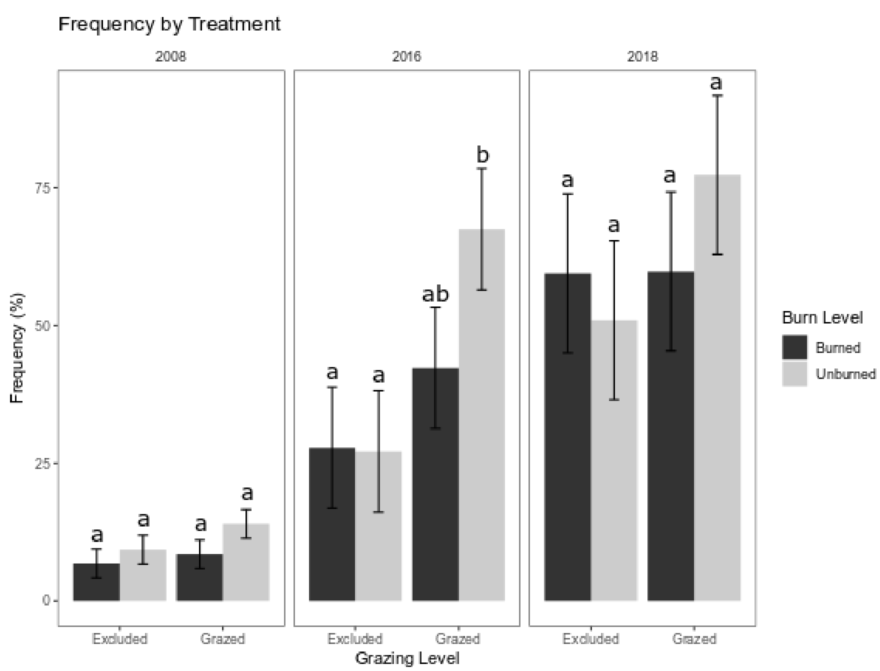

Figure 2.5 Ventenata frequency by treatment combination within sampling years. Different letters note significance ($p < 0.05$) only within sampling year. Error bars represent Standard Error.

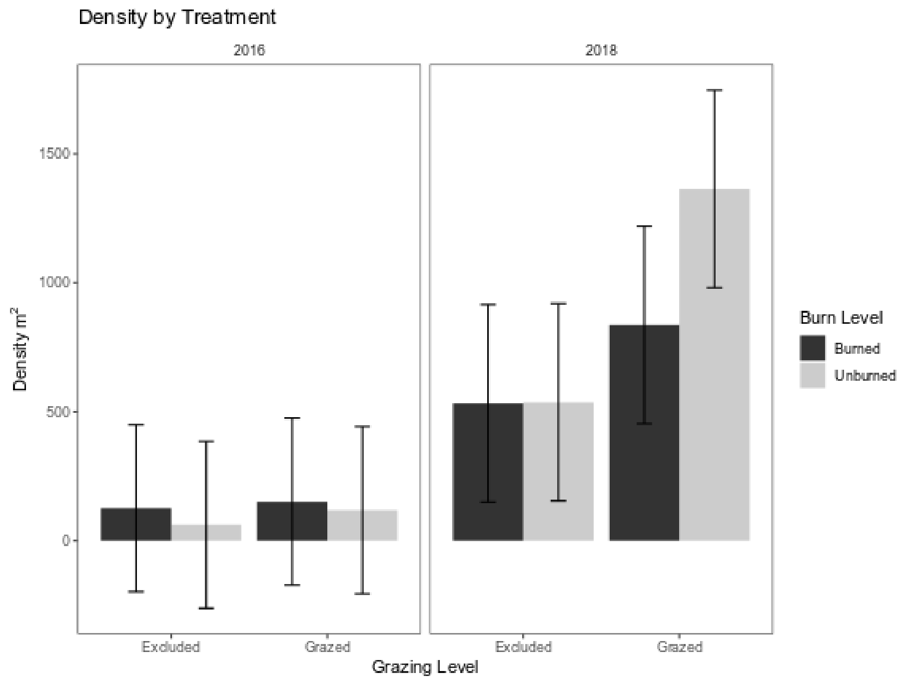

Figure 2.6 Density by treatment combination, with no significance within sampling years. Error bars represent Standard Error.

Chapter 2: Tables

	Cover			Frequency			Density		
Effect	DF	F-value	P>F	DF	F-value	P>F	DF	F-value	P>F
Year	11.2	13.19	**0.0011**	11.2	26.81	**<.0001**	21.6	15.63	**0.0007**
Burn	12	0.37	0.5558	12	0.65	0.4346	24	0.18	0.6744
Graze	12	1.14	0.3066	12	2.93	0.1128	24	1.41	0.2468
Burn*Graze	12	0.32	0.5849	12	1.14	0.3065	24	0.29	0.5925
Graze*Year	11.2	2.25	0.1512	11.2	5.01	**0.0279**	21.6	2.17	0.1553
Burn*Year	11.2	0.21	0.8165	11.2	0.93	0.4217	21.6	0.78	0.3871
Burn*Graze*Year	11.2	0.61	0.5584	11.2	0.59	0.5689	21.6	0.48	0.4958

Table 2.1 Fixed effects table for all three response variables: cover, frequency and density. Significant difference ($p < 0.05$) are emphasized in bold.

