DEVELOPING A DECISION SUPPORT TOOL FOR VENTENATA (*Ventenata dubia*) INTEGRATED PEST MANAGEMENT IN THE INLAND NORTHWEST

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Plant Science

in the

College of Graduate Studies

University of Idaho

by

Andrew M. Mackey

April 2014

Major Professor: Timothy S. Prather, Ph. D.

Authorization to Submit Thesis

This thesis of Andrew Mackey, submitted for the degree of Master of Science with a major in Plant Science and titled "Developing a Decision Support Tool for Ventenata (*Ventenata dubia*) Integrated Pest Management in the Inland Northwest," has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor:

____________________________________ Date: ____________

Dr. Timothy S. Prather

Committee Members:

____________________________________ Date: ____________

Dr. Courtney Conway

____________________________________ Date: ____________

Dr. Glenn Shewmaker

Department Administrator:

____________________________________ Date: ____________

Dr. Paul A. McDaniel

Discipline's College Dean:

____________________________________ Date: ____________

Dr. Larry D. Makus

Final Approval and Acceptance by the College of Graduate Studies:

____________________________________ Date: ____________

Dr. Jie Chen

Abstract

Ventenata [*Ventenata dubia* (Leers) Coss.] is a non-native winter annual grass that has invaded agricultural and rangeland systems throughout the Pacific Northwest. Ventenata invasion reduces timothy hay crop profitability, causes reductions in plant species diversity in Conservation Reserve Program (CRP) and is negatively impacting wildlife in CRP. This research project focused on developing integrated pest management techniques for timothy hay and CRP, as well as documenting the effects ventenata invasion has on wildlife in CRP. In both agricultural systems we evaluated treatment efficacy in two infestations of ventenata (low <25% foliar cover vs. high >50% foliar cover). We evaluated fertilizer-only, fall herbicide only (flufenacet plus metribuzin), fertilizer plus herbicide and a control treatment at 5 cm and 10 cm harvest heights in timothy hay. In CRP, we evaluated the following treatments alone and paired with a fall herbicide (sulfosulfuron): fall prescribed burn, spring prescribed burn, sickle mow and remove, rotary mow, fertilizer, and a control. We found that greater control of ventenata was achieved by integrating treatments and treatments respond differently depending on infestation level. In timothy, we found that timothy yield and ventenata control trended to be greater at the 10 cm harvest height. The fertilizer plus herbicide treatment performed the best in controlling ventenata and increasing yield regardless of infestation level, whereas fertilizer-only treatments increased ventenata biomass in low infestations but decreased biomass in high infestations. CRP treatments responded differently in ventenata control at the two infestation levels however, fall prescribed burn plus herbicide performed the best in both situations. Both the mow-only and mow and remove-only treatments increased ventenata biomass and percent foliar cover. Furthermore,

reproduction of tree swallows was lower in areas with >50% foliar cover of ventenata compared to areas with <10% foliar cover of ventenata. Tree swallows in high ventenata sites exhibited greater hatching asynchrony, lower brood number and fewer fledglings as compared to low ventenata sites. Our results will enable land managers to better control ventenata infestations by integrating prescribed burning, fertilizer, harvest height and herbicide. The decision support tool that we developed provides an effective tool for land managers and producers to apply the most appropriate set of control measures given the infestation level of ventenata conditions. Additionally, we have documented negative impacts to wildlife caused by ventenata invasion, highlighting the need for natural resource professionals to initiate control measures now to minimize impacts to other wildlife species and limit or prevent the spread of ventenata.

Acknowledgements

This project was made possible with the help, guidance and support of many friends, family and colleagues. First, I would like to thank my wife Lori, who provided unprecedented support for me to complete my Master's degree. Lori also provided invaluable on the ground support in helping collect biological data during both field seasons. I would like to express many thanks to my major professor Dr. Timothy Prather, who constantly kept me on the right track and held back the reins when my ideas went to the extreme. Also, I would like to thank him for his willingness for me to develop my own research questions to tailor this project to my interests in both wildlife and invasive plant management. Dr. Prather's open door attitude and speedy responses made my time here at the University of Idaho go smoothly. Dr. John Wallace provided a multitude of suggestions, insightful comments and support throughout my project which I owe him many thanks. I would also like to thank Larry Lass, who helped me keep work study students and the labs in working order. Bill Price provided statistical assistance for this project which was crucial for attaining and interpreting my results.

I would like to thank my graduate committee which included Dr. Courtney Conway and Dr. Glenn Shewmaker, both of which provided insightful comments and suggestions throughout my project. I would like to thank those who worked for me on my project as technicians, work study students and volunteers who collected data in the field and supplied countless hours of lab work: Holly Baker, Hannah Tomlinson, Taylor Ortiz, Janesa Makin, Kelsea Holloway, Zach Reilly, Chase Alexander, Brittney Salinas, Rosa Elinda, and Kameron Perensovich.

Thank you to Nicole Thompson and Dayna Willis for their help in all things administrative. Their help ensured I had a smooth transition into the graduate program and provided exceptional service in answering all of my questions and concerns. I would like to thank Dr. James Johnson for his willingness to help me in designing the insect side study of my project and his willingness to identify insects for this project. Thank you to Tiege Ulschmid, Matt Pieron, Zach Swearingen, Joel Sauder and Justin Barrett of the Idaho Department of Fish and Game, who provided suggestions and materials to conduct my research. Thank you to Pamela Pavek with the Natural Resource Conservation Service's Pullman Plant Materials Center for help in developing my research questions, as well as Jim Knetch with the Latah County Farm Service Agency for helping me locate landowners to conduct my project.

I would like to thank the landowners and neighbors who graciously allowed me to conduct my research on their property: Wayne Olesen, Cindy Carlson, Brent Renfrow, Doug Kinzer, David Jackman, Dale Johnson, Diane Olson, Louise Brown, Robert Anderson, Nadine Morton and Terry Driver. I would like to thank the Palouse Audubon Society for a scholarship and the supporters of two University of Idaho scholarships; Charles Hungerford Scholarship and the Earl V. Horning Scholarship which helped pay for tuition and materials. Lastly, I would like to thank the grant provider, Western Sustainable Agriculture, Research and Education which made this research possible (project number: SW10-103). This project would not have been possible without the collaborative effort of all the parties involved.

Dedication

I would like to thank my wife Lori, for her continuous love, support and patience while working towards my Master's degree. Also, I would like to thank my family and friends that provided constant support and words of encouragement.

Table of Contents

List of Figures

List of Tables

Chapter 1. Thesis Introduction

INTRODUCTION

In the last decade agricultural producers, land managers and researchers have seen increased invasion by ventenata [*Ventenata dubia* (Leers) Coss.] in the Inland Northwest (Old and Callihan 1986; Prather 2009). Infestations have led to economic loss in the hay industry, especially to the timothy hay market (Prather 2012). In addition to hay being rejected for export markets, ventenata's wiry form makes it difficult to harvest by binding up machinery and reduces hay stand longevity. There is also increased concern of habitat degradation in Conservation Reserve Program (CRP) lands, historically native rangeland and Palouse Prairie caused by ventenata invasion (Pamela Pavek, Natural Resource Conservation Service Pullman PMC, personal communication; Tiege Ulschmid and Matt Pieron, IDFG, personal communication). Some county Farm Service Agency offices within the Pacific Northwest are now requiring landowners to control ventenata on CRP (Jim Knetch, Latah County FSA, personal communication). Alteration from perennial grasses to non-native annuals can have a detrimental impact on grassland health and function, such as nutrient cycling, habitat degradation and soil loss (Brooks et al. 2004). Further understanding of integrated control techniques of ventenata is needed to help managers make informed decisions. It is also imperative to understand the ecological impacts ventenata may be having on wildlife that utilize agricultural habitat. Understanding these effects and the control options for ventenata may lead to more resilient agroecosystems.

Biology and Background

Ventenata, also known as North African grass or wiregrass, is an exotic winter annual from North Africa and Eurasia. Ventenata can grow to over 70 cm tall, of which the open panicle is 10-40 cm (Crins 2007; Chambers 1985; Hitchcock et al. 1969). The stems are thin and glabrous, producing a fine litter (Crins 2007; Chambers 1985; Hitchcock et al. 1969). In spring, ventenata can be identified as having a brown colored node, an unusually long ligule (1-8 mm) and the leaves do not have a boat-shaped tip. The inflorescence opens in May and June and is an open panicle, which dries and shatters seed by mid-summer (Crins 2007; Hitchcock et al. 1969; Prather 2009). Ventenata was first identified in the Pacific Northwest in 1952 and in Idaho in 1957 in Kootenai County (Crins 2007; Hitchcock et al. 1969; Prather 2009; Lass and Prather 2007; Scheinost et al. 2008). Since its introduction, ventenata has continuously expanded its range throughout the Pacific Northwest (Figure 1).

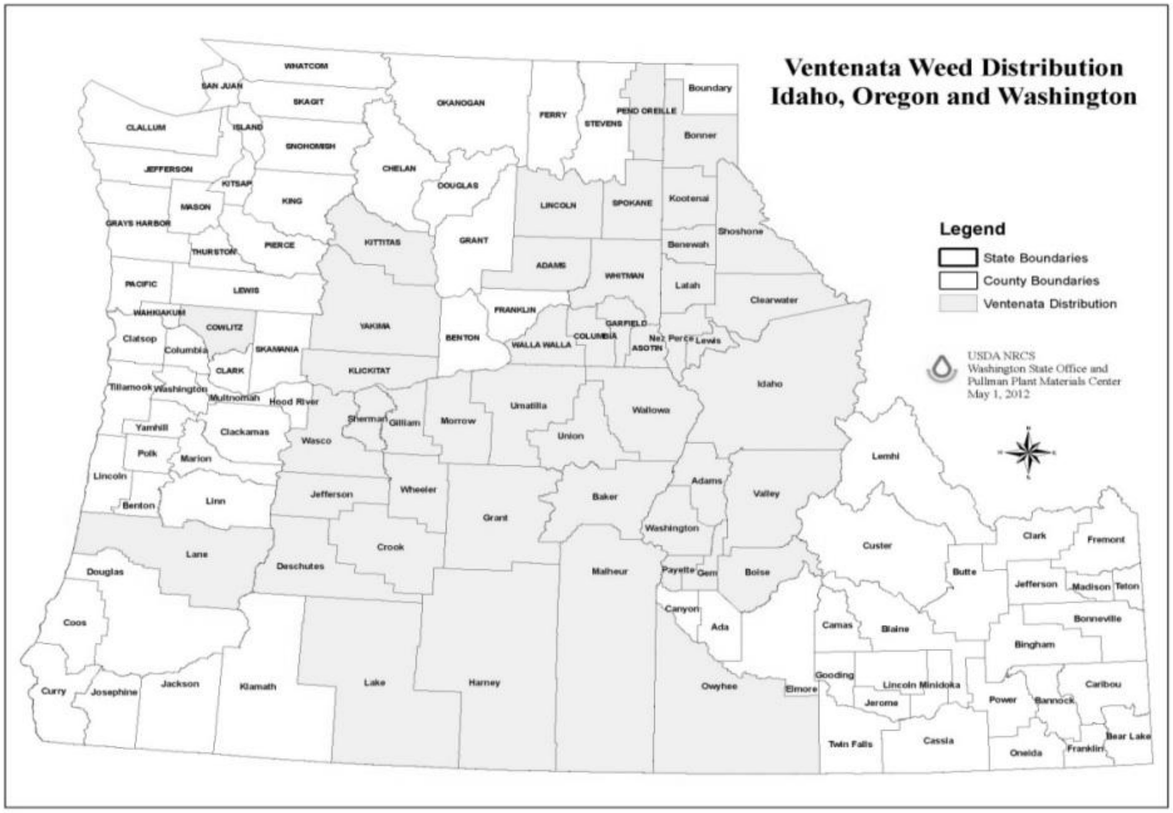

Figure 1. Distribution map for ventenata in Idaho, Oregon and Washington, provided by the USDA NRCS Washington State Office and Pullman Plant Materials Center.

Agroecosystems in the last two decades have seen increased infestation of ventenata throughout the Pacific Northwest (Crins 2007; Prather 2009), which has led to concern about its invasion potential. Currently, there is no published literature on ventenata phenology or integrated control strategies within its invaded range. However, there are ongoing experiments investigating alternative control methods (Wallace and Prather 2009a; Wallace and Prather 2009b), seed viability and longevity in the soil (Pamela Pavek, unpublished data), and how ventenata litter improves seedling survival (John Wallace and Tim Prather, unpublished data). Completed experiments have identified a variety of different herbicides which control ventenata (Wallace and Prather 2009a).

A survey conducted by the Natural Resource Conservation Service's Plant Materials Center in Pullman, WA indicated that the majority of forage producers agreed that integrated measures are needed for long term ventenata control (Prather 2009; Scheinost et al. 2008). Ventenata has dramatically decreased the value of timothy hay and producers are noticing invasions within the first couple years of planting (Prather 2009). Therefore, the need for integrated pest management development is essential for producers in the hay market where ventenata is causing a decrease in crop value and harvested biomass (Prather 2009; Lass and Prather 2007; Scheinost et al. 2008). Within CRP, ventenata may cause reductions in ability to maintain topsoil and loss of perennial grassland habitat for wildlife.

Integrated Pest Management

Integrated Pest Management (IPM) is a relatively well known concept for controlling agricultural and rangeland pests. Strategies for IPM in forage crops such as alfalfa (Summers 1998) exist but in timothy hay systems IPM programs are limited to thrips (Thysanoptera) management (Reisig et al. 2009) and do not include weed management in timothy. Studies focusing on IPM techniques in timothy hay and CRP to control weeds are lacking, especially for the Pacific Northwest. Timothy hay systems are commonly managed with herbicide applications and fertilizer amendments. Most research for timothy hay focuses on herbicide efficacy (Rauch et al. 2012) or fertilizer management (Eftha et al. 2009), but we lack information on the best ways to integrate the timing of these treatments combined with harvest height to target annual grasses and increase yields. CRP fields generally go unmanaged with only herbicide spot treatments being the primary management activity. Management activities are required at the mid-point of the CRP contract, commonly referred to as mid-contract management treatments. Additional research that details effectiveness of mid management treatments would assist landowners with treatment selection.

Control strategies and forage management techniques (i.e. prescribed burning, grazing and mowing) were applied to help remove ventenata and promote perennial vegetation competitiveness and growth in two agroecosystems (timothy and CRP). The summary of a mailed survey conducted by the University of Idaho, which asked landowners about management strategies for ventenata, was used to select IPM strategies for this study. We applied each treatment individually and paired with a selective fall herbicide and evaluated treatment effectiveness in comparison to control treatments. We developed two hypotheses for this research: 1) the combination of treatments will be more effective than the stand-alone treatments at controlling ventenata and increasing perennial vegetation biomass and percent foliar cover in timothy and CRP, and 2) forage and ventenata will respond differently to treatment when ventenata cover is low (<25% foliar cover) versus when ventenata cover is high (>50% foliar cover). These two infestation levels are intended to be an easily measureable parameter for landowners to decide which treatments would be appropriate.

Timothy Hay. Many timothy hay growers in the Pacific Northwest rely on export markets to make the most profit (Prather 2012). However, ventenata invasion causes a loss to these Asian markets since ventenata is not allowed in hay that is exported, affecting grower's overall yearly profit (Prather 2012). When timothy stands decline due to ventenata invasion, forage producers are forced to rotate their fields to other crops to try and control ventenata. However, many areas where timothy is grown, producers have few rotational options and a loss of an export hay market is a serious financial burden. Our research focused on management for healthy timothy and control of ventenata. Enhancing forage involved examining the effect of a 5 cm or 10 cm harvest height and applying macronutrients based on a soil test and timing macronutrients to growth stages of timothy when the macronutrients are needed (Fransen 2005). Control of ventenata was attempted with a fall selective herbicide, flufenacet plus metribuzin (Axiom DF®).

