VARIATION IN PERENNIAL GRASS HEIGHT WITHIN GREATER SAGE-GROUSE NESTING HABITAT

A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Natural Resources

in the

College of Graduate Studies

University of Idaho

by

Janessa C. Julson

Major Professor: Karen L. Launchbaugh, Ph.D.

Committee Members: Courtney J. Conway, Ph.D.; Eva K. Strand, Ph.D.

Department Administrator: P. Charles Goebel, Ph.D.

December 2017

AUTHORIZATION TO SUBMIT THESIS

This thesis of Janessa C. Julson, submitted for the degree of Master of Science with a Major in Natural Resources and titled "VARIATION IN PERENNIAL GRASS HEIGHT WITHIN GREATER SAGE-GROUSE NESTING HABITAT," 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: _____
Karen L. Launchbaugh, Ph.D.

Committee Members: _____ Date: _____
Courtney J. Conway, Ph.D.

_____ Date: _____
Eva K. Strand, Ph.D.

Department
Administrator: _____ Date: _____
P. Charles Goebel, Ph.D.

ABSTRACT

A recent focus on sagebrush obligate species has increased the need to understand sagebrush steppe habitat for rangeland and wildlife management. Plant community attributes, such as perennial grass height, are influencing many decisions by land management agencies throughout sagebrush ecosystems, specifically those where greater sage-grouse (*Centrocercus urophasianus*) reside during their nesting season. In Chapter 1, our objective was to review published research to summarize and compare reported grass heights in sage-grouse nesting habitat between nest sites and available habitat, and between successful and failed nests. In Chapter 2, we assessed three types of perennial grass height in sagebrush steppe communities across four study locations in the Snake River Plains of southern Idaho. The results from both studies indicate variations of heights among grasses and metrics used in ongoing and published research. In our research in southern Idaho, we found that grass heights differed among species, and within species grass height differed among locations, ecological sites, and between years. Our results corroborate other studies that have reported that grass height differs among species and varies both spatially and temporally. This inherent variation should be taken into account when interpreting sage-grouse habitat studies and using results of such studies to set grazing and land-use policies. Our results can provide useful insight to land agencies that are developing management plans, especially those that include thresholds for grass height that are intended to benefit sagebrush obligate species, such as the greater sage-grouse. Given the spatial and temporal variation in grass heights, having a "blanket" grass height requirement across multiple geographic regions may not achieve management goals in areas where sage-grouse nesting occurs. While vegetation structure is important for nest concealment in sage-grouse nesting habitat, land management agencies ought to consider the

extent to which grass height varies across years, in periods of extreme weather conditions, and across geographic locations.

ACKNOWLEDGEMENTS

I want to thank many of those who helped contribute to this thesis, and for all the knowledge, guidance, and up's and down's along the way. A huge thank you to my major professor, Dr. Karen Launchbaugh, for taking me on as a graduate student and for giving me the opportunity to be a part of such a "hot topic". I also want to thank you for your support and never-ending knowledge of rangeland ecology and management. To my committee members, Dr. Courtney Conway and Dr. Eva Strand, who helped in so many ways with their ideas, knowledge, and abundant support throughout my time at University of Idaho. To an honorary committee member, Anthony Locatelli, who provided much insight on the project work, GIS, and statistics. To Dr. April Hulet and Lovina Englund who provided many ideas, suggestions, and support to my thesis. To the BLM Range Management Specialists, Scott Sayer and Jordan Hennefer, who answered many of my phone calls and questions, who were always a joy to talk to on the phone, and are full of knowledge of their project sites and rangeland management "on the ground". To Dave Musil, with the Idaho Department of Fish and Game, for the countless stories, laughs, knowledge, and help with field work. To the many graduate students I shared classes and stress with, Heidi Becker, Molly Kaweck, Chris Schachtschneider, Amanda Stasiewicz, Cat Edgeley, Justin Trujillo, Ian Riley, Dave Gotsch, and all the others I have not the space to mention here. To the undergrad students who helped me find an escape from the dredges of graduate school—Mary Powers, Hannah Belloli, Landon Goolsby, Ben Cochran, Natalie Martin, Jake Gardner—you are all such great friends! Big thanks to the many technicians who helped gather the data in the field. Thank you to my many coworkers at the Palouse Conservation District who helped provide insight to my thesis as the end was nearing. And finally, a thank you to all the sponsors for the University of

Idaho's Grouse and Grazing project, University of Idaho College of Natural Resources, University of Idaho Rangeland Center, USGS Cooperative Fish and Wildlife Research Units, Idaho Department of Fish and Game, Western Association of Fish and Wildlife Agencies, Bureau of Land Management, Idaho Governor's Office of Species Conservation, Great Basin Landscape Conservation Cooperative, Public Lands Council, Idaho Cattle Association, Idaho Sage-Grouse Advisory Committee, and to all the BLM permittees at the Big Butte, Brown's Bench, Jim Sage, and Sheep Creek allotments. Thank you all! This thesis would not have been possible without you!

DEDICATION

To my dad for instilling in me the love of nature and showing me the benefit of persistence.

To my mom for teaching me the value of patience and to always be humble.

To my sister, her family, and my brothers for providing me with love, support, and more laughs than they probably know.

To my three puppies, Mater, Smokey, and Bandit, who always had endless amounts of unconditional love.

And finally, to my husband, Cole, who has been my rock and kept me grounded through this process, especially when I felt like flying off the deep end, and who has supported and loved me in even the most trying of times.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 1

CHAPTER 2

LIST OF FIGURES

CHAPTER 1

CHAPTER 2

INTRODUCTION

Sagebrush (*Artemisia* spp.) communities were estimated to have once occurred on over 62 million hectares in the western U.S. and southwestern Canada (West 1983). This ecosystem has been declining since early European settlement in North America (Welch 2005). In the early 2000s, only 40-50 million hectares of sagebrush communities remained across thirteen U.S. states and three Canadian provinces (West 2000; Connelly et al. 2004). This ecosystem persists on only about half of its historical range and is continuously being fragmented (Knick et al. 2003; Schroeder et al. 2004). Energy development, urban expansion, and conversion to croplands alter and fragment sagebrush communities (Rowland et al. 2006; Davies et al. 2011; Rottler et al. 2015). In low elevations, large frequent wildfires also contribute to the loss of sagebrush and increase the invasion of annual grasses (Chambers et al. 2007). In higher elevations, where areas of significant fire suppression occur, conifer encroachment has led to a change of the vegetation structure and sagebrush community (Miller et al. 2008).

Increased fragmentation and a loss of sagebrush has altered habitat conditions for many species of wildlife, including the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse; Connelly and Braun 1997). This habitat loss and degradation has led to a precipitous decline of sage-grouse populations since the mid-twentieth century (Connelly and Braun 1997; Schroeder et al. 2004). Historically, the greater sage-grouse was found in 13 western U.S. states and western Canada. Today, sage-grouse reside in 11 U.S. states and in the southwestern portions of two Canadian provinces (WAFWA 2015). Sage-grouse abundance varies from year to year (Garton et al. 2015; WAFWA 2015); however, breeding populations have declined an average of 2.1% per year since 1965 (WAFWA 2015). In a

recent population analysis, sage-grouse numbers fell by 56% from 2007 to 2013 (Garton et al. 2015).

Sage-grouse was recently a candidate species under the Endangered Species Act (ESA). A U.S. Fish and Wildlife Service (USFWS) listing decision in 2010 prompted federal, state, and local land management agencies to develop and implement sage-grouse habitat conservation efforts (Copeland et al. 2014). In September 2015, the USFWS found the sage-grouse not warranted for listing under the ESA (USFWS 2015); the implemented conservation actions likely helped support the USFWS's decision. Efforts are ongoing to try to stabilize and possibly increase sage-grouse numbers and conserve critical habitat, which may also help other wildlife species found in sagebrush systems (Rowland et al. 2006; Copeland et al. 2014).

Sage-grouse often migrate and require large patches of sagebrush throughout their lifecycle (Connelly et al. 2000). They have distinct summer, winter, and breeding (including nesting and early brood rearing) ranges, and use sagebrush through most, if not all, of their lifecycle (Connelly et al. 2000). Access to suitable vegetation conditions during nesting and brood rearing are critical for sage-grouse populations to persist (Connelly et al. 2000).

The Idaho and Southwestern Montana petition to list greater sage-grouse included a list of desired conditions for sage-grouse habitat including lek security and nesting and brood rearing habitat (USFWS 2015). Nesting guidelines have been published that intend to offer optimal conditions for successful nesting habitat, including cover and heights of shrubs and herbaceous plants (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007, Stiver et al. 2015). Where present, these habitat conditions may aid in providing concealment from predators (Connelly et al. 2000; Stiver et al. 2015).

Sage-grouse are a sagebrush obligate species, and because of this, emphasis has been placed on sagebrush and perennial herbaceous understory plant cover for sage-grouse, especially during the nesting period. Previous researchers have quantified and recommended vegetation characteristics in sage-grouse nesting habitat for successful nesting, which is vital for population growth. Land management plans include these quantified vegetation characteristics, such as height and cover of shrubs and herbaceous understory, for sage-grouse habitat. Details of requisite habitat conditions are vital for land managers, but optimal habitat features may vary across a species' range and documenting variation is important for managers. For example, average height of perennial grasses could vary regionally and likely varies with environmental conditions. In Chapter 1, my objectives were to summarize what we know from past studies regarding grass heights in sage-grouse nesting habitat, differences in grass heights between nest sites and available habitat, and the relationships between grass height and nest fate. In Chapter 2, my objective was to examine differences in perennial grass height across years, study locations, and ecological sites for six grass species common in sagebrush steppe communities throughout southern Idaho during the sage-grouse nesting season.

Literature Cited

Chambers, J.C., B.A. Roundy, R.R. Blank, S.E. Meyer, and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum?* Ecological Monographs 77(1):117-145.

Connelly, J.W., and C.E. Braun. 1997. Long-term changes in Sage Grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3(4):229-234.

Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of Greater sage-grouse habitats and populations. University of Idaho College of Natural Resources Experiment Station Bulletin 80. University of Idaho, Moscow, ID.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28(4):967-985.

Connelly, J. W., S. T. Knick, M. A. Schroeder, and S. J. Stiver. 2004. Conservation assessment of greater sage-grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies. Cheyenne, Wyoming.

Copeland, H.E., H. Sawyer, K.L. Montheith, D. E. Naugle, A. Pocewicz, N. Graf, and M.J. Kauffman. 2014. Conserving migratory mule deer through the umbrella of sage-grouse. Ecosphere 5(9):117.

Davies, K.W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, and M.A. Gregg. 2011. Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. Biological Conservation 144:2573-2584.

Garton, E.O., A.G. Wells, J.A. Baumgardt, and J.W. Connelly. 2015. Greater sage-grouse population dynamics and probability of persistence. Final Report to Pew Charitable Trusts.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse *Centrocercus urophasianus* nesting and brood-rearing habitats. Wildlife Biology 13 (Supplement 1):42-50.

Knick, S.T., D.S. Dobkin, J.T. Rotenberry, M.A. Schroeder, W.M. Vander Haegen, and C. Van Riper. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. The Condor 105(4):611-634.

Miller. R.F., R.J. Tausch, E.D. McArthur, D.D. Johnson, and S.C. Sanderson. 2008. Age structure and expansion of piñon-juniper woodlands: a regional perspective in the Intermountain West. Res. Pap. RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Rottler, C.M., C.E. Noseworthy, B. Fowers, and J.L. Beck. 2015. Effects of conversion from sagebrush to non-native grasslands on sagebrush-associated species. Rangelands 37(1):1-6.

Rowland, M. M., M.J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation 129(3):323-335.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S.J. Stiver. 2004. Distribution of sage-grouse in North America. The Condor 106(2):363-376.

Stiver, S.J., E.T. Rinkes, D.E. Naugle, P.D. Makela, D.A. Nance, and J.W. Karl, eds. 2015. Sage-grouse habitat assessment framework: a multi-scale assessment tool. Technical Reference 6710-1. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

U.S. Fish and Wildlife Service (USFWS). 2015. Endangered and threatened wildlife and plants; 12-month finding on a petition to list greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened species. [Docket No. FWS–R6–ES–2015–0146]. Retrieved from http://www.fws.gov/greatersagegrouse/PDFs/20150921_GRSG_FR_Signed.pdf

Welch, B.L. 2005. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-144. Fort Collins, Colorado: Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture.

West, N.E. 1983. Western intermountain sagebrush steppe. In *Temperate deserts and semi-deserts*, ed. N.E. West, 351-397. Amsterdam: Elsevier Scientific Publishing Co.

West, N.E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. In *Proceedings of the sagebrush steppe ecosystems symposium*. USDI Bureau of Land Management Publication. Boise State University, Boise, Idaho. Pp 15-26.

Western Association of Fish and Wildlife Agencies (WAFWA). 2015. Greater sage-grouse population trends: An analysis of lek counts databases 1965-2015. Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

CHAPTER 1

PERENNIAL GRASS HEIGHT AS A COMPONENT OF GREATER SAGE-GROUSE NESTING HABITAT: A REVIEW

Abstract

A recent focus on sagebrush obligate species has increased the need to understand sagebrush steppe habitat for rangeland and wildlife management. Plant community attributes, such as perennial grass height, are influencing land management agencies decisions throughout sagebrush ecosystems, specifically those where greater sage-grouse (*Centrocercus urophasianus*) reside during the nesting season. Our objectives were to summarize grass heights in sage-grouse nesting habitat, compare grass heights between nest sites and available habitat, and summarize the relationships between grass height and nest fate. We used key words, phrases, and a combination of both words and phrases (greater sage-grouse, *Centrocercus urophasianus*, nest, nest success, grass height) in search engines including Web of Science, TreeSearch, Google Scholar, and ExLibris Primo. Our search resulted in 38 studies across eleven states and one Canadian province. The metric used to measure grass height was not consistent among past studies—21% of studies reported maximum droop height including inflorescences, 18% reported grass height excluding inflorescences, and 58% of the studies were vague in their description of height characteristics measured. However, 37% of the studies reported a measurement of visual obstruction. Most studies did not provide sufficient detail to determine the metric used to measure grass height. Average grass height differed among the studies, with a range of 25cm between the study with the shortest average grass height and the study with the greatest average grass height reported at nest sites. Our

summary documented differences among studies in the reported grass height, the metrics used to measured grass height, and when grass height measurements were taken. Many of the approved resource management plan amendments have specific grass height listed for desired conditions in sage-grouse nesting habitat. However, from our search of literature, grass heights vary spatially (studies reporting differences among study locations) and temporally (studies reporting differences among years). Having a "blanket" grass height requirement across multiple geographic regions may not be the best approach given the inherent variation. By summarizing and incorporating variation in key habitat traits, our results provide insight to land management agencies that are developing management plans, for sagebrush obligate species, including the greater sage-grouse.

Introduction

Sagebrush (*Artemisia* spp.) communities were estimated to have occurred on over 62 million hectares in the western U.S. and southwestern Canada (West 1983). This ecosystem has been declining since early European settlement in North America (Welch 2005). In the early 2000s, it was estimated that roughly 40-50 million hectares of sagebrush communities remained across thirteen U.S. states and three Canadian provinces (West 2000; Connelly et al. 2004). This ecosystem occupies only about half of its historical range and is continuously being fragmented (Schroeder et al. 2004; Knick et al. 2003). Energy development, urban expansion, and conversion to croplands have altered and fragmented sagebrush communities (Rowland et al. 2006; Davies et al. 2011; Rottler et al. 2015). In low elevations, large frequent wildfires also contribute to the loss of sagebrush and increase the invasion of annual grasses (Chambers et al. 2007). In higher elevations, where areas of significant fire suppression occur,

conifer encroachment has led to a change of the vegetation structure and sagebrush community (Miller et al. 2008).

Increased fragmentation and a loss of sagebrush has altered habitat conditions for many species of wildlife, including the greater sage-grouse (*Centrocercus urophasianus*; hereafter sage-grouse; Connelly and Braun 1997). This habitat loss and degradation has led to a precipitous decline of sage-grouse populations since the mid-twentieth century (Connelly and Braun 1997; Schroeder et al. 2004). Historically, the greater sage-grouse was found throughout western U.S. states and Canada. Today, sage-grouse reside in 11 U.S. states and in the southwestern portions of two Canada provinces (WAFWA 2015). Sage-grouse abundance varies from year to year (Garton et al. 2015; WAFWA 2015); however, breeding populations have declined an average of 2.1% per year since 1965 (WAFWA 2015). In a recent population analysis, sage-grouse numbers fell by 56% from 2007 to 2013 (Garton et al. 2015).

Sage-grouse was recently a candidate species being considered for protection under the Endangered Species Act (ESA). In September 2015, the USFWS determined that the sage-grouse was not warranted for listing as threatened or endangered under the ESA (USFWS 2015). Efforts are ongoing to stabilize and possibly increase sage-grouse numbers and conserve critical habitat, which may also help other wildlife species found in sagebrush systems (Rowland et al. 2006; Copeland et al. 2014).

Adequate nesting and brood rearing habitats are critical for sage-grouse populations to persist (Connelly et al. 2000). Guidelines for cover and heights of shrubs and herbaceous plants needed to support nesting sage-grouse have been described in environmental impact statements and approved resource management plan amendments for each state or region where sage-grouse are found (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007,

Stiver et al. 2015; USDI BLM 2015b). These vegetation characteristics are intended to reflect the conditions necessary for successful nesting and may provide visual and scent concealment from predators (Connelly et al. 2000; Stiver et al. 2015).

Federal, state, and private entities have adjusted their management actions to include conservation efforts for sage-grouse (USDI BLM 2015a; Connelly 2013). The guidelines suggest that perennial grasses in nesting habitat exceeding specific height and percent canopy cover thresholds that provides adequate concealment during nesting and brood rearing. Idaho outlines management for perennial grass height ≥18 cm during the early growing season (i.e., before June 15; USDI BLM 2015b). Oregon set a grass height requirement at ≥18 cm for arid sites, and ≥23 cm for mesic sites (Gregg et al. 1994; Hanf et al. 1994; Crawford and Carver 2000; Hagen et al. 2007; USDI BLM 2015d). Wyoming management guidelines state a minimum of ≥15 cm or a lower minimum grass height set based on the respective ecological site description's potential and local variability (Connelly et al. 2000; Connelly et al. 2003; Doherty et al. 2014; Hagen et al. 2007; Stiver et al. 2015; USDI BLM 2015f [ecological site defined for rangeland as "…a distinctive kind of land with specific physical characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation", USDA NRCS 1997;]). Other states (Utah, Nevada, and northeastern California) have a grass height requirement set to "provide overhead and lateral concealment from predators" (USDI BLM 2015e) and specific heights set by watershed assessments or at the time of the Habitat Assessment Framework assessments (USDI BLM 2015c).

It is important to document how grass height varies across geographic locations because grass height is an attribute being used to define the suitability of sage-grouse habitat. But the morphology of grasses can vary greatly across and within species. Previous studies

have revealed substantial genotypic and phenotypic variation across years, locations, species, subspecies, and even within populations on a local scale for several bunchgrass species common in sagebrush steppe ecosystems, including Indian ricegrass (*Achnatherum hymenoides*), California brome (*Bromus carinatus*), squirreltail (*Elymus elymoides*), and bluebunch wheatgrass (*Pseudoroegneria spicata*; Bohmont and Lang 1957; Passey and Hugie 1963; Huber-Sannwald et al. 1996; Johnson et al. 2010; Parsons et al. 2011; Bradley St. Clair et al. 2013).

Past studies have documented genetically based variations in the presence or absence of awns on individual plants (Passey and Hugie 1963), the length of awns (Bradley St. Clair et al. 2013), and the length and width of seeds produced (Bohmont and Lang 1957), as well as phenotypic variation in leaf length, leaf width, leaf color, and overall plant height (Passey and Hugie 1963; Johnson et al. 2010; Parsons et al. 2011; Bradley St. Clair et al. 2013). In eastern Oregon, researchers collected California brome seeds from various locations and grew plants in a common garden; the results revealed significant variation in height among individual plants based on where they were collected (Johnson et al. 2010). Others found similar results for squirreltail (*Elymus elymoides* subsp. *brevifolius*) resulting in significant differences of plant heights with seeds collected across the western U.S. states and grown in the same greenhouse (Parsons et al. 2011). Studies conducted on bluebunch wheatgrass revealed differences in height not only among populations, but also among seeds collected from the same parent plant (Bradley St. Clair et al. 2013). Some species of grass, like bluebunch wheatgrass, express different morphological characteristics (e.g., leaf-stem ratio and tiller density) depending on whether they are growing with other members of their own species or among other species of grass, such as crested wheatgrass (Huber-Sannwald et al. 1996).

Phenotypic plasticity in grass morphological traits and spatial and temporal variation among individual plants may pose challenges to management based on static height guidelines for grass heights.

Research Purpose

Much is known about the ecology habitat requirements of sage-grouse. Many studies have summarized vegetation characteristics within sage-grouse nesting. Land management plans include recommendations for vegetation characteristics within sage-grouse habitat, such as height and cover of shrubs and herbaceous understory. Details of requisite habitat conditions is vital for land managers, but optimal habitat features may vary across a species' range and documenting variation is important for managers. For example, average height of perennial grasses, could vary regionally and likely varies depending on environmental and changing management practices (such as grazing) may have little influence.

Many of the BLM Resource Management Plan Amendments provide a minimum grass height recommendation in sage-grouse nesting habitat. These recommendations are based on research, but the Resource Management Plan Amendments typically cite a relatively small number of studies, that examined relationships between grass height and sage-grouse nesting habitat. Hagen et al. (2007) provided a meta-analysis of habitat characteristics across studies, but solely focused on sites used by sage-grouse compared to sites randomly located across the landscape. Since the publication of Hagen et al. (2007), others have provided more information regarding nesting habitat characteristics of sage-grouse. Hence, our objectives were to summarize grass heights in sage-grouse nesting habitat, compare grass heights between nest sites and available habitat, and summarize the relationships between grass height and nest fate.

Methods

We focused our search on papers specific to greater sage-grouse nesting habitat. We used key words, phrases, and a combination of both words and phrases (greater sage-grouse, *Centrocercus urophasianus*, nest, nest success, grass height) in search engines including Web of Science, TreeSearch, Google Scholar, and ExLibris Primo. Our search analysis included published articles, technical reports, theses and dissertations, and current studies with unpublished data. All papers that reported grass heights within sage-grouse nesting habitat were used in our summary. Grass heights reported as tall (>18 cm) or short (<18 cm) were excluded from our summarized results for lack of detailed grass heights. For each paper that met our initial search criteria, we recorded the location of the study, sagebrush community, timing of vegetation sampling, sample size, type of grass height, and how grass height was recorded (i.e., species, life form, live/residual plant matter).

Results

Our search resulted in 38 studies across eleven states and one Canadian province (Table 1.1). The 38 studies were conducted in various sagebrush communities including 34% in mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*), 63% in Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*), 34% in little sagebrush (*Artemisia arbuscula*), and 11% in black sagebrush (*Artemisia nova*). Studies varied in the metric used to measure grass height: 21% of the 38 studies reported maximum droop height including inflorescences, 18% reported grass height excluding inflorescences, and 58% of the studies did not give any specifics regarding how grass height was measured (Figure 1.1). Eleven of the 38 studies reported more than one measurement: grass height measurement and visual obstruction measurement (Klott et al. 1993; Popham and Gutierrez 2003; Aldridge 2005;

Herman-Brunson et al. 2009; Bell 2011; Kaczor et al. 2011; Musil 2011; Davis 2014; Foster 2014; Stonehouse et al. 2015; Conway et al. 2016). However, two of these eleven studies, also reported multiple grass height measurements (Musil 2011; Conway et al. 2016).

Average grass height at sage-grouse nests was not very consistent among studies, and varied from 9-34cm. Average grass heights at sage-grouse nests were tallest (~34cm) in Alberta, Idaho, and Utah (Apa 1998; Aldridge 2005; Robinson and Messmer 2013). The shortest average grass height reported for sage-grouse nests was from Idaho; 9 cm (Musil 1989; Musil 2011). Average grass height measurements found in available habitat were similar to those measurements taken at nest sites, and ranged between the shortest average height of 8 cm (Musil 1989) and the greatest average height of 33 cm (Apa 1998). Average grass height at successful nests ranged between 14 cm (Kuipers 2004) and the greatest average height of 32 cm (Aldridge and Brigham 2002); and at failed nests average grass height ranged between the shortest average grass height of 12 cm (Hausleitner 2003; Bell 2011; Hansen et al. 2016) and the greatest average grass height of 28 cm (Conway et al. 2016). Average grass height also varied by metric used, maximum droop height with inflorescence measurements ranged from 34 cm (Robinson and Messmer 2013) to 13 cm (Hansen et al. 2016); maximum droop height excluding inflorescence measurements ranged from 31 cm (Lockyer et al. 2015) to 14 cm (Bell 2011; Musil 2011). Studies that were unclear in how grass height measurements were taken had average grass heights range from 9 cm (Musil 1989) to 34 cm (Apa 1998; Aldridge 2005).

Many of the articles (37%) mentioned the importance of vegetation structure and report a measurement of visual obstruction of woody and herbaceous vegetation at the nest site (Figure 1.1; Klott et al. 1993, Popham and Gutierrez 2003, Aldridge 2005, Baxter et al.

2009, Herman-Brunson et al. 2009, Doherty et al. 2010, Bell 2011, Kaczor et al. 2011, Musil 2011, Kirol et al. 2012, Davis et al. 2014, Foster et al. 2014, Stonehouse et al. 2015, Conway et al. 2016). However, only two of these studies reported a visual obstruction measurement for only perennial grasses at nest sites (Musil 2011, Conway et al. 2016).

Several past studies have reported differences in grass height between sage-grouse nest sites and available habitat (as summarized by Connelly et al. 2000 and Hagen et al. 2007). In our summary, we found 28 studies reported grass height measurements at nest sites and available habitat. Of these 28, we found ten studies where grass height differed significantly between nest sites and available habitat (Wakkinen 1990; Hanf et al. 1994; Holloran 1999; Wik 2002; Hausleitner 2003; Woodward 2006; Kaczor et al. 2011; Davis et al. 2014; Cardinal and Messmer 2016; Conway et al. 2016). Eight of these ten studies reported that grass height was taller at nest sites, but two of the ten studies reported that grass height was taller at available habitat than nest sites (Hausleitner et al. 2005; Cardinal and Messmer 2016). Ten of the 28 studies reported no significant difference detected between nest sites and available sites (Musil 1989; Fischer 1994; Lyon 2000; Aldridge and Brigham 2002; Popham and Gutierrez 2003; Slater 2003; Herman-Brunson et al. 2009; Musil 2011; Woodward 2016; Lane et al. 2017). The remaining eight studies were unclear if a significant difference in grass height existed between nest sites and available habitat (Apa 1998; Klott et al. 1993; Kuipers 2004; Aldridge 2005; Holloran et al. 2005; Bell 2011; Lockyer 2015; Hansen et al. 2016). Across all these studies, the average grass height at nests (18.7 cm) was similar to average grass height found at available habitat (18.1 cm; Figure 1.2).