Treatment		Treatment Compared		Year	Estimate	Probt	Lower	Upper
Burned	Grazed	Burned	Excluded	2008	-0.25	0.864104	-3.36498	2.864984
Burned	Grazed	Unburned	Grazed	2008	-1.375	0.355157	-4.48998	1.739984
Burned	Grazed	Unburned	Excluded	2008	-0.5	0.732607	-3.61498	2.614984
Burned	Excluded	Unburned	Grazed	2008	-1.125	0.446614	-4.23998	1.989984
Burned	Excluded	Unburned	Excluded	2008	-0.25	0.864104	-3.36498	2.864984
Unburned	Grazed	Unburned	Excluded	2008	0.875	0.551946	-2.23998	3.989984
Burned	Grazed	Burned	Excluded	2016	9.125	0.409654	-14.1464	32.39641
Burned	Grazed	Unburned	Grazed	2016	-7.425	0.500191	-30.6964	15.84641
Burned	Grazed	Unburned	Excluded	2016	6.15	0.575394	-17.1214	29.42141
Burned	Excluded	Unburned	Grazed	2016	-16.55	0.14722	-39.8214	6.721408
Burned	Excluded	Unburned	Excluded	2016	-2.975	0.785344	-26.2464	20.29641
Unburned	Grazed	Unburned	Excluded	2016	13.575	0.227827	-9.69641	36.84641
Burned	Grazed	Burned	Excluded	2018	1.799999	0.926332	-39.7347	43.33467
Burned	Grazed	Unburned	Grazed	2018	-15.8083	0.423146	-57.343	25.72633
Burned	Grazed	Unburned	Excluded	2018	4.08611	0.833877	-37.4486	45.62078
Burned	Excluded	Unburned	Grazed	2018	-17.6083	0.373852	-59.143	23.92633
Burned	Excluded	Unburned	Excluded	2018	2.286111	0.906529	-39.2486	43.82078
Unburned	Grazed	Unburned	Excluded	2018	19.89444	0.317236	-21.6402	61.42911

Table 2.2 Individual treatment comparisons for the continuous cover response variable within sampling years.

Treatment		Treatment Compared		Year	Estimate	Probt	Lower	Upper
Burn	Grazed	Burn	Excluded	2008	1.666667	0.65958	-6.37339	9.706728
Burn	Grazed	Unburned	Grazed	2008	-5.5	0.161917	-13.5401	2.540061
Burn	Excluded	Unburned	Grazed	2008	-7.16667	0.075964	-15.2067	0.873395
Burn	Grazed	Unburned	Excluded	2008	-0.83333	0.82514	-8.87339	7.206728
Burn	Excluded	Unburned	Excluded	2008	-2.5	0.51096	-10.5401	5.540061
Unburned	Grazed	Unburned	Excluded	2008	4.666667	0.230018	-3.37339	12.70673
Burn	Grazed	Unburned	Grazed	2016	-25.1667	0.131849	-59.0774	8.744072
Burn	Excluded	Unburned	Grazed	2016	-39.6667	0.025529	-73.5774	-5.75593
Burn	Grazed	Burn	Excluded	2016	14.5	0.369887	-19.4107	48.41074
Burn	Grazed	Unburned	Excluded	2016	15.16667	0.349056	-18.7441	49.07741
Burn	Excluded	Unburned	Excluded	2016	0.666667	0.966538	-33.2441	34.57741
Unburned	Grazed	Unburned	Excluded	2016	40.33333	0.023594	6.422594	74.24407
Burn	Grazed	Unburned	Grazed	2018	-17.5	0.407698	-61.9389	26.93894
Burn	Excluded	Unburned	Grazed	2018	-17.8333	0.399087	-62.2723	26.60561
Burn	Grazed	Burn	Excluded	2018	0.333333	0.987229	-44.1056	44.77228
Burn	Grazed	Unburned	Excluded	2018	8.833333	0.672631	-35.6056	53.27228
Burn	Excluded	Unburned	Excluded	2018	8.5	0.684221	-35.9389	52.93894
Unburned	Grazed	Unburned	Excluded	2018	26.33333	0.220986	-18.1056	70.77228

Table 2.3 Individual treatment comparisons within sampling years for the frequency response variable.

Treatment		Treatment Compared		Year	Estimate	Probt	Lower	Upper
Burn	Grazed	Burn	Excluded	2016	25.86667	0.957846	-4930.46	4982.195
Burn	Grazed	Unburned	Grazed	2016	33.13333	0.933012	-771.935	838.2014
Burn	Grazed	Unburned	Excluded	2016	89.6	0.856261	-4866.73	5045.929
Burn	Excluded	Unburned	Grazed	2016	7.266667	0.988142	-4949.06	4963.595
Burn	Excluded	Unburned	Excluded	2016	63.73333	0.896894	-4892.6	5020.062
Unburned	Grazed	Unburned	Excluded	2016	56.46667	0.908479	-4899.86	5012.795
Burn	Grazed	Burn	Excluded	2018	303.5333	0.54666	-786.356	1393.422
Burn	Grazed	Unburned	Grazed	2018	-527.8	0.303911	-1617.69	562.089
Burn	Grazed	Unburned	Excluded	2018	299.6667	0.551681	-790.222	1389.556
Burn	Excluded	Unburned	Grazed	2018	-831.333	0.119312	-1921.22	258.5556
Burn	Excluded	Unburned	Excluded	2018	-3.86667	0.993812	-1093.76	1086.022
Unburned	Grazed	Unburned	Excluded	2018	827.4667	0.120829	-262.422	1917.356

Table 2.4 Individual treatment comparisons within each sampling year for ventenata density.