CRP. The Conservation Reserve Program was developed with multiple goals in mind including: protection of highly erodible farm ground, soil conservation, provide wildlife habitat and improve water quality (FSA 2008). These lands were planted to a minimum of one desirable perennial plant per square foot to promote soil retention and provide wildlife habitat. Ventenata invasion threatens all of the aforementioned goals. Since ventenata is shallow rooted, it is not suited for retaining soil. Also, since it has limited palatability, is short in structure and dries down quickly, it is not suitable for providing a food source or concealment cover for wildlife (DiTomaso et al. 2013). There are pre-selected mid-contract management strategies for CRP set by the NRCS and FSA (NRCS 2009; NRCS 2013). We selected the following treatments from the approved strategies: fall burning, spring burning, sickle mow and remove, rotary mow, fertilizer and fall herbicide, which were all compared to a control (no treatment).

Wildlife Impacts

Soil conservation programs, such as CRP, have created grasslands that are used by many wildlife species indigenous to the Palouse. Plant community shifts from perennials to annuals caused by non-native plant invasion can lead to degraded habitat and decreased capability for supporting a diverse flora and fauna community. Mid-contract management makes it possible to maintain and increase desirable plant species and diversity. Lack of management allows for weed invasion that can shift desirable perennial plant communities to non-native weed-dominated communities. These types of changes have been documented and show a reduction in the cascade of animal assemblages, including insects (Herrera and Dudley 2003). Changes to insect assemblages may affect species that utilize insects for food or pollination such as insectivorous passerines. My study focuses on two of the most common species of insectivorous passerines that inhabit nest boxes on the Palouse: tree swallows (*Tachycineta bicolor* Vieillot) and western bluebirds (*Sialia mexicana* Swainson). Both of these passerines are secondary-cavity nesters and have altricial young. Hence, they are considered central-place foragers who must repeatedly bring food back to their altricial nestlings. These attributes provide an opportunity to document higher-order effects of ventenata infestation and help understand the overall ecosystem health.

We used growth rates of nestling tree swallows which inhabit CRP as a way to assess the effects of ventenata invasion on the ecosystem services provided by CRP (Ardia 2006). Similar studies have used these same variables to assess habitat quality of other species (Ruehmann et al. 2011; Tremblay et al. 2003). Comparing nesting success and nestling growth rates between areas with high and low levels of ventenata infestation can help determine if the continued spread of ventenata will cause population declines for grassland birds. We hypothesized that tree swallows and western bluebirds would have decreased nestling growth rates and higher nest failures in ventenata infestations greater than 50% foliar cover within CRP as compared to infestations with less than 10% foliar cover.

Research Objectives

There are two objectives of my project: 1) development of an integrated pest management program for controlling ventenata in two infestation levels (<25% and >50% ventenata foliar cover) within timothy hay and CRP, and 2) assessing impacts of habitat degradation caused by ventenata through the evaluation of passerine nestling growth rates. Both objectives will enhance the overall understanding of ventenata's biology, control and ecological impacts within the Pacific Northwest. Additionally, the results from this project will enable land managers to make informed decisions on integrated control options depending on infestation level and agroecosystem.

CONCLUSION

There is a need for increased knowledge of modern integrated management techniques to control weedy species. Timothy hay producers and CRP landowners currently have limited knowledge of integrated management techniques for ventenata control. Furthermore, we know little about the impact of weed invasion (especially ventenata) on wildlife. The results from this research will have two effects: 1) provide a decision support tool for land owners, land managers and land management agencies to assist them in determining what integrated treatments to employ based on their infestation level of ventenata, and 2) communicate the broader impacts that ventenata is having on our natural systems, especially on wildlife. Our research will also add to further understanding of ventenata's biology and its invasion potential. Overall, this research will improve the management and prevention of establishment of ventenata inside and outside its current range.

LITERATURE CITED

Ardia, D. R. 2006. Geographic variation in the trade-off between nestling growth rate and body condition in the tree swallow. The Condor 108:601-611.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. American Institute of Biological Sciences 54:677-688.

Chambers, K. L. 1985. Pitfalls in identifying *Ventenata dubia* (Poaceae). Madroño 32:120-121.

Crins, W. J. 2007. Flora of North America. Volume 24. Oxford University Press, Oxford, New York, USA.

DiTomaso, J. M., G. B. Kyser et al. 2013. Weed control in natural areas in the Western United States. Weed Research and Information Center, University of California. 544 pp.

Efetha, A., T. Dow, R. H. McKenzie, D. R. Bennett, and R. A. Hohm. Effect of irrigation management on yield and water use efficiency of timothy hay in southern Alberta. Canadian Journal of Plant Science 89:1075-1088.

Farm Service Agency. 2008. Conservation Reserve Program (CRP) benefits: Water quality, soil productivity and wildlife estimates. Fact Sheet. United States Department of Agriculture, Washington D.C., USA.

Fransen, S. 2005. Drought advisory: timothy hay. Washington State University Extension Bulletin EM4919E.

Herrera, A. M. and T. L. Dudley. 2003. Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (*Arundo donax*) invasion. Biological Invasions 5:167-177.

Hitchcock, C. L., A. Cronquist, M. Ownbey and J. W. Thompson. 1969. Vascular plants of the pacific northwest. Volume 1. University of Washington Press, Seattle, Washington, USA and London, Great Britain.

Lass, L. and T. Prather. 2007. A scientific evaluation of noxious and invasive weeds of the Highway 95 construction project between the Uniontown cutoff and Moscow. Aquila Vision Inc. 78p.

Natural Resource Conservation Service. 2009. CRP mid-contract management options. Conservation Program Fact Sheet. United States Department of Agriculture, Washington D.C., USA.

Natural Resource Conservation Service. 2013. CRP mid-contract management option: Integrated wildlife management (645). Conservation Practice Job Sheet. United States Department of Agriculture, Washington D. C., USA.

Old, R. R. and R. H. Callihan. 1986. Distribution of *Ventenata dubia* in Idaho. Idaho Weed Control Report 1986:153.

Prather, T. 2009. *Ventenata dubia*: Increasing concern to the Inland Northwest Region. Center for Invasive Plant Management. June:1-2.

Prather, T. 2012. Developing a decision support tool for ventenata IPM in the Inland Northwest. WSARE Annual Report. 7p.

Rauch, T. A., J. M. Campbell, and D. C. Thill. 2012. Tolerance and grass weed control in timothy. WSWS Research Progress Report. Pp 60-62.

Reisig, D. D., L. D. Godfrey, and D. B. Marcum. 2009. Thresholds, injury, and loss relationships for thrips in *Phleum pratense* (Poales: Poaceae). Environmental Entomology 38:1737- 1744.

Ruehmann, M. B., M. J. Desmond, and W. R. Gould. 2011. Effects of smooth brome on Brewer's sparrow nest survival in sagebrush steppe. The Condor 113:419-428.

Scheinost, P., M. Stannard, T. Prather, J. Yenish. 2008. USDA NRCS Plant Guide: *Ventenata dubia*. Pullman, WA; Pullman Plant Materials Center.

Summers, C. G. 1998. Integrated pest management in forage alfalfa. Integrated Pest Management Reviews 3:127-154.

Tremblay, I., W. Thomas, M. M. Lambrechts, J. Blondel, and P. Perret. 2003. Variation in blue tit breeding performance across gradients in habitat richness. Ecology 84:3033-3043.

Wallace, J. and T. Prather. 2009a. Control of *Ventenata dubia* using various selective herbicides. WSWS Research Progress Report. Pp 46-47.

Wallace, J. and T. Prather. 2009b. Development of restoration tools for *Ventenata dubia* infested pastures. WSWS Research Progress Report. Pp 48-50.

Chapter 2. Developing an integrated pest management strategy for controlling ventenata (*Ventenata dubia*) in timothy hay and CRP in the Pacific Northwest.

INTRODUCTION

Ventenata [*Ventenata dubia* (Leers) Coss.], a non-native winter annual grass, is increasingly becoming a concern in the Pacific Northwest. Its invasion threatens Conservation Reserve Program (CRP) grasslands, pastures and timothy (*Phleum pratense* L.) hay by reducing: habitat quality, soil retention, forage quality and hay production. Similar impacts of winter annual grasses have been observed in agricultural systems (Anderson 1998; Ball et al. 1995; DiTomaso 2000; James et al. 2011). However, little research focuses on using integrated treatments to control weeds in timothy hay and CRP. Timothy hay is an intensely managed crop whereas CRP has much less active management, yet ventenata has gained a foothold in both systems. Loss of export markets, due to ventenata, puts pressure on timothy hay producers to control ventenata. The United States Department of Agriculture is also pressuring CRP landowners to control ventenata in some counties in Idaho. Both of these pressures have spurred the need for effective integrated control strategies. Therefore, the development and evaluation of integrated pest management (IPM) strategies for controlling ventenata in these two systems is a high-priority need for both timothy hay producers, CRP landowners and natural resource managers.

Biology and Background

Ventenata, also known as North African grass or wiregrass, is an exotic winter annual from North Africa and Eurasia. Ventenata can grow to over 70 cm tall, of which the open panicle is 10-40 cm (Crins 2007; Chambers 1985; Hitchcock et al. 1969). The stems are thin and glabrous, producing a fine litter (Crins 2007; Chambers 1985; Hitchcock et al. 1969). In spring, ventenata can be identified as having a brown colored node, an unusually long ligule (1-8 mm) and leaves are without a boat-shaped tip. The inflorescence opens in May and June and is an open panicle, which dries and shatters seed by mid-summer (Crins 2007; Hitchcock et al. 1969; Prather 2009). Ventenata uptakes nitrogen at a similar rate regardless of the amount of nitrogen applied (James 2008), making it a poor competitor for nitrogen compared to other annual grasses like downy brome (*Bromus tectorum* L.) and medusahead wildrye [*Taeniatherum caput medusae* (L.) Nevski]. Ventenata was first identified in the Pacific Northwest in 1952 and in Idaho in 1957 in Kootenai County (Crins 2007; Hitchcock et al. 1969; Prather 2009; Lass and Prather 2007; Scheinost et al. 2008). Since its introduction, ventenata has continuously expanded its range throughout the Pacific Northwest (Figure 1).

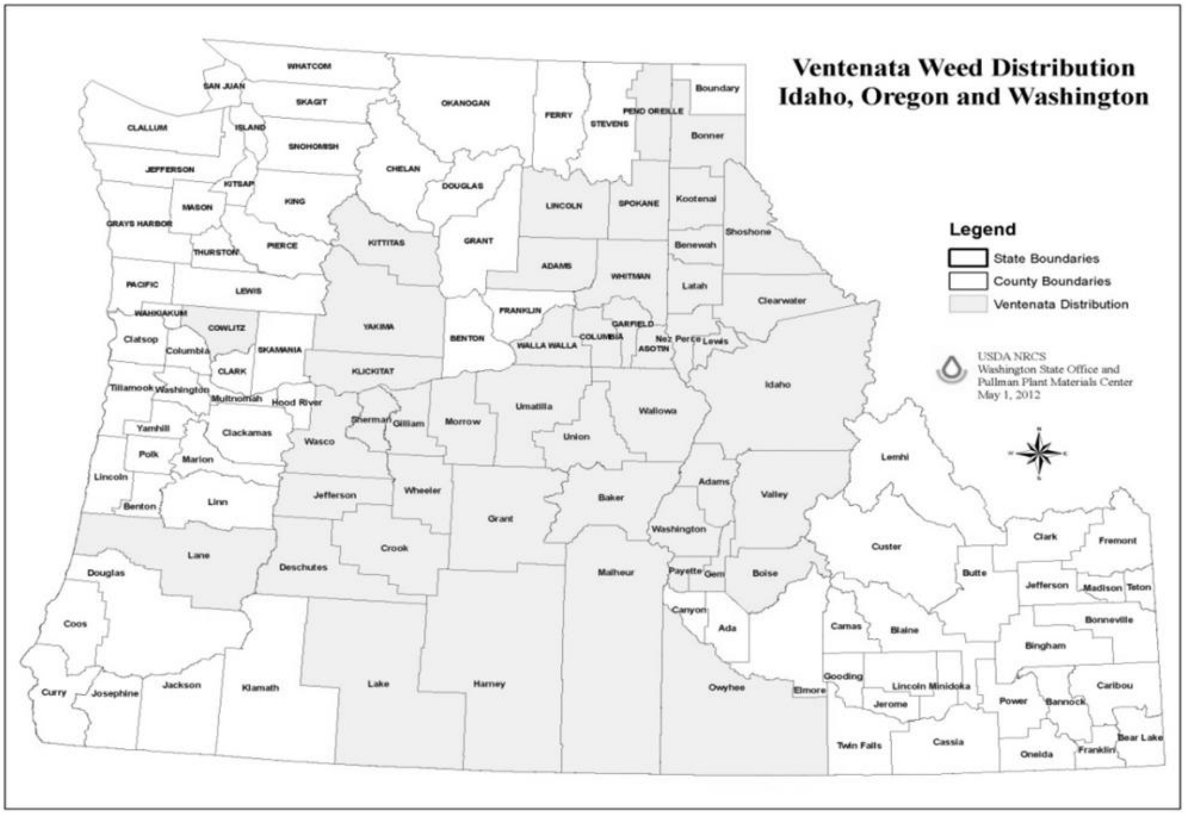

Figure 1. Distribution map for ventenata in Idaho, Oregon and Washington, provided by the USDA NRCS Washington State Office and Pullman Plant Materials Center.

Integrated Pest Management

IPM has long been a recognized management strategy for managing pests and can be applied to invasive plants. The importance of developing and implementing IPM to control exotic weeds which degrade habitat and reduce agricultural viability has been widely acknowledged. Burn and coworkers (1987) defined IPM as efforts “to maximize profit margins, safeguard natural resources and minimize negative impacts on the environment.” Within the context of weed management, IPM strategies should also reduce the overall reliance on pesticide use (Buhler 2002; Elmore 1996; Thill et al. 1991; Sanyal et al. 2008). IPM programs can include strategies that focus on pest phenology and timing of treatments, including: chemical, biological, cultural and mechanical control treatments.

Weed infestations can vary in density and depending on the species of weed, so can treatment efficacy. For example, effectiveness of ventenata treatments may differ depending on infestation level. In the Pacific Northwest, ventenata has invaded fields under active agricultural production as well as CRP fields. Timothy hay production in the Pacific Northwest is managed on a regular basis to maximize profit. In contrast, CRP fields generally go unmanaged for the life of the contract (10 to 15 years) with only one mid-contract management action required. In both types of agricultural systems, we find areas with both low and high infestations of ventenata. Through the use of percent cover estimates, land managers can easily gauge the severity of a weed infestation to help them decide what treatments to apply that will achieve the best control. Differences in treatment efficacy due to infestation level can influence a manager's decision to choose one treatment over another in order to achieve the highest level of control (while also maximizing yield in areas that are under active production).

Leaf litter can facilitate weed invasion, and therefore, the management of leaf litter has proven to be a critical means of vegetation maintenance (Facelli and Pickett 1991; Sheley et al. 2009). Litter dynamics are also important in facilitating weed invasion and establishment (Harrison et al. 2003; Facelli and Pickett 1991; Sheley et al. 2009; Vasquez et al. 2008). Litter can provide thermal protection, nutrients and capture/hold moisture which increases growth of plants. These attributes have been found to increase germination and growth of ventenata (John Wallace and Timothy Prather, unpublished data). Therefore, litter management techniques such as mow and remove, and prescribed burning are potential strategies to consider in ventenata IPM.

Herbicides are often an integral part of many IPM programs, but as stated above, one tenant of IPM is to minimize use of herbicides while maintaining a viable economic return. Previous studies have indicated that ventenata can be controlled through the use of herbicides (Wallace and Prather 2009a; Wallace and Prather 2009b). Our study was designed to build upon prior weed control research to improve the control of ventenata with integrated treatments.