We found 20 studies that reported grass height between successful and failed nests. Five studies reported that grasses were significantly taller at successful nests (Hanf et al.

1994; Alridge and Brigham 2002; Wing 2014; Conway et al. 2016; Hansen et al. 2016), and nine studies found no significant difference in grass height between successful and failed nests (Wakkinen 1990; Fischer 1994; Holloran 1999; Wik 2002; Hausleitner 2003; Popham and Gutierrez 2003; Slater 2003; Woodward 2006; Lane et al. 2017). Six of the 20 studies were unclear if grass height differed significantly between successful and failed nests (Kuipers 2004; Holloran et al. 2005; Bell 2011; Doherty et al. 2011; Davis et al. 2014; Woodward 2016). Across these studies reporting grass heights for successful and failed nests, we found average grass height tended to be greater at successful nests (20.1 cm) than failed nests (17.6 cm; Figure 1.2).

We also found that some studies reported grass height to differ spatially and temporally within that respective study. Three studies reported grass height differed at nests among study locations (Hausleitner 2003; Slater 2003; Robinson and Messmer 2013), two that reported that grass height differed at nests between years (Robinson and Messmer 2013; Woodward et al. 2016), and one reported that grass height differed at nest sites among vegetation communities (Connelly et al. 1991).

The timing of vegetation sampling differed among studies. For the 26 studies that reported measurement timing, all fell within the expected sage-grouse nesting season (April-early July), except one (Klott et al. 1993) that reported vegetation sampling from June through August. Fourteen studies reported that they measured grass height at nest fate determination (Musil 1989; Fischer 1994; Aldridge and Brighman 2002; Hausleitner 2003; Aldridge 2005; Hausleitner et al. 2005; Bell 2011; Kaczor et al. 2011; Robinson and Messmer 2013; Wing 2014; Lockyer et al. 2015; Stonehouse et al. 2015; Cardinal and Messmer 2016; Hansen et al. 2016), and four studies reported that they measured heights at the projected hatch date (Wik

2002; Musil 2011; Davis et al. 2014; Conway et al. 2016). The timing of when observers measure grass height or other measures of nest concealment (relative to nest fate) can influence results and potentially bias comparisons between successful and failed nests (Borgmann and Conway 2015; Gibson et al. 2016).

Only a few studies reported grass height by species, and respective life form (perennial or annual). Six studies reported grass height for perennial grasses (i.e., stated annual grasses were excluded; Popham and Gutierrez 2003; Musil 2011; Kirol et al. 2012; Lockyer et al. 2015; Stonehouse et al. 2015; Conway et al. 2016). Four of these six studies also recorded height measurements by species (Musil 2011; Robinson and Messmer 2013; Wing 2014; Conway et al. 2016). Reporting heights by grass species could prove to be important as different species of grass differ in height (see Chapter 2 of this thesis).

Our summary expands upon previous summaries of grass height in sage-grouse nesting habitat (Connelly et al. 2000; Hagen et al. 2007). The summary used to provide guidelines of grass height for sage-grouse nesting habitat are based off 9 studies (Connelly et al. 2000), and a meta-analysis of greater sage-grouse nesting habitat show 15 studies reporting grass height (Hagen et al. 2007), with seven of the nine studies summarized in the nesting guidelines also reported in the meta-analysis. Of these nine studies used for management guidelines, we included seven into our summary. Our results provide a more current and thorough summary of past and recent literature regarding grass heights in sage-grouse nesting habitat. Of the 38 studies we summarized, 92% report a metric of grass height (this number excluding visual obstruction measurements) in sage-grouse nesting habitat, while many of the studies used to inform sage-grouse nesting habitat guidelines are unclear in the metrics used to report grass height.

Discussion

Many studies have reported grass heights within sage-grouse nesting habitat and have compared average grass height between nest sites and random sites or between successful nests and failed nests. Prior summaries of these types of studies have been used in sage-grouse habitat guidelines, and those guidelines have influenced land-use policies on public lands. However, from our results we found reported grass heights vary across regions and metrics used. Studies used for habitat guidelines that have summarized previous research found differences in average grass height at nest sites ranging between 14 cm to 34 cm (summarized in Connelly et al. 2000).

Results from studies of grass heights in sage-grouse nesting habitat could be biased if the timing of vegetation sampling differed between successful and failed nests which is relatively common in past avian field studies (Borgmann and Conway 2015, Gibson et al. 2016). Sampling grass heights at the same time regardless of fate (e.g., the hatch date for successful nests and the projected hatch date for failed nests) is important to ensure that results are not biased. However, many past studies fail to explain the precise timing of vegetation sampling at failed and successful nests (Borgmann and Conway 2015). Our summary of past studies suggest that the precise timing of vegetation sampling was not explicit in most sage-grouse habitat studies; only 11% explicitly stated that vegetation sampling at failed nests occurred at the projected hatch date.

Few past studies provided information pertaining to the life form of the grass heights measured. Percent cover of cheatgrass (*Bromus tectorum*) and other annual invasive grasses may affect sage-grouse nest-site selection (Connelly et al. 2000; Arkle et al. 2014). With the presence of these annual invasive grasses, important perennial grasses may be absent which

help to provide critical nest concealment and hiding cover. Measuring and reporting perennial and annual grasses separately during vegetation sampling within sage-grouse nesting habitat could provide valuable information regarding the likely effect of conversion of sagebrush dominated communities to annual grasslands.

Recording species of grass present in sage-grouse nesting habitat may prove to be valuable for restoration efforts, especially in areas prone to fire risk or conifer-woodland encroachment. One study mentioned that perennial grass species may also influence the absence or presence of sage-grouse (Arkle et al. 2014). When vegetation sampling is conducted, researchers should take note of herbaceous species present in and near the sage-grouse nesting site.

Vegetation guidelines in environmental impact statements refer only to perennial grass height and cover for sage-grouse nesting, but not specific species. However, some species of perennial grass, such as Sandberg bluegrass (*Poa secunda*), exhibit similar phenology as cheatgrass, and can be found in many different types of shrub steppe communities. In Idaho, ongoing research shows Sandberg bluegrass on > 90% of sampled vegetation plots (Conway et al. 2016). Other species of perennial grass (i.e., bluebunch wheatgrass and squirreltail) may help provide more concealment for sage-grouse nests than Sandberg bluegrass. Including specific grass species in management plans may be difficult as vegetation communities vary across the distribution of sage-grouse, but incorporating locally-relevant, species-specific guidelines into management plans could help ensure that such plans are robust, defensible, and provide adequate concealment.

Many of the approved resource management plan amendments (RMPs) have specific grass height listed for desired conditions in sage-grouse nesting habitat (Buffalo WY,

Lewistown MT, North Dakota, Wyoming, Idaho and Southwestern MT, and Oregon). Three of these approved RMPs provide a statement of desired vegetation to also account for ecological site and local variability for grass height (Buffalo WY, North Dakota, and Wyoming). Others have a grass height desired condition that states to "provide overhead and lateral concealment from predators" with no specific grass height requirement.

Management Recommendations

Efforts to conserve and manage critical sage-grouse nesting habitat will likely be more robust and defensible if it is based on research specific to the local area/conditions. Studies conducted in Montana may not be relevant in a different plant community in Idaho, for example, where climate and site potential differs. Recommended grass height likely varies across and within each region. Past investigators have used different metrics to measure grass height (e.g., including or excluding inflorescences) and the method used should be defined clearly in future research to avoid confusion regarding how research results are incorporated into management decisions and policies. Timing of sampling is another important attribute that could produce biased results and is often not adequately reported. By summarizing and comparing ongoing and completed studies, we can provide useful insight to land agencies that are developing management plans, and tailoring to sagebrush obligate species, including the greater sage-grouse.

Literature Cited

Aldridge, C.L. 2005. Identifying habitats for persistence of greater sage-grouse (*Centrocercus urophasianus*) in Alberta, Canada. PhD thesis, University of Alberta, Edmonton, Canada.

Aldridge, C.L. and R.M. Brigham. 2002. Sage-grouse nesting and brood habitat use in southern Canada. Journal of Wildlife Management 66(2):433-444.

Apa, A.D. 1998. Habitat use and movements of sympatric sage and Columbian sharp-tail grouse in southeastern Idaho. PhD thesis, University of Idaho, Moscow, Idaho, USA.

Arkle, R.S., D.S. Pilliod, S.E. Hanser, M.L. Brooks, J.C. Chambers, J.B. Grace, K.C. Knutson, D.A. Pyke, J.L. Welty, and T.A. Wirth. 2014. Quantifying restoration effectiveness using mult-scale habitat models: implications for sage-grouse in the Great Basin. Ecosphere 5(3):1-32.

Baxter, R.J., J.T. Flinders, D.G. Whiting, D.L. Mitchell. 2009. Factors affecting nest-site selection and nest success of translocated greater sage-grouse. Wildlife Research 36(6):479-487.

Bell, C.B. 2011. Nest site characteristics and nest success of translocated and resident greater sage grouse at clear lake national wildlife refuge. Thesis, Humboldt State University, Arcata, California, USA.

Bohmont, B.L., and R. Lang. 1957. Some variations in morphological characteristics and palatability among geographic strains of Indian ricegrass. Journal of Range Management 10(3):127-131.

Borgmann, K.L., and C.J. Conway. 2015. The nest-concealment hypothesis: new insights from a comparative analysis. The Wilson Journal of Ornithology 127(4):646-660.

Bradley St. Clair, J., F.F. Kilkenny, R.C. Johnson, N.L. Shaw, and G. Weaver. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evolutionary Applications 6(6):933-948.

Cardinal, C.J. and T.A. Messmer. 2016. Ecology of greater sage-grouse populations inhabiting the northwestern Wyoming Basin. Human-Wildlife Interactions 10(2):188-204.

Chambers, J.C., B.A. Roundy, R.R. Blank, S.E. Meyer, and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum?* Ecological Monographs 77(1):117-145.

Connelly, J. 2013. Federal agency responses to greater sage-grouse and the ESA: getting nowhere fast. Northwest Science 88(1):61-64.

Connelly, J.W., and C.E. Braun. 1997. Long-term changes in Sage Grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3(4):229-234.

Connelly, J. W., K. P. Reese, and M. A. Schroeder. 2003. Monitoring of Greater sage-grouse habitats and populations. University of Idaho College of Natural Resources Experiment Station Bulletin 80. University of Idaho, Moscow, ID.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28(4):967-985.

Connelly, J.W., S.T. Knick, M.A. Schroeder, and S.J. Stiver. 2004. Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Western Association of Fish and Wildlife Agencies. Cheyenne, Wyoming.

Connelly, J.W., W.L. Wakkinen, A.D. Apa, and K.P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal of Wildlife Management 55(3):521-524.

Conway, C., K. Launchbaugh, D. Musil, S. Roberts, P. Makela, A. Locatelli, and A. Meyers. 2016. Unpublished data. University of Idaho, Moscow, Idaho, USA.

Copeland, H.E., H. Sawyer, K.L. Montheith, D. E. Naugle, A. Pocewicz, N. Graf, and M.J. Kauffman. 2014. Conserving migratory mule deer through the umbrella of sage-grouse. Ecosphere 5(9):117.

Crawford, J.A., and L.A. Carver. 2000. Habitat use by sage-grouse on the Beatty Butte BLM allotment: final report. Oregon State University, Department of Fisheries and Wildlife. Corvallis, USA.

Davies, K.W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, and M.A. Gregg. 2011. Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. Biological Conservation 144:2573-2584.

Davis, D.M., K.P. Reese, and S.C. Gardner. 2014. Demography, reproductive ecology, and variation in survival of greater sage-grouse in northeastern California. Journal of Wildlife Management 78(8):1343-1355.

Doherty, K.E., D.E. Naugle, and B.L. Walker. 2010. Greater sage-grouse nesting habitat: the importance of managing at multiple scales. Journal of Wildlife Management 74(7):1544-1553.

Doherty, K.E., J.L. Beck, and D.E. Naugle. 2011. Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success. Rangeland Ecology and Management 64(4):344-351.

Doherty, K.E., D.E. Naugle, J.D. Tack, B.L. Walker, J.M. Graham, and J.L. Beck. 2014. Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival. Wildlife Biology 20(6):320-325.

Fischer, R.A. 1994. The effects of prescribed fire on the ecology of migratory sage grouse in southeastern Idaho. PhD thesis, University of Idaho, Moscow, USA.

Foster, M.A., J.T. Ensign, W.N. Davis, and D.C. Tribby. 2014. Greater sage-grouse in the southeast Montana sage-grouse core area. Final Report. Montana Fish, Wildlife and Parks and United States Department of the Interior Bureau of Land Management.

Garton, E.O., A.G. Wells, J.A. Baumgardt, and J.W. Connelly. 2015. Greater sage-grouse population dynamics and probability of persistence. Final Report to Pew Charitable Trusts.

Gregg, M. A., J.A. Crawford, M.S. Drut, and A.K. DeLong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. The Journal of Wildlife Management 58(1):162-166.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse *Centrocercus urophasianus* nesting and brood-rearing habitats. Wildlife Biology 13 (Supplement 1):42-50.

Hanf, J.M., P.A. Schmidt, and E.B. Groshens. 1994. Sage grouse in the high desert of central Oregon: results of a study, 1988-1993. Bureau of Land Management, Portland, Oregon, USA.

Hansen, C.P., L.A. Schreiber, M.A. Rumble, J.J. Millspaugh, R.S. Gamo, J.W. Kehmeier, and N. Wojcik. 2016. Microsite selection and survival of greater sage-grouse nests in south-central Wyoming. Journal of Wildlife Management 80(5):862-876.

Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grose in Moffat County, Colorado. Thesis, University of Idaho, Moscow, USA.

Hausleitner, D., K.P. Reese, and A.D. Apa. 2005. Timing of vegetation sampling at greater sage-grouse nests. Rangeland Ecology and Management 58(5):553-556.

Herman-Brunson, K.M., K.C. Jensen, N.W. Kaczor, C.C. Swansom, M.A. Rumble, and R.W. Klaver. 2009. Nesting ecology of greater sage-grouse *Centrocercus urophasianus* at the eastern edge of their historic distribution. Wildlife Biology 15(3): 237-246.

Holloran, M.J. 1999. Sage grouse (*Centrocercus urophasianus*) seasonal habitat use near Casper, Wyoming. Thesis, University of Wyoming, Laramie, USA,

Holloran, M.J., B.J. Heath, A.G. Lyon, S.J. Slater, J.L. Kuipers, and S.H. Anderson. 2005. Greater sage-grouse nesting habitat selection and success in Wyoming. Journal Wildlife Management 69(2):638-649.

Huber-Sannwald, E., D.A. Pyke, M.M. Caldwell. 1996. Morphological plasticity following species-species recognition and competition in two perennial grasses. American Journal of Botany 83(7):919-931.

Johnson, R.C., V.J. Erickson, N.L. Mandel, J.B. St. Clair, and K.W. Vance-Borland. 2010. Mapping genetic variation and seed zones for *Bromus carinatus* in the Blue Mountains of eastern Oregon, USA. Botany 88(8):725-736.

Kaczor, N.W., K.C. Jensen, R.W. Klaver, M.A. Rumble, K.M. Herman-Brunson, and C.C. Swanson. 2011. Nesting success and resource selection of greater sage-grouse. Pp 107-118 in B.K. Sandercock, K. Martin, and G. Segelbacher (editors). Ecology, conservation, and management of grouse. Studies in Avian Biology (no. 39), University of California Press, Berkeley, CA.

Kirol, C.P., J.L. Beck, J.B. Dinkins, and M.R. Conover. 2012. Microhabitat selection for nesting and brood-rearing by the greater sage-grouse in xeric big sagebrush. The Condor 114(1):75-89.

Klott, J.H., R.B. Smith and C. Vullo. 1993. Sage grouse habitat use in the Brown's Bench area of south-central Idaho. United States Department of Interior, Bureau of Land Management, Idaho State Office, Technical Bulletin 93-4, Boise, Idaho, USA.

Knick, S.T., D.S. Dobkin, J.T. Rotenberry, M.A. Schroeder, W.M. Vander Haegen, and C. Van Riper. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. The Condor 105(4):611-634.

Kuipers, J.L. 2004. Grazing system and linear corridor influences on greater sage-grouse (*Centrocercus urophasianus*) habitat selection and productivity. Thesis, University of Wyoming, Laramie, USA.

Lane, V., J. Sika, C. Wambolt, M.R. Frisina, and B. Sowell. 2017. Vegetative characteristics of sage-grouse nesting and brood rearing sites. Environmental Management and Sustainable Development 6(1):206-219.

Lockyer, Z.B., P.S. Coates, M.L. Casazza, S. Espinosa, and D.J. Delehanty. 2015. Nest-site selection and reproductive success of greater sage-grouse in a fire-affected habitat of northwestern Nevada. Journal of Wildlife Management 79(5):785-797.

Lyon, A.G. 2000. The potential effects of natural gas development on sage grouse near Pinedale, Wyoming. Thesis, University of Wyoming, Laramie, USA.

Miller. R.F., R.J. Tausch, E.D. McArthur, D.D. Johnson, and S.C. Sanderson. 2008. Age structure and expansion of piñon-juniper woodlands: a regional perspective in the Intermountain West. Res. Pap. RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Musil, D.D. 1989. Movements, survival, and habitat use of sage grouse translocated into the Sawtooth Valley, Idaho. Thesis, University of Idaho, Moscow, USA.

Musil, D.D. 2011. Use of dwarf sagebrush by nesting greater sage-grouse. Pp. 119-163 in B.K. Sandercock, K. Martin, and G. Segelbacher (editors). Ecology, conservation, and management of grouse. Studies in Avian Biology (no. 39), University of California Press, Berkley, CA.

Parsons, M.C., T.A. Jones, S.R. Larson, I.W. Mott, and T.A. Monaco. 2011. Ecotypic variation in *Elymus elymoides* subsp. *brevifolious* in the Northern Intermountain West. Rangeland Ecology and Management 64(6):649-648.

Passey, H.B. and V.K. Hugie. 1963. Variation in bluebunch wheatgrass in relation to environment and geographic location. Ecology 44(1):158-161.

Popham, G.P., and R.J. Gutierrez. 2003. Greater sage-grouse *Centrocercus urophasianus* nesting success and habitat se in northeastern California. Wildlife Biology 9(4):327-334.

Robinson, J.D., and T.A. Messmer. 2013. Vitals rates and seasonal movements of two isolated greater sage-grouse populations in Utah's west desert. Human-Wildlife Interactions 7(2):182-194.

Rottler, C.M., C.E. Noseworthy, B. Fowers, and J.L. Beck. 2015. Effects of conversion from sagebrush to non-native grasslands on sagebrush-associated species. Rangelands 37(1):1-6.

Rowland, M. M., M.J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation 129(3):323-335.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S.J. Stiver. 2004. Distribtuion of sage-grouse in North America. The Condor 106(2):363-376.

Slater, S.J. 2003. Sage-grouse (*Centrocercus urophasianus*) use of different-aged burns and the effects of coyote control in southwestern Wyoming. Thesis, University of Wyoming, Laramie, USA.

Stiver, S.J., E.T. Rinkes, D.E. Naugle, P.D. Makela, D.A. Nance, and J.W. Karl, eds. 2015. Sage-grouse habitat assessment framework: a multiscale assessment tool. Technical Reference 6710-1. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

Stonehouse, K.F., L.A. Shipley, J. Lowe, M.T. Atamian, M.E. Swanson, and M.A. Schroeder. 2015. Habitat selection and use by sympatric translocated greater sage-grouse and Columbian sharp-tailed grouse. Journal of Wildlife Management 79(9):1308-1326.

U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). 1997. National range and pasture handbook. Available at https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17737.wba.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015a. Fact sheet: BLM, USFS greater sage-grouse conservation effort. Retrieved from http://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/public_affairs/sagegrouse_planning/documents.Par.32336. File.dat/BLM-USFS%20Plans%20Fact%20Sheet%20Final915.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015b. Idaho and southwestern Montana greater sage-grouse approved resource management plan amendment. Retrieved from https://eplanning.blm.gov/epl-front-office/projects/lup/31652/63338/68680/ IDMT_ARMPA_web.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015c. Nevada and northeastern California greater sage-grouse proposed land use plan amendment and final environmental impact statement. Retrieved from https://eplanning.blm.gov/epl-front-office/projects/lup/21152/58696/63759/1_Volume_1_NVCA_Cover-Abstract_FEIS.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015d. Oregon greater sage-grouse approved resource management plan amendment. Retrieved from https:// www.blm.gov/or/energy/opportunity/files/or_armpa.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015e. Utah greater sage-grouse proposed land use plan amendment. Retrieved from https://www.blm.gov/wo/st/ en/prog/more/sagegrouse/final_eiss/utah.html.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015f. Wyoming approved resource management plan amendment for greater sage-grouse. Retrieved from https://eplanning.blm.gov/epl-front- office/eplanning/planAndProjectSite.do?methodName =dispatchToPatternPage&currentPageId=18704.

U.S. Fish and Wildlife Service (USFWS). 2015. Endangered and threatened wildlife and plants; 12-month finding on a petition to list greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened species. [Docket No. FWS–R6–ES–2015–0146]. Retrieved from http://www.fws.gov/greatersagegrouse/PDFs/20150921_GRSG_FR_Signed.pdf

Wakkinen, W.L. 1990. Nest site characteristics and spring-summer movements of migratory sage grouse in southeastern Idaho. Thesis, University of Idaho, Moscow, USA.

Welch, B.L. 2005. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-

GTR-144. Fort Collins, Colorado: Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture.

West, N.E. 1983. Western intermountain sagebrush steppe. In *Temperate deserts and semi-deserts*, ed. N.E. West, 351-397. Amsterdam: Elsevier Scientific Publishing Co.

West, N.E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. In *Proceedings of the sagebrush steppe ecosystems symposium*. USDI Bureau of Land Management Publication. Boise State University, Boise, Idaho. Pp 15-26.

Western Association of Fish and Wildlife Agencies (WAFWA). 2015. Greater sage-grouse population trends: An analysis of lek counts databases 1965-2015. Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

Wik, P.A. 2002. Ecology of greater sage-grouse in southcentral Owyhee County, Idaho. Thesis, University of Idaho, Moscow, USA.

Wing, B.R. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, USA.

Woodward, J.K. 2006. Greater sage-grouse (*Centrocercus urophasianus*) habitat in central Montana. Thesis, Montana State University, Bozeman, USA.

Woodward, J., J. Sika, C. Wambolt, J. Newell, S. Schroff, and B. Sowell. 2016. Sage-grouse nesting, brood and winter habitat characteristics in Montana. Environmental Management and Sustainable Development 5(1):114-12.

Table 1.1. Summary of past studies that have described vegetation associated with greater sage-grouse nesting habitat. Sagebrush type includes *Artemisia arbuscula* (ARAR8), *Artemisia cana* (ARCA13), *Artemisia nova* (ARNO4), *Artemisia pygmaea* (ARPY2), *Artemisia rigida* (ARRI2), *Artemisia tridentata* spp. (ARTR), *Artemisia tridentata* ssp. *tridentata* (ARTRT), *Artemisia tridentata* ssp. *vaseyana* (ARTRV), *Artemisia tridentata* ssp. *wyomingensis* (ARTRW8). Grass height was recorded by species (S), live and/or residual (L/R), or grouped (G); also recorded by perennial (P), annual (A), grouped (G). Height type classified as maximum droop height with inflorescence (DH w/FS), maximum droop height without inflorescence (DH w/o FS), and visual obstruction height (VO). All measurements recorded in cm unless otherwise stated. Mean (±SE) reported for each height type. ND=not reported. *=No units provided.