Chapter 3 *Ventenata dubia* response to herbivory on the Pacific Northwest Bunchgrass Prairie.

3.1 Introduction

Exotic plant invasions, particularly winter annual grasses, are a well documented threat to the integrity of grasslands around the globe (Drake et al. 1989) In the western US, the rapid dominance by cheatgrass (*Bromus tectorum*) has resulted in a significant increased fire frequency which favors its own lifecycle (D'Antonio and Vitousek, 1992) and can result in the native shrub communities' inability to recover (Whisenant 1990). A relatively new exotic annual grass, ventenata (*Ventenata dubia*), is rapidly spreading across much of the Palouse and the Pacific Northwest Bunchgrass Prairie (Nyamai et al. 2011). It was first recorded in the US in 1952 in the state of Washington, and has been documented in at least ten states as well as several provinces of southwestern and southeastern Canada (Scheinost et al. 2008). It is well established now in pasturelands, croplands, and a variety of ecosystems including grasslands, sagebrush steppe, ponderosa pine forests and woodlands (Bernards and Morris, 2016; Averett et al. 2016; Fryer, 2017; Jones et al. 2018). Despite this wide ecological distribution, the basic ecology and dynamics of this annual grass are just beginning to be studied (Wallace et al. 2015; Jones et al. 2018).

Ventenata is quickly raising concerns about impacts on agricultural production, wildlife habitat, plant community composition, and watershed services. Ventenata is already linked with forage yields declines by up to 75% (Wallace and Prather, 2011 abstracts) and hay producers being forced to adjust their Timothy (*Phelum pretense* L.)

hay harvesting schedules to reduce negative impacts (Fountain, 2011; Mackey, 2014). Ventenata also hosts the barley/cereal yellow dwarf virus, a pathogen that may infect plant species in both native ecosystems and croplands (Ingwell and Bosque-Pérez, 2014). Some suggest ventenata might be decreasing native species diversity and could even be competitively replacing other invasive winter annual grasses (Northam and Callihan, 1986; Johnson and Swanson, 2005). However, the only published competition study available demonstrated a competitive effect only on the native perennial grass bluebunch wheatgrass (*Pseudoroegnaria spicata* [Pursh] A. Löve) and no effect on other annual grasses (McKay et al. 2017). Still, it is spreading into the habitat of several federally-listed rare grassland plants across a variety of plant associations and successional stages (Bernards and Morris, 2016; Fryer, 2017; Endress et al. In Revision). It may also have cascading impacts on wildlife given that 50% ventenata cover shows effects on survival and fitness of tree swallows (*Tachycineta bicolor*) through reduced plant diversity, insect communities, and insect abundances (Mackey, 2014). Finally, ventenata may also increase the risk of soil erosion, due to its shallow rooting depth, leading to further habitat degradation and altered nutrient cycling within grassland ecosystems (Brooks et al. 2004; Mackey, 2014).

Many studies across a variety of ecosystem types have demonstrated a connection between overgrazing by livestock (mainly cattle) and the invasion of the exotic annual cheatgrass (Young, 1943; Wright and Wright, 1948; Hutchings and Stewart, 1953; Pickford, 1932; Costello and Schwan, 1946; Spilsbury and Tisdale, 1944;

Billings 1952). These connections can include spreading seeds, soil disturbance, and unpalatability. However, there are still many unanswered questions about the dynamics between large ungulate herbivory and this newer invasive species in the region. Cattle and elk are capable of spreading seeds of invasive plants in two different ways. One is endozoochory, which is the passage of seeds through the digestive tract, and the other is epizoochory which is when the seeds are attached to the animal's body (Janzen, 1984). Not only do ungulates have the potential to transport the seeds of invasive plants, they are also known to increase bare ground, erosion and soil compaction, all of which, are disturbances that can facilitate the establishment and germination of invasive plants (Schulz and Leininger, 1990; Sheley and Petroff, 1999). Further, palatability of plants in the ecosystem is a key factor to how the landscape is going to be effected by grazing (Augustine and McNaughton, 1998). The relatively high levels of silica (~2.7%) in ventenata have reportedly made it an undesirable forage species for herbivores (Pavek et al. 2011). In fact, livestock producers, land managers, and researchers report anecdotally that cattle, elk, and horses avoid eating ventenata or bite off seed heads and spit it the rest of it out. However, Pekin et al. (2016) found no significant increase in cover of exotic annuals grasses (including ventenata) in plots grazed by elk (*Cervus canadensis*) or grazed by cattle in semi-arid conifer forests. In contrast, others have reported ventenata increases in areas that are heavily used by elk populations (Johnson et al. 2013; Pavek et al. 2011). Bryant et al. (2013) found that exotic species including ventenata had a cover value that was 5 times greater on grazed Mima Mounds than ungrazed mounds that were underlain by basalt. Cleary, more work is needed to understand the invasion dynamics between both domestic and wild ungulates with this rapidly increasing exotic annual grass.