Timothy Hay. Within the Pacific Northwest, timothy hay production is driven by an export market, which is more profitable than domestic markets (Bowen and Hultquist 2013). Ventenata invasion into timothy fields causes a loss of these markets affecting grower's overall yearly profit (Prather 2012). Also, high infestation levels makes harvest difficult and forces producers to disk under and reseed fields or rotate to other crops in shorter intervals, both of which increase grower's costs and inputs. Timothy hay, an introduced perennial cool-season grass, grows in mesic and cooler regions of the Pacific Northwest and is grown almost exclusively for forage (Barkworth 2007). Timothy grows in clumps, has a shallow and fibrous root system and contains a corm which is used for carbohydrate storage and stem production (Barkworth 2007; Bush 2002; Fransen 2005). The corm is located at the base of the culm and retaining >10 cm of the stem prevents damage to the corm which is important for next year's growth (Fransen 2005).

Harvest height can directly affect timothy's ability to produce new stems which allows it to compete with weeds such as ventenata. Maintaining timothy hay competitiveness is important for maintaining a high yielding crop. Under current management in the Pacific Northwest, most timothy hay producers harvest timothy at 5 cm in an effort to maximize their yield. Additionally, some producers will use cattle to graze their fields in the fall (post-harvest). Harvesting and grazing timothy at these shorter harvest heights can damage the corm and reduce timothy's ability to store carbohydrates, making timothy less competitive for the following season (Bush 2002; Fransen 2005). However, harvesting timothy at a height of >10 cm can improve the plant's carbohydrate storage which promotes increased competitiveness going into the following season (Fransen 2005). Therefore, less stressed plants can compete better for limited resources compared to stressed plants harvested at a shorter height.

Research for IPM in timothy hay systems for the Pacific Northwest are virtually nonexistent, especially those that focus on annual grass control. Past research has focused on increasing dry matter yield, water use efficiency and nutrient quality as well as controlling insects. A focus on integrating common strategies already employed by producers to control ventenata and increase timothy yields will benefit hay producers. Additionally, our research will set the platform for developing similar IPM programs for pests that might invade timothy fields in the future.

CRP. The Conservation Reserve Program was developed with multiple goals in mind: protection of highly erodible farm ground, soil conservation, provide wildlife habitat, and improve water quality (FSA 2008). CRP lands are required to have a minimum of one desirable perennial plant per square foot to promote soil retention and provide wildlife habitat. Ventenata invasion threatens the aforementioned goals. Since ventenata is shallow rooted it is not suited for retaining soil. Similar to medusahead, ventenata has limited palatability due to high silica content (2.7%), is short in structure and dries down quickly (DiTomaso et al. 2013) which might make it less suitable for wildlife in CRP fields.

Mid-contract management is required for all land enrolled in CRP and specific management treatments are set by the Natural Resource Conservation Service (NRCS) and the Farm Service Agency (FSA) and varies by state and county. These management activities are tailored to best fit the grass stand condition of each field. In Idaho, the following mid management activities can be used: fertilizing, light disking, light chiseling, harrowing, strip or re-seeding, prescribed burning, mow and remove, rotary mowing and biological control (NRCS 2009; NRCS 2013). In addition to the required mid management activities, landowners are also required to control state and county listed noxious weeds on an annual basis for the life of the CRP contract.

Prescribed burning is often an effective management tool for rejuvenating perennial grasses, improving soil quality, increasing seed production and controlling weeds (DiTomaso 2006; Dyer 2002; Hatch et al. 1999; Vasquez et al. 2008). Furthermore, integrating prescribed burning with herbicide applications can be an effective tool for controlling weeds (DiTomaso et al. 2013; Robertson et al. 2013). However, the effectiveness of integrating these treatments in CRP to control weeds has not been evaluated. The use of integrating treatments for CRP mid management is widely used in other parts of the U.S. for warm-season tall grass species. Past research has focused on improving grass stand health for wildlife benefits (Gill et al. 2006; McCoy et al. 2001; Negus et al. 2010). Our research will be one of the first to use integrated treatments for the dual purpose of controlling weeds and increasing yields of cool-season grasses CRP.

Hypotheses. The main objective of this chapter is to evaluate integrated pest management (IPM) strategies for controlling ventenata in timothy and CRP agroecosystems. We sought to test the following hypotheses: 1) the combination of treatments versus that of the stand-alone treatments will effectively control ventenata and increase perennial forage and percent foliar cover in both agroecosystems; and 2) treatments would increase forage percent cover and biomass more in low infestations (<25% foliar cover) of ventenata than in high infestations (>50% foliar cover) of ventenata. Such information will enable land managers to make informed decisions on integrated control options depending on infestation level and agroecosystem. Furthermore, the results will enhance the overall understanding of ventenata and its positive or negative response to common agricultural practices.

MATERIALS AND METHODS

Study Area

Timothy Hay. Field experiments were conducted from 2012 to 2013 on four study sites in northeastern Washington and north-central Idaho. Field sites with similar soil characteristics, aspect, and management objectives were selected to enhance trial replication. All sites have been in agricultural production for at least five years. Both hay sites were near Cusick, WA (477539 N 5348457 E); the north timothy site was 0.34 km from the south timothy site. Soils at these sites are comprised of Cusick silty clay loam series which are moderately deep and poorly drained. Slopes were 0 to 3%. Average annual precipitation was 69 cm (Deer Park station; 40 km from field site). The most common plant species within the timothy hay sites were timothy (*Phleum pratense* L.), ventenata, meadow foxtail (*Alopecurus pratensis* L.), Kentucky bluegrass (*Poa pratensis* L.) and Canada thistle [*Cirsium arvense* (L.) Scop.].

CRP. The two CRP sites were located near Troy, ID. The south CRP site (5175159 N 520960 E) was approximately 4.3 km from the north CRP site (5178763 N 523363 E).

The CRP sites are primarily comprised of Taney and Southwick silt loam series, which are moderately deep and well drained. Slopes ranged from 0 to 25%. Average annual precipitation was 59 cm (Moscow station; 20 km from field sites). The most common plant species within these sites include; ventenata, orchardgrass (*Dactylis glomerata* L.), Japanese brome (*Bromus japonicas* Thunb. Ex Murr.), meadow foxtail and autumn willowherb (*Epilobium brachycarpum*), all of which comprise of 75% of the total plant composition.

Experimental Design

The experimental design was a randomized complete block split-plot design, similar to that used by Wallace et al. (2010) and Nyamai et al. (2011). The perennial vegetation removal or nutrient addition treatments (mowing, prescribed burning, and fertilizing) were applied to the whole plot and the ventenata removal treatment (herbicide) was applied randomly as the split-plot within the whole plot. Each block was placed within each field where soil and plant communities were similar (Gotelli and Ellison 2004). We evaluated treatments within two infestation levels: low (<25% foliar cover of ventenata) and high (>50% foliar cover of ventenata) hereafter referred to low and high respectively. Each set of treatments was replicated three times within the field, and repeated at two different fields per system (timothy hay and CRP). Duration of the experiment spanned the fall of 2012 through the spring of 2013, with data collected before treatment in the summer of 2012 and data collected after treatments were applied at the peak of forage production during the summer of 2013.

Foliar cover and biomass were the two variables used to evaluate the effectiveness of ventenata control and perennial vegetation response to treatments. All data were collected along permanent transects within the center of each plot. The line-point intercept method was used to determine percent foliar cover estimates (Herrick et al. 2005). Plants were recorded by species at each point along the transect and biomass samples were collected within a 25 cm by 50 cm frame (0.125 m^2) for each treatment. Biomass samples were split into two equal parts. One part was then sorted into ventenata biomass and forage biomass (all desirable vegetation) and the other half of the sample was left combined. All biomass samples were then oven-dried at 60 degrees Celsius for 72 hours and subsequently weighed to the nearest hundredth gram. The mass of the combined samples were weighted and then added to the ventenata and foliage samples to result in a final mass.

Treatments

Timothy Hay. Our treatments included three harvest strategies: 5 cm harvest height, 10 cm harvest height, and 5 cm harvest height with light (low stocking number) post-harvest grazing (Fransen 2005). We applied four treatments to each of those harvest strategies: fertilizer-only, fall-applied herbicide only, fertilizer with herbicide and a control treatment (Table 2). We examined the effectiveness of these treatments on fields with the two infestation levels of ventenata. The three harvest strategies allowed us to contrast hay production at the different harvest heights in conjunction with fertilization and herbicide application. Fransen (2005) suggests that harvesting timothy taller than 10 cm harvest height will increase the plant's ability to better compete through increased storage capability of carbohydrates. Each plot measured 4.9 m by 6 m. Foliar cover estimates were based off of one meter increments and one biomass sample was collected within each plot.

Flufenacet plus metribuzin[1] (Axiom® DF) was applied to the timothy plots at a rate of 0.38 kg ai ha^{-1}, based on prior research (Wallace and Prather 2010). The fertilizer amendments were applied as a split application in the fall and spring, following recommendations provided by Shewmaker and Bohle (2010) and Mahler (2005a and 2005b). Soil samples were taken to a depth of 30 cm two weeks prior to fertilizer applications to determine recommended rates of fertilizer application (Table 1). The selected fertilizer analysis (46-62-45) was applied in the form of a dry granular with phosphorus[3] and potassium[4] applied in the fall. Nitrogen[5] was applied as a split application to the timothy sites as 11.3 kg in the fall and 11.3 kg in the spring. The fertilizer treatment was to help promote perennial vegetation carbohydrate storage and increase next season growth by increasing plant competitiveness (Fransen 2005).

CRP. Treatments were selected from currently approved cost-share mid-contract management treatments outlined by the NRCS and the FSA (NRCS 2009; NRCS 2013). The following treatments were selected; fall prescribed burn, spring prescribed burn, sickle mow and remove, rotary mow, fertilize and herbicide (Table 2). These treatments are common management techniques employed in north-central Idaho. Each plot measured 5 m by 5 m. Foliar cover estimates were based off of half meter increments along the permanent transect. Two biomass samples were collected within each plot on alternate sides of the transect, collected one meter away from the transect.

Fall herbicide applications included the use of sulfosulfuron[2] (Outrider®) 52.6 g ai ha^{-1} on the CRP sites. Wallace and Prather (2009a) found that sulfosulfuron can achieve up to 100% control of ventenata nine months after treatment at a rate of 21.3 g ai ha^{-1}. Fertilizer amendments were based on the same analyses used in the timothy experiments. Phosphorus and potassium rates were calculated from 30 cm soil sample results (Table 1). Since perennial grass production is typically no the goal in CRP, trials received only 11.3 kg nitrogen in the fall but not in the spring.

Prescribed burning, whether fall or spring, can restore and rejuvenate native ecosystem processes within some grasslands (DiTomaso 2000; Towne and Kemp 2003). We used prescribed burning to achieve three goals 1) remove leaf litter, 2) stimulate growth of perennial grasses, and 3) provide nutrients to the soil (DiTomaso 2000; Masters and Sheley 2001). Fall prescribed burning may have the additional impact of increasing herbicide to-soil contact and subjecting any emerged ventenata seedlings to frost injury. In contrast, spring prescribed burning was used to remove all vegetation in spring which would subject seedlings to frost injury. Sickle mow and remove was used to reduce standing vegetation and remove most of the litter, which would allow for greater herbicide to soil contact. The rotary mow treatment left mulched vegetation within the plot which could increase litter and promote ventenata survival.

Table 1. Soil sample results to a depth of 30 cm for each agrosystem by infestation level. Ventenata cover is expressed as low (< 25%) and high (>50%) ventenata foliar cover. N-P-K is listed as the amount available. OM is organic matter.

Agro System	Site	Ventenata Cover	P µg/g	K µg/g	NO_3-N µg/g	NH_4-N µg/g	OM %	pH
Timothy	North	Low	3.9	49	< 0.72	2.2	4.2	5.1
		High	2.8	47	< 0.72	2.9	4.1	5.1
	South	Low	1.6	39	< 0.72	2.9	4.2	5.2
		High	1.2	39	< 0.72	2.0	3.9	5.4
CRP	North	Low	2.9	110	< 0.72	1.9	2.0	5.7
		High	2.7	120	< 0.72	1.5	1.8	5.7
	South	Low	1.9	110	< 0.72	2.3	2.3	5.5
		High	2.1	100	< 0.72	2.7	2.1	5.5

Table 2. Selected treatments for timothy hay and CRP field trials and the date(s) of application.

Agro System	Treatment	Date(s) Applied
Timothy	sickle mow and remove	07/25/2012
	split fertilize application	10/23/2012, 04/17/2013
	herbicide (flufenacet plus metribuzin)	11/02/2012
	fall graze	10/08/2012 to 12/14/13
CRP	sickle mow and remove	08/16/2012
	rotary mow	08/21/2012
	fertilize	10/25/2012
	fall prescribed burn	11/07/2012
	herbicide (sulfosulfuron)	11/16/2012
	spring prescribed burn	04/02/2013

Statistical Analysis

Changes in forage cover and biomass were analyzed by comparing post-treatment data to controls and by comparing change in pre-data to post-data to contrast response of treatment to controls. The results reported for ventenata cover and biomass was derived from the comparison of treatments to the control using only post-treatment data. Pre-treatment to post-treatment data are expressed as the change (Δ) in percent vegetative cover and the change (Δ) in weight (kilograms per hectare). Biomass was expressed as kilograms per hectare.

All data were analyzed with a general linear model, the PROC MIXED procedure in SAS[6]. Biomass data were log transformed [Log10(x + 10)] to meet the assumptions of PROC MIXED and back transformed when reporting results. Infestation level, treatment and their interactions were considered as fixed effects in the model. Field site, block and their interactions were considered random effects. Fixed and random effects were analyzed for significance at $\alpha = 0.1$ level. Pairwise comparisons of least-square means were conducted to identify treatment differences ($P < 0.05$). The 5 cm harvest with light post-harvest grazing strategy was omitted from the analysis due to a lack of utilization by cattle on the timothy fields.

RESULTS

Timothy Hay. Flufenacet plus metribuzin applications resulted in control of ventenata and increased timothy yields. When herbicide treatment was combined with other treatments, control of ventenata increased. Effectiveness of the treatments differed between the two infestation levels for ventenata biomass (P=0.0063, df =7), but not for ventenata percent cover (P=0.9476, df=7). Additionally, there was no evidence of an infestation-by-treatment interaction for either timothy hay biomass (P=0.23, df=7) or percent cover (P=0.93, df=7). Therefore, overall means are reported for ventenata percent cover, timothy biomass and timothy percent cover. High and low infestations are discussed separately for ventenata biomass. The point-intercept technique appeared to underestimate cover, likely because the timothy was planted in rows and the crop was vertically orientated. The point estimate technique is limited to accurately describing cover in crops planted in rows in the manner that timothy typically is (Herrick et al. 2005). However, the results from the foliar cover estimates were similar to that of the biomass data.

The flufenacet plus metribuzin only treatment significantly reduced ventenata percent cover (Table 3) and ventenata biomass (Tables 4 and 5). Further reductions in ventenata were observed when fertilizer was applied with flufenacet plus metribuzin. In high ventenata infestations, significantly greater control of ventenata biomass was achieved when harvesting timothy at 10 cm harvest height with the fertilizer and flufenacet plus metribuzin treatment as compared to the 5 cm harvest height with the fertilizer and flufenacet plus metribuzin treatment (Table 4). Conversely, when ventenata infestations were low, there was a trend toward greater control at the 5 cm harvest height when applying the fertilizer and flufenacet plus metribuzin treatment instead at the 10 cm harvest height with the fertilizer and flufenacet plus metribuzin treatment (Table 5). Interestingly, in high infestations, ventenata biomass trended to decrease (Table 4), whereas in low infestations ventenata biomass trended to increase (Table 5) when applying only fertilizer.

Table 3. Mean (± SE) percent foliar cover of ventenata from post-treatment data in timothy hay plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	14.40 a	±6.2	0.0022
10 cm harvest and fertilizer + flufenacet plus metribuzin	15.70 a	±6.2	0.0394
10 cm harvest + flufenacet plus metribuzin	20.30 a b	±6.2	0.1004
5 cm harvest + flufenacet plus metribuzin	29.30 a b c	±6.2	0.0545
10 cm harvest control	36.30 b c d	±6.2	–
10 cm harvest and fertilizer	43.80 c d	±6.2	0.4235
5 cm harvest control	48.30 d	±6.2	–
5 cm harvest and fertilizer	50.60 d	±6.2	0.8074

Treatments with the same letter are non-significant from each other.