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Conway et al. (2016)	ID	ARTRW8 ARAR8	Projected Hatch	S	P	97	63	33	367	28.0 (± 0.2)[a]	29.0 (± 0.3)[b]	27.5 (± 0.2)[b]	26.9 (± 0.1)[a]	DH w/FS
Hansen et al. (2016)	WY	ARTRW8 ARTRV ARCA13 ARNO4	Fate	ND	ND	109	37	71	217	13.0 (± 0.6)	15.0 (± 2.0)[b]	11.5 (± 0.4)[b]	11.5 (± 0.3)	DH w/FS
Musil (2011)	ID	ARTRW8 ARTRV ARTRT ARAR8 ARNO4	Projected Hatch	S L/R	P A	156	68	88	138	27.1 (± 1.3)	ND	ND	26.9 (± 1.5)	DH w/FS
Robinson and Messmer (2013) Deep Creek 2005	UT	ARTRW8 ARTRV ARAR8	Fate	S	ND	ND	ND	ND	ND	33.6 (± 2.1)	ND	ND	ND	DH w/FS

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Robinson and Messmer (2013) Deep Creek 2006	UT	ARTRW8 ARTRV ARAR8	Fate	S	ND	ND	ND	ND	ND	13.2 (± 1.0)	ND	ND	ND	DH w/FS
Robinson and Messmer (2013) Sheeprock 2005	UT	ARTRW8 ARTRV ARAR8	Fate	S	ND	ND	ND	ND	ND	34.0 (± 4.2)	ND	ND	ND	DH w/FS
Robinson and Messmer (2013) Sheeprock 2006	UT	ARTRW8 ARTRV ARAR8	Fate	S	ND	ND	ND	ND	ND	22.6 (± 1.2)	ND	ND	ND	DH w/FS
Hausleitner et al. (2005)	CO	ARTRV ARTRW8	Fate	ND	ND	30	ND	ND	ND	15.6 (± 1.1)	ND	ND	ND	DH w/FS
Stonehouse et al. (2015)	WA	ARTR ARRI2	Fate	ND	P	30	ND	ND	ND	26.0 (± 3.0)	ND	ND	ND	DH w/FS
Wik (2002)	ID NV	ARTRW8 ARTRV ARTRT ARAR8	Projected Hatch	L/R	ND	38	17	21	38	25.0 (± 1.2)[a]	28.0 (± 1.8)	23.0 (± 1.5)	19.0 (± 1.2)[a]	DH w/FS
Wing (2014)	UT	ARTR ARNO4 ARAR8 ARPY2	Fate	S	ND	36	19	17	ND	ND	23.4 (± 0.6)[b]	16.6 (± 0.5)[b]	ND	DH w/FS
Bell (2011)	CA	ARAR8 ARTR	Fate	L/R	ND	63	27	36	63	14.0 (± 0.0)	15.0 (± 0.0)	12.0 (± 0.0)	13.0 (± 0.0)	DH w/o FS
Conway et al. (2016)	ID	ARTRW8 ARAR8	Projected Hatch	S	P	97	63	33	367	16.0 (± 0.1)	16.3 (± 0.2)	15.9 (± 0.1)	15.4 (± 0.1)	DH w/o FS

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Holloran et al. (2005)	WY	ARTRW8	May/Jun	L/R	ND	457	ND	ND	563	ND	16.7 (± 1.0)	15.6 (± 1.0)	15.0 (± 0.8)	DH w/o FS
Lane et al. (2017)	MT	ARTRW8	ND	L/R	ND	146	51	50	146	16.0	18.0	17.0	15.0	DH w/o FS
Lockyer et al. (2015)	NV	ARTRW8	Fate	L/R	P	71	ND	ND	71	30.5 (± 3.6)	ND	ND	30.1 (± 3.6)	DH w/o FS
Musil (2011)	ID	ARTRW8 ARTRV ARTRT ARAR8 ARNO4	Projected Hatch	S L/R	P A	156	68	88	138	14.4 (± 0.6)	ND	ND	12.8 (± 0.7)	DH w/o FS
Popham and Gutierrez (2003)	CA	ARTRW8 ARAR8 ARCA13	ND	L/R	P	88	35	53	45	ND	22.1 (± 2.7)	24.2 (± 3.1)	18.2 (± 1.9)	DH w/o FS
Aldridge (2005)	AB	ARCA13	Fate	G	ND	93	ND	ND	93	33.9 (± 2.1)	ND	ND	27.4 (± 1.8)	ND
Aldridge and Brigham (2002)	AB	ARCA13	Fate	G	ND	29	14	15	29	27.9 (± 2.3)	31.6 (± 4.1)[b]	24.4 (± 2.3)[b]	26.6 (± 1.8)	ND
Apa (1998)	ID	ND	ND	G	ND	41	18	23	ND	34.4 (± 1.7)	ND	ND	33.4 (± 2.3)	ND
Cardinal and Messmer (2016)	ID UT WY	ARTRW8 ARTRV ARTRT ARNO4	Fate	ND	ND	26	ND	ND	21	16.3 (± 1.9)[a]	ND	ND	20.0 (± 3.1)[a]	ND

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Connelly et al. (1991) Sagebrush nest site	ID	ARTRV ARTRT	ND	ND	ND	66	35	24	ND	19.0 (± 0.6)	ND	ND	ND	ND
Connelly et al. (1991) Non-sagebrush nest site	ID	ARTRV ARTRT	ND	ND	ND	18	4	12	ND	23.0 (± 1.7)	ND	ND	ND	ND
Davis et al. (2014)	CA	ARTRW8 ARTRV ARAR8	Projected Hatch	ND	ND	63	ND	ND	63	17.6 (± 0.7)[a]	ND	ND	13.9 (± 0.7)[a]	ND
Doherty et al. (2011)	WY	ARTRW8	ND	ND	ND	119	80	38	134	ND	21.5 (± 0.8)	15.3 (± 1.0)	ND	ND
Fischer (1994)	ID	ARTRW8	Fate	ND	ND	138	59	65	154	21.0 (± 0.6)	20.4 (± 0.7)	21.7 (± 1.0)	19.6 (± 0.5)	ND
Foster et al. (2014)	MT	ND	ND	L/R	ND	142	62	80	ND	25.6 (± 0.2)	ND	ND	ND	ND
Hanf et al. (1994)	OR	ARTRV ARAR8	ND	ND	ND	20	6	14	40	22.0 (± 3.0)[a]	28.0 (± 6.0)[b]	19.0 (± 3.0)[b]	16.0 (± 1.0)[a]	ND
Hausleitner (2003)	CO	ARTR	Fate	ND	ND	100	50	42	93	13.8 (± 0.7)	15.4 (± 0.9)[a]	11.7 (± 0.9)	15.5 (± 1.0)[a]	ND
Herman-Brunson et al. (2009)	ND MT	ARTRW8 ARCA13	May/Jun	ND	ND	34	ND	ND	50	25.9 (± 0.6)	ND	ND	28.4 (± 0.5)	ND
Holloran (1999)	WY	ND	May/Jun	L/R	ND	87	45	32	131	18.4 (± 0.4)[a]	18.6 (± 0.7)	18.7 (± 0.5)	17.3 (± 0.3)[a]	ND

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Kaczor et al. (2011)	SD	ARTRW8 ARCA13	Fate	ND	ND	73	ND	ND	74	26.7 (± 1.0)[a]	ND	ND	22.8 (± 0.7)[a]	ND
Klott et al. (1993)	ID	ARTRW8	Jun/Jul/ Aug	ND	ND	4	2	2	ND	14.5	ND	ND	9.1	ND
Klott et al. (1993)	ID	ARAR8	Jun/Jul/ Aug	ND	ND	2	1	1	ND	15.2	ND	ND	12.9	ND
Kuipers (2004)	WY	ARTRW8	Jun	L/R	ND	95	36	52	164	13.3 (± 0.7)	14.3 (± 1.1)	12.7 (± 1.0)	12.5 (± 0.6)	ND
Lyon (2000)	WY	ARTRW8 ARTRT ARAR8 ARNO4	May/Jun	L/R	ND	50	ND	ND	63	21.3 (± 0.6)	ND	ND	21.8 (± 0.5)	ND
Musil (1989)	ID	ARTRV ARAR8	Fate	ND	ND	6	ND	ND	7	9.3 (± 1.8)	ND	ND	8.2 (± 3.0)	ND
Slater (2003) Collett Creek	WY	ARTRW8 ARTRV ARAR8	June	L/R	ND	50	17	37	60	18.7 (± 0.4)	18.5 (± 0.7)	18.9 (± 0.6)	17.5 (± 0.5)	ND
Slater (2003) Salt Creek	WY	ARTRW8 ARTRV ARAR8	June	L/R	ND	21	6	14	24	16.2 (± 0.7)	16.5 (± 1.3)	16.3 (± 0.9)	16.0 (± 0.6)	ND
Wakkinen (1990)	ID	ARTRW8	ND	ND	ND	49	24	16	70	18.2 [a]	19.0	16.5	15.3 [a]	ND
Woodward (2006)	MT	ARTRW8	ND	L/R	ND	99	ND	ND	99	12.1 (± 0.3)[a]	14.6	13.2	11.1 (± 0.3)[a]	ND
Woodward et al. (2016)	MT	ARTRW8	ND	L/R	ND	ND	ND	ND	ND	12.0	ND	ND	11.0	ND

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Aldridge (2005)	AB	ARCA13	Fate	G	ND	93	ND	ND	93	26.3 (± 1.4)	ND	ND	13.1 (± 0.8)	VO
Baxter et al. (2009)	UT	ARTRV ARCA13	ND	ND	ND	87	59	28	87	ND	0.9* (± 0.0)	1.0* (± 0.0)	0.9* (± 0.0)	VO
Bell (2011)	CA	ARAR8 ARTR	Fate	L/R	ND	63	27	36	63	ND	82.8% (± 0.0)	83.6% (± 0.0)	ND	VO
Conway et al. (2016) VO of grass height only	ID	ARTRW8 ARAR8	Projected Hatch	S	P	97	63	33	367	7.4 (± 0.0)	7.9 (± 0.1)	7.1 (± 0.1)	7.4 (± 0.1)	VO
Davis et al. (2014)	CA	ARTRW8 ARTRV ARAR8	Projected Hatch	ND	ND	63	ND	ND	63	46.0 (± 0.24)[a]	ND	ND	29.0 (± 0.21)[a]	VO
Doherty et al. (2010)	WY MT	ARTRW8	ND	G	ND	527	ND	ND	ND	15.6 (± 0.4)	ND	ND	11.7 (± 0.4)	VO
Foster et al. (2014)	MT	ND	ND	L/R	ND	142	62	80	ND	39.6 (± 0.4)	ND	ND	ND	VO
Herman-Brunson et al. (2009)	ND MT	ARTRW8 ARCA13	May/Jun	ND	ND	34	ND	ND	50	6.6 (±0.2)[a]	ND	ND	5.3 (± 0.2)[a]	VO
Kaczor et al. (2011)	SD	ARTRW8 ARCA13	Fate	ND	ND	73	ND	ND	74	8.5 (± 0.7)	ND	ND	4.4 (± 0.4)	VO
Kirol et al. (2012)	WY	ARTRW8 ARTRV	May/Jun	L/R	P	115	ND	ND	114	38.0 (± 0.2)	ND	ND	28.0 (± 0.1)	VO
Klott et al. (1993)	ID	ARTRW8	Jun/Jul/ Aug	ND	ND	4	2	2	ND	46.0	ND	ND	23.0	VO

Study	State	Sagebrush Type	Timing of Sampling	Grass Height Recorded By:		Sample Size				Grass Height				Height Type
				Designation	Life Span	Nests	Successful Nests	Failed Nests	Available Habitat	Nests	Successful Nests	Failed Nests	Available Habitat	
Klott et al. (1993)	ID	ARAR8	Jun/Jul/ Aug	ND	ND	2	1	1	ND	13.0	ND	ND	7.0	VO
Musil (2011) VO of grass height only	ID	ARTRW8 ARTRV ARTRT ARAR8 ARNO4	Projected Hatch	S L/R	P A	156	68	88	138	9.3 (± 0.7)	ND	ND	6.8 (± 0.6)	VO
Popham and Gutierrez (2003)	CA	ARTRW8 ARAR8 ARCA13	ND	L/R	P	88	35	53	45	ND	0.2 (± 2.6)[b]	32.5 (± 2.0)[b]	31.9 (± 2.4)	VO
Stonehouse et al. (2015)	WA	ARTR ARRI2	Fate	ND	P	30	ND	ND	ND	27.0 (± 3.0)	ND	ND	ND	VO

Bolded indicates articles cited in habitat guidelines (Connelly et al. 2000)

[a]Indicates significant differences reported between nest sites and available habitat

[b]Indicates significant differences reported between nest fates

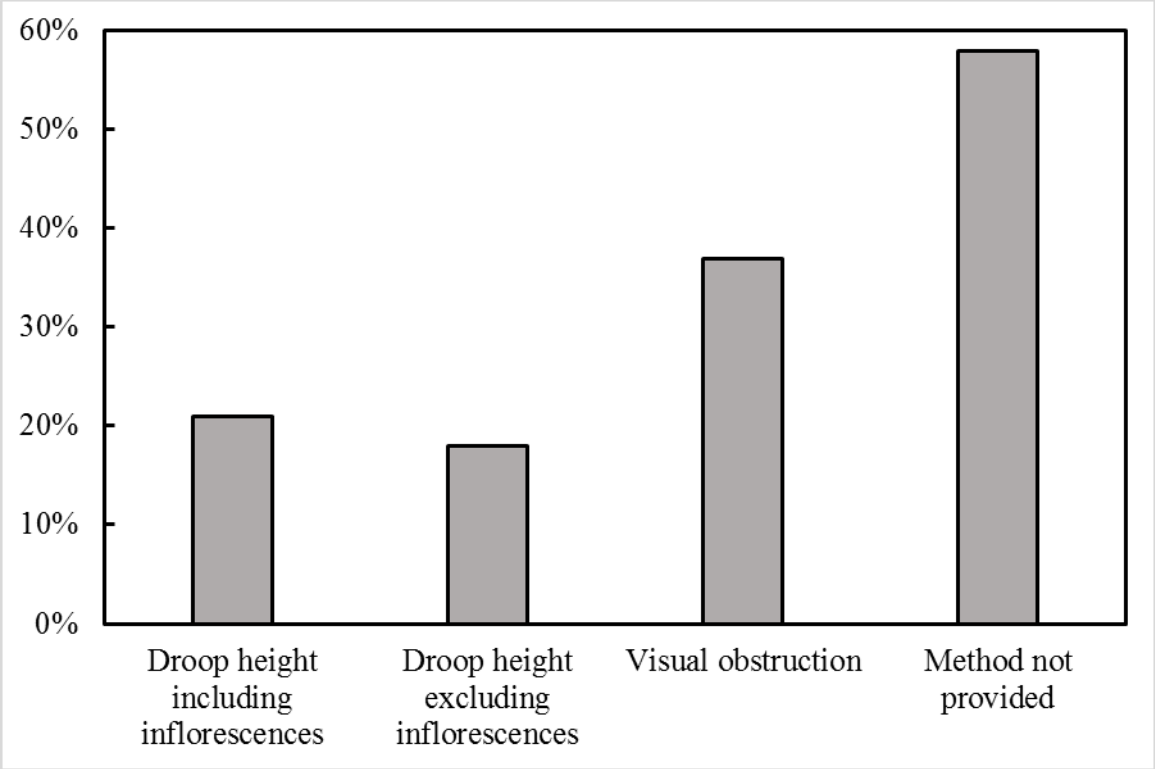

Figure 1.1. Percent of height metrics used from summarized studies reporting grass height in greater sage-grouse nesting habitat.

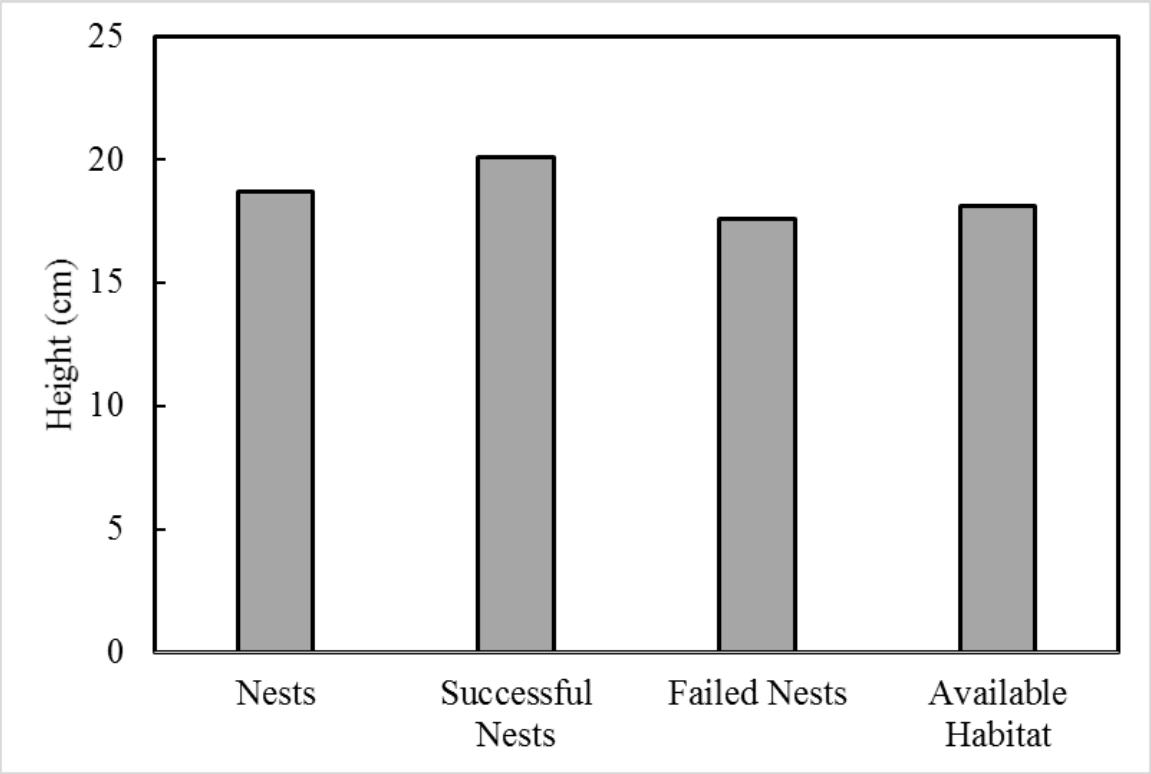

Figure 1.2. Average droop height of grass reported across studies summarized in Table 1.1.

CHAPTER 2

VARIATION OF PERENNIAL GRASS HEIGHTS IN RELATION TO SPECIES, LOCATION, AND YEAR IN SAGEBRUSH STEPPE COMMUNITIES

Abstract

A recent focus on sagebrush obligate species has increased the need to understand sagebrush steppe habitat for rangeland and wildlife management. Plant community attributes, such as perennial grass height, are influencing the decisions of land management agencies in critical areas, specifically those where greater sage-grouse (*Centrocercus urophasianus*) reside during nesting season. We assessed three types of perennial grass height (maximum droop height including inflorescence, maximum droop height excluding inflorescence, and effective height) in sagebrush steppe communities across four study locations in the Snake River Plains of southern Idaho. Vegetation sampling occurred at randomly selected plots during the sage-grouse nesting period (i.e., mid-April to June) for two years (2015-2016). We used an analysis of covariance with a generalized linear mixed model (PROC GLIMMIX, SAS 9.4, SAS Institute Inc., Cary, NC USA) to examine whether grass heights varied by species between years, among study locations, and across ecological sites within study locations. Differences were considered significant if p-values were ≤ 0.05. We used covariates of percent shrub, grass, and forb cover, expected soil type/ecological site productivity, day of measurement, and cumulative precipitation for each plot sampled and developed candidate models using these covariates. We used Akaike's Information Criterion (AIC) to rank the candidate models for each grass species. The difference in AIC scores ($\triangle$AIC) between each

of the models was used to identify the best model (i.e., the covariates that explain variation in height) for each grass species. Results indicated a three-way interaction among species, location, and year. Because of this three-way interaction, each type of grass height was analyzed by species. We found that grass heights varied by species, among locations, among ecological sites, and between years. Our findings support the work of others that grass height differs among species, and varies both spatially and temporally within species. While vegetation structure is important for nest concealment in sage-grouse nesting habitat, it may be beneficial for land management agencies to incorporate local information regarding grass heights, which vary in periods of extreme weather conditions, and across geographic locations.

Introduction

In the grassland plains and western states of the U.S., successful nesting habitat is crucial for population growth in many ground-nesting birds. Visual obstruction may aid in successful nesting, and perennial grasses help to provide concealment of the nests. This structure of vegetation is reported to be an important nesting feature in northern bobwhite (*Colinus virginianus*) in Kansas (Taylor et al. 1999) and Texas (Rader et al. 2007); lesser prairie-chicken (*Tympanuchus pallidicinctus*) in New Mexico (Riley et al. 1992; Davis 2009), and Kansas (Pitman et al. 2005); greater prairie-chicken (*Tympanuchus cupido*) in Missouri (Mckee et al. 1998) and Kansas (McNew et al. 2014); long-billed curlew (*Numenius americanus*) in South Dakota (Clarke 2006); sharp-tailed grouse (*Tympanuchus phasianellus*) in North Dakota (Kirby and Grosz 1995); Gunnison sage-grouse (*Centrocercus minimus*) in Colorado (Standley et al. 2015); and greater sage-grouse (*Centrocercus urophasianus*) throughout the western US (summarized by Connelly et al. 2000 and Hagen et al. 2007). Land

management agencies have placed a focus on conserving nesting habitat for many of these species experiencing declining populations, often attributed to altered or loss of vital habitat.

Recently, the greater sage-grouse (hereafter sage-grouse) was a candidate species being considered for protection under the Endangered Species Act (ESA). However, in September 2015, the U.S. Fish and Wildlife Service (USFWS) determined that the sage-grouse was not warranted for listing as threatened or endangered under the ESA (USFWS 2015). Efforts are ongoing to stabilize and possibly increase sage-grouse population numbers while conserving critical habitat, which may also help other wildlife species found in declining sagebrush (*Artemisia* spp.) ecosystems (Rowland et al. 2006; Copeland et al. 2014).

Historically, the sage-grouse was found in 13 western U.S. states and western Canada. Today, sage-grouse reside in 11 U.S. states and in the southwestern portions of two Canada provinces (WAFWA 2015). Sage-grouse abundance varies from year to year (Garton et al. 2015; WAFWA 2015); however, breeding populations have declined an average of 2.1% per year since 1965 (WAFWA 2015). In a recent population analysis, sage-grouse numbers fell by 56% from 2007 to 2013 (Garton et al. 2015).

Increased fragmentation and a loss of sagebrush has altered habitat conditions for the sage-grouse (Connelly and Braun 1997). Sagebrush communities were estimated to have occurred on over 62 million hectares in the western U.S. and southwestern Canada (West 1983). This ecosystem has been declining since early European settlement in North America (Welch 2005). Modern anthropogenic changes (Rowland et al. 2006; Davies et al. 2011; Rottler et al. 2015), large frequent wildfires coupled with the invasion of annual grasses (Chambers et al. 2007), and conifer encroachment (Miller et al. 2008) have negatively influenced sagebrush communities. This habitat loss and degradation has led to a precipitous

decline of sage-grouse populations since the mid-twentieth century (Connelly and Braun 1997; Schroeder et al. 2004).

Nesting and brood-rearing habitat is critical for sage-grouse populations to persist (Connelly et al. 2000). Guidelines for canopy cover and heights of shrubs and herbaceous plants needed to support nesting sage-grouse have been provided in environmental impact statements and approved resource management plan amendments for each respective state or region where sage-grouse are found (Connelly et al. 2000, Connelly et al. 2003, Hagen et al. 2007, Stiver et al. 2015; USDI BLM 2015b). These vegetation characteristics are intended to reflect the conditions necessary for successful nesting and may aid in providing visual and scent concealment from predators (Connelly et al. 2000; Stiver et al. 2015).

Federal, state, and private entities have adjusted their management actions to include conservation efforts for sage-grouse (USDI BLM 2015a; Connelly 2013). The guidelines regarding perennial grasses in nesting habitat recommend that height and percent canopy cover be above a threshold that provides adequate concealment during nesting and brood rearing. Idaho and Southwest Montana outlines management for perennial grass height ≥18 cm during the early growing season (i.e., before June 15; USDI BLM 2015b). Oregon set a grass height requirement at ≥18 cm for arid sites, and ≥23 cm for mesic sites (Gregg et al. 1994; Hanf et al. 1994; Crawford and Carver 2000; Hagen et al. 2007; USDI BLM 2015d). Wyoming management guidelines state a minimum of ≥15 cm or a lower minimum grass height set based on the respective ecological site description's potential and local variability (Connelly et al. 2000; Connelly et al. 2003; Doherty et al. 2014; Hagen et al. 2007; Stiver et al. 2015; USDI BLM 2015f). Other states (Utah, Nevada, and northeastern California) have a grass height requirement set to "provide overhead and lateral concealment from predators"

(USDI BLM 2015e) and specific heights set by watershed assessments or at the time of the Habitat Assessment Framework assessments (USDI BLM 2015c).

While herbaceous vegetation provides valuable cover for nests and brood rearing, heterogeneity in environmental conditions may present challenges to land managers developing decisions based on perennial grass height. Precipitation accounts for much of the above ground plant productivity and composition in arid environments, especially for herbaceous plant species (Mock 1996; Bates et al. 2006). Competition from neighboring plants can also have an influence on individual plants growth (Huber-Sannwald et al. 1996). From this, managers may have a difficult time determining effects of environmental conditions from those related to management activities (Bates et al. 2006).

Research Purpose

It is important to document how grass height varies across geographic locations independent of management actions and land use because grass height is an attribute being used to define the suitability of sage-grouse habitat, but morphology of grasses can vary greatly within species. Previous studies have revealed substantial genotypic and phenotypic variation within bunchgrass species common in sagebrush steppe ecosystems (Indian ricegrass, *Achnatherum hymenoides*; California brome, *Bromus carinatus*; squirreltail, *Elymus elymoides*; bluebunch wheatgrass, *Pseudoroegneria spicata*), including variation across years, locations, species, subspecies, and even within populations on a local scale (Bohmont and Lang 1957; Passey and Hugie 1963; Huber-Sannwald et al. 1996; Johnson et al. 2010; Parsons et al. 2011; Bradley St. Clair et al. 2013).

Past studies have documented genetically based variations in the presence or absence of awns on individual plants (Passey and Hugie 1963), length of awns (Bradley St. Clair et al.

2013), and the length and width of seeds produced (Bohmont and Lang 1957), as well as phenotypic variations leaf length, width, color, and overall plant height (Passey and Hugie 1963; Johnson et al. 2010; Parsons et al. 2011; Bradley St. Clair et al. 2013). In eastern Oregon, researchers collected California brome (*Bromus carinatus*) seeds from various locations in and grew plants in a common garden; the results revealed a significant variation in height among individual plants based on where they were collected (Johnson et al. 2010). Others found similar results for squirreltail (*Elymus elymoides* subsp. *brevifolius*) resulting in significant differences of plant heights from seeds collected across western U.S. states and grown in the same greenhouse (Parsons et al. 2011). Studies conducted on bluebunch wheatgrass (*Psuedoroegneria spicata*) revealed a significant difference in height not only among populations, but also among seeds collected from the same parent plant (Bradley St. Clair et al. 2013). One study found that some species of grass (*Psuedoroegneria spicata*) were able to recognize neighboring grasses of the same species or of other species (*Agropyron cristatum*; Huber-Sannwald et al. 1996). These individual grasses were able to exhibit structural plasticity based on apparent interspecific competition (Huber-Sannwald et al. 1996).

These observed phenotypic plasticity of morphological traits and spatial/temporal variation among individual plants may present challenges to management based on guidelines with specific heights of grass. We examined variation in grass height across years and study locations for six species of perennial grass in sagebrush steppe communities throughout southern Idaho during the sage-grouse nesting season.

Methods

Study Area

We measured grass height in 2015 and 2016 at four study locations in the Snake River Plain of southern Idaho: Sheep Creek, Brown's Bench, Jim Sage, and Big Butte (Figure 2.1). The Sheep Creek study area was located in southwestern Idaho, Owyhee County, roughly 45 km south of Grasmere, Idaho. Brown's Bench location was in Twin Falls County, about 22 km southwest of Rogerson, Idaho. The Jim Sage study location was in Cassia County, about 17 km southwest of Malta, Idaho. Big Butte site was located in Butte and Blaine counties, about 24 km southwest of Atomic City, Idaho.

The climate for all study locations was typical of cold deserts, having cold winters and hot summers. Average temperatures ranged from -15°C in the winter to 31°C in the summer for each study location during 2015 and 2016. During the study, Sheep Creek, Brown's Bench, and Jim Sage study locations had annual precipitation greater than the long-term average, while the Big Butte location had an annual precipitation less than the long-term average (Western Regional Climate Center 2017; Figure 2.2). However, each study location showed seasonal precipitation patterns in 2015 and 2016 similar to the long-term average, with a spike in precipitation during the spring months and a slight increase during the winter months (Figure 2.2).

Elevation was similar among the four study locations: Big Butte, ranged from 1500-1600 m, Brown's Bench elevation from 1500-1700 m, and Jim Sage and Sheep Creek areas ranged from 1500-1800 m. Soil types varied across study locations; the majority of plots sampled were located on loamy soils at Big Butte and Sheep Creek, shallow loamy at Jim Sage, and a very shallow stony soil type at Brown's Bench (Soil Survey Staff 2016).

At each study location, we selected at least three pastures as experimental pastures where vegetation sampling occurred. Pastures ranged in size from 500 ha to 5500 ha. In 2015, six pastures were grazed, while in 2016 only five pastures were grazed. However, we only assessed ungrazed vegetation for our analyses of grass height in this chapter.

Vegetation Community

The vegetation community on all four study locations had an overstory of shrubs dominated by Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) or little sagebrush (*Artemisia arbuscular*), with a perennial bunchgrass understory consisting largely of bluebunch wheatgrass (*Pseudoroegneria spicata*), squirreltail (*Elymus elymoides*), and Sandberg bluegrass (*Poa secunda*). Many native forbs occurred throughout each of the study locations. A full list of plant species found at the study locations is provided in the Appendix Table A.1.