The overarching objective in this study was to examine the relationship between *Ventenata dubia* biomass and cover with large ungulates on the Pacific Northwest Bunchgrass Prairie (PNB). To meet this objective, I used a set of livestock grazing exclosures that were established in 2004. Specifically, I tested for differences in ventenata cover and standing crop between paddocks with only elk access and paddocks with both cattle and elk. Although the PNB has a history with livestock grazing (Bartuszevige et al., 2012), the plant associations in this grassland did not evolve with large herds of ungulates (Mancuso and Mosley, 1994). It is believed that grazing has had a significant effect on plant community and structure since the introduction of livestock in the late 18th and early 19th centuries (Daubenmire, 1940; Johnson, 1994). Heavy livestock grazing is known to potentially replace native bunchgrass on the PNB resulting in degraded sites with decreased topsoil, increased exotic plants, reduced productive potential, and a decreased biological diversity (Johnson, 1994). Given these findings, I expected that the paddocks grazed by cattle and elk would have higher cover and standing crop of ventenata than paddocks with elk herbivory only. A comparative understanding between cattle and elk and elk only herbivory on the invasion of ventenata will add to the research needed about this relatively new invasive annual grass. It should also be helpful for management and conservation of the PNB, considered one of the most threatened and understudied grasslands in North America (Tisdale, 1982)

3.2 Methods

3.2.1 Study Site

This study was conducted on The Nature Conservancy's Zumwalt Prairie Preserve (ZPP) in northeastern Oregon (45° 34′ N, 116° 58′ W). The ZPP is a 13,300 ha remnant of the Pacific Northwest Bunchgrass prairie (PNB), a grassland that once covered eight million hectares of the Pacific Northwest, including several states and portions of British Colombia in Canada (Tisdale, 1982). The Nez Perce Tribe historically grazed both horses and cattle on the ZPP prior to their forced removal in 1877 (Bartuszevige et al 2010). When Euro-American settlers acquired land on the prairie through the Homestead Acts of 1862 and 1909, they brought large herds of livestock with them (Reid, 1985; Bartuszevige et al. 2012). Crop production did not last for long on the ZPP, due to short growing seasons and shallow soils, but livestock grazing for beef cattle has remained the major land use in the area for over fifty years (Bartuszevige et al 2010; Jansen et al. 2016).

The ZPP is dominated by native perennial bunchgrass species including *Festuca idahoensis* Elmer, *Psuedoroegnaria spicata*, *Poa secunda* J. Presl and *Koeleria macrantha* (Ledeb.) Schult. (Kennedy et al. 2009), and includes a high diversity of native forbs (Kennedy et al. 2009). Soils on the ZPP consist of colluvium and loess over basalt and are mostly classified as Xerolls (Schmalz et al. 2013). The climate of the Zumwalt Prairie is characterized by cold, wet winters and warm, dry summers. Winter (Dec-Feb) temperatures reported from the Zumwalt Weather Station, located near the center of the study area (elevation of 1,335 m) averaged -2.7°C over the 2006-15 period and average summer (July-Aug) temperatures were 15.0 °C (Taylor, 2016). Total annual precipitation over this period averaged 34.9 cm, 14.7 cm of which fell during the main growing season (April 1st - July 31st). Summers are very dry with an average of only 2.7 cm of rain falling each year. The year 2015 represented the warmest year on record and total precipitation received was 31.9 cm, approximately 3cm lower than the 2005-2008 average (Taylor, 2016). Spring and early fall precipitation patterns in 2018 were above the 13-year average for the ZPP (2006-2018). April and May experienced precipitation totals that exceeded 145% the 13-year average for those months, followed by a drier than normal July-September. Rainfall in October was close to doubling the 13-year average (Thomas and Rossman, 2018).

3.2.2 Study Design

To address my research question, I resurveyed a subset of plots that were originally part of a larger, multidisciplinary study examining the effects of livestock grazing on grassland food webs (Damirian et al. 2007; Johnson et al. 2011; Johnson et al. 2012; Schmalz et al. 2013; Darambazar et al. 2007) established in 2004. The study design I utilized (from the larger study) was a randomized complete block design with four blocks (A, B, C, D) and two treatment levels: 1) grazed (1.3-1.6 ha/AUM), and 2) fenced to exclude cattle, but open to elk (excluded). The experimental units (treatment paddocks) under the excluded treatment have maintained this treatment since 2004, and the grazed treatment experimental units were selected form the original study based on the most consistent grazing history. Each experimental unit is 40 ha in size. To guard against confounding conditions based on the legacy of grazing, I conducted preliminary analysis on the standing crop of ventenata on the dataset from the original study and found no treatment effect. In fact, ventenata represented only a fraction of the biomass of annual grasses (data not shown) and all exotic annual grasses made up only 4% of total production in the paddocks in 2006 (Darambazar et al. 2007). Within each experimental unit were 18 equally spaced sampling plots (for a total of 144 for the entire study) (Figure 3.1). The Nature Conservancy maintained a moderate grazing intensity since 2009 (Table 3.1).

3.2.3 Sampling

Data collection was completed between June 12th and July 9th, 2018. I relocated the monitoring plots using a handheld GPS. Following previous methods (Damiran et al. 2007), I placed a rectangular frame (0.5 x 1 m) lengthwise on the East side of the sampling plot. Prior to sampling, I took photos of each frame. I collected cover data using ocular estimation by functional group (ventenata, forb, annual grass, perennial grass) instead of by species (Damiran et al. 2007). Cover data were recorded as a continuous variable. Standing crop was collected by using two categories, ventenata and other vegetation, rather than separating by all species. Standing crop was collected by clipping all vegetation within the 0.5 x 1 m rectangular frame to ground level, removing dead plant material, and then separating and bagging the vegetation by category. All the samples were oven dried at 60 C° for at least 24 hours prior to weighing them to the nearest 100th gram. Standing crop in grams per meter squared was calculated by doubling the weights.