Table 4. Mean (± SE) biomass (kg/ha) of ventenata from post-treatment data within high ventenata infestation timothy hay plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
10 cm harvest and fertilizer + flufenacet plus metribuzin	26.20 a	±87.4	0.0007
5 cm harvest and fertilizer + flufenacet plus metribuzin	34.60 a	±87.4	0.0025
5 cm harvest + flufenacet plus metribuzin	63.60 a	±87.4	0.0035
10 cm harvest + flufenacet plus metribuzin	109.50 a	±87.4	0.0016
5 cm harvest and fertilizer	408.10 b	±87.4	0.0805
10 cm harvest and fertilizer	609.60 b	±87.4	0.0933
5 cm harvest control	10050 b	±87.4	–
10 cm harvest control	1258.00 b	±87.4	–

Treatments with the same letter are non-significant from each other.

Table 5. Mean (± SE) biomass (kg/ha) of ventenata from post-treatment data within low ventenata infestation timothy hay plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	15.60 a	±87.4	0.5549
10 cm harvest and fertilizer + flufenacet plus metribuzin	20.30 a	±87.4	0.9126
10 cm harvest + flufenacet plus metribuzin	24.70 a	±87.4	0.9324
5 cm harvest + flufenacet plus metribuzin	31.40 a	±87.4	0.6148
10 cm harvest control	39.80 a	±87.4	–
10 cm harvest and fertilizer	117.90 a	±87.4	0.6783
5 cm harvest control	126.40 a	±87.4	–
5 cm harvest and fertilizer	168.70 a	±87.4	0.8348

Treatments with the same letter are non-significant from each other.

Plots with flufenacet plus metribuzin applied singly or combined with fertilizer significantly increased timothy percent cover when contrasted to control plots (Table 6). However, the change in percent timothy cover from pre-treatment to post-treatment was only significant for plots with 5 cm harvest height that received fertilizer and flufenacet plus metribuzin and those with 10 cm harvest height that received flufenacet plus metribuzin only treatments (Table 7). All four treatments that included fertilizer significantly increased timothy yield as compared to control treatment plots (Tables 8, 9). Interestingly, there was a decrease in timothy yield at the 5 cm harvest height with flufenacet plus metribuzin treatment and an increase in timothy yield at the 10 cm harvest height with flufenacet plus metribuzin treatment (Table 9).

Table 6. Mean (± SE) percent foliar cover of forage from post-treatment data in timothy hay plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	82.80 a	±5.8	0.001
10 cm harvest and fertilizer + flufenacet plus metribuzin	79.30 a	±5.8	0.0435
10 cm harvest + flufenacet plus metribuzin	78.10 a	±5.8	0.0558
5 cm harvest + flufenacet plus metribuzin	67.80 a b	±5.8	0.0292
10 cm harvest control	59.80 b c	±5.8	–
10 cm harvest and fertilizer	53.80 b c	±5.8	0.4982
5 cm harvest control	46.60 c	±5.8	–
5 cm harvest and fertilizer	46.00 c	±5.8	0.9467

Treatments with the same letter are non-significant from each other.

Table 7. Mean (± SE) percent change in foliar cover of forage from pre to post-treatment data in timothy hay plots. Data expressed as the change (Δ) in percent. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	25.80 a	±7.7	0.016
10 cm harvest + flufenacet plus metribuzin	17.70 a b	±7.7	0.0488
10 cm harvest and fertilizer + flufenacet plus metribuzin	15.40 a b c	±7.7	0.0728
5 cm harvest + flufenacet plus metribuzin	13.60 a b c	±7.7	0.134
5 cm harvest control	-3.40 b c d	±7.7	–
10 cm harvest control	-5.30 c d	±7.7	–
5 cm harvest and fertilizer	-12.20 d	±7.7	0.4227
10 cm harvest and fertilizer	-17.30 d	±7.7	0.277

Treatments with the same letter are non-significant from each other.

Table 8. Mean (± SE) biomass (kg/ha) of forage from post-treatment data in timothy hay plots expressed as kg/ha. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	4543.10 a	±825.3	<0.0001
10 cm harvest and fertilizer + flufenacet plus metribuzin	4071.80 a b	±825.3	0.0013
10 cm harvest and fertilizer	3923.80 a b	±825.3	0.0021
5 cm harvest and fertilizer	3385.90 b c	±825.3	0.0011
10 cm harvest + flufenacet plus metribuzin	3019.40 c d	±825.3	0.1747
10 cm harvest control	2551.10 d e	±825.3	–
5 cm harvest + flufenacet plus metribuzin	2269.00 e	±825.3	0.4391
5 cm harvest control	2049.00 e	±825.3	–

Treatments with the same letter are non-significant from each other.

Table 9. Mean (± SE) change in biomass (kg/ha) of forage from pre to post-treatment data in timothy hay plots. Data expressed as the change (Δ) in biomass as kg/ha. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
5 cm harvest and fertilizer + flufenacet plus metribuzin	2103.20 a	±631	<0.0001
10 cm harvest and fertilizer	1287.10 a b	±631	0.0075
10 cm harvest and fertilizer + flufenacet plus metribuzin	1260.80 a b	±631	0.0101
5 cm harvest and fertilizer	952.80 b c	±631	0.0116
10 cm harvest + flufenacet plus metribuzin	295.20 c d	±631	0.4766
10 cm harvest control	-8.70 d	±631	–
5 cm harvest control	-252.00 d	±631	–
5 cm harvest + flufenacet plus metribuzin	-306.40 d	±631	0.8984

Treatments with the same letter are non-significant from each other.

There were no statistical differences between the two different harvest heights with respect to ventenata control or timothy yield. However, there was a trend exhibiting a decrease in forage yield at 5 cm harvest height for the fertilizer only treatment compared to the control treatment (Tables 8, 9). Timothy yield responded similarly when harvested at 10 cm in the fertilizer-only and fertilizer with flufenacet plus metribuzin treatments (Tables 8, 9). The similarity in response of timothy yield between these two treatments suggests that timothy is better able to compete with ventenata for limited resources when harvested at 10 cm. There was a marginal difference between the 5 cm harvest height fertilizer with flufenacet plus metribuzin treatment and the 5 cm harvest height fertilizer-only treatment (P=0.066). Once again, this response to timothy yield suggests that timothy harvested at 5 cm is less able to compete with ventenata. There was marginal difference between the two harvest heights in respect to the fertilizer with flufenacet plus metribuzin treatment (P=0.0688) when looking at the change in timothy biomass.

CRP. Statistical analysis identified an infestation level by treatment interaction with ventenata foliar percent cover (P=0.12, df=11) and biomass (P=0.12, df=11). There was no infestation by treatment interaction for forage foliar percent cover (*P*=0.55, df=11) or forage biomass (*P*=0.73, df=11). Therefore, means are reported for high and low infestations for the ventenata data and overall means of both infestation levels combined for the forage. In high infestations, the fall prescribed burn with sulfosulfuron and the spring prescribed burn with sulfosulfuron reduced ventenata percent foliar cover (Table 10) and biomass (Table 11) more than other treatments. Conversely, the rotary mow-only treatment resulted in an increase in both ventenata percent foliar cover (Table 10) and biomass (Table 11). However, in high infestations, applying sulfosulfuron alone or with another treatment significantly reduced ventenata percent cover (Table 10) and biomass (Table 11). The only non-herbicide treatment to significantly reduce ventenata percent cover (*P*=0.0006, Table 11) and biomass (*P*=0.007, Table 11) was fall prescribed burn only.

Table 10. Mean (± SE) percent foliar cover of ventenata from post-treatment data within high ventenata infestation CRP plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fall prescribed burn + sulfosulfuron	10.20 a	±6.1	0.0005
spring prescribed burn + sulfosulfuron	12.80 a b	±6.1	0.0010
fall prescribed burn only	19.70 a b c	±6.1	0.0067
fertilizer + sulfosulfuron	21.80 a b c	±6.1	0.0119
sulfosulfuron only	23.00 a b c	±6.1	0.0161
mow remove + sulfosulfuron	23.80 a b c	±6.1	0.0200
rotary mow + sulfosulfuron	28.00 b c	±6.1	0.0554
spring prescribed burn only	35.30 c d	±6.1	0.2556
control	45.30 d	±6.1	–
fertilizer-only	42.70 d	±6.1	0.7585
mow remove-only	45.80 d	±6.1	0.9540
rotary mow-only	50.30 d	±6.1	0.5654

Treatments with the same letter are non-significant from each other.

Table 11. Mean (± SE) biomass (kg/ha) of ventenata from post-treatment data within high ventenata infestation CRP plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
spring prescribed burn + sulfosulfuron	4.30 a	±5	0.0002
mow remove + sulfosulfuron	5.70 a	±5	0.0003
fall prescribed burn + sulfosulfuron	6.50 a	±5	0.0003
rotary mow + sulfosulfuron	11.20 a b	±5	0.0006
fertilizer + sulfosulfuron	17.20 a b	±5	0.0016
sulfosulfuron only	19.10 a b	±5	0.0021
fall prescribed burn only	27.60 a b	±5	0.007
spring prescribed burn only	40.10 b	±5	0.0342
control	83.90 c	±5	–
fertilizer-only	100.40 c	±5	0.4541
rotary mow-only	106.80 c	±5	0.3073
mow remove-only	117.00 c	±5	0.1514

Treatments with the same letter are non-significant from each other.

In low infestations, the fertilizer with sulfosulfuron, fall prescribed burn with sulfosulfuron, spring prescribed burn with sulfosulfuron, sulfosulfuron only, and the sickle mow and remove with sulfosulfuron treatments reduced ventenata cover (Table 12) and biomass (Table 13). The rotary mow-only, sickle mow and remove-only and the fertilizer-only treatments all increased ventenata cover (Table 12) and biomass (Table 13). Control of ventenata with sulfosulfuron varied in cover (Table 12) and biomass (Table 13) in low infestations as compared to the control in high ventenata infestations.

Table 12. Mean (± SE) percent foliar cover of ventenata from post-treatment data within low ventenata infestation CRP plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fertilizer + sulfosulfuron	1.30 a	±6.1	0.0019
fall prescribed burn + sulfosulfuron	1.70 a	±6.1	0.0021
spring prescribed burn + sulfosulfuron	2.20 a b	±6.1	0.0024
sulfosulfuron only	2.50 a b	±6.1	0.0027
mow remove + sulfosulfuron	9.20 a b	±6.1	0.0161
spring prescribed burn only	17.30 a b c	±6.1	0.1124
fall prescribed burn only	17.80 a b c	±6.1	0.1249
rotary mow + sulfosulfuron	19.30 b c d	±6.1	0.1696
control	31.50 c e	±6.1	–
fertilizer-only	32.30 c d e	±6.1	0.9234
mow remove-only	35.80 d e	±6.1	0.6180
rotary mow-only	38.30 e	±6.1	0.4336

Treatments with the same letter are non-significant from each other.

Table 13. Mean (± SE) biomass (kg/ha) of ventenata from post-treatment data within low ventenata infestation CRP plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fall prescribed burn + sulfosulfuron	1.80 a	±5	0.102
sulfosulfuron only	3.00 a	±5	0.1186
mow remove + sulfosulfuron	4.40 a	±5	0.1393
fertilizer + sulfosulfuron	8.20 a b	±5	0.2117
fall prescribed burn only	12.90 a b	±5	0.3347
spring prescribed burn + sulfosulfuron	14.20 a b	±5	0.3773
rotary mow + sulfosulfuron	15.10 a b	±5	0.4059
control	29.10 a b c	±5	–
spring prescribed burn only	32.80 a b c	±5	0.8288
rotary mow-only	40.00 b c d	±5	0.5375
mow remove-only	50.70 c d	±5	0.2352
fertilizer-only	70.40 d	±5	0.0358

Treatments with the same letter are non-significant from each other.

The only treatments to significantly increase forage foliar cover, relative to controls, were spring prescribed burn with sulfosulfuron, fall prescribed burn with sulfosulfuron and sulfosulfuron only (Table 14). However, numerous other treatments were marginally significant at increasing forage percent foliar cover (Table 14). The only treatment to significantly increase forage biomass, relative to controls, was the fall prescribed burn with sulfosulfuron treatment (199.51 kg/ha^{-1}) vs (330.02 kg/ha^{-1}), respectively (Table 15). All integrated treatments plus the sulfosulfuron only and fall prescribed burn only treatments significantly increased forage percent foliar cover from pre-treatment to post-treatment (Table 16). No treatment significantly increased forage biomass from pre-treatment to post-treatment (Table 17).

Table 14. Mean (± SE) percent foliar cover of forage from post-treatment data in CRP plots. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
spring prescribed burn + sulfosulfuron	58.50 a	±5.7	0.0013
fall prescribed burn + sulfosulfuron	56.20 a b	±5.7	0.0027
sulfosulfuron only	46.00 a b c	±5.7	0.0494
fall prescribed burn only	44.40 a b c d	±5.7	0.074
fertilizer + sulfosulfuron	43.70 a b c d e	±5.7	0.089
mow remove + sulfosulfuron	42.90 c d e	±5.7	0.1065
rotary mow + sulfosulfuron	40.80 c d e	±5.7	0.1742
spring prescribed burn only	39.90 c d e	±5.7	0.2081
mow remove-only	36.60 c d e	±5.7	0.3946
fertilizer-only	29.80 d e	±5.7	1.000
control	29.80 d e	±5.7	–
rotary mow-only	28.80 e	±5.7	0.8904

Treatments with the same letter are non-significant from each other.

Table 15. Mean (± SE) biomass (kg/ha) of forage from post-treatment data in CRP plots expressed as kg/ha. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fall prescribed burn + sulfosulfuron	330.00 a	±46.4	0.0165
mow remove + sulfosulfuron	271.10 a b	±46.4	0.1292
spring prescribed burn + sulfosulfuron	256.30 a b c	±46.4	0.2121
spring prescribed burn only	248.20 a b	±46.4	0.2887
fertilizer + sulfosulfuron	233.20 a b c	±46.4	0.4331
sulfosulfuron only	231.80 a b c	±46.4	0.4504
fall prescribed burn only	229.80 a b c	±46.4	0.4763
rotary mow-only	228.00 a b c	±46.4	0.5015
rotary mow + sulfosulfuron	208.20 b c	±46.4	0.8299
fertilizer-only	202.30 b c	±46.4	0.9438
control	199.50 b c	±46.4	–
mow remove-only	167.20 c	±46.4	0.3782

Treatments with the same letter are non-significant from each other.

Table 16. Mean (± SE) change in percent foliar cover of forage from pre to post-treatment data in CRP plots. Data expressed as the change (Δ) in percent foliar cover. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fall prescribed burn + sulfosulfuron	16.20 a	±6.7	0.0003
spring prescribed burn + sulfosulfuron	6.20 a b	±6.7	0.0101
mow remove + sulfosulfuron	4.50 a b	±6.7	0.0176
rotary mow + sulfosulfuron	3.90 a b	±6.7	0.0213
sulfosulfuron only	2.60 b c	±6.7	0.0326
fall prescribed burn only	1.80 b c	±6.7	0.0412
fertilizer + sulfosulfuron	-0.50 b c d	±6.7	0.0825
spring prescribed burn only	-5.40 b c d	±6.7	0.29
rotary mow-only	-9.40 c d	±6.7	0.6318
fertilizer-only	-9.50 c d	±6.7	0.64505
mow remove-only	-12.10 d	±6.7	0.9313
control	-12.70 d	±6.7	–

Treatments with the same letter are non-significant from each other.