Experimental Design and Measurements

We used the random point generator in ArcGIS (ERSI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute) to place twenty plots within each experimental pasture. A total of 174 random plots in 12 pastures were sampled from mid-April to early July in 2015 and 2016. The random plots used in this analysis are a subset of a larger study being conducted during the sage-grouse nesting season (Conway et al. 2016). The center of each random plot was moved so that the plot was centered on a shrub capable of supporting a sage-grouse nest.

Vegetation Sampling

We measured height of perennial grasses and other vegetation characteristics along transects at each random plot. Two 30-m perpendicular transects intersected at 15-m, centered

over a sagebrush (plant with dimensions similar to sage-grouse nest shrubs), and extending in each cardinal direction. We measured grass height of up to three species of perennial grasses every two meters along each transect line (a possible 90 individual grasses measured per plot). The nearest individual of the nearest three species of grass that fell within one meter of the respective meter mark was recorded. Grass height was measured in three ways: 1) the maximum droop height *with* inflorescence (the highest unaltered height of the tallest stem, leaf, or flower stalk; maximum droop height); 2) maximum droop height *excluding* inflorescence (unaltered height of the tallest stem or leaf without the flower stalk; maximum leaf height); and 3) effective height (maximum height that a modified Robel pole was visually obstructed; following Musil 2011). To estimate effective height a meter stick painted with inch-wide bands was placed behind an individual grass plant and the first band above the ground that was >50% obstructed was recorded as viewed at a 1-meter height and about 30 cm perpendicular to the meter stick (Musil 2011). We did not differentiate between live and residual plant material when measuring these three height metrics. Grass heights used in our statistical analysis were for *ungrazed* grasses. We used the line intercept method to estimate shrub canopy cover (Canfield 1941), and a 20 x 50 cm Daubenmire frame, placed every three meters along transect lines to estimate canopy cover of herbaceous understory plants (Daubenmire 1959).

Statistical Analyses

We recorded 18 perennial grass species at the random plots in 2015 and 2016, and conducted analyses on six of the 18 species for which we had height measurements for >20 individuals: Indian ricegrass (*Achnatherum hymenoides*), crested wheatgrass (*Agropyrum cristatum*), squirreltail (*Elymus elymoides*), western wheatgrass (*Pascopyrum smithii*),

Sandberg bluegrass (*Poa secunda*), and bluebunch wheatgrass (*Pseudoroegneria spicata*). We used an analysis of covariance with a generalized linear mixed model (PROC GLIMMIX, SAS 9.4, SAS Institute Inc., Cary, NC USA) to examine whether grass heights varied by species between years, among study locations, and across ecological sites within study locations. Differences were considered significant if p-values were ≤ 0.05. We used continuous variables (covariates) of percent shrub, grass, and forb canopy cover, time of measurement (Julian Date), cumulative precipitation at time of measurement (starting from October 1 the previous year), and expected productivity of soil type/ecological site for each plot sampled. We selected these variables as covariates because of their potential influence on grass height. Competition from neighboring plants can reduce available resources to the plant being assessed, thus we included shrub, grass, and forb canopy cover to account for this competition. Time of measurement reflects phenological state and is known to affect grass height during sage-grouse nesting season (Gibson et al. 2015). Cumulative precipitation was gathered starting from the beginning of the hydrological year (October 1 the previous year; Western Regional Climate Center 2017) to the date of grass height measurement to account for snowfall and rainfall events that may influence grass height (Mock 1996). Productivity of an ecological site is an important variable to consider, as these sites are recognized for producing differing kinds and amount of vegetation (USDA NRCS 1997). A correlation analysis (PROC CORR, SAS 9.4, SAS Institue Inc., Cary, NC USA) was completed for the covariates listed above. Results of correlation analysis determined the covariates used in modeling were not highly correlated ($r < 0.60$).

Model Selection

Models were developed separately for the three height measurements for each of the six grass species examined; a total of 18 different analyses. We developed candidate models using all the covariates listed above (Day, Precipitation, Soil Productivity, Shrub Cover, Forb Cover, and Grass Cover), different combinations of covariates, and a null model with no covariates (Appendix Table A.2 for all candidate models developed). Year, Location, and Year by Location were included into every model (except the null). We also conducted analyses with ecological site within a location as a class variable, and for ecological sites that occurred on > 1 study location. For analyses within a study location among different ecological sites, the variable ecological site replaced location. We used Akaike's Information Criterion (AIC) to rank the candidate models for each grass species (Akaike 1974). The difference in AIC scores (△AIC) between each respective model was used to identify the best model for each grass species height analysis (Appendix Table A.2).

Results

Sandberg bluegrass was the most abundant grass species sampled and was observed on 99% of the plots. Squirreltail was the second most abundant grass found on 78% of the plots sampled. Bluebunch wheatgrass was the third most abundant grass species found on 58% of the plots sampled. Crested and western wheatgrass were observed on three study locations, Big Butte, Brown's Bench, and Jim Sage, with crested wheatgrass occurring on only 22% of the plots sampled, and western wheatgrass on 10% of plots sampled. Indian ricegrass was grouped with needlegrasses in 2015, and we did not conduct a statistical analysis on this species for 2015. We recorded heights for Indian ricegrass on all four study

locations in 2016. Indian ricegrass was the least abundant grass sampled, found on only 6% of the plots sampled.

When all species were examined together, a three-way interaction was detected between species, location, and year for each height measurement ($p < 0.05$). Because of this interaction, we developed a model for each height measurement by individual species. When all the species were examined together by year, a two-way interaction was detected between species and year ($p < 0.05$). However, a trend existed of all species having greater maximum droop height in 2015 than 2016 (Figure 2.3; $p < 0.05$), except for western wheatgrass, which had greater variation among the small sample size; all species having similar maximum leaf heights in both years ($p > 0.05$), except for Sandberg bluegrass which had a greater maximum leaf height in 2015 than 2016 ($p < 0.05$); while, only two species had differences in effective height between years ($p < 0.05$), crested wheatgrass and squirreltail.

The average height of each species across locations for the three different height measurements confirmed known trends in height differences by species. Maximum droop height of each species showed Indian ricegrass having the greatest height, then bluebunch wheatgrass, crested wheatgrass, squirreltail, and then western wheatgrass, and Sandberg bluegrass having the shortest heights among all the species (Figure 2.4). Maximum leaf height had a similar trend, but Indian ricegrass always had the greatest height, followed by bluebunch wheatgrass, then crested wheatgrass, squirreltail and western wheatgrass were similar, while Sandberg had the least mean maximum leaf height. Similar to the other height measurements, Indian ricegrass and bluebunch had the greatest effective height ($p > 0.05$), crested wheatgrass, then squirreltail, western wheatgrass, and Sandberg bluegrass had the least effective height ($p < 0.05$; Figure 2.4).

Maximum Droop Height with Inflorescence

During 2015 and 2016, the majority of grass species had an average droop height greater than the desired perennial grass height of 18 cm suggested for sage-grouse nesting habitat (Figure 2.5). The exception, Sandberg bluegrass, had an average height ≥ 18 cm on two locations in 2015, Big Butte and Brown's Bench, and only in 2016 on the Sheep Creek location. Average height of Sandberg bluegrass did not reach the recommended height for either year at the Jim Sage location.

The height of grasses was generally greater in 2015 than 2016, but differences in height between the 2 years varied by location for crested wheatgrass, squirreltail, western wheatgrass, and Sandberg bluegrass (i.e., year by location interaction $p < 0.05$; Figure 2.5). For these four species, there was no consistent trend of height being greater one year or at one location than the others. The average droop height of western wheatgrass varied between 20 and 60 centimeters with no consistent variation attributed to year or location. The fact that only 356 western wheatgrass plants were measured may have contributed to the high variability and lack of consistency across years and location. Maximum droop height of crested wheatgrass was found to be comparable at Big Butte and Jim Sage, but was greater in 2015 than 2016 at Brown's Bench. Squirreltail showed no consistency of height by year or location. Sandberg bluegrass height was greater in 2015 than 2016 at two locations, but not at the other two sites. Indian ricegrass was only measured in 2016 and only 48 plants were assessed, so no variation due to year was analyzed. Of the six species assessed, bluebunch wheatgrass was the only one that had a consistent trend of heights greater in 2015 than 2016, and to have a different mean maximum droop height across locations ($p < 0.05$), Big Butte having the greatest, then Sheep Creek, Jim Sage, and Brown's Bench with the shortest.

We found a number of variables to have an important ($p < 0.05$) influence on maximum droop height for some species of grass (Table 2.1). Across all locations, mean maximum droop height of Indian ricegrass was positively influenced by day, but negatively influenced by shrub cover and forb cover. The maximum droop height of Sandberg bluegrass was influenced by the same variables; however, canopy cover of shrubs and forbs had a slightly positive influence. Day of measurement influenced grass height for both crested wheatgrass and western wheatgrass. Bluebunch wheatgrass and squirreltail were positively influenced by an increase in precipitation, while soil productivity seemed to influence height of squirreltail (for relationships of variables influencing height refer to Appendix Figures A.1-A.7).

Maximum Droop Height Excluding Inflorescence

No general trend of year having greater heights was detected for average maximum leaf height and varied among study locations with no consistent pattern. For Sandberg bluegrass the maximum leaf height was greater in 2015 than 2016 ($p < 0.05$). Maximum leaf height also varied among locations with Brown's Bench having the greatest heights, Big Butte and Jim Sage having similar heights, and Sheep Creek having the shortest heights. There was no consistent pattern of one study location having greater average maximum leaf height than the other locations for all grass species. The influence of year on maximum leaf height varied by study location for crested wheatgrass, squirreltail, and bluebunch wheatgrass (Figure 2.6). Squirreltail showed a slight trend of greater heights in 2016, but had no consistent trend of one location having greater heights than another. Crested wheatgrass and bluebunch wheatgrass had similar heights in 2015 and 2016, and no one location had greater heights than the other locations.

Similar to maximum droop height, mean maximum leaf height Indian ricegrass was negatively influenced by increasing canopy cover of shrubs and forbs (Table 2.2). Day influenced maximum leaf height for only two of the six species, western wheatgrass and bluebunch wheatgrass (Table 2.2). Interestingly, precipitation had a negative influence on Sandberg bluegrass, and a positive influence on bluebunch wheatgrass mean maximum leaf height (Table 2.2).

Effective Height

Similar to maximum droop height and leaf height, no consistent trend for year was detected for effective height in all species. Bluebunch wheatgrass had greater effective heights in 2016 than 2015 (Figure 2.4). Bluebunch wheatgrass also showed a similar pattern of effective height to maximum droop height differing across locations with Big Butte having the greatest height, then Sheep Creek, Jim Sage, and Brown's Bench having the least effective height (Figure 2.7). Western wheatgrass also differed across locations for effective height, with Jim Sage having the greatest heights, and Big Butte having the least effective height (Figure 2.7). The influence of year on height varied by study location for crested wheatgrass, squirreltail, and Sandberg bluegrass (Figure 2.7). There was no consistent pattern of one study location or year having greater or lower effective height for these grass species.

Only a few grass species' mean effective height were influenced by covariates analyzed in this study (Table 2.3). Across all locations, bluebunch wheatgrass mean effective height was positively influenced as precipitation increased, forb cover had a positive influence on squirreltail, while shrub cover negatively influenced effective height of Indian ricegrass.

Ecological Site

We assessed differences in grass height across ecological sites within each study location for the three most common grasses (squirreltail, Sandberg bluegrass, and bluebunch wheatgrass). Measurements for grass height were taken on six different ecological sites for Brown's Bench and Jim Sage each, and on two different ecological sites at Big Butte and Sheep Creek (Appendix Table A.3). Ecological sites varied from very shallow stony soils, low annual precipitation, dwarf sagebrush communities, to more productive loamy soil, greater annual precipitation, and big sagebrush communities. Bunchgrass species expected to be found among these ecological sites differed among bluebunch wheatgrass, Idaho fescue (*Festuca idahoensis*), Indian ricegrass, and Thurber's needlegrass (*Acnatherum thurberianum*). A list and description of ecological sites where vegetation sampling occurred for each study location provided in the Appendix (Table A.3). Three ecological sites were found at more than one study location (Loamy 8-12" was found at Big Butte and Jim Sage, Shallow calcareous loam 10-16" found at Brown's Bench and Jim Sage, and Claypan 12-16" found at Brown's Bench and Sheep Creek).

Within study locations, grass heights varied by species, and some species varied across ecological sites, while others varied between years. At Big Butte, Sandberg bluegrass differed between years, but not at ecological sites (Table 2.4). Squirreltail and Sandberg bluegrass both differed across ecological sites found at Brown's Bench. Maximum droop height of bluebunch wheatgrass ranged between 45 cm, however year had an influence on height across ecological sites for bluebunch wheatgrass found at Brown's Bench and no consistent trend of height across ecological sites was determined. At Jim Sage, both squirreltail and bluebunch wheatgrass maximum droop height differed between years, but not

across ecological sites. Sandberg heights were similar between years and across ecological sites at Jim Sage. At Sheep Creek, squirreltail and bluebunch differed between years, but not among ecological sites.

Grasses assessed on the same ecological site, but found at different study locations didn't appear to vary in maximum droop height, and an interaction of year on height between locations was detected for all three species found on the same ecological site at Big Butte and Jim Sage, and for Sandberg bluegrass found at Brown's Bench and Jim Sage, and again at Brown's Bench and Sheep Creek (Table 2.5). Bluebunch wheatgrass maximum droop height differed among locations, Brown's Bench and Sheep Creek, but was only assessed in 2016 at Brown's Bench, so no variation in year was analyzed (Table 2.5). Absence of this grass in 2015 at Brown's Bench may be due to plot location varying on ecological sites when field measurement were taken, since plot locations were not assessed in the same exact location every year.

On three of the four study locations, Sandberg bluegrass maximum droop height seemed to be influenced the canopy cover of surrounding vegetation (shrub, grass, and forb cover) among ecological sites within study locations (Table 2.1). Precipitation played an important role influencing mean maximum droop height for squirreltail found at Brown's Bench, and on the same ecological site (R011BY001ID) between study locations, Big Butte and Jim Sage. While grass cover was important to squirreltail at Jim Sage, and between study locations Brown's Bench and Jim Sage (R025XY016ID; Table 2.1). Day of measurement influenced maximum droop height for squirreltail found on the same ecological site (R025XY010ID) at Brown's Bench and Sheep Creek. Cover of forbs influenced bluebunch wheatgrass height found at Brown's Bench, between Brown's Bench and Jim Sage

(R025XY016ID), while grass cover was influential on height between Big Butte and Jim Sage (R011BY001ID; Table 2.1). Day influenced on height for bluebunch wheatgrass at Big Butte, and precipitation had an influence on bluebunch wheatgrass found on the same ecological site between Brown's Bench and Sheep Creek (R025XY010ID; Table 2.1).

Similar to maximum droop height, no difference in maximum leaf height was determined for all three species found at Big Butte and Sheep Creek across ecological sites or between years (Table 2.6). Squirreltail varied across ecological sites at Brown's Bench and between years at Jim Sage (Table 2.6), and seemed to be influenced by grass cover at Jim Sage. Bluebunch wheatgrass differed among ecological sites at Jim Sage, and was influenced by forb cover at both Brown's Bench and Jim Sage (Table 2.2).

Across study locations for the same ecological site, mean maximum leaf height for Sandberg bluegrass differed between study locations (Brown's Bench and Jim Sage for R025XY016ID; Brown's Bench and Sheep Creek for R025XY010ID) found on the same ecological site, while height of bluebunch wheatgrass differed between Big Butte and Jim Sage (R011BY001ID; Table 2.7). Precipitation was found to be an important variable for maximum leaf height of Sandberg bluegrass at Brown's Bench and Sheep Creek found on the same ecological site (R025XY010ID; Table 2.2). Bluebunch wheatgrass varied between Big Butte and Jim Sage found on the same ecological site (R025XY016ID; Table 2.7), and canopy cover of grass was determined to have an influence on the maximum leaf height (Table 2.2).

No general trend was detected for effective height across ecological sites within study locations by species (Table 2.8). Year had an influence on effective height for squirreltail, Sandberg bluegrass, and bluebunch wheatgrass at Big Butte, for Sandberg bluegrass at Jim

Sage, and bluebunch wheatgrass at Sheep Creek. No difference in effective height for the three grass species was determined among ecological sites at all four study locations. Bluebunch wheatgrass and squirreltail effective heights were influenced by forb cover at Brown's Bench, while only squirreltail was influenced by forb cover at Sheep Creek (Table 2.3).

Squirreltail found on the same ecological site (R025XY016ID) at Brown's Bench and Jim Sage, and Brown's Bench and Sheep Creek (R025XY010ID), had an effective height that differed between study locations, and bluebunch wheatgrass effective height differed between Brown's Bench and Sheep Creek for the same ecological site (R025XY010ID; Table 2.9). Grass cover also influenced effective height of bluebunch wheatgrass between Brown's Bench and Sheep Creek (R025XY010ID).

There was no clear evidence of one ecological site consistently having heights greater than the other ecological sites in our study. It is expected, though, that soil type and neighboring vegetation may have an overriding influence on grass height. This trend was noticeable in each height type analyzed throughout the ecological sites. Generally, grass height was greater in ecological sites with loamy type soils and greater annual precipitation than stony or clay type soils with less annual precipitation. However, grass heights were usually greater when surrounding vegetation consisted of dwarf sagebrush (little and black sagebrush) versus big sagebrush (Wyoming and mountain big sagebrush) regardless of soil type and annual precipitation. These trends were not consistent across all ecological sites found across the study locations. Soil types across all the ecological sites were found to be similar (majority of ecological sites were consistent of loam) and may also explain why no definite trend of one ecological site having greater heights than other sites.

We found that metrics used in grass height differed among metric type. Maximum droop height varied the most among species and within species across locations, ecological sites, and between years. Maximum leaf height measurements had less variation within each species. Effective height measurements varied within some species, but did not vary as greatly as maximum droop height measurements.

Discussion

Our results indicate that grass height varies among species, and can vary within a species among years, locations, and ecological sites. Some study locations had greater mean heights in 2015 than 2016, while others study locations did not. Precipitation was generally greater in 2015 than 2016 and was found to have had an effect on some species' heights and different height measurements. While we found no consistent trend or pattern of heights among study locations or ecological sites, this may be explained by each study location having similar characteristics of vegetation communities, elevation, amount of precipitation, and soil types. Similar to our results though, others found variations of grass height among vegetation communities (Connelly et al. 1991), years (Robinson and Messmer 2013; Woodward et al. 2016), and study locations (Hausleitner 2003; Robinson and Messmer 2013; Slater 2003) throughout sage-grouse nesting habitat.

Differences in height measurements showed maximum droop height had the greatest variation among species, years, and locations. Maximum leaf showed some consistency of individual species measurements being similar across years and locations. However, effective height measurements were mainly determined by growth characteristics of specific species (i.e., Indian ricegrass having greater effective height than Sandberg bluegrass, even with both classified as bunchgrasses). When incorporating grass height measurements into land

management actions, it would be important to consider the different types of height measurements because some height measurements may vary more across a landscape than other measurements.

Growth characteristics, such as biomass and height of herbaceous plants can vary greatly over a wide range of spatial and temporal scales. Our findings show that some grass species and different height measurements had an influence from the covariates we accounted for in our analysis. All three height measurements of Indian ricegrass were negatively influenced by an increase in surrounding vegetation canopy cover. This could be explained by Indian ricegrass's growth characteritistics of establishing in open or disturbed areas (USDA NRCS 2006). However, the height of other species, such as Sandberg bluegrass, were taller with an increase in shrub cover and forb cover at three of the study locations. Sandberg bluegrass is unique in its growth characteristics from other bunchgrass species, because it has similar growing features as invasive annuals in that it matures quickly during the early part of the growing season and competes well with annuals to fill in small interspacing of shrubs and forbs (USDA NRCS 2008). Growth characteristics are important for perennial grasses to become established and compete with other vegetation, especially in arid climates.

Other grass species, bluebunch wheatgrass and squirreltail were commonly influenced by day of measurement and increase in precipitation. The day when grass height is measured during the growing season is an important variable to consider when analyzing vegetation characteristics found in breeding habitat of many species, including sage-grouse. Others have found that results may be biased and favored towards greater grass heights at successful nests when heights are assessed at a later date than unsuccessful nests (Borgmann and Conway 2015; Gibson et al. 2016).

Precipitation patterns have been correlated with height of many plant species (Moles et al. 2009). Areas of low annual precipitation that experience a few years of drought could have much lower grass heights. The locations for our study did have varying annual precipitation amounts during 2015 and 2016 when compared to the long-term average. Big Butte was the only study location to have an average annual precipitation amount less than the long-term average, while the other three locations received more annual precipitation than the long-term average. However, we found no consistent trend of one study location having greater grass heights than the other locations even with differing amounts of precipitation. Our findings did show that precipitation was an important variable influencing grass height of several species found in sagebrush steppe communities.

Land managers that develop management decisions based on variable plant attributes, such as grass height, may need to be cautious when interpreting those characteristics on a landscape scale. By having an understanding of vegetation communities, ecological sites, and environmental variables, managers could create management plans for multiple scales and specific ecosystems based on varying climatic and environmental conditions. This would be especially important when addressing concerns for declining populations of obligate wildlife species, such as the greater sage-grouse.

While the results presented here were for only two years, future research should examine grass heights across multiple years in differing climates among several geographic locations for the same or similar species of grass found in the same vegetation community or if possible the same ecological site. By having this information, research could offer vital information to provide an alternative to the blanket approach of federal agencies applying a

management decision across a wide range of geographic locations with varying vegetation, climates, and environmental conditions.

Literature Cited

Akaike, H. 1974. A new look at the statistical model identification. IEEE transactions on automatic control, 19(6):716-723.

Aldridge, C.L. and R.M. Brigham. 2002. Sage-grouse nesting and brood habitat use in southern Canada. Journal of Wildlife Management 66(2):433-444.

Bates, J.D., T. Svejcar, R.F. Miller, and R.A. Angell. 2006. The effects of precipitation timing on sagebrush steppe vegetation. Journal of Arid Environmentals 64(4):670-697.

Bell, C.B. 2011. Nest site characteristics and nest success of translocated and resident greater sage grouse at clear lake national wildlife refuge. Thesis, Humboldt State University, Arcata, California, USA.

Bohmont, B.L., and R. Lang. 1957. Some variations in morphological characteristics and palatability among geographic strains of Indian ricegrass. Journal of Range Management 10(3):127-131.

Bradley St. Clair, J., F.F. Kilkenny, R.C. Johnson, N.L. Shaw, and G. Weaver. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evolutionary Applications 6(6):933-948.

Canfield, R.H. 1941. Application of the line interception method in sampling range vegetation. Journal of Forestry 39:388-394.

Cardinal, C.J. and T.A. Messmer. 2016. Ecology of greater sage-grouse populations inhabiting the northwestern Wyoming Basin. Human-Wildlife Interactions 10(2):188-204.

Chambers, J.C., B.A. Roundy, R.R. Blank, S.E. Meyer, and A. Whittaker. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum?* Ecological Monographs 77(1):117-145.

Clarke, J.N. 2006. Reproductive ecology of long-billed curlews breeding in grazed landscapes of western South Dakota. Thesis, South Dakota State University, Brookings, USA.

Connelly, J. 2013. Federal agency responses to greater sage-grouse and the ESA: getting nowhere fast. Northwest Science 88(1):61-64.

Connelly, J.W., and C.E. Braun. 1997. Long-term changes in Sage Grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3(4):229-234.

Connelly, J.W., K.P. Reese, and M.A. Schroeder. 2003. Monitoring of Greater sage-grouse habitats and populations. University of Idaho College of Natural Resources Experiment Station Bulletin 80. University of Idaho, Moscow, ID.

Connelly, J.W., M.A. Schroeder, A.R. Sands, and C.E. Braun. 2000. Guidelines to manage sage grouse populations and their habitats. Wildlife Society Bulletin 28(4):967-985.

Connelly, J.W., S.T. Knick, M.A. Schroeder, and S.J. Stiver. 2004. Conservation Assessment of Greater Sage-grouse and Sagebrush Habitats. Western Association of Fish and Wildlife Agencies. Cheyenne, Wyoming.

Connelly, J.W., W.L. Wakkinen, A.D. Apa, and K.P. Reese. 1991. Sage grouse use of nest sites in southeastern Idaho. Journal of Wildlife Management 55(3):521-524.

Conway, C., K. Launchbaugh, D. Musil, S. Roberts, P. Makela, A. Locatelli, and A. Meyers. 2016. Unpublished data. University of Idaho, Moscow, Idaho, USA.

Copeland, H.E., H. Sawyer, K.L. Montheith, D. E. Naugle, A. Pocewicz, N. Graf, and M.J. Kauffman. 2014. Conserving migratory mule deer through the umbrella of sage-grouse. Ecosphere 5(9):117.

Crawford, J.A., and L.A. Carver. 2000. Habitat use by sage-grouse on the Beatty Butte BLM allotment: final report. Oregon State University, Department of Fisheries and Wildlife. Corvallis, USA.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:43-64.

Davis, D.M. 2009. Nesting ecology and reproductive success of lesser prairie-chickens in shinnery oak-dominated rangelands. 2009. The Wilson Journal of Ornithology 121(2):322-327.

Davis, D.M., K.P. Reese, and S.C. Gardner. 2014. Demography, reproductive ecology, and variation in survival of greater sage-grouse in northeastern California. Journal of Wildlife Management 78(8):1343-1355.

Davies, K.W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, and M.A. Gregg. 2011. Saving the sagebrush sea: an ecosystem conservation plan for big sagebrush plant communities. Biological Conservation 144:2573-2584.

Doherty, K.E., D.E. Naugle, J.D. Tack, B.L. Walker, J.M Graham, and J.L. Beck. 2014. Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival. Wildlife Biology 20(6):320-325.

Garton, E.O., A.G. Wells, J.A. Baumgardt, and J.W. Connelly. 2015. Greater sage-grouse population dynamics and probability of persistence. Final Report to Pew Charitable Trusts.

Gregg, M. A., J.A. Crawford, M.S. Drut, and A.K. DeLong. 1994. Vegetational cover and predation of sage grouse nests in Oregon. The Journal of Wildlife Management 58(1):162-166.

Hanf, J.M., P.A Schmidt, and E.B. Groshens. 1994. Sage grouse in the high desert of central Oregon: results of a study, 1988-1993. Bureau of Land Management, Portland, Oregon, USA.

Hagen, C. A., J. W. Connelly, and M. A. Schroeder. 2007. A meta-analysis of greater sage-grouse *Centrocercus urophasianus* nesting and brood-rearing habitats. Wildlife Biology 13 (Supplement 1):42-50.

Hausleitner, D. 2003. Population dynamics, habitat use and movements of greater sage-grose in Moffat County, Colorado. Thesis, University of Idaho, Moscow, USA.

Hausleitner, D., K.P. Reese, and A.D. Apa. 2005. Timing of vegetation sampling at greater sage-grouse nests. Rangeland Ecology and Management 58(5):553-556.

Holloran, M.J. 1999. Sage grouse (*Centrocercus urophasianus*) seasonal habitat use near Casper, Wyoming. Thesis, University of Wyoming, Laramie, USA.