3.2.4 Data Analysis

Cover and standing crop (g/m^2) plot data were averaged at the experimental unit level. For cover there were four functional group responses: ventenata, annual grasses which consisted of only nonnative species, perennial grasses and forbs. A mixed linear model ANOVA using Proc MIXED in SAS 9.4 was used to analyze both standing crop and functional group cover response with treatment (grazed or excluded) as the fixed effect and block as the random effect. Residuals were examined to ensure assumptions were met and none were violated therefore no transformations were needed. Interpretation of all analysis was conducted with an *a priori* alpha value of 0.05. However, given the growing acceptance that p values of 0.05 do not provide full context, all comparisons are reported (Wasserstein and Lazar 2016).

3.3 Results

Ventenata cover and standing crop did not significantly differ between treatments (Table 3.2). The difference between paddocks grazed by cattle and the excluded paddocks in ventenata biomass was an estimated 14 g/m^2 (Table 3.2). The difference for ventenata cover was 4.27% (Table 3.2; 3.3). Annual grass also had a treatment difference of 1.38%, where the other two functional groups, perennial grass, and forbs showed a very minimal response with 0.79% and 2.19% (Table 3.3). There appeared to be a difference in treatment effect between blocks. All but one block saw an increase in ventenata cover and biomass with block B being the exception (Table 3.4). Block A had almost 8 times more ventenata cover in the grazed paddock than the excluded, where blocks C and D had at least 2 times more ventenata in the grazed paddock. Block B had the opposite effect with 3% more ventenata cover in the excluded paddock than the grazed (Table 3.4). A similar trend was observed with standing crop of ventenata.

3.4 Discussion

The results of my study did not strongly support my expectation that paddocks with both cattle and elk herbivory would have higher cover and standing crop of ventenata than those excluded from cattle. Although I did not find a significant difference between grazed and excluded experimental units in 2018, my study does document an overall increase in ventenata since these paddocks were established and monitoring on them began. When data collection was initiated, percent cover of ventenata was not even mentioned and exotic annual grasses were reported to make up only 4% of the overall standing crop across all paddocks (Darambazar et al. 2007). By

2018, ventenata contributed 14% of overall standing crop (19% and 16% in grazed and excluded, respectively Table 3.5). My finding that ventenata cover was not significantly different is consistent with another study that found no differences in cover of annual grasses (including vententata) with herbivory by cattle and elk (Pekin et al., 2016). Average standing crop of ventenata was only about 32 g.m2, as ventenata has a lower above-ground biomass than other annual exotic grasses and native species (McKay et al. 2017; James 2008). I found there was a 14g/m2 difference between grazed paddocks and excluded paddocks (P = 0.14). This pattern may be biologically relevant and important in a management context.

Interestingly, my findings do not necessarily exclude the possibility that livestock grazing is aiding the invasion of ventenata. Blocks A, C, and D all had at least double standing crop and cover of ventenata in the grazed paddocks than the excluded paddocks with block B as the lone exception with the opposite trend (Table 3.4). Therefore, it is possible that variability between blocks contributed to the lack of statistical significance in this study. This could suggest the possibility that combined herbivory by cattle and elk may lead to more ventenata in the future even though the effect was not captured here. The variability in cover and standing crop between blocks could be the result of several factors that I could not examine with this study design including the overlapping dynamics with elk herbivory, soil differences, stocking rates and timing of use.

This is an observational study and I did not employ different experimental stocking rates, something that often reveals significant responses in soils (Willatt and Pullar, 1984; Potter et al. 2001; Schmalz et al. 2013), vegetation structure (Fuhlendorf et al. 2001; Johnson et al. 2011) and species composition (Willms et al. 1985). So, it is possible that my findings show no significant difference with cattle grazing because the overall moderate level of grazing in the Zumwalt Prairie Preserve (Table 3.1), a characteristic of management that makes it a model system for positive interactions (Wyfells, 2009).

In this study the cattle herbivory treatment occurred with existing elk herbivory as exclosure fencing did not exclude elk. The effect of cattle grazing may be quite different in the absence of elk grazing. In this study area wild ungulate grazing pressure is high. Elk herds on the ZPP have been increasing over recent decades from approximately 586 individuals in 1990 with 20% being counted on the Zumwalt to approximately 2577 individuals in 2017 with 66% being counted on the Zumwalt, where they use this prairie as a winter range (TNC unpublished data). Banks and Baker (2011) found that areas within elk winter range had a higher percent cover of cheatgrass than did the areas outside the winter range. In nearby Hells Canyon Recreation Area, Johnson et al. (2013) found an increase of ventenata on sites that were impacted by elk when compared to non-impacted sites, even where cattle had been excluded for 17 years. The elk population in this study area had been similarly increasing from 2,000 animals and peaking at over 5,000 (Johnson et al. 2013). Conversely, research in the Blue Mountains of eastern Oregon found that richness of exotic annual grasses increased in cattle only plots, decreased with elk only plots but had no difference with control of both ungulates (Pekin et al. 2016). Since this study did not have elk excluded pastures, the direct effects of elk herbivory compared to cattle herbivory on cover and standing crop of ventenata cannot be addressed, however, the issue may be challenging for managers to address given the high population of elk now sustained throughout the region (TNC unpublished data). Since this study did not incorporate elk exclosures nor did we collect utilization data in the excluded paddocks the effects of elk in the paddocks that were excluded from livestock are unknown aside from their presence.