Table 17. Mean (± SE) change in biomass (kg/ha) of forage from pre to post-treatment data in CRP plots. Data expressed as the change (Δ) in biomass as kg/ha. P-values represent pair-wise comparison of each treatment to control.

Treatment	Mean	SE	*P*-value
fall prescribed burn + sulfosulfuron	18.10 a	±46.1	0.4666
mow remove + sulfosulfuron	15.30 a	±46.1	0.4964
spring prescribed burn + sulfosulfuron	14.80 a	±46.1	0.5016
fertilizer + sulfosulfuron	6.20 a	±46.1	0.5996
spring prescribed burn only	2.90 a	±46.1	0.6443
rotary mow-only	-3.20 a	±46.1	0.7175
rotary mow + sulfosulfuron	-11.90 a	±46.1	0.8332
fertilizer-only	-14.40 a	±46.1	0.8668
control	-24.10 a	±46.1	–
fall prescribed burn only	-28.90 a	±46.1	0.9329
sulfosulfuron only	-58.80 a	±46.1	0.5478
mow remove-only	-64.90 a	±46.1	0.4809

Treatments with the same letter are non-significant from each other.

DISCUSSION

Timothy Hay. Our objectives for this study were met by controlling ventenata and increasing timothy yield with the use of integrated treatments in both high and low infestation levels of ventenata. Fertilizer-only treatments in high infestations had a greater effect on ventenata by decreasing biomass. However, we observed the opposite in low infestations with ventenata biomass increasing with fertilizer-only treatments. Ventenata capturing excess phosphorous could explain why ventenata biomass increased after the fertilizer-only treatment, however additional research would be required to fully understand these effects. The increase in ventenata biomass observed in low infestations when applying fertilizer could be negated by harvesting timothy hay at 10 cm and applying flufenacet plus metribuzin only treatment. Although there was no statistical difference between harvest height in either timothy hay yield or ventenata control for fertilizer and flufenacet plus metribuzin application, we did observe biologically significant trends. These trends parallel that of other studies which reported that timothy hay yields increase when harvested at taller heights (Efetha et al. 2009; Fransen 2005; Mislevy et al. 1977). Our data suggests that when harvesting timothy hay at 10 cm, plants are less stressed and able to capture more resources than timothy harvested at 5 cm.

The soil sample results trended to have more available phosphorous in low infestations than high infestations of ventenata in both agricultural systems and this result suggests that ventenata is capturing more available phosphorous (Table 3) (James 2008). We saw an increase in ventenata percent cover and biomass when the fertilizer treatment was applied alone which further suggests that ventenata may be taking advantage of phosphorous. As we observed in this study, control of ventenata can vary given the infestation level when applying fertilizer. Therefore, it would be best to fertilize and apply flufenacet plus metribuzin when you have higher infestations of ventenata. Fertilizing in low infestations could lead to increases of ventenata and should be avoided in these situations.

CRP. Integrating treatments to control ventenata in CRP was achieved in both high and low infestation levels. Ventenata infestations below 25% foliar cover should be managed differently than fields that are heavily infested by ventenata. The herbicide sulfosulfuron, significantly decreased ventenata percent cover and biomass, however we saw increased control when integrating sulfosulfuron with other treatments. All treatments paired with sulfosulfuron application, regardless of infestation level, had significant control of ventenata when measuring percent cover and biomass. However, not all treatments performed equally as well in stimulating perennial vegetation and decreasing ventenata percent cover and biomass.

When evaluating how percent cover and biomass of both forage and ventenata responded to treatments, we see that fall prescribed burn with sulfosulfuron performs the best regardless of the infestation level. Spring prescribed burn with sulfosulfuron performs equally as well as fall prescribed burn with sulfosulfuron in high infestations but not in low infestations. Therefore, when choosing to use prescribed burning as a management tool for controlling ventenata, either spring or fall prescribed burning with sulfosulfuron can be used in high infestations. In low infestations, fall prescribed burning was superior to spring prescribed burning to achieve the best control of ventenata. Alternatively, prescribed burning in CRP provided the greatest increase in percent cover and biomass of perennial vegetation as compared to all other treatments.

Sickle mow and remove with a fall application of sulfosulfuron application would be an effective alternative for controlling ventenata, regardless of infestation level, when prescribed burning is not an option. However, caution should be used when applying mechanical treatments on ventenata since ventenata had a positive response to the mow and remove-only treatment and the mow-only treatment when sulfosulfuron was not applied. Mowing fields with low ventenata infestations will increase ventenata biomass and percent cover and these treatments should be avoided unless sulfosulfuron is applied. In high infestations, the rotary mow-only treatment increased percent cover and biomass of ventenata. While in low infestations both sickle mow and remove-only and the rotary mow-only treatments increased ventenata percent cover and biomass. These treatments should be avoided if sulfosulfuron cannot be applied in the fall or following spring. Similar to that seen in the timothy agroecosystem, the fertilizer-only treatment appeared to have a greater effect on ventenata when infestations were low (James 2008).

CONCLUSION

Timothy Hay. Strong consideration should be made to what fertilizer to apply and when to apply it given the ventenata infestation level. Additionally, fertilizer treatments should be based off of soil sample results to ensure the proper amount of fertilizer is applied. Given the differences we found in ventenata's response to fertilizer treatments and that infestation levels could vary throughout a field, managers should avoid applying fertilizer to low infestations if flufenacet plus metribuzin is not going to be applied. Though we found no statistical difference in yield between the two harvest heights, prior studies suggest to harvest timothy hay at a minimum of 10 cm to maximize growth and competitiveness. These management techniques will overall decrease grower input and increase the longevity of fields.

CRP. Prescribed burning has proven to be a valuable management tool in controlling ventenata in the Pacific Northwest, however other invasive species such as downy brome and ripgut brome (*Bromus diandrus* Roth) can react positively to prescribed burning (DiTomaso et al. 2006). Much consideration must be made to other invasive species which are currently established or have the possibility to establish post-burning. Furthermore, mechanical treatments such as mowing can attain good control of other weeds, but in the case of ventenata it facilitates spread and growth. Additional consideration must be given to any treatment to ensure that it will not have off target effects such as stimulating additional weed problems or hinder other ecosystem processes or functions.

We saw from this research that in low infestations removal of the litter prior to herbicide application increased the control of ventenata. The removal of litter may have increased herbicide to soil contact and the lack of litter may have decreased fall germination. Both of these effects may have improved control as seen in the fall prescribed burn with sulfosulfuron and sickle mow and remove with sulfosulfuron treatments. Concurrent research (Wallace and Prather, unpublished data) suggests that ventenata can have a small percent of spring germinates. Due to litter removal treatments, these spring germinates are no longer protected and can become subject to freezing and subsequently reducing or killing the plants. All of these factors can help explain why we saw increased control in fall prescribed burn with sulfosulfuron and sickle mow and remove with sulfosulfuron treatments as compared to the other treatments.

Future research will need to focus on understanding how ventenata is utilizing fertilizer under these two infestation levels. Observing that both agroecosystems responded similarly to fertilizing in low infestations signifies that ventenata may be taking advantage of nitrogen, phosphorous and/or potassium. The fact that our soil sample results indicate an excess of available phosphorous in low infestation sites than in high infestation sites indicates that ventenata may be responding to the phosphorous in the fertilizer application.

SOURCES OF MATERIALS

[1] Flufenacet and Metibuzin, Axiom® DF, Bayer Crop Science, Durham, NC 27709.

[2] Sulfosulfuron, Outrider®, Monsanto, St. Louis, MO 63167.

[3] Triple Super Phosphate, Wilbur-Wllis Company, Halsey, OR 97348.

[4] Muriate of potash, Wilbur-Wllis Company, Halsey, OR 97348.

[5] Urea, Wilbur-Wllis Company, Halsey, OR 97348.

[6] SAS version 9.2, SAS Institute, Cary, NC 27513.

ACKNOWLEDGEMENTS

I would like to thank my major professor Dr. Timothy Prather for his suggestive comments, guidance and thoughtful editorial recommendations throughout the duration of this project. I would like to thank the dedication and strong work ethic of; Holly Baker, Hannah Tominlson, Taylor Ortiz, Zach Reilly, Kameron Perensovich, Janesa Mackin, Chase Alexander, Rose Elinda, and Brittney Salinas. All of which, helped either in the field collection of data or in the lab to sort biomass samples and enter data. Specifically, I would like thank Dr. John Wallace who provided countless suggestions and hands on assistance with my project. Thank you to Larry Lass for help organizing the labs and work study students and thanks to Bill Price for statistical advice. I would like to thank the gracious landowners who allowed me to conduct these trials on their property: Cindy Carlson, David Jackman, Doug Kinzer, Wayne Olesen and Terry Driver. Without the use of their property this project could not have been possible. The technical assistance from personnel with the following agencies was greatly appreciated: Idaho Department of Fish and Game, Natural Resource Conservation Service and the Farm Service Agency. I would also like to thank Pamela Pavek, Tiege Ulschmid and Matt Pieron who provided insight into my project. Most of all, I would like to thank my wife who provided constant support and patience throughout the duration of my project. This project would not have been possible without a grant from Western Sustainable Agriculture Research and Education (project number: SW10-103).

LITERATURE CITED

Anderson, R. L. 1998. Ecological characteristics of three winter annual grasses. Weed Technology 12:478-483.

Ball, D. A., B. Klepper, D. J. Rydrych. 1995. Comparative above-ground development rates for several annual grass weeds and cereal grains. Weed Science 43:410-416.

Barkworth, M. E. 2007. Flora of North America. Volume 24. Oxford University Press, Oxford, New York, USA.

Bowen, J. T., Jr., and N. B. Hultquist. 2013. Compressing nature: The development of the export hay industry in the western United States. Yearbook of the Association of Pacific Coast Geographers 75:88-103.

Buhler, D. D. 2002. Challenges and opportunities for integrated weed management. Weed Science 50:273-280.

Burn, A. J., T. H. Coaker, and P. C. Jepson. 1987. Integrated Pest Management. University of Cambridge, Cambridge, UK.

Bush, T. 2002. USDA NRCS plant fact sheet: Timothy. East Lansing, MI; Rose Lake Plant Materials Center.

Chambers, K. L. 1985. Pitfalls in identifying *Ventenata dubia* (Poaceae). Madroño 32:120-121.

Crins, W. J. 2007. Flora of North America. Volume 24. Oxford University Press, Oxford, New York, USA.

DiTomaso, J. M. 2000. Invasive weeds in rangelands: species, impacts, and management. Weed Science 48:255-265.

DiTomaso, J. M., M. L. Brooks, E. B. Allen, R. Minnich, P. M. Rice, and G. B. Kyser. 2006. Control of invasive weeds with prescribed burning. Weed Technology 20:535-548.

DiTomaso, J. M., G. B. Kyser et al. 2013. Weed control in natural areas in the Western United States. Weed Research and Information Center, University of California. 544 pp.

Dyer, A. R. 2002. Burning and grazing management in a California grassland: Effect on bunchgrass seed viability. Restoration Ecology 10:107-111.

Efetha, A., T. Dow, R. H. McKenzie, D. R. Bennett, and R. A. Hohm. Effect of irrigation management on yield and water use efficiency of timothy hay in southern Alberta. Canadian Journal of Plant Science 89:1075-1088.

Elmore, C. L. 1996. A reintroduction to integrated weed management. Weed Science 44:409-412.

Facelli, J. M. and T. A. Pickett. 1991. Plant Litter: Its dynamics and effects on plant community structure. Botanical Review 57:1-32.

Farm Service Agency. 2008. Conservation Reserve Program (CRP) benefits: Water quality, soil productivity and wildlife estimates. Fact Sheet. United States Department of Agriculture, Washington D.C., USA.

Fransen, S. 2005. Drought advisory: timothy hay. Washington State University Extension Bulletin EM4919E.

Gotelli, N. J. and A. M. Ellison. 2004. A bestiary of experimental and sampling designs. Pages 163-205 *in* A primer of ecological statistics. Sinauer Associates, Inc., Sunderland, Massachusetts, USA.

Harrison, S., B. D. Inouye, and H. D. Safford. 2003. Ecological heterogeneity in the effects of grazing and fire on grassland diversity. Conservation Biology 17:837-845.

Hatch, D. A., J. W. Bartolome, J. S. Fehmi, D. S. Hillyard. 1999. Effects of burning and grazingon a coastal California grassland. Restoration Ecology 7:376-381.

Herrick, J. E., J. W. Van Zeek, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Volumes I and II, monitoring manual for grassland, shrubland, and savanna ecosystems. USDA-ARS Jornada Experimental Range, Las Cruces, NM.

Hitchcock, C. L., A. Cronquist, M. Ownbey and J. W. Thompson. 1969. Vascular plants of the pacific northwest. Volume 1. University of Washington Press, Seattle, Washington, USA and London, Great Britain.

James, J. J. 2008. Effect of soil nitrogen stress on the relative growth rate of annual and perennial grasses in the Intermountain West. Plant Soil 310:201-210.

James, J. J., R. E. Drenovsky, T. A. Monaco, and M. J. Rinella. 2011. Managing soil nitrogen to restore annual grass-infested plant communities: effective strategy or incomplete framework?. Ecological Applications 21:490-502.

Lass, L. and T. Prather. 2007. A scientific evaluation of noxious and invasive weeds of the Highway 95 construction project between the Uniontown cutoff and Moscow. Aquila Vision Inc. 78p.

Mahler. R. L. 2005a. Northern Idaho fertilizer guide: Grass seedings for conservation programs. University of Idaho College of Agricultural and Life Sciences Extension Bulletin CIS 820.

Mahler. R. L. 2005b. Northern Idaho fertilizer guide: Grass pastures. University of Idaho College of Agricultural and Life Sciences Extension Bulletin CIS 853.

Masters, R. A. and R. L. Sheley. 2001. Principles and practices for managing rangeland invasive plants. Journal of Range Management 54:502-517.

McCoy, T. D., E. W. Kurzejeski, L. W. Burger, Jr., and M. R. Ryan. 2001. Effects of conservation practice, mowing, and temporal changes on vegetation structure on CRP fields in Northern Missouri. Wildlife Society Bulletin 29:979-987.

Mislevy, P., J. B. Washko, J. D. Harrington. 1977. Influence of plant stage at initial harvest and height of regrowth at cutting on forage yield and quality of timothy and orchardgrass. Agronomy Journal 69:353-356.

Natural Resource Conservation Service. 2009. CRP mid-contract management options. Conservation Program Fact Sheet. United States Department of Agriculture, Washington D.C., USA.

Natural Resource Conservation Service. 2013. CRP mid-contract management option: Integrated wildlife management (645). Conservation Practice Job Sheet. United States Department of Agriculture, Washington D. C., USA.NRCS

Negus, L. P., C. A. Davis, and S. E. Wessel. 2010. Avian response to mid-contract management of Conservation Reserve Program fields. American Midland Naturalist 164:296-310.

Nyamai, P. A., T. S. Prather, and J. M. Wallace. 2011. Evaluating restoration methods across a range of plant communities dominated by invasive annual grasses to native perennial grasses. Invasive Plant Science and Management 4:306-316.

Prather, T. 2009. *Ventenata dubia*: Increasing concern to the Inland Northwest Region. Center for Invasive Plant Management. June:1-2.

Prather, T. 2012. Developing a decision support tool for ventenata IPM in the Inland Northwest. WSARE Annual Report. 7p.

Robertson, S., K. R. Hickman, K. R. Harmoney, and D. M. Leslie, Jr. 2013. Combining glyphosate with burning or mowing improves control of yellow bluestem (*Bothriochloa ischaemum).* Rangeland Ecology and Management 66:376-381.

Sanyal, D., P. C. Bhowmik, R. L. Anderson, and A. Shretha. 2008. Revisiting the perspective and progress of integrated weed management. Weed Science 56:161-167.

Scheinost, P., M. Stannard, T. Prather, J. Yenish. 2008. USDA NRCS Plant Guide: *Ventenata dubia*. Pullman, WA; Pullman Plant Materials Center.