Huber-Sannwald, E., D.A. Pyke, M.M. Caldwell. 1996. Morphological plasticity following species-species recognition and competition in two perennial grasses. American Journal of Botany 83(7):919-931.

Johnson, R.C., V.J. Erickson, N.L. Mandel, J.B. St. Clair, and K.W. Vance-Borland. 2010. Mapping genetic variation and seed zones for *Bromus carinatus* in the Blue Mountains of eastern Oregon, USA. Botany 88(8):725-736.

Kaczor, N.W., K.C. Jensen, R.W. Klaver, M.A. Rumble, K.M. Herman-Brunson, and C.C. Swanson. 2011. Nesting success and resource selection of greater sage-grouse. Pp 107-118 in B.K. Sandercock, K. Martin, and G. Segelbacher (editors). Ecology, conservation, and management of grouse. Studies in Avian Biology (no. 39), University of California Press, Berkeley, CA.

Kirby, D.R., and K.L. Grosz. 1995. Cattle grazing and sharp-tailed grouse nesting success. Rangelands 17(4):124-126.

Knick, S.T., D.S. Dobkin, J.T. Rotenberry, M.A. Schroeder, W.M. Vander Haegen, and C. Van Riper. 2003. Teetering on the edge or too late? Conservation and research issues for avifauna of sagebrush habitats. The Condor 105(4):611-634.

Mckee, G., M.R. Ryan, and L.M. Mechlin. 1998. Predicting greater prairie-chicken nest success from vegetation and landscape characteristics. Journal of Wildlife Management 62(1):314-321.

McNew, L.B., L.M. Hunt, A.J. Gregory, S.M. Wisely, and B.K. Sandercock. 2014. Effects of wind energy development on nesting ecology of greater prairie-chickens in fragmented grasslands. Conservation Biology 28(4):1089-1099.

Miller. R.F., R.J. Tausch, E.D. McArthur, D.D. Johnson, and S.C. Sanderson. 2008. Age structure and expansion of piñon-juniper woodlands: a regional perspective in the Intermountain West. Res. Pap. RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Mock, C.J. 1996. Climate controls and spatial variations of precipitations in the western United States. Journal of Climate 9(5):1111-1125.

Moles, A.T., D.I. Warton, L. Warman, N.G. Swenson, S.W. Laffan, A.E. Zanne, A. Pitman, F.A. Hemmings, and M.R. Leishman. 2009. Global patterns in plant height. Journal of Ecology 97(5):923-932.

Musil, D. D. 2011. Use of dwarf sagebrush by nesting greater sage-grouse. Ecology, conservation and management of grouse. Studies in Avian Biology 39:119-136.

Parsons, M.C., T.A. Jones, S.R. Larson, I.W. Mott, and T.A. Monaco. 2011. Ecotypic variation in *Elymus elymoides* subsp. *brevifolious* in the Northern Intermountain West. Rangeland Ecology and Management 64(6):649-648.

Passey, H.B. and V.K. Hugie. 1963. Variation in bluebunch wheatgrass in relation to environment and geographic location. Ecology 44(1):158-161.

Pitman, J.C., C.A. Hagen, R.J. Robel, T.M. Loughin, and R.D. Applegate. 2005. Location and success of lesser prairie-chicken nests in relation to vegetation and human disturbance. Journal of Wildlife Management 69(3):1259-1269.

Rader, M.J., L.A. Brennan, F. Hernadez, N.J. Silvy, and B. Wu. 2007. Nest-site selection and nest survival of northern bobwhite in southern Texas. The Wilson Journal of Ornithology 119(3):392-399.

Riley, T.Z., C.A. Davis, M. Ortiz, and M.J. Wisdom. 1992. Vegetative characteristics of successful and unsuccessful nests of lesser prairie-chickens. Journal of Wildlife Management 56(2):383-387.

Robinson, J.D., and T.A. Messmer. 2013. Vitals rates and seasonal movements of two isolated greater sage-grouse populations in Utah's west desert. Human-Wildlife Interactions 7(2):182-194.

Rottler, C.M., C.E. Noseworthy, B. Fowers, J.L. Beck. 2015. Effects of conversion from sagebrush to non-native grasslands on sagebrush-associated species. Rangelands 37(1):1-6.

Rowland, M. M., M.J. Wisdom, L. H. Suring, and C. W. Meinke. 2006. Greater sage-grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation 129(3):323-335.

Schroeder, M.A., C.L. Aldridge, A.D. Apa, J.R. Bohne, C.E. Braun, S.D. Bunnell, J.W. Connelly, P.A. Deibert, S.C. Gardner, M.A. Hilliard, G.D. Kobriger, S.M. McAdam, C.W. McCarthy, J.J. McCarthy, D.L. Mitchell, E.V. Rickerson, and S.J. Stiver. 2004. Distribtuion of sage-grouse in North America. The Condor 106(2):363-376.

Slater, S.J. 2003. Sage-grouse (*Centrocercus urophasianus*) use of different-aged burns and the effects of coyote control in southwestern Wyoming. Thesis, University of Wyoming, Laramie, USA Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. 2016. Available at http://websoilsurvey.nrcs.usda.gov/.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. 2017. Available online at http://websoilsurvey.nrcs.usda.gov/.

Stanley, T.R., C.L. Aldridge, D.J. Saher, and T.M. Childers. 2015. Daily nest survival rates of Gunnison sage-grouse (*Centrocercus minimus*): assessing local- and landscape-scale drivers. The Wilson Journal of Ornithology 127(1):59-71.

Stiver, S.J., E.T. Rinkes, D.E. Naugle, P.D. Makela, D.A. Nance, and J.W. Karl, eds. 2015. Sage-grouse habitat assessment framework: a multiscale assessment tool. Technical Reference 6710-1. Bureau of Land Management and Western Association of Fish and Wildlife Agencies, Denver, Colorado.

Taylor, J.S., K.E. Church, and D.H. Rusch. 1999. Microhabitat selection by nesting and brood-rearing northern bobwhite in Kansas. Journal of Wildlife Management 63(2):686-694.

U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). 1997. National range and pasture handbook. Available at https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17737.wba.

U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). 2006. Plant guide Indian ricegrass. Available at https://plants.usda.gov/plantguide/pdf/pg_achy.pdf.

U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS). 2008. Plant guide Sandberg bluegrass. Available at https://plants.usda.gov/plantguide/pdf/pg_pose.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015a. Fact sheet: BLM, USFS greater sage-grouse conservation effort. Available at http://www.blm.gov/style/medialib/blm/wo/Communications_Directorate/ public_affairs/

sagegrouse_planning/documents.Par.32336. File.dat/BLM-USFS% 20Plans% 20Fact%20Sheet%20Final915.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015b. Idaho and southwestern Montana greater sage-grouse approved resource management plan amendment. Available at https://eplanning.blm.gov/epl-front-office/projects/ lup/31652/63338/68680/IDMT_ARMPA_web.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015c. Nevada and northeastern California greater sage-grouse proposed land use plan amendment and final environmental impact statement. Available at https://eplanning.blm.gov/epl-front-office/projects/lup/21152/58696/63759/1_Volume_1_NVCA_Cover-Abstract_FEIS.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015d. Oregon greater sage-grouse approved resource management plan amendment. Available at https:// www.blm.gov/or/energy/opportunity/files/or_armpa.pdf.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015e. Utah greater sage-grouse proposed land use plan amendment. Available at https://www.blm.gov/ wo/st/en/prog/more/sagegrouse/final_eiss/utah.html.

U.S. Department of Interior Bureau of Land Management (USDI BLM). 2015f. Wyoming approved resource management plan amendment for greater sage-grouse. Available at https://eplanning.blm.gov/epl-front-office/eplanning/planAndProjectSite.do? methodName =dispatchToPatternPage&currentPageId=18704.

U.S. Fish and Wildlife Service (USFWS). 2015. Endangered and threatened wildlife and plants; 12-month finding on a petition to list greater sage-grouse (*Centrocercus urophasianus*) as an endangered or threatened species. [Docket No. FWS–R6–ES–2015–0146]. Available at http://www.fws.gov/ greatersagegrouse/PDFs/ 20150921_GRSG_FR_Signed.pdf

Wakkinen, W.L. 1990. Nest site characteristics and spring-summer movements of migratory sage grouse in southeastern Idaho. Thesis, University of Idaho, Moscow, USA.

Welch, B.L. 2005. Big sagebrush: A sea fragmented into lakes, ponds, and puddles. USDA Forest Service, Rocky Mountain Research Station General Technical Report RMRS-GTR-144. Fort Collins, Colorado: Rocky Mountain Research Station, Forest Service, U.S. Department of Agriculture.

West, N.E. 1983. Western intermountain sagebrush steppe. In *Temperate deserts and semi-deserts*, ed. N.E. West, 351-397. Amsterdam: Elsevier Scientific Publishing Co.

West, N.E. 2000. Synecology and disturbance regimes of sagebrush steppe ecosystems. In *Proceedings of the sagebrush steppe ecosystems symposium*. USDI Bureau of Land Management Publication. Boise State University, Boise, Idaho. Pp 15-26.

Western Association of Fish and Wildlife Agencies (WAFWA). 2015. Greater sage-grouse population trends: An analysis of lek counts databases 1965-2015. Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

Western Regional Climate Center. 2017. Available at www.wrcc@dri.edu.

Wik, P.A. 2002. Ecology of greater sage-grouse in southcentral Owyhee County, Idaho. Thesis, University of Idaho, Moscow, USA.

Wing, B.R. 2014. The role of vegetation structure, composition, and nutrition in greater sage-grouse ecology in northwestern Utah. Thesis, Utah State University, Logan, USA.

Woodward, J.K. 2006. Greater sage-grouse (*Centrocercus urophasianus*) habitat in central Montana. Thesis, Montana State University, Bozeman, USA.

Woodward, J., J. Sika, C. Wambolt, J. Newell, S. Schroff, and B. Sowell. 2016. Sage-grouse nesting, brood and winter habitat characteristics in Montana. Environmental Management and Sustainable Development 5(1):114-127.

Table 2.1. Selected candidate models for mean maximum droop height *including* inflorescences based on △AIC values (Appendix Table A.2) and variables influencing grass height. Refer to Appendix Figures A.1-A.7 for relationships of variables influencing height.

Maximum Droop Height

Location	Species	Selected Model	Variables	p-value
All	Indian Ricegrass	Year + Location + (Year * Location) + Day + Shrub Cover + Grass Cover + Forb Cover	Year	Not recorded in 2015
			Location	0.45
			Year*Location	Not recorded in 2015
			Day	<0.05
			Shrub Cover	<0.05
			Grass Cover	0.08
			Forb Cover	<0.05
	Crested Wheatgrass	Year + Location + (Year*Location) + Day	Year	0.96
			Location	0.94
			Year*Location	<0.05
			Day	<0.05
	Squirreltail	Year + Location + (Year*Location) + Day + Precip + Soil Productivity	Year	0.40
			Location	0.07
			Year*Location	<0.05
			Day	0.67
			Precip	<0.05
			Soil Productivity	<0.05
	Western Wheatgrass	Year + Location + (Year*Location) + Day	Year	0.39
			Location	<0.05
			Year*Location	<0.05
			Day	<0.05
	Sandberg Bluegrass	Year + Location + (Year * Location) + Day + Shrub Cover + Grass Cover + Forb Cover	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
			Day	<0.05
			Shrub Cover	<0.05
			Grass Cover	0.85
			Forb Cover	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year * Location) + Precip	Year	<0.05
			Location	<0.05
			Year*Location	0.15
			Precip	<0.05
Big Butte	Squirreltail	Year + EcoSite + (Year * EcoSite)	Year	0.07
			EcoSite	0.32
			Year*EcoSite	0.51
	Sandberg Bluegrass		Year	<0.05
			EcoSite	0.74

Maximum Droop Height

Location	Species	Selected Model	Variables	p-value
		Year + EcoSite + (Year * EcoSite) + Shrub Cover + Grass Cover + Forb Cover	Year*EcoSite	0.65
			Shrub Cover	<0.05
			Grass Cover	0.05
			Forb Cover	<0.05
	Bluebunch Wheatgrass	Year + EcoSite + (Year * EcoSite) + Day	Year	0.23
			EcoSite	0.46
			Year*EcoSite	0.11
			Day	<0.05
Brown's Bench	Squirreltail	Year + EcoSite + (Year * EcoSite) + Precip	Year	0.53
			EcoSite	<0.05
			Year*EcoSite	0.73
			Precip	<0.05
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	<0.05
			EcoSite	<0.05
			Year*EcoSite	0.16
			Forb Cover	<0.05
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	0.16
			EcoSite	<0.05
			Year*EcoSite	<0.05
			Forb Cover	<0.05
Jim Sage	Squirreltail	Year + EcoSite + (Year*EcoSite) + Grass Cover	Year	<0.05
			EcoSite	0.87
			Year*EcoSite	0.56
			Grass Cover	<0.05
	Sandberg	Year + EcoSite + (Year*EcoSite)	Year	0.57
			EcoSite	0.57
			Year*EcoSite	0.99
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite)	Year	<0.05
			EcoSite	0.33
			Year*EcoSite	0.86
Sheep Creek	Squirreltail	Year + EcoSite + (Year*EcoSite)	Year	<0.05
			EcoSite	0.39
			Year*EcoSite	0.76
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	Year	0.30
			EcoSite	0.61
			Year*EcoSite	0.48
			Grass Cover	<0.05
			Forb Cover	<0.05
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite)	Year	<0.05
			EcoSite	0.82

Maximum Droop Height

Location	Species	Selected Model	Variables	p-value
			Year*EcoSite	0.55
Big Butte and Jim Sage	Squirreltail	Year + Location + (Year*Location) + Precip	Year	0.56
			Location	<0.05
			Year*Location	<0.05
			Precip	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location) + Forb Cover	Year	<0.05
			Location	0.12
			Year*Location	<0.05
			Forb Cover	0.06
	Bluebunch Wheatgrass	Year + Location + (Year*Location) +Grass Cover	Year	0.10
			Location	0.233
			Year*Location	<0.05
			Grass Cover	0.10
Brown's Bench and Jim Sage	Squirreltail	Year + Location + (Year*Location) +Grass Cover	Year	0.07
			Location	0.88
			Year*Location	0.06
			Grass Cover	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location) + Forb Cover	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
			Forb Cover	0.06
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Forb Cover	Year	0.08
			Location	0.15
			Year*Location	0.12
			Forb Cover	0.28
Brown's Bench and Sheep Creek	Squirreltail	Year + Location + (Year*Location) + Day	Year	0.70
			Location	0.84
			Year*Location	0.43
			Day	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location)	Year	0.50
			Location	<0.05
			Year*Location	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Precip	Year	Not recorded in 2015
			Location	<0.05
			Year*Location	Not recorded in 2015
			Precip	<0.05

Table 2.2. Selected candidate models for mean maximum droop height *excluding* inflorescences based on △AIC values (Appendix Table A.2) and variables influencing grass height. Refer to Appendix Figures A.1-A.7 for relationships of variables influencing height.

Maximum Leaf Height

Location	Species	Selected Model	Variables	p-value
All	Indian Ricegrass	Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	Year	Not recorded in 2015
			Location	0.18
			Year*Location	Not recorded in 2015
			Shrub Cover	<0.05
			Grass Cover	0.89
			Forb Cover	<0.05
	Crested Wheatgrass	Year + Location + (Year*Location)	Year	0.94
			Location	0.84
			Year*Location	<0.05
	Squirreltail	Year + Location + (Year*Location)	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
	Western Wheatgrass	Year + Location + (Year*Location) + Day	Year	0.77
			Location	<0.05
			Year*Location	0.38
			Day	<0.05
	Sandberg Bluegrass	Year + Location + (Year * Location) + Precip	Year	<0.05
			Location	<0.05
			Year*Location	0.12
			Precip	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year * Location) + Day + Precip	Year	0.99
			Location	<0.05
			Year*Location	<0.05
			Day	<0.05
			Precip	<0.05
Big Butte	Squirreltail	Year + EcoSite + (Year * EcoSite)	Year	0.29
			EcoSite	0.45
			Year*EcoSite	0.74
	Sandberg Bluegrass	Year + EcoSite + (Year * EcoSite)	Year	0.07
			EcoSite	0.44
			Year*EcoSite	0.85
	Bluebunch Wheatgrass	Year + EcoSite + (Year * EcoSite) + Day	Year	0.07
			EcoSite	0.97
			Year*EcoSite	0.27
			Day	0.57
Brown's Bench	Squirreltail	Year + EcoSite + (Year * EcoSite)	Year	0.70
			EcoSite	<0.05
			Year*EcoSite	0.99

Maximum Leaf Height

Location	Species	Selected Model	Variables	p-value
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite)	Year	0.60
			EcoSite	0.39
			Year*EcoSite	0.64
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	0.80
			EcoSite	0.62
			Year*EcoSite	0.95
			Forb Cover	<0.05
Jim Sage	Squirreltail	Year + EcoSite + (Year*EcoSite) + Grass Cover	Year	<0.05
			EcoSite	0.61
			Year*EcoSite	0.77
			Grass Cover	<0.05
	Sandberg	Year + EcoSite + (Year*EcoSite)	Year	0.82
			EcoSite	0.19
			Year*EcoSite	0.51
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	0.17
			EcoSite	<0.05
			Year*EcoSite	0.70
			Forb Cover	<0.05
Sheep Creek	Squirreltail	Year + EcoSite + (Year*EcoSite)	Year	0.67
			EcoSite	0.29
			Year*EcoSite	0.79
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite)	Year	0.90
			EcoSite	0.13
			Year*EcoSite	0.13
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite)	Year	0.88
			EcoSite	0.37
			Year*EcoSite	0.30
Big Butte and Jim Sage	Squirreltail	Year + Location + (Year*Location) + Precip	Year	0.09
			Location	<0.05
			Year*Location	0.05
			Precip	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location)	Year	0.05
			Location	0.73
			Year*Location	0.73
	Bluebunch Wheatgrass	Year + Location + (Year*Location) +Grass Cover	Year	0.46
			Location	<0.05
			Year*Location	0.30
			Grass Cover	<0.05
Brown's Bench and Jim Sage	Squirreltail	Year + Location + (Year*Location) + Day	Year	0.12
			Location	0.88

Maximum Leaf Height

Location	Species	Selected Model	Variables	p-value
			Year*Location	0.96
			Day	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location)	Year	<0.05
			Location	<0.05
			Year*Location	0.29
	Bluebunch Wheatgrass	Year + Location + (Year*Location)	Year	0.71
			Location	0.45
			Year*Location	<0.05
Brown's Bench and Sheep Creek	Squirreltail	Year + Location + (Year*Location)	Year	0.80
			Location	0.49
			Year*Location	0.72
	Sandberg Bluegrass	Year + Location + (Year*Location) + Precip	Year	<0.05
			Location	<0.05
			Year*Location	0.59
			Precip	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year*Location)	Year	Not recorded in 2015
			Location	0.23
			Year*Location	Not recorded in 2015

Table 2.3. Selected candidate models for effective height based on △AIC values (Appendix Table A.2) and variables influencing grass height. Refer to Appendix Figures A.1-A.7 for relationships of variables influencing height.

Effective Height

Location	Species	Selected Model	Variables	p-value
All	Indian Ricegrass	Year + Location + (Year*Location) + Shrub Cover	Year	Not recorded in 2015
			Location	0.37
			Year*Location	Not recorded in 2015
			Shrub Cover	<0.05
	Crested Wheatgrass	Year + Location + (Year*Location) + Day	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
			Day	<0.05
	Squirreltail	Year + Location + (Year*Location) + Forb Cover	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
			Forb Cover	<0.05
	Western Wheatgrass	Year + Location + (Year*Location)	Year	0.70
			Location	<0.05
			Year*Location	0.69
	Sandberg Bluegrass	Year + Location + (Year * Location)	Year	<0.05
			Location	<0.05
			Year*Location	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year * Location) + Precip	Year	<0.05
			Location	<0.05
			Year*Location	0.63
			Precip	<0.05
Big Butte	Squirreltail	Year + EcoSite + (Year * EcoSite)	Year	<0.05
			EcoSite	0.26
			Year*EcoSite	0.83
	Sandberg Bluegrass	Year + EcoSite + (Year * EcoSite)	Year	<0.05
			EcoSite	0.17
			Year*EcoSite	0.61
	Bluebunch Wheatgrass	Year + EcoSite + (Year * EcoSite)	Year	<0.05
			EcoSite	0.57
			Year*EcoSite	0.26
Brown's Bench	Squirreltail	Year + EcoSite + (Year * EcoSite) + Forb Cover	Year	0.31
			EcoSite	0.81
			Year*EcoSite	0.74
			Forb Cover	<0.05
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite)	Year	0.67
			EcoSite	0.79
			Year*EcoSite	<0.05

Effective Height				
Location	**Species**	**Selected Model**	**Variables**	**p-value**
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	0.24
			EcoSite	0.41
			Year*EcoSite	0.97
			Forb Cover	<0.05
Jim Sage	Squirreltail	Year + EcoSite + (Year*EcoSite)	Year	0.80
			EcoSite	0.95
			Year*EcoSite	0.71
	Sandberg	Year + EcoSite + (Year*EcoSite)	Year	<0.05
			EcoSite	0.19
			Year*EcoSite	0.50
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite)	Year	0.18
			EcoSite	0.36
			Year*EcoSite	0.58
Sheep Creek	Squirreltail	Year + EcoSite + (Year*EcoSite) + Forb Cover	Year	0.08
			EcoSite	0.47
			Year*EcoSite	0.48
			Forb Cover	<0.05
	Sandberg Bluegrass	Null		
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite)	Year	<0.05
			EcoSite	0.86
			Year*EcoSite	0.86
Big Butte and Jim Sage	Squirreltail	Year + Location + (Year*Location)	Year	<0.05
			Location	0.25
			Year*Location	<0.05
	Sandberg Bluegrass	Year + Location + (Year*Location)	Year	0.84
			Location	<0.05
			Year*Location	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year*Location) +Grass Cover	Year	0.80
			Location	<0.05
			Year*Location	<0.05
			Grass Cover	<0.05
Brown's Bench and Jim Sage	Squirreltail	Year + Location + (Year*Location)	Year	0.28
			Location	<0.05
			Year*Location	0.39
	Sandberg Bluegrass	Year + Location + (Year*Location)	Year	0.95
			Location	<0.05
			Year*Location	<0.05
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Grass Cover	Year	<0.05
			Location	<0.05
			Year*Location	<0.05

Effective Height

Location	Species	Selected Model	Variables	p-value
			Grass Cover	<0.05
Brown's Bench and Sheep Creek	Squirreltail	Year + Location + (Year*Location)	Year	0.28
			Location	<0.05
			Year*Location	0.40
	Sandberg Bluegrass	Null		
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Grass Cover	Year	Not recorded in 2015
			Location	<0.05
			Year*Location	Not recorded in 2015
			Grass Cover	<0.05

Table 2.4. Mean maximum droop height *with* inflorescence of three perennial grass species by ecological site in sage-grouse nesting habitat at four study location—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek— in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3.

Study Location	Ecological Site ID	Maximum Droop Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
Big Butte	R011BY001ID	24.2 ±3.8	17.0 ±3.8	21.8 ±3.2	10.9 ±3.2	37.6 ±4.0	39.5 ±4.0
	R011BY010ID	25.2 ±1.4	21.7 ±1.5	23.8 ±1.6	13.4 ±1.6	41.2 ±2.0	34.3 ±2.0
	Effects	Year p <0.05					
Brown's Bench	R025XY003ID	27.4 ±2.2	32.0 ±2.0	27.2 ±2.1	11.7 ±2.1	47.9 ±6.6	66.9 ±5.4
	R025XY010ID	24.2 ±5.0	18.5 ±5.0	19.1 ±5.2	6.3 ±5.2		21.1 ±13.2
	R025XY011ID	30.7 ±2.5	27.2 ±2.5	22.9 ±1.6	9.4 ±1.6	44.3 ±7.6	21.6 ±6.6
	R025XY016ID	26.2 ±1.4	25.5 ±1.4	26.2 ±1.4	16.8 ±1.4	52.9 ±4.2	53.0 ±5.4
	R025XY040ID	23.3 ±0.7	22.3 ±0.8	25.5 ±0.7	15.4 ±0.8		
	R024XY030NV	27.3 ±5.0	25.0 ±5.0	28.6 ±5.2	10.7 ±5.2	43.4 ±3.3	32.7 ±4.0
	Effects	EcoSite p <0.05		Year p <0.05; EcoSite <0.05		Year p <0.05; Year*Ecosite p <0.05	
Jim Sage	R011BY001ID	22.6 ±1.7	22.8 ±1.9	12.3 ±1.2	11.1 ±1.2	52.6 ±6.2	27.3 ±4.4
	R011BY013ID	22.6 ±1.8	32.3 ±3.6	12.3 ±1.2	11.6 ±1.2	46.9 ±4.1	34.6 ±3.4
	R013XY014ID			11.2 ±2.1	7.2 ±2.1	39.6 ±5.6	23.6 ±5.6
	R025XY016ID	22.5 ±2.1	26.2 ±6.2	13.9 ±1.5	14.1 ±1.5	50.7 ±7.2	29.0 ±6.2
	R025XY038ID	23.2 ±6.2	20.8 ±6.2	19.9 ±4.6	12.5 ±4.6	41.0 ±12.4	30.8 ±12.4
	R028AY013ID		37.5 ±6.2	5.1 ±4.6	5.9 ±4.6	57.8 ±12.4	34.5 ±12.4
	Effects	Year p <0.05				Year p <0.05	
Sheep Creek	R025XY010ID	29.0 ±2.5	18.5 ±2.5	15.7 ±3.2	24.3 ±3.2	52.5 ±4.7	34.1 ±4.7
	R025XY019ID	29.1 ±1.3	21.9 ±1.3	16.1 ±1.5	19.4 ±1.5	49.4 ±2.6	33.5 ±2.4
	Effects	Year p <0.05		16.0 ±1.1	20.4 ±1.1	Year p <0.05	

Table 2.5. Mean maximum droop height *with* inflorescence of three perennial grass species measured on the same ecological site found across study locations in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3.

Ecological Site ID	Study Location	Maximum Droop Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
R011BY00ID	Big Butte	24.2 ±3.8	17.0 ±3.8	21.8 ±3.2	10.9 ±3.2	37.6 ±4.0	39.5 ±4.0
	Jim Sage	22.6 ±1.7	22.8 ±1.9	12.3 ±1.2	11.1 ±1.2	52.6 ±6.2	27.3 ±4.4
	Effects	Location p <0.05; Year*Location p <0.05		Location p <0.05; Year*Location p <0.05		Year*Location p <0.05	
R025XY016ID	Brown's Bench	26.2 ±1.4	25.5 ±1.4	26.2 ±1.4	16.8 ±1.4	52.9 ±4.2	53.0 ±5.4
	Jim Sage	22.5 ±2.1	26.2 ±6.2	13.9 ±1.5	14.1 ±1.5	50.7 ±7.2	29.0 ±6.2
	Effects			Year p <0.05; Location p <0.05; Year*Location p <0.05			
R025XY010ID	Brown's Bench	24.2 ±5.0	18.5 ±5.0	19.1 ±5.2	6.3 ±5.2		21.1 ±13.2
	Sheep Creek	29.0 ±2.5	18.5 ±2.5	15.7 ±3.2	24.3 ±3.2	52.5 ±4.7	34.1 ±4.7
	Effects			Location p <0.05; Year*Location p <0.05		Location p <0.05	

Table 2.6. Mean maximum droop height *excluding* inflorescence of three perennial grass species by ecological site in sage-grouse nesting habitat at four study locations—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek— in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3.