There could also be a confounding effect of soils influencing the cover and standing crop of ventenata in my study. Bryant et al. (2013) found that exotic species, including ventenata, had 5 times greater cover on grazed Mima Mounds than ungrazed mounds that were underlain by basalt. Likewise, Jones et al. (2018) found positive relationship between ventenata cover and clay soils in the sagebrush steppe. The soils on the ZPP are also largely from a Basalt substrate and were described at each of the monitoring points in previous work (Schmalz et al. 2013). This could contribute to an explanation to the variability between blocks, however, our sampling did not specifically address this question.

In addition, I did not test for differences between stocking rates or timing of use. Stocking rate is known to have a significant impact on species composition of grasslands (Willms et al. 1985). Further, since overgrazing is known to decrease the more palatable species (Crawley, 1983) while increasing annual exotic species (Mack, 1989; Reisner et al. 2013), it is possible that higher stocking rates could result in higher ventenata cover and standing crop in the future or in other locations. Timing of grazing could also impact the effects grazing on ventenata cover, and standing crop. With other grass species, timing of grazing could impact these measures primarily through the reduction of seed production limiting the seed bank (O'Connor and Pickett, 1992). For example, Daubenmire (1940) found that if cheatgrass is grazed uniformly in the spring it can potentially be a control method. However, ventenata is considered unpalatable (Pavek et al. 2011) and therefore, control with grazing in spring may not limit its seed production. Its late phenological development and growth rate may contribute to its increase with spring grazing pressure because it is simply too short to be consumed by cattle (Wallace and Prather 2015). Both palatability and timing of use could likely contribute to the differences in block B in my study since grazing starts earliest in block A and proceeds through summer to block D. It is possible that differences in ventenata cover and standing crop were higher in block A since it is too early to be eaten by cattle, then reaches a height were it can be eaten by cattle and is not coarse and unpalatable in Block B, but when the grazing treatment reaches blocks C and D it has matured enough to be unpalatable. It is also more likely that cattle contribute to spread of the ventenata seed as they move from blocks B, C, and into D, potentially explaining the overall increase in the exotic species there. It has been predicted that cattle can disperse more exotic seed than either elk and deer per animal (Bartuszevige and Endress 2008).

3.5 Conclusion

This study is the first of its kind to document the differences in standing crop of ventenata between areas with cattle grazing and elk and those with only elk herbivory in uplands of the Pacific Northwest Bunchgrass Prairie. It adds to the knowledge of potential interactions between large ungulate herbivores and to the ecological understanding of herbivory and exotic invasion in temperate grasslands. However, it does not answer all questions about the invasion dynamics of ventenata in relation to livestock and native ungulates. Clearly, more work is needed to understand how the timing of use by livestock and elk contribute to the invasion process. In addition, it would be useful to know if and when either livestock or native ungulates will consume ventenata. Further, if they are eating the seeds and then spitting out the culms, does the seed spread via endozoochary with cattle or elk or both? The Zumwalt Prairie and the Zumwalt Prairie Preserve represent the last intact portions of the PNB in the region and in conservation respectively. Given the rate of increase in ventenata on this grassland (Ridder et al. In Revision, Averett et al. in prep) and the conservation needs of this and other temperate grasslands in the region, research will need to keep pace if there is to be any chance to protect these unique and endangered grasslands.