Sheley, R., E. Vasquez, and C. Hoopes. 2009. Functional group responses to reciprocal plant litter exchanges between native and invasive plant dominated grasslands. Invasive Plant Science and Management 2:158-165.

Shewmaker, G. E. and M. G. Bohle, editors. 2010. Pasture and Grazing Management in the Northwest. Pacific Northwest Extension Publication. PNW 614.

Thill, D. C., J. M. Lish, R. H. Callihan, E. J. Bechinski. 1991. Integrated weed management: A component of integrated pest management: A critical review. Weed Technology 5:648- 656.

Towne, E. G. and K. E. Kemp. 2003. Vegetation dynamics from annually burning tallgrass prairie in different seasons. Journal of Range Management 56:185-192.

Vasquez, E., R. Sheley, and T. Svejcar. 2008. Creating invasion resistant soils via nitrogen management. Invasive Plant Science and Management 1:304-314.

Wallace, J. and T. Prather. 2009a. Control of *Ventenata dubia* using various selective herbicides. WSWS Research Progress Report. Pp 46-47.

Wallace, J. and T. Prather. 2009b. Development of restoration tools for *Ventenata dubia* infested pastures. WSWS Research Progress Report. Pp 48-50.

Wallace, J. and T. Prather. 2010. Ventenata and downy brome control in timothy hay production. WSWS Research Progress Report. Pp 88.

Wallace, J. M., T. S. Prather, and L. M. Wilson. 2010. Plant community response to integrated management of meadow hawkweed (*Hieracium caespitosum*) in the Pacific Northwest. Invasive Plant Science and Management 3:268-275.

CHAPTER 3. Impacts on tree swallow (*Tachycineta bicolor*) nestling growth due to ventenata (*Ventenata dubia*) infestation in CRP

INTRODUCTION

The Palouse Prairie and much of the Inland Northwest have seen significant losses of contiguous upland habitat since the 1890's, primarily due to agriculture (Tisdale 1961) leaving less than 1% of Palouse Prairie as scattered remnants (Noss et al. 1995). Soil conservation initiatives, such as the Conservation Reserve Program (CRP) have mitigated some losses by creating grasslands that allow species indigenous to the Palouse to persist. Unfortunately, perennial grass and forb-dominated ecosystems have been converted to exotic annual plant communities. The importance of CRP to upland flora and fauna is paramount to maintain diverse and native communities. Ventenata [*Ventenata dubia* (Leers) Coss.] is an exotic annual grass that poses a particularly severe threat to native plant communities and its invasion is now threatening CRP functions such as erosion control, water quality and wildlife habitat within the Inland Pacific Northwest.

Ventenata, a non-indigenous winter annual grass from North Africa, is thin and wiry, shallow rooted, and completes its life cycle by mid-June (Crins 2007; Hitchcock et al. 1969). Ventenata is replacing native and desirable perennial grasses and may be causing changes in ecosystem function (Crins 2007; Prather 2009). A conversion to ventenata-dominated communities may change food resources available to vertebrates living within a grassland-agricultural matrix that includes CRP. Currently, we have no information on the impacts of ventenata invasion on wildlife. Secondary cavity-nesting passerine birds are commonly used to assess impacts to wildlife by comparing nestling growth rates and nesting success among different areas or management treatments (Ardia 2006; Tremblay et al. 2005). Nestling birds are useful indicators of habitat quality due their sensitivity to environmental changes such as temperature fluctuation, precipitation, prey abundance, competition for resources and weed invasion (Rosenberg and McKelvey 1999; Ruehmann et al. 2011; Tremblay et al. 2003, Tremblay et al. 2005).

Adult birds that must care for their altricial nestlings are classic examples of central-place foragers because they must forage in the area surrounding the nest and bring the collected food back to the nest site. For some bird species, adults make as many as 14 trips per hour to deliver food to their nestlings (Conway and Martin 2000). If food is not abundant, parents may be unable to provide sufficient food to their nestlings causing negative effects on the growth and survivorship of nestlings. Hence, nestling growth rates are useful indicators to changes in insect abundance and other environmental changes (McCarty and Winkler 1999b). By monitoring nestling growth rates and nesting success within CRP that differ in the extent of ventenata infestations, we sought to assess the impact of ventenata invasion on wildlife and ecosystem health.

Ventenata invasion of CRP may foster ecosystem shifts from desirable perennial plant communities to annual weed-dominated communities. Conversion to non-indigenous plant communities often causes changes or reductions in the local animal assemblage including changes in insect abundance and diversity (Herrera and Dudley 2003). Changes to insect assemblages may have cascading affects for vertebrates that rely on insects for food or pollination such as insectivorous passerines. Tree swallows (*Tachycineta bicolor* Vieillot) and western bluebirds (*Sialia mexicana* Swainson) are two examples of insectivorous passerines that would likely be affected by changes in insect abundance and diversity. Both of these species are central-place foragers while feeding their altricial nestlings and, hence, provide an opportunity to document higher order effects of ventenata infestations and help understand the overall ecosystem health of ventenata-infested plant communities.

The study hypotheses were that tree swallows within high ventenata infested CRP (>50% foliar cover) will have: 1) decreased growth rates of nestlings 2) increased nest failures and 3) natal recruitment will be fewer as compared to CRP with low ventenata infestations (<10% foliar cover). Understanding how increases in ventenata are affecting wildlife on the Palouse will further assist landowners and land management agencies to make informed habitat management decisions in agricultural systems. Broader comprehension of ventenata's impacts will also help communicate its invasion potential to areas outside of its current invaded range. Furthermore, ventenata is invading rangelands and sagebrush steppe of the Pacific Northwest and may pose a threat to wildlife in these systems as well. Many endemic, threatened and endangered species depend on these ecosystems and may also be adversely affected by ventenata in the future.

MATERIALS and METHODS

Study Area

We used artificial nest boxes to compare the direct effects of two different levels of ventenata infestations in CRP upon secondary-cavity nesting passerines. We selected CRP fields based on percent foliar cover of ventenata to compare CRP with low ventenata infestations (<10% foliar cover) to CRP with high ventenata infestations (>50% foliar cover). Sampling was conducted during the 2012 and 2013 breeding season on the Palouse near Moscow, Troy and Deary, ID. In 2012, we had five study areas: two sites in low ventenata infestations and three sites in high ventenata infestations (Table 1). Two more sites were added in 2013: one in low ventenata infestation and one in high infestation (Table 1). The number of nest boxes per site was contingent upon field size (a total of 70 in 2012 and 80 in 2013). The three low ventenata sites were located near Troy and Deary ID, whereas the four high ventenata sites were located near Moscow and Troy, ID (Table 1). CRP sites were selected based upon similar species composition including; orchardgrass (*Dactylis glomerata*), mountain brome (*Bromus marginatus*), smooth brome (*Bromus inermis*) and similar ventenata infestation levels. We also tried to choose sites with similar patterns of juxtaposition to forest, water and human structures. Nest boxes were placed in areas with similar habitat characteristics: distance to field edges and predator perches (>300m) (Munro and Rounds 1985), distance between nest boxes (>100m) (Fiehler et al. 2006), adjacent habitat types and percent perennial cover (ocular estimates of percent cover).

Table 1. Sampling dates, number of nest boxes and location for each study site.

Ventenata Cover	**Site**	**Seasons Sampled**		**No. Nest Boxes**	**UTM Zone 11 North**	
					Northing	**Easting**
High	Moscow North	2012	-	13	5181986	501432
	Iverson Rd.	2012	2013	12	5169703	503724
	Larson Rd.	2012	2013	14	5174026	510545
	Lonestar Rd.	-	2013	14	5167478	509881
Low	Camps Canyon Rd.	2012	2013	13	5175159	520960
	Gun Club Rd.	2012	2013	18	5180618	527570
	Johnson Rd.	-	2013	9	5178933	529639

Nestling Data Collection

Nest boxes allow for convenient data collection and monitoring of nests to measure nestling growth rates and survivorship, especially for tree swallows (Jones 2003). Our study was conducted with prior approval from the University of Idaho Animal Care and Use

Committee (Appendix A). We affixed nest boxes to steel posts, one meter off the ground, with the entrance oriented southeast and boxes were placed on southerly facing aspects (Rendell and Robertson 1994; Ardia et al. 2006b). Nest boxes were placed at least 100 m from each other to account for territory size of western bluebirds (Fiehler et al. 2006); tree swallows, our primary occupants, have much smaller territorial sizes of 20-30 m (Hussell 2012). We placed nest boxes greater than 300 m from field edges to minimize edge effects (Fiehler et al. 2006).

Boxes were monitored twice a week until nest initiation (Droge et al. 1991; Johnson et al. 2006). Once egg laying was initiated, boxes were monitored every one to two days. When nestlings hatched, they were marked with non-toxic nail polish on their claws for temporary identification (Fair et al. 2010). The first weight measurement was at four days after hatching, with date of the first chick hatched being day one (McCarty 2001). A digital scale (Ohaus Valor 3000) was used to measure nestling weight to the nearest hundredth gram. Weight measurements were then collected subsequently on the sixth, tenth and twelfth days after hatching (Dickinson and Weathers 1999). Monitoring did not continue after nestlings reached 12 days old to ensure no nestlings were force fledged (Fiehler et al. 2006), at which point nestlings were then banded with an aluminum band provided by the United States Geological Survey, National Banding Laboratory. All nestlings were taken directly out of the nest box by hand while wearing nitrile gloves. Handling of nestling was minimized by limiting the amount of time spent at each box to prevent nest abandonment per guidelines provided by the Ornithological Council (Fair et al. 2010).

Three growth rates were contrasted to detect possible changes in nestling growth. The first growth rate was calculated between the fourth and sixth day weight measurements, hereafter referred to as early growth rate. The second growth rate was calculated between the tenth and twelfth day weight measurements, hereafter referred to as late growth rate. We also examined the overall growth by calculating the weights of the fourth and twelfth measurements, hereafter referred to as total growth rate. Growth rates were calculated as weight over the number of days between weight measurements and expressed as the number of grams gained per day.

We also investigated hatching asynchrony by examining the difference in mass between the heaviest nestling and the lightest nestling for each nest box using the 4^{th} day weight measurements (Ardia et al. 2009; Clotfelter et al. 2000). Other studies indicated that there is a direct relationship between laying order and hatching order which can be identified by body mass of nestlings up to eight days old (Blancher and McNicol 1988; Clotfelter et al. 2000). The value we generate from this calculation is a ratio between the first and last hatched nestling which can be used to identify hatching asynchrony (Ardia et al. 2006a), with the greater the ratio the greater the hatching asynchrony that occurred. These data allowed us to identify if tree swallow nestlings are hatching more asynchronously in high ventenata sites than in low ventenata sites.

Vegetation Data Collection

The line-point intercept method was used to collect plant species cover at each nest box to measure the percentage of ventenata, perennial grasses, forbs and weedy forbs (Herrick et al. 2005). A sampling design by Ruehmann and coworkers (2011) was modified and used to capture more variability in plant composition surrounding each box. Percent foliar cover was recorded along four 50 m transects at two meter intervals. Transects ran north to south and east to west for each nest box. Vegetation height data were collected and correlated to species cover data with the use of a Robel pole at 25 m intervals along each transect (Robel et al. 1970). Species diversity indices (Shannon–Weiner and Simpson reciprocal) were calculated for total plant composition.

Shannon–Weiner diversity equation:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Simpson reciprocal diversity equation:

$$D' = \left(\sum_{i=1}^{s} p_i^2\right)^{-1}$$

During the second field season (2013), we randomly selected a subset of two nest boxes per site and recorded internal and external ambient air temperatures at one-hour intervals similar to methods in Ardia (2006) with the use of temperature data loggers (ECH$_2$O Dielectric probes, Decagon Devices Inc.). We used the hourly temperature records to identify the daily high internal box temperature and the daily high external box temperature during the peak incubation period (16 May to 25 June) and then compared both of these metrics between high and low ventenata sites. We compared our external nest box temperatures to local area weather stations to validate temperature readings.

Tree swallows will capture insects of various sizes and species when feeding nestlings. However, tree swallows primarily take insects that are 3 to 13 mm in total length with no preference for any particular insect taxa (Mengelkoch et al. 2004; Quinney & Ankney 1985; McCarty and Winkler 1999a). In 2013, we sampled relative insect abundance during three sampling periods (29 May to 4 June, 17 June to 25 June, and 9 July to 15 July) corresponding to peak incubation, early nestling growth, and late nestling growth, respectively (Herrera and Dudley 2003). Traps were deployed for seven days for the first trapping period, eight days for the second, and six days for the third. One trap station per site was randomly located in the field and each trap station contained four aerial sticky traps. Two aerial sticky traps were set perpendicular to each other (at a 90° angle) at 4 m and 8 m above the ground with the apex of each set of two traps facing the primary wind direction (Figure 1) (James Johnson, personal communication). Aerial sticky traps were made of 6.35 mm hardware cloth measuring 20 cm by 25 cm and covered with Tanglefoot® insect barrier (James Johnson, personal communication). We counted the number of insects in the <3.0 mm length size class within a 10 cm by 10 cm square at the center of each sticky trap, and we counted the number of all other size classes (3.1-5.0 mm, 5.1-10.0 mm, >10.1 mm total length) on the entire 20 cm by 25 cm sticky trap (McCarty and Winkler 1999a). We excluded thrips from the analysis due to their small size and as indicated by McCarty and Winkler (1999) thrips are not likely to be part of tree swallow diet.

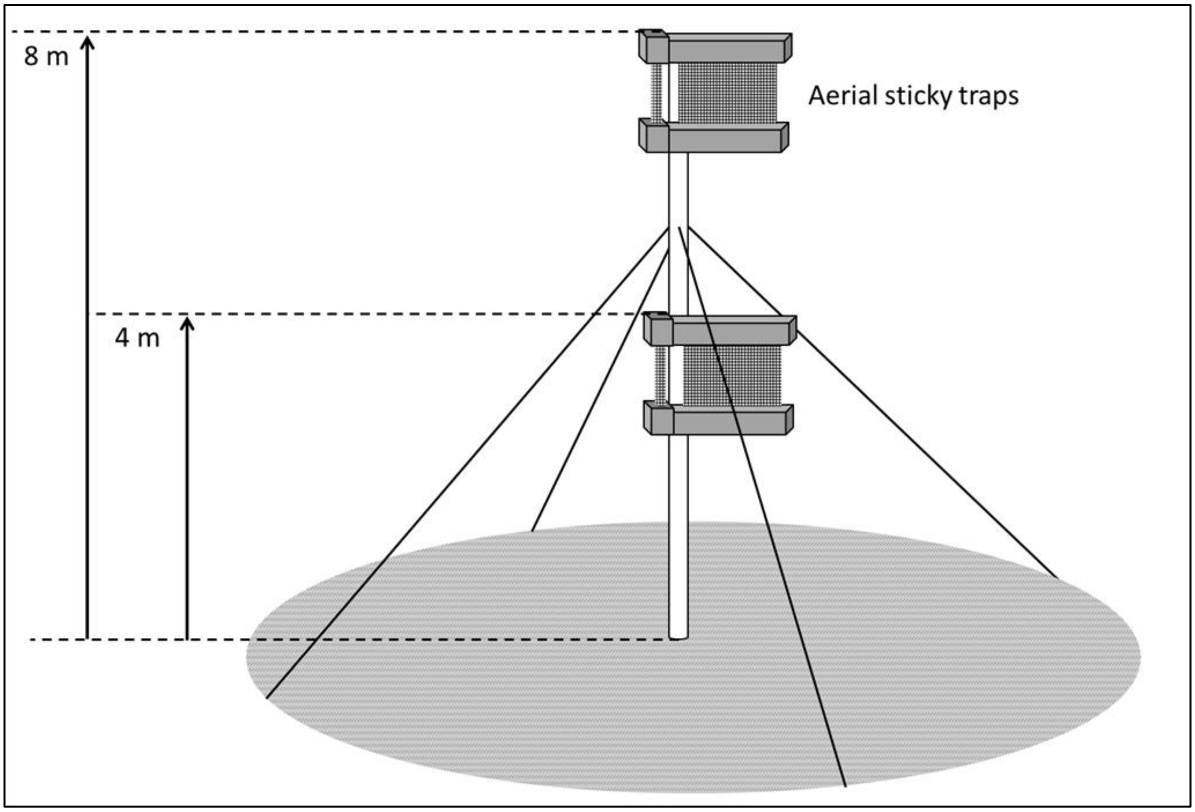

Figure 1. Aerial insect trap design.