Study Location	Ecological Site ID	Maximum Leaf Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
Big Butte	R011BY001ID	15.0 ±3.2	16.8 ±3.2	8.7 ±1.0	7.0 ±1.0	20.8 ±2.4	22.5 ±2.4
	R011BY010ID	16.0 ±1.2	19.5 ±1.3	9.2 ±0.5	7.8 ±0.5	18.7 ±1.2	24.8 ±1.2
	Effects					Year p <0.05	
Brown's Bench	R025XY003ID	19.4 ±1.5	18.6 ±1.4	7.3 ±0.8	5.5 ±0.8	28.5 ±4.7	38.8 ±3.8
	R025XY010ID	18.3 ±3.5	18.5 ±3.5	10.6 ±1.9	5.7 ±1.9		21.1 ±9.3
	R025XY011ID	20.2 ±1.7	21.0 ±1.7	7.0 ±0.6	4.8 ±0.6	29.5 ±5.4	21.6 ±4.7
	R025XY016ID	20.3 ±1.0	18.5 ±1.0	7.4 ±0.5	6.2 ±0.5¥	27.4 ±3.0	39.0 ±3.8
	R025XY040ID	18.4 ±0.5	17.0 ±0.5	6.8 ±0.3	6.1 ±0.3	28.1 ±2.3	25.4 ±2.8
	R024XY030NV	24.6 ±3.5	25.0 ±3.5	6.2 ±1.9	6.1 ±1.9		
	Effects	EcoSite p <0.05				Year p <0.05; EcoSite p <0.05	
Jim Sage	R011BY001ID	19.0 ±1.4	21.1 ±1.5	8.2 ±0.4	7.0 ±0.4	28.5 ±2.9	23.4 ±2.0
	R011BY013ID	18.4 ±1.4	23.0 ±2.9	7.3 ±0.4	6.8 ±0.4	26.9 ±1.9	23.0 ±1.6
	R013XY014ID			5.7 ±0.7	4.6 ±0.7	22.7 ±2.6	20.6 ±2.6
	R025XY016ID	19.0 ±1.7	22.5 ±2.5	8.5 ±0.5	6.6 ±0.5	37.4 ±3.3	23.6 ±2.9
	R025XY038ID	16.8 ±5.1	20.8 ±5.1	8.1 ±1.5	7.1 ±1.5	17.0 ±5.8	27.7 ±5.8
	R028AY013ID		32.0 ±5.1	4.8 ±1.5	5.9 ±1.5	26.6 ±5.8	28.8 ±5.8
	Effects	Year p <0.05				EcoSite p <0.05	
Sheep Creek	R025XY010ID	20.1 ±1.5	19.1 ±1.5	6.5 ±0.1	4.8 ±0.7	26.3 ±2.8	28.5 ±2.8
	R025XY019ID	20.2 ±0.8	21.5 ±0.8	5.3 ±0.3	5.2 ±0.3	29.6 ±1.6	30.8 ±1.4
	Effects	Year p <0.05					

Table 2.7. Mean maximum droop height *excluding* inflorescence of three perennial grass species measured on the same ecological site found across study locations in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3.

Ecological Site ID	Study Location	Maximum Leaf Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
R011BY00ID	Big Butte	15.0 ±3.2	16.8 ±3.2	8.7 ±1.0	7.0 ±1.0	20.8 ±2.4	22.5 ±2.4
	Jim Sage	19.0 ±1.4	21.1 ±1.5	8.2 ±0.4	7.0 ±0.4	28.5 ±2.9	23.4 ±2.0
	Effects					Location p <0.05	
R025XY016ID	Brown's Bench	20.3 ±1.0	18.5 ±1.0	7.4 ±0.5	6.2 ±0.5	27.4 ±3.0	39.0 ±3.8
	Jim Sage	19.0 ±1.7	22.5 ±2.5	8.5 ±0.5	6.6 ±0.5	37.4 ±3.3	23.6 ±2.9
	Effects			Location p <0.05		Location p <0.05; Year*Location p <0.05	
R025XY010ID	Brown's Bench	18.3 ±3.5	18.5 ±3.5	10.6 ±1.9	5.7 ±1.9		21.1 ±9.3
	Sheep Creek	20.1 ±1.5	19.1 ±1.5	6.5 ±0.1	4.8 ±0.7	26.3 ±2.8	28.5 ±2.8
	Effects			Location p <0.05		Location p <0.05; Year*Location p <0.05	

Table 2.8. Mean effective height of three perennial grass species by ecological site in sage-grouse nesting habitat at four study locations—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek—in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3

Study Location	Ecological Site ID	Effective Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
Big Butte	R011BY001ID	4.0 ±2.1	10.5 ±2.1	2.9 ±0.5	3.8 ±0.5	6.8 ±1.5	10.0 ±1.5
	R011BY010ID	6.2 ±0.8	11.9 ±0.8	3.3 ±0.2	4.5 ±0.2	6.1 ±0.8	12.1 ±0.8
	Site Effects	Year p <0.05		Year p <0.05		Year p <0.05	
Brown's Bench	R025XY003ID	9.0 ±1.2	14.3 ±1.1	3.3 ±0.3	4.0 ±0.3	12.2 ±2.9	25.0 ±2.3
	R025XY010ID	6.8 ±2.8	6.4 ±2.8	4.2 ±0.8	2.9 ±0.8		3.2 ±5.7
	R025XY011ID	7.2 ±1.4	15.3 ±1.4	2.8 ±0.2	3.4 ±0.2	11.1 ±3.3	6.1 ±2.9
	R025XY016ID	7.7 ±0.8	11.3 ±0.8	3.1 ±0.2	4.4 ±0.2	9.7 ±1.8	22.8 ±2.3
	R025XY040ID	7.4 ±0.4	8.2 ±0.4	3.4 ±0.1	4.0 ±0.1	10.1 ±1.4	9.0 ±1.7
	R024XY030NV	7.3 ±2.8	7.6 ±2.8	5.6 ±0.8	3.2 ±0.8		
	Site Effects			Year*EcoSite p <0.05			
Jim Sage	R011BY001ID	9.1 ±0.8	8.4 ±0.9	4.9 ±0.3	3.9 ±0.3	15.8 ±2.2	9.8 ±1.6
	R011BY013ID	7.8 ±0.8	11.1 ±1.7	4.9 ±0.3	4.0 ±0.3	13.7 ±1.5	12.0 ±1.2
	R013XY014ID			4.3 ±0.5	2.9 ±0.5	11.8 ±2.0	11.1 ±2.0
	R025XY016ID	7.8 ±1.0	5.0 ±1.4	5.0 ±0.3	3.7 ±0.3	11.5 ±2.6	10.3 ±2.2
	R025XY038ID	5.1 ±2.9	8.8 ±2.9	4.5 ±1.1	4.5 ±1.1	2.5 ±4.5	14.2 ±4.5
	R028AY013ID			2.6 ±1.1	3.7 ±1.1	18.7 ±4.5	15.5 ±4.5
	Site Effects			Year p <0.05			
Sheep Creek	R025XY010ID	14.4 ±1.6	10.8 ±1.6	4.1 ±0.4	4.1 ±0.4	18.4 ±2.3	12.5 ±2.3
	R025XY019ID	11.0 ±0.8	9.3 ±0.8	3.6 ±0.2	3.7 ±0.2	15.0 ±1.3	11.6 ±1.2
	Site Effects					Year p <0.05	

Table 2.9. Mean effective height of three perennial grass species measured on the same ecological site found across study locations in southern Idaho. Heights recorded in cm. List of ecological site IDs and descriptions with respective study locations found in Appendix Table A.3.

Ecological Site ID	Study Location	Effective Height					
		Squirreltail		Sandberg Bluegrass		Bluebunch Wheatgrass	
		2015	2016	2015	2016	2015	2016
R011BY00ID	Big Butte	4.0 ±2.1	10.5 ±2.1	2.9 ±0.5	3.8 ±0.5	6.8 ±1.5	10.0 ±1.5
	Jim Sage	9.1 ±0.8	8.4 ±0.9	4.9 ±0.3	3.9 ±0.3	15.8 ±2.2	9.8 ±1.6
	Effects	Location p <0.05; Year*Location p <0.05		Location p <0.05; Year*Location p <0.05		Location p <0.05; Year*Location p <0.05	
R025XY016ID	Brown's Bench	7.7 ±0.8	11.3 ±0.8	3.1 ±0.2	4.4 ±0.2	9.7 ±1.8	22.8 ±2.3
	Jim Sage	7.8 ±1.0	5.0 ±1.4	5.0 ±0.3	3.7 ±0.3	11.5 ±2.6	10.3 ±2.2
	Effects	Location p <0.05; Year*Location p <0.05		Location p <0.05; Year*Location p <0.05		Location p <0.05; Year*Location p <0.05	
R025XY010ID	Brown's Bench	6.8 ±2.8	6.4 ±2.8	4.2 ±0.8	2.9 ±0.8		3.2 ±5.7
	Sheep Creek	14.4 ±1.6	10.8 ±1.6	4.1 ±0.4	4.1 ±0.4	18.4 ±2.3	12.5 ±2.3
	Effects	Location p <0.05		Location p <0.05		Location p <0.05; Year*Location p <0.05	

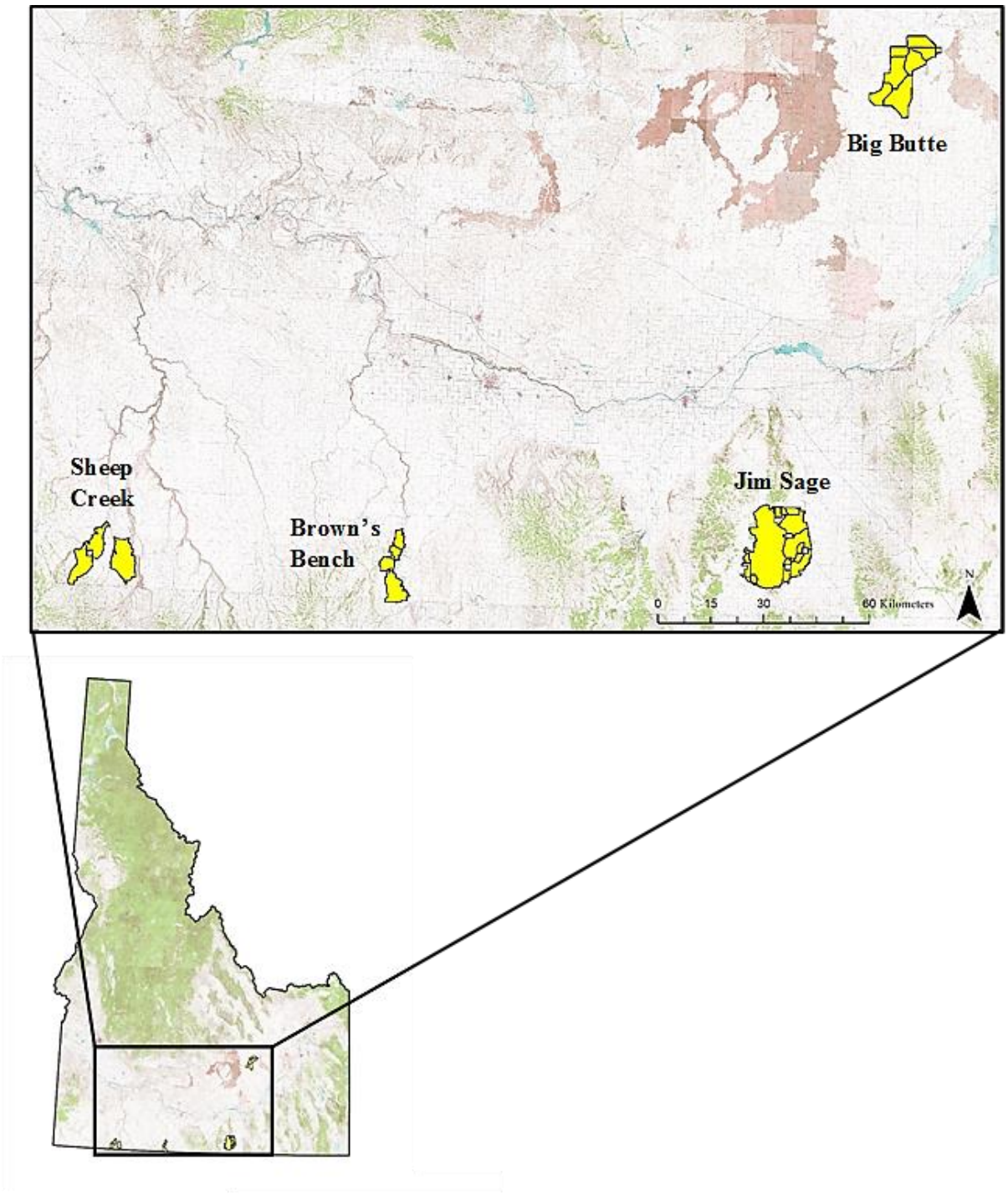

Figure 2.1. Four study locations in southern Idaho selected as part of University of Idaho's Grouse and Grazing research project.

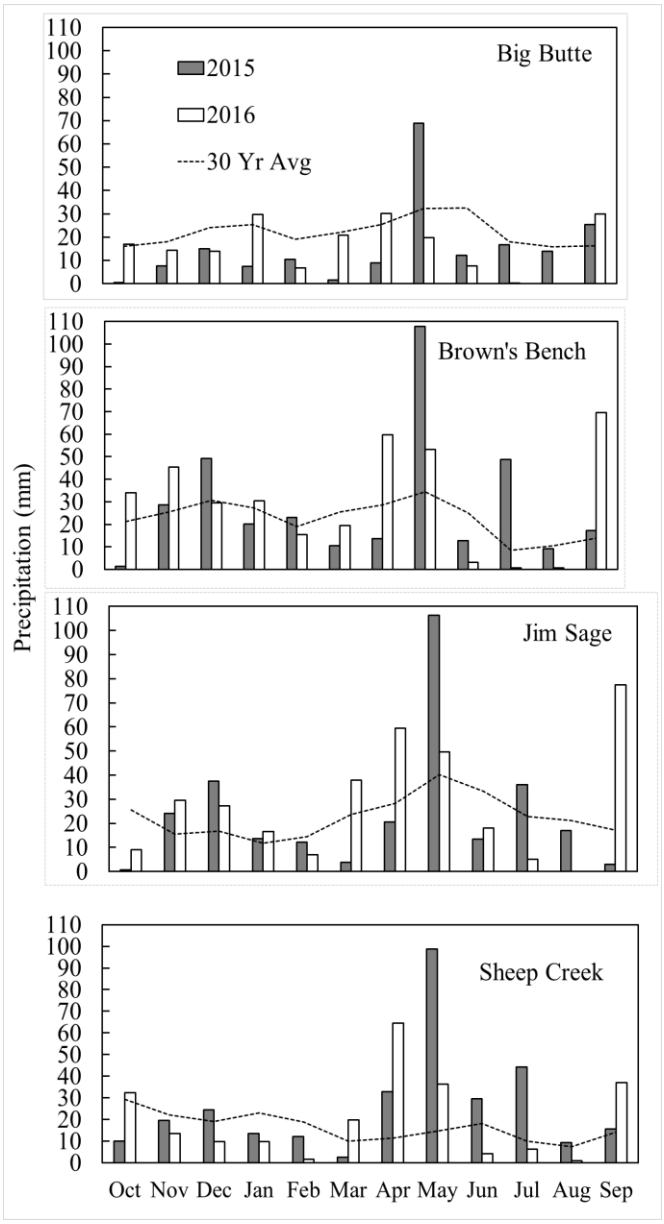

Figure 2.2. The monthly mean precipitation for 2015, 2016, and the 30-year average (by hydrological year starting in October the previous year) for each study location in southern Idaho (Western Regional Climate Center 2017).

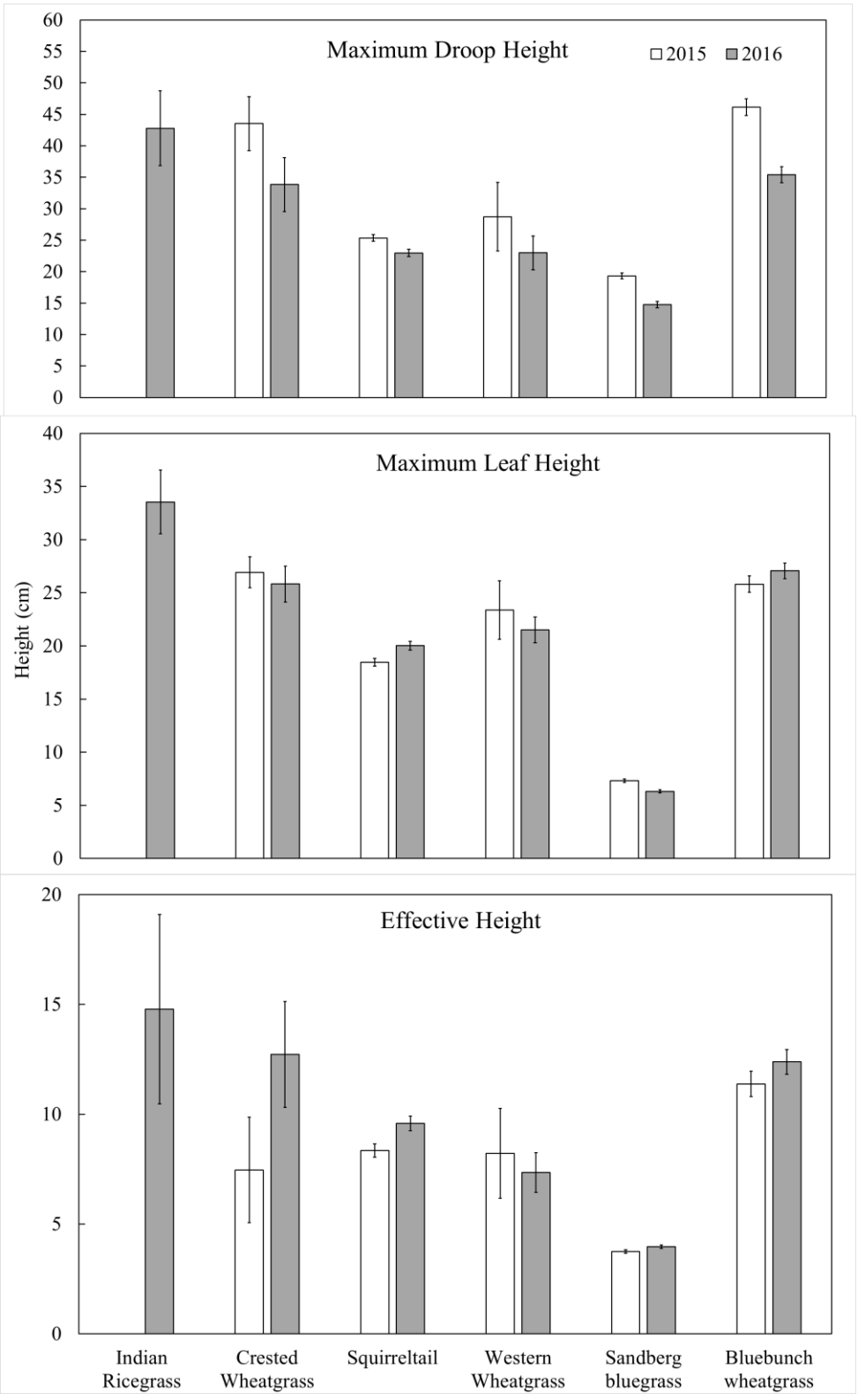

Figure 2.3. Mean height of six perennial grass species in sagebrush steppe communities across four study locations in Southern Idaho during 2015 and 2016. Indian ricegrass heights were not examined in 2015.

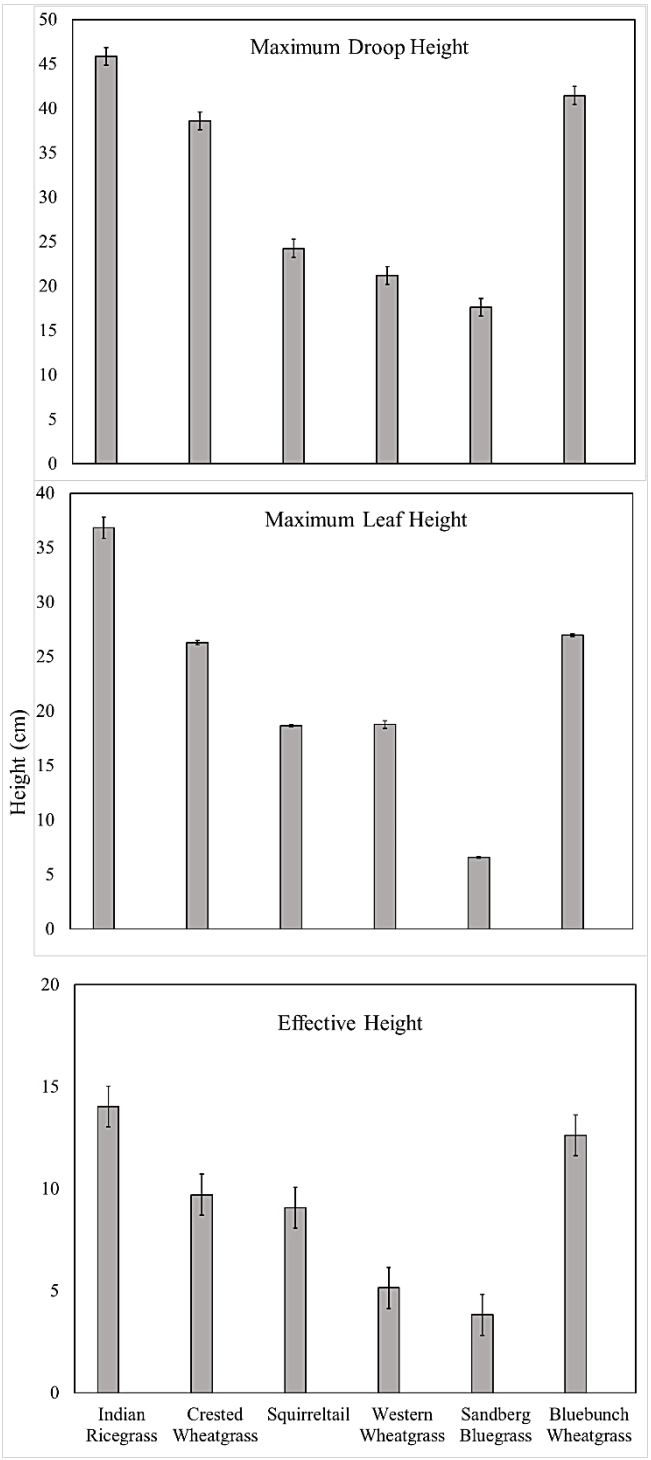

Figure 2.4. Mean height of six perennial grass species in sagebrush steppe communities across four study locations in southern Idaho.

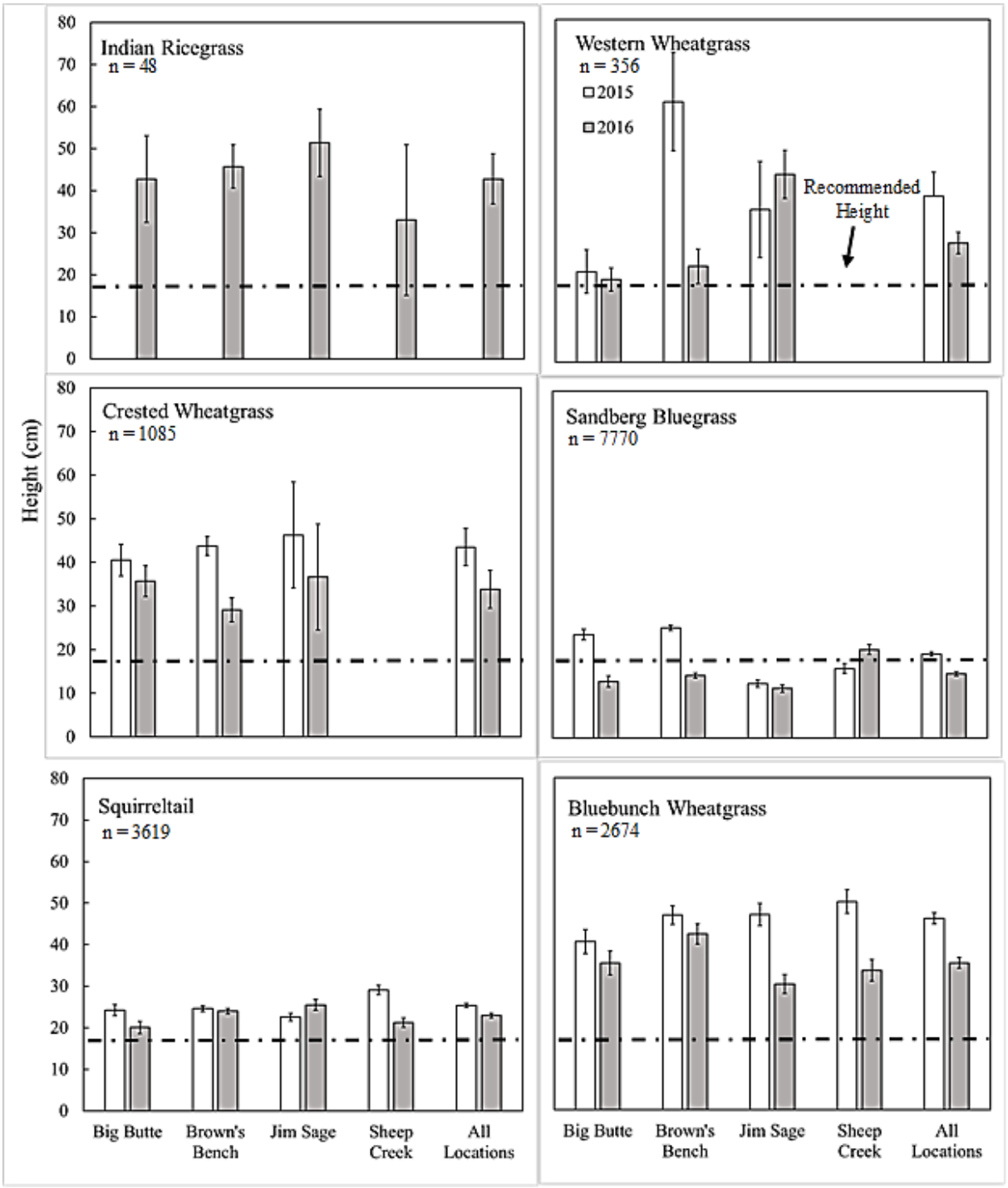

Figure 2.5. Mean maximum droop height *with* inflorescence of six perennial grass species in sage-grouse nesting habitat at four study locations—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek—in southern Idaho. The dashed line represents the recommended height of perennial grasses (18 cm) in the Greater Sage-Grouse Resource Management Plan Amendment for the sub-region of Idaho and Southwestern Montana. P-values associated with each species can be found in Table 2.4.