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Chapter 3: Figures

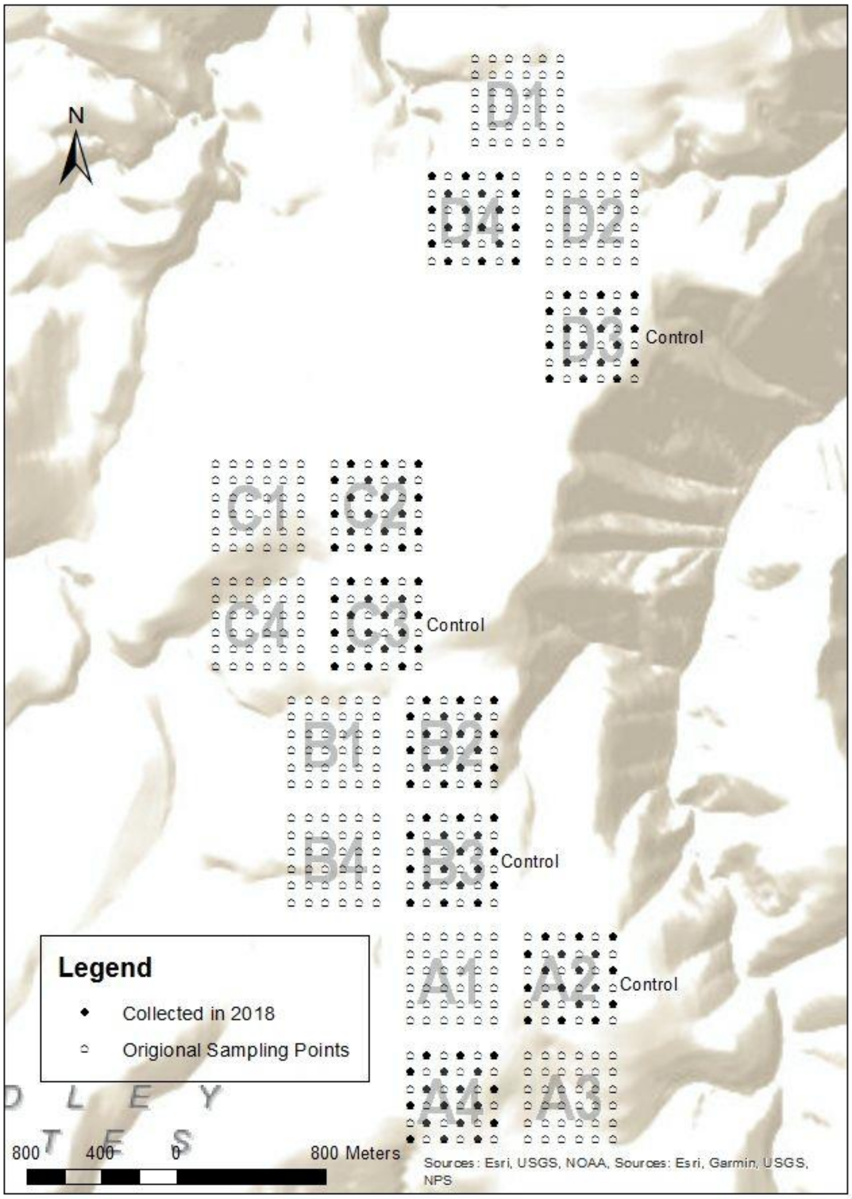

Figure 3.1 Map of collected sampling points from 2018. Control paddocks (A2, B3, C3, and D3) have been excluded from livestock grazing since 2004.

Chapter 3: Tables

Paddock	Year	In Date	Out Date	AUM/Acre	AUM/Hectare
A4	2010	9/1/2010	9/17/2010	0.29	0.72
B2	2010	9/10/2010	10/1/2010	0.24	0.60
C2	2010	9/10/2010	10/1/2010	0.20	0.50
D4	2010	10/13/2010	10/29/2010	0.26	0.65
A4	2011	9/15/2011	9/25/2011	0.12	0.30
B2	2011	6/23/2011	7/8/2011	0.33	0.81
C2	2011	10/16/2011	11/14/2011	0.14	0.35
D4	2011	9/8/2011	9/28/2011	0.13	0.32
A4	2012	10/5/2012	11/7/2012	0.40	0.99
B2	2012	7/27/2012	10/4/2012	0.36	0.88
C2	2012	6/17/2012	7/22/2012	0.38	0.94
D4	2012	5/31/2012	6/21/2012	0.33	0.81
A4	2013	6/1/2013	6/6/2013	0.41	1.02
B2	2013	6/19/2013	6/23/2013	0.35	0.85
C2	2013	7/22/2013	8/5/2013	0.34	0.85
D4	2013	10/14/2013	11/13/2013	0.24	0.60
A4	2014	8/29/2014	10/1/2014	0.29	0.72
B2	2014	NA	NA	NA	NA
C2	2014	8/29/2014	10/1/2014	0.29	0.72
D4	2014	7/24/2014	8/28/2014	0.31	0.77
A4	2015	8/31/2015	9/30/2015	0.34	0.84
B2	2015	NA	NA	NA	NA
C2	2015	NA	NA	NA	NA
D4	2015	9/7/2015	9/12/2015	0.14	0.35
A4	2016	9/21/2016	9/25/2016	0.24	0.60
B2	2016	6/5/2016	6/7/2016	0.22	0.55
C2	2016	NA	NA	NA	NA
D4	2016	10/16/2016	11/19/2016	0.40	0.99
A4	2017	5/23/2017	5/26/2017	0.29	0.72
B2	2017	6/8/2017	6/11/2017	0.29	0.72
C2	2017	6/23/2017	6/26/2017	0.29	0.72
D4	2017	7/9/2017	7/19/2017	0.29	0.71
A4	2018	6/19/2018	6/21/2018	0.30	0.73
B2	2018	6/28/2018	6/30/2018	0.30	0.73
C2	2018	7/10/2018	7/12/2018	0.30	0.73
D4	2018	7/13/2018	7/15/2018	0.30	0.73

Table 3.1 Grazing history for the experimental units sampled in 2018.

Measure	Effect	Estimate	DF	t-Value	P>t	Lower	Upper
Cover (%)	Treatment	-4.2778	3	-1.76	0.1768	-12.02	3.47
Standing Crop (g/m^2)	Treatment	-14.0489	3	-1.98	0.1425	-36.66	8.57

Table 3.2 Differences of Least Squares Means for cover and standing crop of ventenata. "Estimate" represents estimated difference of unit between excluded and Grazed treatments.

CATEGORY	EXCLUDED	GRAZED	Estimate	P>t	Lower	Upper
VEDU	5.91%	10.19%	-4.28%	0.1768	-12.0171	3.4616
A-GRASS	3.45%	4.83%	-1.38%	0.5089	-7.0085	4.3418
P-GRASS	28.84%	28.05%	0.79%	0.7653	-6.8574	8.4267
FORB	26.38%	24.19%	2.19%	0.5023	-6.9889	11.3776

Table 3.3 Differences of Least Squares Means for cover of functional groups between grazing treatments. (VEDU = *Ventenata dubia*, A-Grass = all annual grass aside from *Ventenata dubia*, P-Grass = all perennial grasses, Forb = all forbs.