Statistical Analysis

Descriptive statistics were computed on habitat characteristics and tree swallow parameters to help ordinate data with the Principle Component Analysis (PCA) with PROC PRINCOMP. The following variables were averaged for each nest box and used when analyzing the PCA: ventenata (%), perennial grass (%), forbs (%), clutch number, brood number, fledge number, non-viable eggs (%), and asynchrony. A series of *t*-tests were used to examine differences between high and low ventenata sites for the following variables: vegetation measurements (percent foliar cover of ventenata, perennial grasses, forbs, weeds, vegetation height, and weed diversity), nestling characteristics (early nestling growth rate, late nestling growth rate, total nestling growth rate, fledge weight, clutch number, brood number, percent non-viable eggs, percent mortality, and hatching asynchrony), temperature, and insect abundance between high and low ventenata sites. Univariate tests were conducted in SAS[1] with our confidence interval set at $\alpha=0.05$. There were nine re-nesting attempts by tree swallows which were included in the analysis. Tree swallows were the most common occupants during both field seasons with the only other occupants of the nest boxes being western bluebirds, however only tree swallows were used in the analysis. The Moscow North study site was lost during the first season due to agricultural conversion and therefore all data collected from this site was omitted.

RESULTS

Percent cover of ventenata ($P \leq 0.0001$) and perennial grass ($P \leq 0.0001$) differed between high and low ventenata infested CRP sites (Table 2). Percent ventenata cover, forb cover and weed cover were greater in high ventenata sites. Within high ventenata sites, most of the forbs were weedy species, while forbs in low ventenata sites were primarily perennial, non-weedy species. Vegetation was 57% taller in low ventenata sites ($P \leq 0.0001$; Table 2) compared to high ventenata sites. Total species diversity was significantly greater in high versus low ventenata sites for both of the species diversity indices (Table 2), however diversity was influenced by a large abundance of weedy species associated with high ventenata sites.

Table 2. Results of *t* -tests conducted on nest-site vegetative characteristics between high and low ventenata sites. Variables were calculated by averaging the four transects associated with each nest box.

Variables		High Ventenata $\bar{x} \pm SE$	Low Ventenata $\bar{x} \pm SE$	*P*-value
Ventenata cover (%)		53 ± 0.02	4 ± 0.008	<0.0001
Grass cover (%)		10 ± 0.01	76 ± 0.02	<0.0001
Forb cover (%)		23 ± 0.02	15 ± 0.02	0.0051
Weed cover (%)		14 ± 0.02	5 ± 0.01	<0.0001
Vegetation height (dm)		1.48 ± 0.07	3.46 ± 0.3	<0.0001
Total plant diversity	Shannon-Wiener Diversity Index	1.43 ± 0.05	1.14 ± 0.05	<0.0001
	Simpson Reciprocal Diversity Index	0.78 ± 0.02	0.56 ± 0.02	<0.0001

During the 2012 season, occupancy of nest boxes was similar between high and low ventenata sites, 69% and 71% respectively. There was 88% occupancy in the high and 100% in the low ventenata sites during the 2013 field season. We did not detect differences in nestling growth rates (early, late or total) or fledge weight between high and low ventenata sites (Table 3). We also did not detect a difference in percent mortality of nestlings (Table 4). However, high ventenata sites had smaller clutches (P=0.06), smaller broods (P=0.02) and fewer fledglings (P=0.005) than low ventenata sites (Table 4). Variation between the weights of the largest and smallest nestlings, hereafter referred to as hatching asynchrony, indicated a significant separation between high and low ventenata sites (P=0.001, Table 4).

Table 3. Growth rates and body mass at fledging of tree swallow nestlings at high and low ventenata sites.

Variables	High Ventenata $\bar{x} \pm SE$	*n*	Low Ventenata $\bar{x} \pm SE$	*n*	*P*-value
Early Growth Rate (g/day)	2.04 ± 0.06	103	2.01 ± 0.05	205	0.7
Late Growth Rate (g/day)	1.58 ± 0.10	104	1.58 ± 0.07	185	0.9
Total Growth Rate (g/day)	1.85 ± 0.03	96	1.84 ± 0.03	178	0.9
Fledge Weight (g)	19.93 ± 0.26	105	19.88 ± 0.17	192	0.9

Table 4. Reproductive parameters of tree swallows at high and low ventenata sites.

Variables	High Ventenata (n=56) $\bar{x} \pm$ SE	Low Ventenata (n=60) $\bar{x} \pm$ SE	P-value
Clutch Number	5.41 ± 0.14	5.50 ± 0.12	0.06
Brood Number	3.98 ± 0.26	4.73 ± 0.17	0.02
Fledge Number	2.30 ± 0.27	3.38 ± 0.26	0.005
Non-viable eggs (%)	0.20 ± 0.04	0.12 ± 0.02	0.12
Mortality (%)	0.27 ± 0.05	0.24 ± 0.05	0.7
Hatching Asynchrony (%)	0.61 ± 0.02 [a]	0.70 ± 0.02 [a]	0.001

[a] Sample size is 36 for high and 54 for low ventenata sites.

We selected variables that suggested differences between high and low ventenata sites for the PCA analysis. PCA suggested a direct relationship between ventenata infestations and the effect on nesting success of tree swallows. Principle component 1 (PC1) was predominately comprised of vegetative characteristics consisting of an inverse relationship between percent cover of ventenata and perennial grass (Table 5). Principle component 2 (PC2) had the strongest positive loading with brood number (Table 5). Principle component 3 (PC3) only contained an additional 15% of the variability and but there was strong inverse relationship between percent non-viable eggs and hatching asynchrony. The PCA specified that 56% of the variability was accounted for in the first two principle components (Table 2). When comparing the PC1 with PC2 we observed a clear separation between high and low ventenata sites, which suggests that brood number is influenced by percent ventenata (Figure 2). Though the relationship is less clear, there is still a clear separation between high and low ventenata sites when comparing PC1 to PC3 in comparison to percent non-viable eggs and hatching asynchrony (Figure 3). The percent forb cover and fledge number variables did not have as strong loadings as the other variables, suggesting they were less influential in the analysis.

Table 5. Results of principle component analysis on nest-site characteristics (n = 88). Includes variables which are significantly different between high and low ventenata sites.

	Principle components		
	I	II	III
Percentage total variance	31.2	25.0	14.6
Cumulative percentage of total	31.2	56.2	70.8
Correlations of components to nest-site variables			
Ventenata %	-0.56	0.16	0.07
Perennial Grass (%)	0.59	-0.22	0.05
Forbs (%)	-0.38	0.27	-0.25
Clutch number	0.21	0.41	0.52
Brood number	0.26	0.62	-0.02
Fledge number	0.18	0.22	-0.03
Non-viable eggs (%)	-0.16	-0.45	0.58
Asynchrony	0.16	-0.24	-0.57

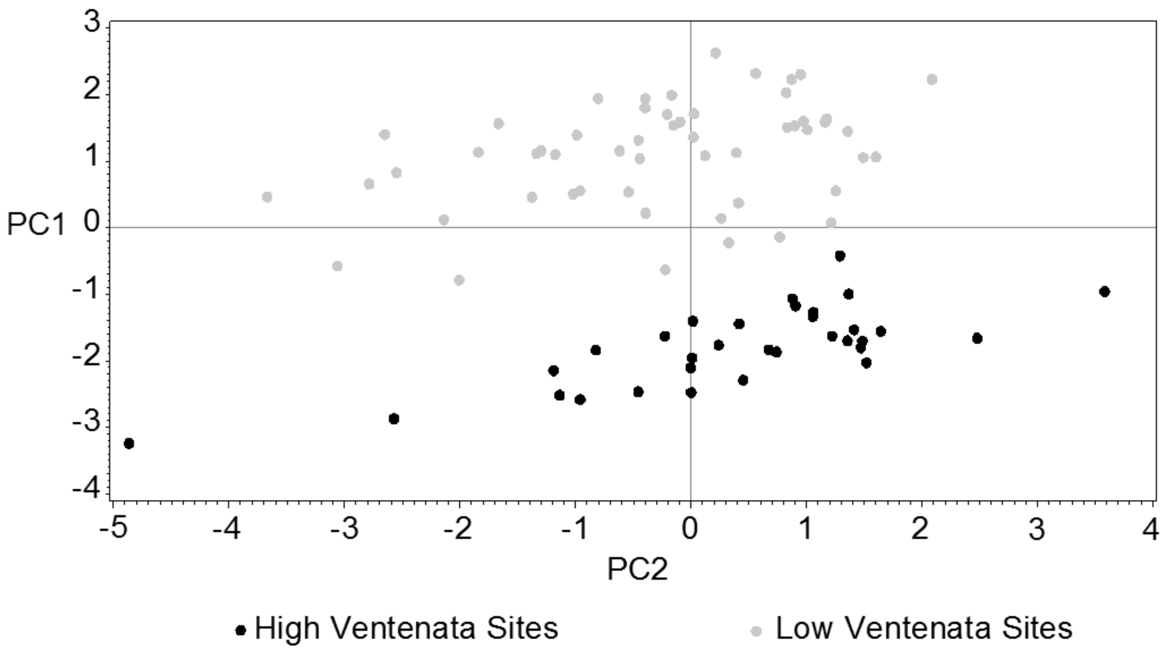

Figure 2. Relationship between vegetative nest-site characteristics (PC1) and nest box occupancy (PC2) (n = 88).

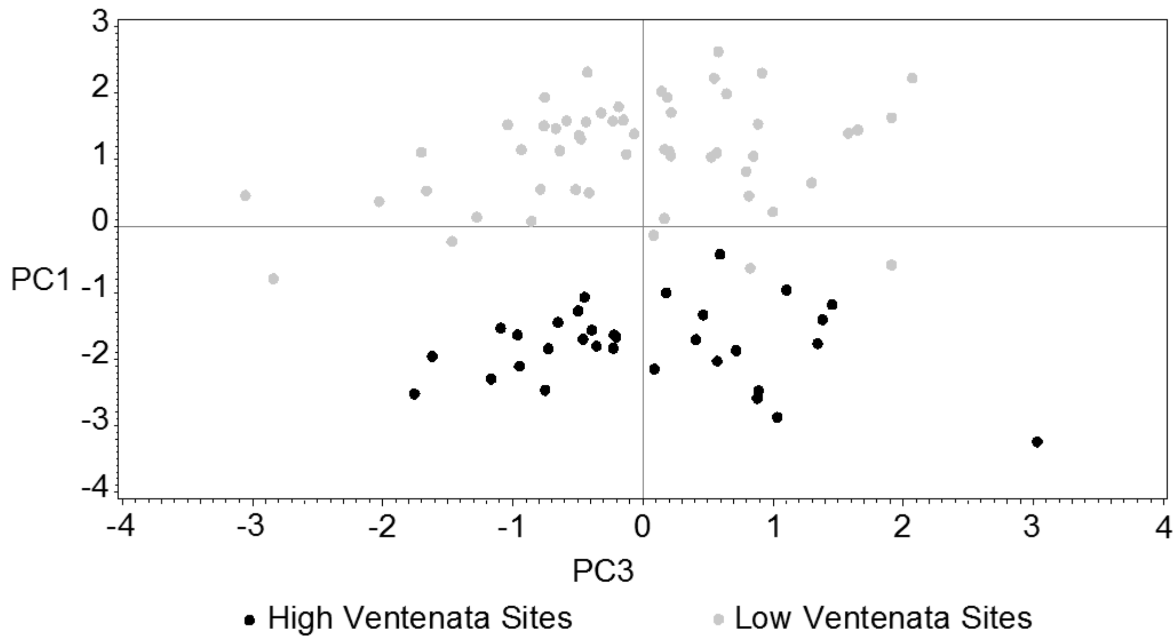

Figure 3. Relationship between vegetative nest-site characteristics (PC1) and egg viability and hatching asynchrony (PC3) (*n* = 88).

Nest Box Temperature Side Study

In the first year of the study, many eggs laid in high ventenata sites were not viable (25%) and in five boxes, no eggs were viable. Temperature within the box was suspected to contribute to egg viability, so in the second year we measured air temperature within boxes and compared box temperature between high and low ventenata sites. Other research (Dawson et al. 2005; Winkler et al. 2013) indicated that internal nest box temperatures can become high enough to prohibit embryo development. However, no differences were detected between high and low ventenata sites in either internal or external nest box temperatures (data not shown). During the 2013 field season, we observed a significant decrease (P =0.052) in the number of non-viable eggs (15%) in high ventenata sites from that of the 2012 field season (25%), but there was no difference in egg viability between the two years at low ventenata sites between both years. Clearly temperature within the nest boxes was not affecting egg viability differentially between high and low ventenata sites.

Prey Abundance Side Study

We observed no significant difference during the first trapping period in number of insects captured for any of the size classes between high and low ventenata sites. However, we detected a significant difference in number of insects captured between high and low ventenata sites during the second and third trapping periods for the 0-3.0 mm size class (Table 6). Additionally, we detected a significant difference in number of insects captured between high and low ventenata sites for the 3.1-5.0 mm size class during the third trapping period (Table 6). Due to unseasonably lower temperatures and precipitation during the second trapping period, we observed a decrease in insect abundance in both high and low ventenata sites but maintained a significant difference between sites in insect abundance. Overall, insect abundance increased as the season progressed at the low ventenata sites but not at the high ventenata sites (Figure 4).

Table 6. Average number of insects captured on all four sticky traps during three trapping sessions pooled between high and low ventenata sites. The 0-3.1 mm size class is expressed as number of insects per 100 sq. cm. All other size classes are represented as the number of insects per 500 sq. cm.

Trapping Period	Ventenata Cover	Size Classes (mm) 0-3.0	3.1-5.0	5.1-10.0	10.1+
1	Low	39.2	1.8	1.4	0.6
	High	38.8	2.8	1.3	0.4
2	Low	33.3 [a]	2.0	1.8	0.1
	High	21.8 [a]	1.3	0.8	0.1
3	Low	85.7 [a]	7.2 [a]	0.7	0.0
	High	48.8 [a]	1.7 [a]	0.8	0.2

[a] Indicates a significant difference between high and low ventenata sites at $\alpha = 0.05$.

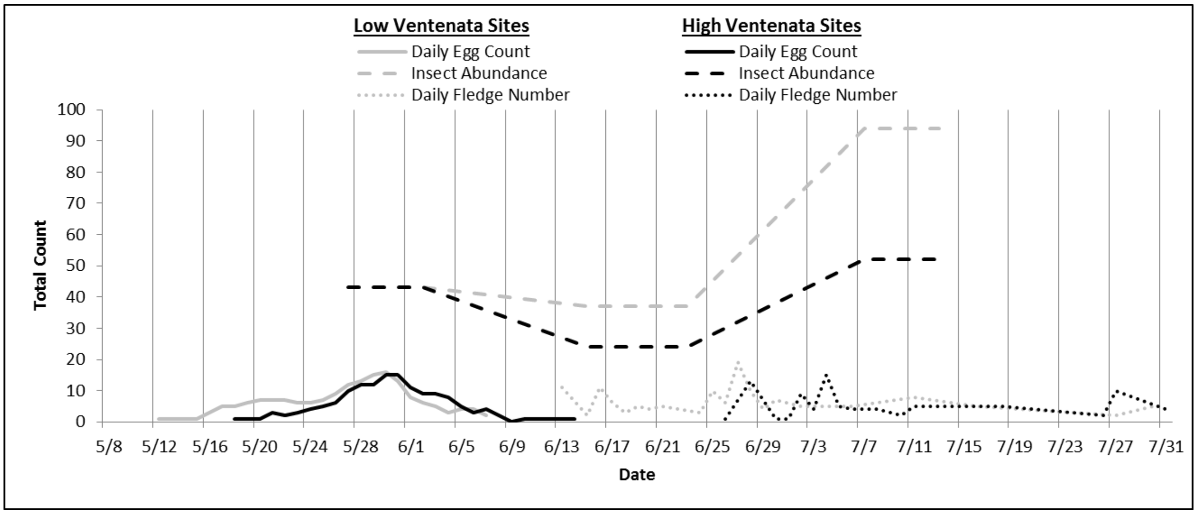

Figure 4. Seasonal phenology of insect abundance, eggs laid per day, and fledge number per day for the 2013 field season at both high and low ventenata sites.