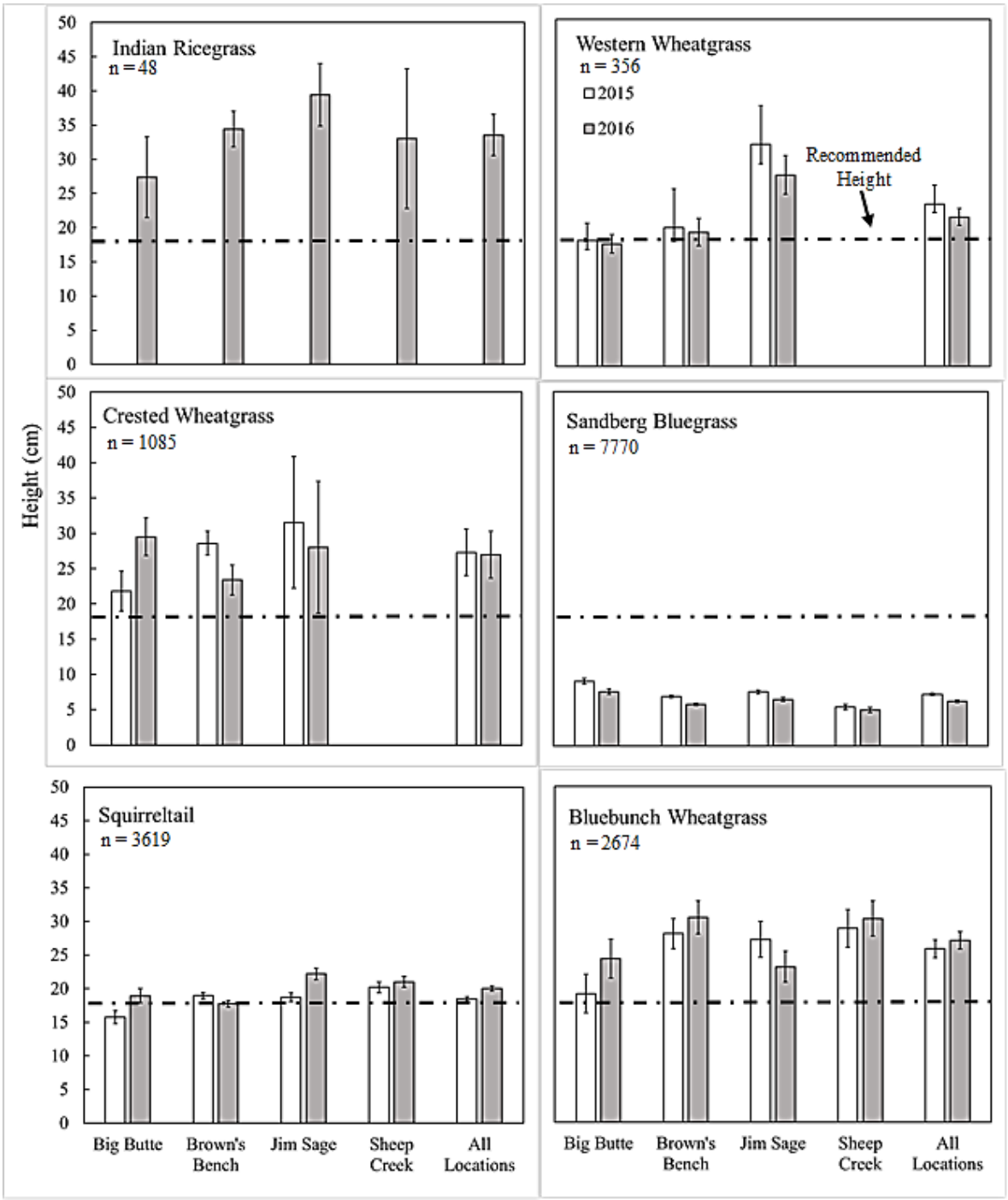

Figure 2.6. Mean maximum droop height *excluding* inflorescence of six perennial grass species in sage-grouse nesting habitat at four study locations—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek— in southern Idaho. The dashed line represents the recommended height of perennial grasses (18 cm) in the Greater Sage-Grouse Resource Management Plan Amendment for the sub-region of Idaho and Southwestern Montana. P-values associated with each species can be found in Table 2.5.

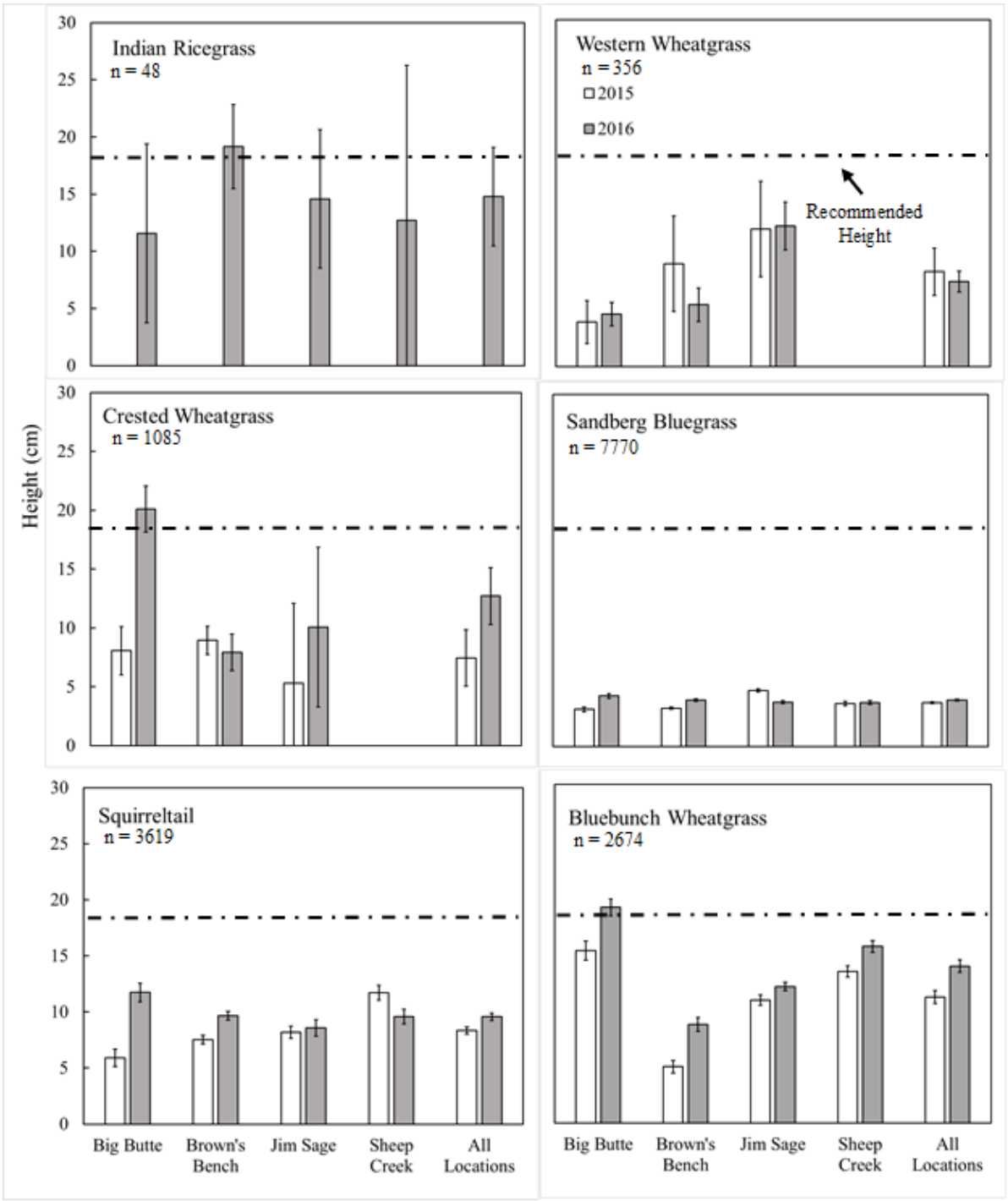

Figure 2.7. Mean effective height (visual obstruction with modified Robel pole technique; Musil 2011) of six perennial grass species in sage-grouse nesting habitat at four study locations—Big Butte, Brown's Bench, Jim Sage, and Sheep Creek—in southern Idaho. The dashed line represents the recommended height of perennial grasses (18 cm) in the Greater Sage-Grouse Resource Management Plan Amendment for the sub-region of Idaho and Southwestern Montana. P-values associated with each species can be found in Table 2.6.

CONCLUSIONS AND FUTURE WORK

In this thesis, we summarized past and current literature and compared reported grass heights in sage-grouse nesting habitat between nest sites and available habitat, and between nesting fate. We also examined differences in heights across years and study locations for six species of perennial grass in sagebrush steppe communities throughout southern Idaho during the sage-grouse nesting season.

Prior to our summary of current literature in Chapter 1, others had conducted a meta-analysis of literature summarizing and quantifying vegetation characteristics in sage-grouse nesting habitat. However, this research focused solely on nesting sites and available habitat. We provided a summary not only of nesting sites and available habitat, but also between nesting fates, specific to grass height. Our results indicate that research studies vary in reporting grass height and metrics associated with grass in sage-grouse nesting habitat. Management decisions based on past research regarding perennial grass height may present limits not attainable in specific regions. Our findings can provide useful insight to land agencies that are developing management plans, and tailoring to sagebrush obligate species, including the greater sage-grouse. In the future, summaries of literature should include other galliform species found in shrub steppe communities (e.g. Gunnison sage-grouse, *Centrocercus minimus*; sharp-tailed grouse, *Tympanuchus phasianellus*; lesser prairie chicken, *Tympanuchus pallidicintus*) that may use perennial grass for concealment during nesting.

The results from Chapter 2 indicate perennial grass species can vary spatially, temporally, and among species. However, these results only represent two years of data across four study locations in one state. Future research should analyze grass height by species across a set number of study locations for multiple years. Replicated studies for the same points

across a landscape, similar to that used in photo point monitoring, would provide information of variation for a particular location. This information would provide useful information to land management agencies that are developing decisions based on grass height for critical sage-grouse habitat.

In conclusion, we found that only a few studies influence guidelines for sage-grouse nesting habitat, and that these guidelines are being applied across states and regions as a blanket approach. Our summary of past and current research expands upon these studies used for the guidelines and provides valuable information for vegetation characteristics, specifically grass height. We found that reported grass heights differed across studies and the metrics used to report heights varied. Our examination on perennial grass height gives insight on how heights can vary among species, and within a species across study locations, ecological sites occurring within those study locations, and between years. We also provide information on different variables that may potentially influence grass height. The information presented in this thesis can therefore usefully inform management decisions aimed at perennial grass height in sage-grouse nesting habitat.

APPENDIX

Table A.1. Plant species found on study locations used in data analysis**.** Woody plants and grasses listed as individual species. Forbs recorded in groups developed by research team leads based on sage-grouse palatability and preference found in Stiver et al. 2015.

Scientific name	Common Name	Big Butte	Brown's Bench	Jim Sage	Sheep Creek
Woody Plants					
Acer glabrum	Rocky Mountain maple			X	
Amelanchier alnifolia	Saskatoon serviceberry		X	X	
Artemisia arbuscula	Little sagebrush	X	X	X	X
Artemisia nova	Black sagebrush	X	X	X	X
Artemisia tripartite	Threetip sagebrush	X		X	
Artemisia tridentata subspecies *tridentata*	Basin big sagebrush	X	X	X	X
Artemisia tridentata subspecies *vaseyana*	Mountain big sagebrush	X		X	
Artemisia tridentata subspecies *wyomingensis*	Wyoming big sagebrush	X	X	X	X
Arctostaphylos uva-ursi	Kinnikinnick	X		X	
Atriplex confertifolia	Shadscale saltbush	X	X	X	X
Atriplex gardneri	Gardner's saltbush		X	X	
Cercocarpus montanus	Alderleaf mountain mahogany			X	
Chrysothamnus viscidiflorus	Green rabbitbrush	X	X	X	X
Ericamerica nauseosus	Rubber rabbitbrush	X	X	X	X
Eriogonum microthecum	Slender buckwheat	X			
Grayia spinosa	Spiny hopsage		X		X
Gutierrezia sarothrae	Broom snakeweed	X	X	X	X
Holodiscus discolor	Oceanspray			X	
Juniperus occidentalis	Western juniper			X	
Krascheninnikovia lanata	Winterfat			X	
Picrothamnus	Bud sagebrush		X		
Purshia tridentata	Antelope bitterbrush	X	X		
Ribes cereum	Wax currant			X	
Rosa woodsii	Woods' rose			X	
Sarcobatus vermiculatus	Greasewood		X	X	X

Scientific name	Common Name	Big Butte	Brown's Bench	Jim Sage	Sheep Creek
Symphoricarpos albus	Common snowberry			X	
Tetradymia canescens	Spineless horsebrush	X	X	X	
Tetradymia glabrata	Littleleaf horsebrush				X
Tetradymia spinosa	Shortspine horsebrush			X	
Grasses					
Achnatherum hymenoides	Indian ricegrass	X	X	X	X
Achnatherum thurberianum	Thurber's needlegrass	X	X	X	X
Agropyron cristatum	Crested wheatgrass	X	X	X	
Alopecurus pratensis	Meadow foxtail		X		
Bromus tectorum	Cheatgrass	X	X	X	X
Carex sp.	Sedges	X	X	X	X
Elymus elymoides	Squirreltail	X	X	X	X
Elymus trachycaulus	Slender wheatgrass			X	
Festuca idahoensis	Idaho Fescue		X	X	X
Hesperostipa comata	Needle and thread	X	X	X	X
Juncus sp.	Rushes		X		
Koeleria macrantha	Prairie junegrass	X	X		
Leymus cinereus	Basin wildrye	X	X	X	X
Melica bulbosa	Oniongrass	X			
Pascopyrum smithii	Western wheatgrass	X	X	X	X
Poa bulbosa	Bulbous bluegrass	X	X		
Poa pratensis	Kentucky bluegrass			X	X
Poa secunda	Sandberg bluegrass	X	X	X	X
Psathyrostachys juncea	Russian wildrye			X	
Pseudoroegneria spicata	Bluebunch wheatgrass	X	X	X	X
Thinopyrum intermedium	Intermediate wheatgrass		X	X	
Vulpia octoflora	Sixweeks fescue		X	X	X
Forbs					
Achillea	Yarrow		X	X	X
Agoseris, Microseris	Prairie Dandelion	X	X	X	X
Antennaria	Pussytoes	X	X	X	X
Astragalus	Milkvetch	X	X	X	X
Castilleja	Indian Paintbrush	X	X	X	X

Scientific name	Common Name	Big Butte	Brown's Bench	Jim Sage	Sheep Creek
Other than daisies & dandelions including *Anaphalis, Arctium, Carduus, Centaurea, Circium, Cnicus, Crupina, Echinops, Filago, Gnaphalium, Hieracium, Inula, Layia, Machaerantherea, Madia, Micropus, Onopordum, Psilocarphus, Saussurea, Stylocline*	Coarse Composites	X	X	X	X
Boraginaceae, +coarse genera, Amsinckia, Cryptantha, Lithosperumu), Brassicaceae (Sisymbrium), Ranunculaceae, Cleomaceae (Cleome), Linaceae (Linum), Euphorbiaceae, Hypericaceae, Onagraceae, Asclepidaceae, Convolvulaceae, Lamiaceae (Monarda), Solanaceae, Santalaceae (Comandra), Orobanchaceae, Hypericaceae, Chenopodiaceae	Coarse Forbs	X	X	X	X
Crepis	Hawksbeard	X	X	X	X
Adenocaulon, Arnica, Aster, Balsamorhiza, Bidens, Blepharipappus, Chaenactis, Coreopsis, Conyza, Chriyopsis, Crocidium, Enceliopsis, Echinacea, Erimerica, Erigeron, Eriophyllum, Gallardia, Haplopappus,	Daisies, Aster, Erigeron (non-milky sap)	X	X	X	X

Scientific name	Common Name	Big Butte	Brown's Bench	Jim Sage	Sheep Creek
Helenium, Helianthella, Helianthus, Hulsea, Hymenoxys, Iva, Ratibida, Rubeckia, Senecio, Solidago, Tetradymia, Townsendia, Xanthium, Wyehtia					
Eriogonum	Buckwheats	X	X	X	X
Ambrosia, Anthemis, Brickellia, Chrysanthemum, Eupatorium, Grindelia, Liatris, Matricaria, Tanacetium	Yellow Gummy Composite		X		
Lactuca serriola	Prickly lettuce		X	X	X
Dalea, Lathyrus, Medicago, Melilotus, Trifolium, Hedysarum, Lotus, Vicia	Legumes	X	X	X	X
Calochortus, Fritillaria	Lily	X	X	X	X
Lomatium, Cymopterus, Perideridia	Desert parsley	X	X	X	X
Penstemon	Penstemons	X	X	X	X
Gilia, Linanthus, Microsteris, Phlox	Phlox	X	X	X	X
Taraxacum	Common dandelion	X	X	X	X
Lupinus, Glycyrrhiza, Psoralea	Toxic legumes	X	X	X	X
Tragopogon	Salsify	X	X	X	X

Table A.2. Model selection based on AIC values. Bolded text indicate selected model based on △AIC values.

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
All	Indian Ricegrass	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	160.5	11.2	153.9	14.1	140.5	20.6
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	165.7	16.4	156.5	16.7	136.2	16.3
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	**149.3**	**0.0**	141.2	1.4	125.7	5.8
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	166.4	17.1	156.7	16.9	136.8	16.9
		Year + Location + (Year*Location) + Day + Soil Productivity	163.4	14.1	153.6	13.8	132.0	12.1
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	161.2	11.9	151.9	12.1	137.8	17.9
		Year + Location + (Year*Location) + Day + Precip	159.0	9.7	148.0	8.2	126.4	6.5
		Year + Location + (Year*Location) + Soil Productivity	167.0	17.7	150.6	10.8	129.5	9.6
		Year + Location + (Year*Location) + Precip	159.3	10.0	146.4	6.6	124.3	4.4
		Year + Location + (Year*Location) + Day	156.7	7.4	145.0	5.2	122.2	2.3
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	161.5	12.2	143.1	3.3	122.5	2.6
		Year + Location + (Year*Location) + Grass Cover	161.8	12.5	143.8	4.0	121.6	1.7
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	161.0	11.7	144.0	4.2	124.1	4.2
		Year + Location + (Year*Location) + Forb Cover	161.6	12.3	143.4	3.6	123.4	3.5
		Year + Location + (Year*Location) + Shrub Cover	161.3	12.0	141.8	2.0	**119.9**	**0.0**
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	158.9	9.6	**139.8**	**0.0**	123.4	3.5
		Year + Location + (Year*Location)	161.6	12.3	142.5	2.7	120.4	0.5
		Null	177.3	28.0	156.5	16.7	129.2	9.3

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
	Crested Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	573.4	18.7	554.7	25.3	386.7	32.1
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	568.2	13.5	548.0	18.6	374.2	19.6
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	561.1	6.4	539.7	10.3	367.4	12.8
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	568.2	13.5	549.7	20.3	378.1	23.5
		Year + Location + (Year*Location) + Day + Soil Productivity	564.5	9.8	543.3	13.9	368.0	13.4
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	578.9	24.2	550.8	21.4	387.1	32.5
		Year + Location + (Year*Location) + Day + Precip	558.4	3.7	537.7	8.3	360.8	6.2
		Year + Location + (Year*Location) + Soil Productivity	575.5	20.8	539.8	10.4	370.3	15.7
		Year + Location + (Year*Location) + Precip	563.8	9.1	533.9	4.5	361.6	7.0
		Year + Location + (Year*Location) + Day	**554.7**	**0.0**	533.0	3.6	**354.6**	**0.0**
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	568.6	13.9	534.7	5.3	365.3	10.7
		Year + Location + (Year*Location) + Grass Cover	568.1	13.4	533.4	4.0	363.2	8.6
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	569.9	15.2	533.5	4.1	364.6	10.0
		Year + Location + (Year*Location) + Forb Cover	567.5	12.8	529.6	0.2	358.1	3.5
		Year + Location + (Year*Location) + Shrub Cover	565.3	10.6	531.1	1.7	360.4	5.8
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	570.7	16.0	535.4	6.0	367.5	12.9
		Year + Location + (Year*Location)	565.5	10.8	**529.4**	**0.0**	356.9	2.3
		Null	600.2	45.5	551.9	22.5	385.6	31.0
	Squirreltail	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	1694.6	10.9	1554.1	29.1	934.7	27.5

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	**1683.7**	**0.0**	1542.4	17.4	927.2	20.0
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	1703.1	19.4	1539.4	14.4	925.6	18.4
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	1689.7	6.0	1546.1	21.1	934.3	27.1
		Year + Location + (Year*Location) + Day + Soil Productivity	1691.7	8.0	1537.4	12.4	924.6	17.4
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	1688.4	4.7	1550.4	25.4	925.5	18.3
		Year + Location + (Year*Location) + Day + Precip	1692.3	8.6	1533.5	8.5	931.8	24.6
		Year + Location + (Year*Location) + Soil Productivity	1713.1	29.4	1533.6	8.6	920.5	13.3
		Year + Location + (Year*Location) + Precip	1686.3	2.6	1532.9	7.9	923.8	16.6
		Year + Location + (Year*Location) + Day	1699.5	15.8	1528.5	3.5	928.9	21.7
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	1719.6	35.9	1529.9	4.9	929.0	21.8
		Year + Location + (Year*Location) + Grass Cover	1713.2	29.5	1527.9	2.9	923.3	16.1
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	1717.0	33.3	1533.2	8.2	913.3	6.1
		Year + Location + (Year*Location) + Forb Cover	1718.5	34.8	1529.1	4.1	**907.2**	**0.0**
		Year + Location + (Year*Location) + Shrub Cover	1723.1	39.4	1529.8	4.8	925.6	18.4
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	1723.4	39.7	1534.7	9.7	920.3	13.1
		Year + Location + (Year*Location)	1717.7	34.0	**1525.0**	**0.0**	923.7	16.5
		Null	1751.8	68.1	1559.0	34.0	963.1	55.9
	Western Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	255.2	17.0	224.7	18.8	174.1	37.8
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	247.4	9.2	213.4	7.5	157.2	20.9

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	245.9	7.7	215.6	9.7	158.2	21.9
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	250.5	12.3	217.4	11.5	163.6	27.3
		Year + Location + (Year*Location) + Day + Soil Productivity	243.7	5.5	208.4	2.5	150.2	13.9
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	255.6	17.4	221.8	15.9	168.7	32.4
		Year + Location + (Year*Location) + Day + Precip	241.7	3.5	210.6	4.7	147.7	11.4
		Year + Location + (Year*Location) + Soil Productivity	255.8	17.6	210.8	4.9	144.5	8.2
		Year + Location + (Year*Location) + Precip	243.9	5.7	208.6	2.7	142.5	6.2
		Year + Location + (Year*Location) + Day	**238.2**	**0.0**	**205.9**	**0.0**	140.8	4.5
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	253.1	14.9	212.5	6.6	148.1	11.8
		Year + Location + (Year*Location) + Grass Cover	250.8	12.6	209.7	3.8	142.4	6.1
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	252.6	14.4	212.9	7.0	147.8	11.5
		Year + Location + (Year*Location) + Forb Cover	253.2	15.0	212.8	6.9	141.8	5.5
		Year + Location + (Year*Location) + Shrub Cover	253.3	15.1	211.3	5.4	142.0	5.7
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	254.8	16.6	215.8	9.9	153.5	17.2
		Year + Location + (Year*Location)	252.1	13.9	210.0	4.1	**136.3**	**0.0**
		Null	293.7	55.5	236.3	30.4	149.8	13.5
	Sandberg Bluegrass	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	2173.1	14.0	1411.6	43.6	384.5	67.9
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	2170.3	11.2	1389.9	21.9	356.7	40.1
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	**2159.1**	**0.0**	1400.6	32.6	354.5	37.9

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	2171.4	12.3	1397.1	29.1	364.6	48.0
		Year + Location + (Year*Location) + Day + Soil Productivity	2164.4	5.3	1392.9	24.9	344.0	27.4
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	2168.0	8.9	1403.5	35.5	373.7	57.1
		Year + Location + (Year*Location) + Day + Precip	2165.9	6.8	1376.3	8.3	340.6	24.0
		Year + Location + (Year*Location) + Soil Productivity	2167.1	8.0	1405.6	37.6	332.6	16.0
		Year + Location + (Year*Location) + Precip	2160.0	0.9	**1368.0**	**0.0**	329.3	12.7
		Year + Location + (Year*Location) + Day	2160.1	1.0	1379.1	11.1	327.8	11.2
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	2168.1	8.0	1405.4	37.4	335.5	18.9
		Year + Location + (Year*Location) + Grass Cover	2169.3	9.2	1398.5	30.5	328.2	11.6
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	2167.0	6.9	1405.4	37.4	336.7	20.1
		Year + Location + (Year*Location) + Forb Cover	2161.5	1.4	1400.0	32.0	325.9	9.3
		Year + Location + (Year*Location) + Shrub Cover	2161.9	1.8	1397.2	29.2	323.6	7.0
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	2164.1	4.0	1412.2	44.2	343.7	27.1
		Year + Location + (Year*Location)	2163.2	4.1	1391.4	23.4	**316.6**	**0.0**
		Null	2388.4	228.3	1470.2	102.2	364.3	47.7
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	1556.8	17.2	1371.8	19.0	901.9	19.1
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity	1553.7	14.1	1364.2	11.4	899.3	16.5
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	1550.3	10.7	1370.4	17.6	894.2	11.4
		Year + Location + (Year*Location) + Day + Precip + Soil Productivity + Shrub Cover	1558.0	18.4	1368.9	16.1	906.7	23.9