Block	Excluded % Cover	Grazed % Cover	Excluded g/m^2	Grazed g/m^2
A	1.36%	9.00%	0.98	26.38
B	7.94%	4.63%	31.86	25.92
C	7.76%	16.33%	17.76	31.66
D	9.57%	18.18%	49.97	72.81

Table 3.4 Average percent cover and standing crop of ventenata by block and treatment.

Treatment	VEDU (g/m^2)	OTHER (g/m^2)	TOTAL (g/m^2)	% VEDU	% OTHER
Grazed	39.19	199.15	235.78	18.82	81.19
Excluded	25.15	194.23	220.61	15.96	84.03

Table 3.5 Mean of "VEDU", "OTHER" and "TOTAL" standing crop measurements by treatment presented as g/m^2. (VEDU = Ventenata dubia, OTHER = All other vegetation in the plot)

Chapter 4 Conclusions

4.1 Conclusion

Like so many other exotic annual invasive grasses, ventenata (*Ventenata dubia*) has become a serious concern for managers across the Pacific Northwest with impacts to Timothy hay producers (Fountain, 2011; Mackey, 2014), forage production (Wallace and Prather, 2011), and Tree Swallow survival (Mackey, 2014). It is also a concern because it hosts a virus that can infect both crop species and native plants (Ingwell and Bosque-Perez, 2014) while it occupies habitat with federally-listed grassland plants (Bernards and Morris, 2016; Fryer, 2017; Endress et al. in prep). It is also has rapidly invaded the last of the intact Pacific Northwest Bunchgrass Prairie, a grassland system that is both endangered and understudied (Tisdale 1982). Unfortunately, since ventenata is a recent invader, its invasion dynamics are just beginning to be studied (Wallace et al. 2015). The studies described in this thesis provide useful knowledge regarding the response of ventenata when exposed to common management disturbances such as prescribed fire and grazing.

My first study (Chapter 2) explored the effects of fall prescribed fire, summer grazing and their interactions on ventenata abundance using long term monitoring plots established by the Nature Conservancy in 2004 (Taylor and Schmalz, 2012). Since ventenata is an invasive winter annual grass it is often assumed to respond similarly these disturbances as the common invasive winter annual *Bromus tectorum* (cheatgrass) (Nyamai et al. 2011). The response of cheatgrass to fire has been well documented, particularly in the Great Basin (Young and Evans, 1978; Billings, 1994; D'Antonio and

Vitousek, 1992). This study highlights the differences of these grasses in these two different ecosystems. The findings of this first study are consistent with others that report an increase of ventenata over time, regardless of fire (Taylor and Schmalz, 2012; Ridder et al. In Revision). My findings suggest the use of fall prescribed burns do not exacerbate ventenata, rather cattle grazing, which has been used in many instances to control cheatgrass in other systems (Diamond et al. 2009), may result in undesirable expansion of ventenata in the PNB system. There are numerous possible explanations to this that my study did not examine. One hypothesis for the overall pattern of higher ventenata abundance in the grazed sites is the possibility for cattle to be distributing ventenata seeds either through their digestive tract or through external transport. The implemented measure that would be most sensitive to observing this would be frequency, which had statistically significant results for the sampling year 2016. This year was also the year that had the longest time since burn (ten years), compared to both 2008 and 2018 which were recorded 2 years post fall prescribed burns. It is clear that more research is need to determine the different effects that cattle and elk grazing may have on the abundance of ventenata.

The second study (Chapter 3) compared ventenata cover and standing crop between paddocks grazed by both cattle and elk to paddocks where cattle had been excluded since 2004 (Damirian et al. 2007; Johnson et al. 2011; Johnson et al. 2012; Schmalz et al. 2013; Darambazar et al. 2007). Although the findings of this study were statistically insignificant for both cover and standing crop of ventenata, examining the results by block revealed there were differences between grazed and excluded paddocks for three of the four blocks. Based on the pattern of the other three blocks, I proposed that livestock grazing may be influencing the increase in ventenata over time. Ventenata was not mentioned in the original study in 2006 (Darambazar et al. 2007) where in 2018 it is contributing to 14% overall standing crop. I suggested that timing of use may be part of the reason for the different response in one block. My study did not exclude elk so there was an unmeasured amount of use from the growing population of elk that inhabit the study area (TNC unpublished data). Overall, ventenata cover and standing crop had clearly increased since cattle were first excluded, supporting the work of others showing increases in ventenata on areas that have been excluded from cattle for 17 years and elk were present (Johnson et al., 2013). However, more research is clearly needed to explain the response of ventenata to large ungulate herbivory since my study design did not allow me to test for exclusion of elk herbivory, increasing stocking rates, or differences with timing of use.

This thesis provides much needed information regarding the dynamics of ventenata with prescribed fire and large ungulate herbivory. Given the limited literature on this topic much more is needed to examine the effects on other systems, and in other management scenarios. This was the first study to examine these disturbances on the Pacific Northwest Bunchgrass prairie system and the first to look at these questions with ventenata. The information that this thesis provides will help managers, particularly on the PNB system, by providing insight as to how these two common management tools impact the abundance and standing crop of ventenata.

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