DISCUSSION

Principal component analysis suggested there was a relationship between the vegetation characteristics and reproductive output. Both the univariate tests and the PCA exhibited an association between reduced reproductive output and ventenata infestation. Nests in high ventenata sites had smaller clutches, a larger proportion of non-viable eggs, smaller broods, and fewer fledglings than low ventenata sites. Fledglings in high ventenata sites were similar in fledge weight (actually 1% heavier) despite lower prey abundance, likely because the smaller broods allowed sufficient food per nestling for those that survived (Hussell 2012; Leonard et al. 1999). Hatching asynchrony may have allowed tree swallows in high ventenata sites to maintain adequate nestling growth rates despite lower prey abundance via adaptive reductions in brood size (Leonard and Horn 1996).

The brood-reduction hypothesis is a well-supported hypotheses to explain the evolution of hatching (Stoleson and Beissinger 1995). The hypothesis suggests that hatching asynchrony allows parents to adjust their brood size to match ambient prey abundance. Tree swallows and many other passerine species commonly use brood reduction as a tradeoff when food abundances are low (Clotfelter et al. 2000). The inherent size hierarchy of nestlings allows sibling competition to eliminate offspring that parents can't support when prey abundance is low (Lack and Lack 1951). The smaller brood size coupled with the lower insect abundance at high ventenata sites provides evidence that high ventenata sites are less suitable for tree swallows relative to low ventenata sites. The adaptive reduction in brood size at high ventenata sites explains why growth rates were similar between high and low ventenata sites.

Tree swallows in low ventenata sites also had a mean egg laying date that was eight days earlier than that of tree swallows in high ventenata sites. We failed to detect differences in internal or external nest box temperature between high and low ventenata sites. Furthermore, we could not detect a difference in insect abundances during the first sampling period between high and low ventenata sites. The difference in our measure of hatching asynchrony between high and low ventenata sites was likely caused by the larger number of non-viable eggs in high ventenata sites. Hence, the reason for the larger proportion of non-viable eggs in high ventenata sites is not clear.

Our study suggests that tree swallows that nest in high ventenata sites may be reassessing environmental conditions and reducing clutch sizes (Nooker et al. 2005; Winkler et al. 2002; Winkler and Allen 1995; and Winkler and Allen 1996). Reduced clutch size and lower rates of egg viability may explain the differences in hatching asynchrony between high and low ventenata sites. Increases in foliar cover of ventenata may have even larger effects on bird species with synchronous hatching that have fewer mechanisms for dealing with the reduced prey availability in fields with large amounts of ventenata. Future studies should examine the effects of ventenata on other grassland bird species, especially those that don't exhibit hatching asynchrony.

Our results suggest that greater than 50% ventenata foliar cover had negative effects on reproductive output of tree swallows, including reduced brood and fledge number and a larger proportion of non-viable egg. Ventenata's invasion into CRP has likely had a cascade of effects on the plant and animal communities. Our results corroborate those of past studies (Herrera and Dudley 2003) which have shown that weed invasion can alter insect assemblages and abundances with negative consequences to insectivorous birds. The invasion by ventenata into CRP makes habitat less suitable for at least some wildlife species and understanding the magnitude and ubiquity of these effects can help guide management decisions in these systems.

MANAGEMENT IMPLICATIONS

Invasion by ventenata into CRP can jeopardize survival and fitness of wildlife through a cascade of effects related to reduced desirable plant diversity, changes to insect abundance, and reductions in reproductive output. By understanding these effects, managers can make informed decisions regarding effective management of CRP and other grassland ecosystems. Alteration of habitat structure and function due to weed invasion can have consequences on selection of those habitats by wildlife which has been seen by other grassland species (Scheiman et al. 2003). Mid-contract management activities on CRP fields to increase grassland health has been shown to benefit the avian community (Negus et al. 2010) as well as increase desirable vegetation characteristics that improve wildlife food and cover (Greenfield 2003). However, some mid-contract management strategies, such as mowing, have little to no wildlife benefits (McCoy et al. 2001). In general, CRP is crucial for the survival of declining species such as the Henslow's sparrow (Herkert 2007) and by managing weeds such as ventenata, we can help negate some of the negative impacts on wildlife.

SOURCE OF MATERIALS

[1] SAS version 9.2, SAS Institute, Cary, NC 27513

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Timothy Prather, for allowing me to develop this research question. His guidance and advice in this project was greatly appreciated and allowed me to tailor my interests of invasive plant management and wildlife. Additionally, I would like to thank Dr. Courtney Conway for his insight, suggestions and helping me through the permitting process to complete this project. Also, I would like thank Joel Sauder, Justin Barrett and Zach Swearingen from the Idaho Department of Fish and Game for donating tools and materials needed for this study. Thanks to Matt Pieron from Idaho Department of Fish and Game for many engaging conversations on my study design and analysis. I would like to thank my technicians Holly Baker, Hannah Tomlinson and Taylor Ortiz for many dedicated long and hot days, early mornings and late evenings for accurate data collection and monitoring of nest boxes. I would to thank Kelsea Holloway, and my wife Lori Mackey, for volunteering time to monitor nest boxes and assist with data collection. Lastly, I would like to thank the Western Sustainable Agriculture Research and Education who funded this project (project number: SW10-103).

LITERATURE CITED

Ardia, D. R. 2006. Geographic variation in the trade-off between nestling growth rate and body condition in the tree swallow. The Condor 108:601-611.

Ardia, D. R., C. B. Cooper, and A. A. Dhondt. 2006a. Warm temperatures lead to early onset of incubation, shorter incubation periods and greater hatching asynchrony in tree swallows *Tachycineta bicolor* at the extremes of their range. Journal of Avian Biology 37:137-142.

Ardia, D. R., J. H. Perez, E. K. Chad, M. A. Voss, and E. D. Clotfelter. 2009. Temperature and life history: experimental heating leads female tree swallows to modulate egg temperature and incubation behavior. Journal of Animal Ecology 78:4-13.

Ardia, D. R., J. H. Perez, and E. D. Clotfelter. 2006b. Nest box orientation affects internal temperature and nest-site selection by tree swallows. Journal of Field Ornithology 77:339-344.

Blancher, P. J. and D. K. McNicol. 1988. Breeding biology of tree swallows in relation to wetland acidity. Canadian Journal of Zoology 66:842-849.

Clotfelter, E. D., L. A. Whittingham, and P. O. Dunn. 2000. Laying order, hatching asynchrony and nestling body mass in tree swallows (*Tachycineta bicolor*). Journal of Avian Biology 31:329-334.

Conway, C. J. and T. E. Martin. 2000. Evolution of passerine incubation behavior: Influence of food, temperature, and nest predation. Evolution 54:67-685.

Crins, W. J. 2007. Flora of North America. Volume 24. Oxford University Press, Oxford, New York, USA.

Dawson, R. D., C. C. Lawrie, and E. L. O'Brien. 2005. The importance of microclimate variation in determining size, growth and survival of avian offspring: experimental evidence from a cavity nesting passerine. Oecologia 144:499-507.

Dickinson, J. L. and W. W. Weathers. 1999. Replacement males in the western bluebird: Opportunity for paternity, chick-feeding rules, and fitness consequences of male parental care. Behavioral Ecology and Sociobiology 45:201-209.

Droge, D. L., P. A. Gowaty, and W. W. Weathers. 1991. Sex-biased provisioning: A test for differences in field metabolic rates of nestling eastern bluebirds. The Condor 93:793-798.

Fair, J., E. Paul, and J. Jones, Eds. 2010. Guidelines to the use of wild birds in research. Washington, D.C.: Ornithological Council.

Fiehler, C. M., W. D. Tietje, and W. R. Fields. 2006. Nesting success of western bluebirds (*Sialia mexicana*) using nest boxes in vineyard and oak-savannah habitats of California. Wilson Journal of Ornithology 118:552-557.

Gill, D. E., P. Blank, et al. 2006. Plants and breeding bird response on a managed Conservation Reserve Program grassland in Maryland. Wildlife Society Bulletin 34:944-956.

Greenfield, K. C., M. J. Chamberlain, L. W. Burger, Jr., and E. W. Kurzejeski. 2003. Effects of burning and discing Conservation Reserve Program fields to improve habitat quality for Northern Bobwhite (*Colinus virginianus*). American Midland Naturalist 149:344-353.

Herkert, J. R. 2007. Conservation Reserve Program benefits on Henslow's sparrows within the United States. Journal of Wildlife Management 71:2749-2751.

Herrera, A. M. and T. L. Dudley. 2003. Reduction of riparian arthropod abundance and diversity as a consequence of giant reed (*Arundo donax*) invasion. Biological Invasions 5:167-177.

Herrick, J. E., J. W. Van Zeek, K. M. Havstad, L. M. Burkett, and W. G. Whitford. 2005. Volumes I and II, monitoring manual for grassland, shrubland, and savanna ecosystems. USDA-ARS Jornada Experimental Range, Las Cruces, NM.

Hitchcock, C. L., A. Cronquist, M. Ownbey and J. W. Thompson. 1969. Vascular plants of the pacific northwest. Volume 1. University of Washington Press, Seattle, Washington, USA and London, Great Britain.

Hussell, D. J. 2012. The influence of food abundance on nest-box occupancy and territory size in the tree swallow, a species that does not defend a feeding territory. The Condor 114:595-605.

Johnson, L. S., E. Ostlind, J. L. Brubaker, S. L. Balenger, B. G. P. Johnson, and H. Golden. 2006. Changes in egg size and clutch size with elevation in a Wyoming population of mountain bluebirds. The Condor 108:591-600.

Jones J. 2003. Tree swallows (*Tachycineta bicolor*): a new model organism? Auk 120:591-599.

Lack, D., and E. Lack. 1951. The breeding biology of the Swift *Apus apus*. Ibis 93:501-546.

Leonard M. and A. Horn. 1996. Provisioning rules in tree swallows. Behavioral Ecology and Sociobiology 38:341-347.

Leonard, M. L., A. G. Horn, A. Gozna, and S. Ramen. 1999. Brood size and begging intensity in nestling birds. Behavioral Ecology 11:196-201.

McCarty, J. P. 2001. Variation in growth of nestling tree swallows across multiple temporal and spatial scales. The Auk 118:176-190.

McCarty, J. P. and D. W. Winkler. 1999a. Foraging ecology and diet selectivity of tree swallows feeding nestlings. The Condor 101:246-254.

McCarty, J. P. and D. W. Winkler. 1999b. Relative importance of environmental variables in determining the growth of nestling tree swallows *Tachycineta bicolor*. Ibis 141:286-296.

McCoy, T. D., E. W. Kurzejeski, L. W. Burger, Jr., and M. R. Ryan. 2001. Effects of conservation practice, mowing, and temporal changes on vegetation structure on CRP fields in Northern Missouri. Wildlife Society Bulletin 29:979-987.

Mengelkoch, J. M., G. J. Niemi, and R. R. Regal. 2004. Diet of the nestling tree swallow. The Condor 106:423-429.

Munro, H. L. and R. C. Rounds. 1985. Selection of artificial nest sites by five sympatric passerines. Journal of Wildlife Management 49:264-276.

Negus, L. P., C. A. Davis, and S. E. Wessel. 2010. Avian response to mid-contract management of Conservation Reserve Program fields. American Midland Naturalist 164:296-310.

Nooker, J. K., P. O. Dunn, and L. A. Whittingham. 2005. Effects of food abundance, weather, and female condition on reproduction in tree swallows (*Tachycineta bicolor*). The Auk 122:1225-1238.

Noss, R. F., E. T. LaRoe III, and J. M. Scott. 1995. Endangered ecosystems of the United States: A preliminary assessment of loss and degradation. National Biological Service, Washington, D.C., Biological Report 28.

Prather, T. 2009. *Ventenata dubia*: Increasing concern to the Inland Northwest Region. Center for Invasive Plant Management.

Quinney, T. E. and C. D. Ankney. 1985. Prey size selection by tree swallows. The Auk 2:245-250.

Rendell, W. B. and R. J. Robertson. 1994. Cavity-entrance orientation and nest-site use by secondary hole-nesting birds. Journal of Field Ornithology 65:27-35.

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295-297.

Rosenberg, D. K. and K. S. McKelvey. 1999. Estimation of habitat selection for central-place foraging animals. Journal of Wildlife Management 63:1028-1038.

Ruehmann, M. B., M. J. Desmond, and W. R. Gould. 2011. Effects of smooth brome on Brewer's sparrow nest survival in sagebrush steppe. The Condor 113:419-428.

Scheiman, D. M., E. K. Bollinger, and D. H. Johnson. 2003. Effects of leafy spurge infestation on grassland birds. Journal of Wildlife Management 67:115-121.

Stoleson, S. H. and S. R. Beissinger. 1995. Hatching asynchrony and the onset of incubation in birds, revisited. Current Ornithology 12:191-270.

Tisdale, E. W. 1961. Ecologic changes in the Palouse. Northwest Science 35:134-138.

Tremblay, I., W. Thomas, M. M. Lambrechts, J. Blondel, and P. Perret. 2003. Variation in blue tit breeding performance across gradients in habitat richness. Ecology 84:3033-3043.

Tremblay, I., D. Thomas, J. Blondel, P. Perret, and M. M. Lambrechts. 2005. The effect of habitat quality on foraging patterns, provisioning rate and nestling growth in Corsican blue tits *Parus caeruleus*. Ibis 147:17-24.

Winkler, D. W., M. K. Luo, and E. Rakhimberdiev. 2013 Temperature effects on food supply and chick mortality in tree swallows (*Tachycineta bicolor*). Oecologia 173:129-138.

Winkler, D. W. and P. E. Allen. 1995. Effects of handicapping on female condition and reproduction in tree swallows (*Tachycineta bicolor*). Auk 112:737-747.

Winkler, D. W. and P. E. Allen. 1996. The seasonal decline in tree swallow clutch size: Physiological constraint or strategic adjustment? Ecology 77:922-932.

Winkler, D. W., P. O. Dunn, and C. E. McCulloch. 2002. Predicting the effects of climate change on avian life-history traits. Proceeding of the National Academy of Sciences USA 99:13595-13599.

Appendix A

University of Idaho Animal Care and Use Committee Approval Verification.

University of Idaho
Animal Care and Use Committee

Date: Friday, April 27, 2012

To: Timothy S. Prather

From: University of Idaho

Re: Protocol 2012-34
Developing a Decision Support Tool for Ventenata (*Ventenata dubia*) Integrated Pest Management in the Inland Northwest

Your animal care and use protocol for the project shown above was reviewed and approved by the University of Idaho on Friday, April 27, 2012.

This protocol was originally submitted for review on: Tuesday, March 20, 2012
The original approval date for this protocol is: Friday, April 27, 2012
This approval will remain in affect until: Saturday, April 27, 2013
The protocol may be continued by annual updates until: Monday, April 27, 2015

Federal laws and guidelines require that institutional animal care and use committees review ongoing projects annually. For the first two years after initial approval of the protocol you will be asked to submit an annual update form describing any changes in procedures or personnel. The committee may, at its discretion, extend approval for the project in yearly increments until the third anniversary of the original approval of the project. At that time, the protocol must be replaced by an entirely new submission.

Brad Williams, DVM
Campus Veterinarian
University of Idaho
208-885-8958