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Soil Productivity	1560.4	20.8	1378.3	25.5	908.8	26.0
		Year + Location + (Year*Location) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	1553.1	13.5	1370.7	17.9	896.0	13.2
		Year + Location + (Year*Location) + Day + Precip	1543.8	4.2	**1352.8**	**0.0**	886.6	3.8
		Year + Location + (Year*Location) + Soil Productivity	1587.2	47.6	1377.7	24.9	909.5	26.7
		Year + Location + (Year*Location) + Precip	**1539.6**	**0.0**	1354.4	1.6	**882.8**	**0.0**
		Year + Location + (Year*Location) + Day	1550.1	10.5	1367.0	14.2	896.0	13.2
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	1581.0	41.4	1369.3	16.5	945.6	62.8
		Year + Location + (Year*Location) + Grass Cover	1576.9	37.3	1366.1	13.3	894.0	11.2
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	1577.8	38.2	1368.6	15.8	891.0	8.2
		Year + Location + (Year*Location) + Forb Cover	1577.3	37.7	1367.6	14.8	890.7	7.9
		Year + Location + (Year*Location) + Shrub Cover	1581.8	42.2	1371.1	18.3	904.3	21.5
		Year + Location (Year*Location)+Shrub Cover + Grass Cover + Forb Cover	1581.9	42.3	1371.8	19.0	898.7	15.9
		Year + Location + (Year*Location)	1577.8	38.2	1366.5	13.7	897.1	14.3
		Null	1643.6	104.0	1415.6	62.8	926.0	43.2
Big Butte	Squirreltail	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	206.3	16.3	201.4	20.4	186.7	30.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	201.7	11.7	193.4	12.4	173.4	16.9
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	200.1	10.1	193.2	12.2	176.6	20.1
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	203.4	13.4	196.6	15.6	178.8	22.3
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	199.3	9.3	193.2	12.2	171.0	14.5

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	203.2	13.2	200.4	19.4	183.0	26.5
		Year + EcoSite + (Year*EcoSite) + Day + Precip	194.3	4.3	185.4	4.4	164.5	8.0
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	197.0	7.0	188.7	7.7	165.4	8.9
		Year + EcoSite + (Year*EcoSite) + Precip	191.5	1.5	185.5	4.5	160.7	4.2
		Year + EcoSite + (Year*EcoSite) + Day	191.9	1.9	185.3	4.3	162.2	5.7
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	195.7	5.7	185.2	4.2	166.5	10.0
		Year + EcoSite + (Year*EcoSite) + Grass Cover	194.0	4.0	184.6	3.6	161.3	4.8
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	197.3	7.3	188.2	7.2	165.7	9.2
		Year + EcoSite + (Year*EcoSite) + Forb Cover	193.3	3.3	184.6	3.6	160.9	4.4
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	192.5	2.5	183.6	2.6	162.0	5.5
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	198.9	8.9	188.8	7.8	170.9	14.4
		Year + EcoSite + (Year*EcoSite)	**190.0**	**0.0**	**181.0**	**0.0**	**156.5**	**0.0**
		Null	202.2	12.2	191.1	10.1	183.1	26.6
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	252.3	5.1	204.1	30.6	155.5	41.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	262.0	14.8	191.5	18.0	137.7	23.4
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	247.9	0.7	192.1	18.6	140.6	26.3
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	256.8	9.6	194.5	21.0	142.7	28.4
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	261.8	14.6	189.2	15.7	132.1	17.8
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	248.3	1.1	200.9	27.4	148.4	34.1
		Year + EcoSite + (Year*EcoSite) + Day + Precip	254.4	7.2	183.5	10.0	127.0	12.7

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	261.4	14.2	182.0	8.5	125.3	11.0
		Year + EcoSite + (Year*EcoSite) + Precip	251.3	4.1	180.0	6.5	119.9	5.6
		Year + EcoSite + (Year*EcoSite) + Day	254.3	7.1	180.8	7.3	121.6	7.3
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	250.8	3.6	182.7	9.2	125.9	11.6
		Year + EcoSite + (Year*EcoSite) + Grass Cover	258.1	10.9	179.9	6.4	122.3	8.0
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	254.3	7.1	181.5	8.0	128.9	14.6
		Year + EcoSite + (Year*EcoSite) + Forb Cover	250.4	3.2	174.9	1.4	121.0	6.7
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	249.3	2.1	176.3	2.8	118.9	4.6
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	**247.2**	**0.0**	184.9	11.4	132.9	18.6
		Year + EcoSite + (Year*EcoSite)	254.0	6.8	**173.5**	**0.0**	**114.3**	**0.0**
		Null	282.1	34.9	178.1	4.6	124.0	9.7
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	283.9	14.2	251.8	19.3	227.0	26.6
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	277.6	7.9	243.3	10.8	214.1	13.7
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	277.8	8.1	244.7	12.2	218.5	18.1
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	279.1	9.4	245.9	13.4	219.7	19.3
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	276.8	7.1	245.4	12.9	214.1	13.7
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	286.7	17.0	249.5	17.0	223.4	23.0
		Year + EcoSite + (Year*EcoSite) + Day + Precip	270.6	0.9	235.5	3.0	206.4	6.0
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	277.9	8.2	240.2	7.7	207.9	7.5
		Year + EcoSite + (Year*EcoSite) + Precip	272.0	2.3	235.4	2.9	205.0	4.6
		Year + EcoSite + (Year*EcoSite) + Day	**269.7**	**0.0**	237.9	5.4	206.9	6.5

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	275.8	6.1	234.9	2.4	207.0	6.6
		Year + EcoSite + (Year*EcoSite) + Grass Cover	274.7	5.0	235.5	3.0	202.1	1.7
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	277.6	7.9	239.2	6.7	207.0	6.6
		Year + EcoSite + (Year*EcoSite) + Forb Cover	273.9	4.2	236.3	3.8	205.1	4.7
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	272.7	3.0	234.7	2.2	205.9	5.5
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	278.7	9.0	239.0	6.5	211.8	11.4
		Year + EcoSite + (Year*EcoSite)	271.0	1.3	**232.5**	**0.0**	**200.4**	**0.0**
		Null	284.3	14.6	249.1	16.6	227.3	26.9
Brown's Bench		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	812.0	21.9	750.0	31.5	704.7	32.0
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	801.5	11.4	737.5	19.0	723.7	51.0
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	808.1	18.0	738.8	20.3	687.7	15.0
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	807.6	17.5	744.2	25.7	719.7	47.0
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	805.0	14.9	731.4	12.9	717.8	45.1
	Squirreltail	Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	806.2	16.1	745.3	26.8	698.3	25.6
		Year + EcoSite + (Year*EcoSite) + Day + Precip	795.3	5.2	731.7	13.2	714.8	42.1
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	810.7	20.6	724.1	5.6	709.9	37.2
		Year + EcoSite + (Year*EcoSite) + Precip	**790.1**	**0.0**	727.4	8.9	709.4	36.7
		Year + EcoSite + (Year*EcoSite) + Day	798.5	8.4	725.9	7.4	708.9	36.2
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	810.9	20.8	730.8	12.3	696.3	23.6
		Year + EcoSite + (Year*EcoSite) + Grass Cover	805.2	15.1	724.6	6.1	695.2	22.5
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	807.5	17.4	725.5	7.0	676.7	4.0

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Forb Cover	803.7	13.6	720.0	1.5	**672.7**	**0.0**
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	809.5	19.4	725.1	6.6	695.3	22.6
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	813.1	23.0	731.3	12.8	680.0	7.3
		Year + EcoSite + (Year*EcoSite)	803.7	13.6	**718.5**	**0.0**	700.9	28.2
		Null	856.3	66.2	734.3	15.8	722.7	50.0
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	996.5	28.9	711.8	44.5	474.6	44.8
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	988.6	21.0	689.8	22.5	458.9	29.1
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	983.3	15.7	693.7	26.4	453.6	23.8
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	993.8	26.2	697.5	30.2	467.8	38.0
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	981.8	14.2	681.8	14.5	448.9	19.1
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	991.8	24.2	704.1	36.8	465.4	35.6
		Year + EcoSite + (Year*EcoSite) + Day + Precip	980.4	12.8	679.4	12.1	450.7	20.9
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	975.9	8.3	677.7	10.4	438.1	8.3
		Year + EcoSite + (Year*EcoSite) + Precip	974.8	7.2	671.7	4.4	441.7	11.9
		Year + EcoSite + (Year*EcoSite) + Day	973.6	6.0	671.4	4.1	440.6	10.8
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	976.9	9.3	682.7	15.4	444.7	14.9
		Year + EcoSite + (Year*EcoSite) + Grass Cover	972.7	5.1	675.0	7.7	435.2	5.4
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	972.9	5.3	681.9	14.6	433.5	3.7
		Year + EcoSite + (Year*EcoSite) + Forb Cover	**967.6**	**0.0**	674.4	7.1	433.0	3.2
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	973.0	5.4	675.5	8.2	438.0	8.2
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	977.3	9.7	689.7	22.4	442.8	13.0
		Year + EcoSite + (Year*EcoSite)	967.7	0.1	**667.3**	**0.0**	**429.8**	**0.0**

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Null	1124.1	156.5	684.6	17.3	432.9	3.1
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	462.5	12.9	433.3	18.0	399.9	23.0
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	462.3	12.7	435.9	20.6	408.9	32.0
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	454.2	4.6	423.5	8.2	388.9	12.0
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	465.1	15.5	438.8	23.5	412.3	35.4
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	460.3	10.7	431.7	16.4	404.1	27.2
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	460.2	10.6	430.1	14.8	396.1	19.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip	456.1	6.5	431.5	16.2	404.6	27.7
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	458.2	8.6	427.4	12.1	400.0	23.1
		Year + EcoSite + (Year*EcoSite) + Precip	453.5	3.9	428.4	13.1	401.3	24.4
		Year + EcoSite + (Year*EcoSite) + Day	454.0	4.4	427.3	12.0	399.8	22.9
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	453.2	3.6	423.7	8.4	396.4	19.5
		Year + EcoSite + (Year*EcoSite) + Grass Cover	450.6	1.0	421.3	6.0	392.3	15.4
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	450.7	1.1	417.0	1.7	379.0	2.1
		Year + EcoSite + (Year*EcoSite) + Forb Cover	**449.6**	**0.0**	**415.3**	**0.0**	**376.9**	**0.0**
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	454.8	5.2	426.2	10.9	399.5	22.6
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	453.4	3.8	418.7	3.4	383.5	6.6
		Year + EcoSite + (Year*EcoSite)	452.0	2.4	423.1	7.8	395.9	19.0
		Null	518.7	69.1	456.8	41.5	427.9	51.0
Jim Sage	Squirreltail	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	362.0	20.3	335.2	21.6	307.3	28.7

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	356.2	14.5	328.6	15.0	291.7	13.1
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	352.4	10.7	324.0	10.4	296.4	17.8
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	360.5	18.8	333.2	19.6	297.6	19.0
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	352.2	10.5	324.2	10.6	287.7	9.1
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	358.8	17.1	331.3	17.7	302.8	24.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip	350.3	8.6	322.5	8.9	284.7	6.1
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	348.6	6.9	320.5	6.9	286.0	7.4
		Year + EcoSite + (Year*EcoSite) + Precip	346.9	5.2	318.5	4.9	280.0	1.4
		Year + EcoSite + (Year*EcoSite) + Day	346.2	4.5	318.1	4.5	280.6	2.0
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	346.3	4.6	317.6	4.0	290.7	12.1
		Year + EcoSite + (Year*EcoSite) + Grass Cover	**341.7**	**0.0**	**313.6**	**0.0**	284.8	6.2
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	344.3	2.6	316.4	2.8	288.3	9.7
		Year + EcoSite + (Year*EcoSite) + Forb Cover	345.2	3.5	317.7	4.1	282.2	3.6
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	347.3	5.6	319.7	6.1	284.6	6.0
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	348.8	7.1	320.5	6.9	294.2	15.6
		Year + EcoSite + (Year*EcoSite)	342.8	1.1	314.8	1.2	**278.6**	**0.0**
		Null	369.9	28.2	345.1	31.5	291.0	12.4
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	544.8	30.8	375.8	36.4	319.0	46.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	531.2	17.2	357.8	18.4	298.7	25.9
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	533.6	19.6	361.2	21.8	301.1	28.3

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	536.2	22.2	362.6	23.2	307.1	34.3
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	526.4	12.4	350.6	11.2	290.2	17.4
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	541.5	27.5	369.2	29.8	312.0	39.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip	524.1	10.1	354.7	15.3	290.3	17.5
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	521.2	7.2	342.1	2.7	281.1	8.3
		Year + EcoSite + (Year*EcoSite) + Precip	521.0	7.0	348.8	9.4	282.8	10.0
		Year + EcoSite + (Year*EcoSite) + Day	519.4	5.4	347.9	8.5	281.8	9.0
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	524.1	10.1	348.6	9.2	289.6	16.8
		Year + EcoSite + (Year*EcoSite) + Grass Cover	519.8	5.8	344.4	5.0	281.6	8.8
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	524.0	10.0	347.8	8.4	283.5	10.7
		Year + EcoSite + (Year*EcoSite) + Forb Cover	518.3	4.3	342.0	2.6	274.7	1.9
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	518.6	4.6	341.9	2.5	280.9	8.1
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	528.2	14.2	352.6	13.2	291.8	19.0
		Year + EcoSite + (Year*EcoSite)	**514.0**	**0.0**	**339.4**	**0.0**	**272.8**	**0.0**
		Null	538.7	24.7	355.6	16.2	288.3	15.5
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	392.1	14.6	333.9	19.1	316.3	23.4
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	386.5	9.0	328.4	13.6	307.7	14.8
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	386.1	8.6	324.3	9.5	306.6	13.7
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	387.6	10.1	329.6	14.8	309.7	16.8
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	385.5	8.0	324.8	10.0	305.5	12.6

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	391.7	14.2	331.2	16.4	314.7	21.8
		Year + EcoSite + (Year*EcoSite) + Day + Precip	381.6	4.1	322.8	8.0	300.3	7.4
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	382.3	4.8	320.4	5.6	300.4	7.5
		Year + EcoSite + (Year*EcoSite) + Precip	381.4	3.9	320.1	5.3	299.2	6.3
		Year + EcoSite + (Year*EcoSite) + Day	380.6	3.1	319.2	4.4	298.2	5.3
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	381.7	4.2	320.8	6.0	297.7	4.8
		Year + EcoSite + (Year*EcoSite) + Grass Cover	380.0	2.5	318.0	3.2	294.5	1.6
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	381.3	3.8	317.5	2.7	298.2	5.3
		Year + EcoSite + (Year*EcoSite) + Forb Cover	378.8	1.3	**314.8**	**0.0**	296.6	3.7
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	378.9	1.4	317.4	2.6	295.0	2.1
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	382.9	5.4	319.8	5.0	301.4	8.5
		Year + EcoSite + (Year*EcoSite)	**377.5**	**0.0**	315.4	0.6	**292.9**	**0.0**
		Null	451.1	73.6	363.4	48.6	326.3	33.4
Sheep Creek		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	325.8	28.8	282.8	33.0	283.3	30.6
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	316.4	19.4	268.7	18.9	276.2	23.5
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	312.0	15.0	266.2	16.4	269.1	16.4
	Squirreltail	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	319.6	22.6	273.6	23.8	280.7	28.0
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	312.4	15.4	263.0	13.2	270.8	18.1
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	322.6	25.6	278.8	29.0	278.2	25.5
		Year + EcoSite + (Year*EcoSite) + Day + Precip	306.5	9.5	257.6	7.8	268.5	15.8

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	307.1	10.1	260.7	10.9	264.6	11.9
		Year + EcoSite + (Year*EcoSite) + Precip	303.1	6.1	253.4	3.6	263.5	10.8
		Year + EcoSite + (Year*EcoSite) + Day	302.4	5.4	251.9	2.1	263.2	10.5
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	304.6	7.6	260.3	10.5	265.3	12.6
		Year + EcoSite + (Year*EcoSite) + Grass Cover	301.0	4.0	255.4	5.6	260.9	8.2
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	303.4	6.4	259.3	9.5	258.2	5.5
		Year + EcoSite + (Year*EcoSite) + Forb Cover	299.1	2.1	254.0	4.2	**252.7**	**0.0**
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	300.5	3.5	254.6	4.8	261.0	8.3
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	306.9	9.9	264.1	14.3	262.6	9.9
		Year + EcoSite + (Year*EcoSite)	**297.0**	**0.0**	**249.8**	**0.0**	256.8	4.1
		Null	322.1	25.1	253.5	3.7	264.6	11.9
	Sandberg Bluegrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	364.4	21.0	230.9	40.7	183.6	43.3
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	363.2	19.8	216.6	26.4	167.3	27.0
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	350.9	7.5	211.5	21.3	162.2	21.9
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	366.3	22.9	219.4	29.2	174.9	34.6
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	359.1	15.7	209.5	19.3	159.1	18.8
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	361.1	17.7	224.2	34.0	177.6	37.3
		Year + EcoSite + (Year*EcoSite) + Day + Precip	353.8	10.4	204.1	13.9	154.9	14.6
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	353.8	10.4	202.8	12.6	158.5	18.2
		Year + EcoSite + (Year*EcoSite) + Precip	350.1	6.7	197.1	6.9	149.7	9.4
		Year + EcoSite + (Year*EcoSite) + Day	349.7	6.3	197.1	6.9	146.6	6.3

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	349.7	6.3	200.5	10.3	160.2	19.9
		Year + EcoSite + (Year*EcoSite) + Grass Cover	346.9	3.5	197.4	7.2	153.0	12.7
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	**343.4**	**0.0**	200.5	10.3	151.4	11.1
		Year + EcoSite + (Year*EcoSite) + Forb Cover	344.7	1.3	194.5	4.3	147.4	7.1
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	347.6	4.2	193.1	2.9	152.7	12.4
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	345.8	2.4	204.0	13.8	158.4	18.1
		Year + EcoSite + (Year*EcoSite)	344.4	1.0	**190.2**	**0.0**	145.2	4.9
		Null	355.5	12.1	192.2	2.0	**140.3**	**0.0**
	Bluebunch Wheatgrass	Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	345.9	17.7	313.5	27.8	296.3	27.2
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity	338.9	10.7	304.3	18.6	286.5	17.4
		Year + EcoSite + (Year*EcoSite) + Day + Shrub Cover + Grass Cover + Forb Cover	338.6	10.4	300.2	14.5	283.8	14.7
		Year + EcoSite + (Year*EcoSite) + Day + Precip + Soil Productivity + Shrub Cover	341.4	13.2	307.5	21.8	290.4	21.3
		Year + EcoSite + (Year*EcoSite) + Day + Soil Productivity	336.4	8.2	300.1	14.4	282.5	13.4
		Year + EcoSite + (Year*EcoSite) + Precip + Soil Productivity + Shrub Cover + Grass Cover + Forb Cover	344.3	16.1	309.9	24.2	292.7	23.6
		Year + EcoSite + (Year*EcoSite) + Day + Precip	334.7	6.5	294.9	9.2	278.7	9.6
		Year + EcoSite + (Year*EcoSite) + Soil Productivity	333.1	4.9	295.2	9.5	277.3	8.2
		Year + EcoSite + (Year*EcoSite) + Precip	332.8	4.6	291.1	5.4	275.3	6.2
		Year + EcoSite + (Year*EcoSite) + Day	332.0	3.8	290.7	5.0	274.6	5.5
		Year + EcoSite + (Year*EcoSite) + Shrub Cover + Grass Cover	333.3	5.1	292.7	7.0	277.6	8.5
		Year + EcoSite + (Year*EcoSite) + Grass Cover	331.2	3.0	289.4	3.7	273.9	4.8
		Year + EcoSite + (Year*EcoSite) + Grass Cover + Forb Cover	332.8	4.6	291.9	6.2	274.8	5.7

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + EcoSite + (Year*EcoSite) + Forb Cover	330.0	1.8	288.6	2.9	270.9	1.8
		Year + EcoSite + (Year*EcoSite) + Shrub Cover	330.4	2.2	289.1	3.4	272.9	3.8
		Year + EcoSite (Year*EcoSite) + Shrub Cover + Grass Cover + Forb Cover	334.8	6.6	295.1	9.4	278.3	9.2
		Year + EcoSite + (Year*EcoSite)	**328.2**	**0.0**	**285.7**	**0.0**	**269.1**	**0.0**
		Null	359.9	31.7	293.7	8.0	280.4	11.3
Big Butte and Jim Sage	Squirreltail	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	180.9	5.9	167.1	11.0	151.0	20.3
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	180.7	5.7	163.9	7.8	147.1	16.4
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	183.9	8.9	164.3	8.2	145.8	15.1
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	177.4	2.4	163.6	7.5	146.1	15.4
		Year + Location + (Year*Location) + Day + Precip	175.1	0.1	159.2	3.1	142.2	11.5
		Year + Location + (Year*Location) + Precip	**175.0**	**0.0**	**156.1**	**0.0**	138.3	7.6
		Year + Location + (Year*Location) + Day	178.1	3.1	157.2	1.1	137.0	6.3
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	186.9	11.9	170.4	14.3	138.3	7.6
		Year + Location + (Year*Location) + Grass Cover	183.7	8.7	167.5	11.4	135.4	4.7
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	184.5	9.5	167.8	11.7	135.3	4.6
		Year + Location + (Year*Location) + Forb Cover	182.3	7.3	165.8	9.7	132.5	1.8
		Year + Location + (Year*Location) + Shrub Cover	184.3	9.3	167.9	11.8	134.6	3.9
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	187.3	12.3	171.2	15.1	139.7	9.0
		Year + Location + (Year*Location)	181.3	6.3	164.3	8.2	**130.7**	**0.0**
		Null	190.6	15.6	174.0	17.9	141.0	10.3
	Sandberg Bluegrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	220.1	16.0	173.6	27.2	136.5	30.1
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	216.9	12.8	168.5	22.1	130.6	24.2

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	215.5	11.4	167.3	20.9	131.2	24.8
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	216.5	12.4	165.4	19.0	124.3	17.9
		Year + Location + (Year*Location) + Day + Precip	212.1	8.0	159.2	12.8	119.1	12.7
		Year + Location + (Year*Location) + Precip	209.7	5.6	154.0	7.6	113.1	6.7
		Year + Location + (Year*Location) + Day	207.3	3.2	153.4	7.0	113.8	7.4
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	212.3	8.2	158.7	12.3	119.6	13.2
		Year + Location + (Year*Location) + Grass Cover	208.6	4.5	152.5	6.1	113.6	7.2
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	207.9	3.8	155.4	9.0	119.2	12.8
		Year + Location + (Year*Location) + Forb Cover	**204.1**	**0.0**	149.4	3.0	112.0	5.6
		Year + Location + (Year*Location) + Shrub Cover	209.3	5.2	152.7	6.3	112.3	5.9
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	211.0	6.9	161.6	15.2	125.2	18.8
		Year + Location + (Year*Location)	205.2	1.1	**146.4**	**0.0**	**106.4**	**0.0**
		Null	225.3	21.2	149.8	3.4	116.0	9.6
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	141.7	5.9	122.4	13.5	115.5	16.8
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	141.2	5.4	119.6	10.7	112.0	13.3
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	139.7	3.9	118.7	9.8	111.1	12.4
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	141.8	6.0	126.2	17.3	114.1	15.4
		Year + Location + (Year*Location) + Day + Precip	140.6	4.8	123.8	14.9	110.4	11.7
		Year + Location + (Year*Location) + Precip	138.8	3.0	120.9	12.0	106.8	8.1
		Year + Location + (Year*Location) + Day	138.3	2.5	121.1	12.2	107.0	8.3
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	137.8	2.0	112.7	3.8	103.1	4.4
		Year + Location + (Year*Location) + Grass Cover	**135.8**	**0.0**	**108.9**	**0.0**	**98.7**	**0.0**

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	136.5	0.7	111.0	2.1	102.0	3.3
		Year + Location + (Year*Location) + Forb Cover	137.1	1.3	119.3	10.4	105.0	6.3
		Year + Location + (Year*Location) + Shrub Cover	138.2	2.4	120.6	11.7	106.1	7.4
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	138.5	2.7	114.8	5.9	106.3	7.6
		Year + Location + (Year*Location)	136.4	0.6	123.8	14.9	102.2	3.5
		Null	159.8	24.0	128.3	19.4	117.4	18.7
Brown's Bench and Jim Sage		Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	239.8	16.3	232.8	11.3	197.1	19.4
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	236.3	12.8	230.9	9.4	194.6	16.9
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	236.0	12.5	228.3	6.8	191.9	14.2
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	236.9	13.4	230.7	9.2	190.1	12.4
		Year + Location + (Year*Location) + Day + Precip	231.6	8.1	225.8	4.3	183.4	5.7
		Year + Location + (Year*Location) + Precip	228.7	5.2	226.2	4.7	183.7	6.0
	Squirreltail	Year + Location + (Year*Location) + Day	228.7	5.2	**221.5**	**0.0**	179.5	1.8
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	228.3	4.8	228.3	6.8	187.3	9.6
		Year + Location + (Year*Location) + Grass Cover	**223.5**	**0.0**	226.5	5.0	181.7	4.0
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	226.1	2.6	228.8	7.3	183.8	6.1
		Year + Location + (Year*Location) + Forb Cover	225.7	2.2	226.1	4.6	179.2	1.5
		Year + Location + (Year*Location) + Shrub Cover	228.9	5.4	227.8	6.3	184.1	6.4
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	231.0	7.5	230.8	9.3	189.6	11.9
		Year + Location + (Year*Location)	223.6	0.1	225.8	4.3	**177.7**	**0.0**
		Null	230.2	6.7	230.2	8.7	201.0	23.3
	Sandberg Bluegrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	297.0	17.6	191.8	27.0	173.0	36.9

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	293.7	14.3	185.1	20.3	166.0	29.9
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	294.2	14.8	186.9	22.1	164.7	28.6
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	291.4	12.0	179.6	14.8	159.2	23.1
		Year + Location + (Year*Location) + Day + Precip	287.0	7.6	173.7	8.9	151.6	15.5
		Year + Location + (Year*Location) + Precip	285.2	5.8	166.5	1.7	145.2	9.1
		Year + Location + (Year*Location) + Day	285.7	6.3	168.0	3.2	143.4	7.3
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	289.2	9.8	176.8	12.0	151.0	14.9
		Year + Location + (Year*Location) + Grass Cover	284.9	5.5	171.4	6.6	144.3	8.2
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	284.3	4.9	176.1	11.3	149.8	13.7
		Year + Location + (Year*Location) + Forb Cover	**279.4**	**0.0**	169.7	4.9	141.6	5.5
		Year + Location + (Year*Location) + Shrub Cover	284.6	5.2	169.5	4.7	143.2	7.1
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	289.0	9.6	181.8	17.0	156.7	20.6
		Year + Location + (Year*Location)	280.0	0.6	**164.8**	**0.0**	**136.1**	**0.0**
		Null	321.7	42.3	178.4	13.6	153.0	16.9
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	180.4	3.0	165.4	6.6	145.2	12.7
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	181.2	3.8	166.1	7.3	142.4	9.9
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	180.3	2.9	164.4	5.6	141.7	9.2
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	179.8	2.4	163.8	5.0	143.0	10.5
		Year + Location + (Year*Location) + Day + Precip	178.1	0.7	162.3	3.5	139.2	6.7
		Year + Location + (Year*Location) + Precip	181.1	3.7	162.3	3.5	136.9	4.4
		Year + Location + (Year*Location) + Day	180.2	2.8	160.3	1.5	137.3	4.8

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	178.9	1.5	161.8	3.0	136.2	3.7
		Year + Location + (Year*Location) + Grass Cover	178.4	1.0	160.8	2.0	**132.5**	**0.0**
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	178.0	0.6	161.6	2.8	134.3	1.8
		Year + Location + (Year*Location) + Forb Cover	**177.4**	**0.0**	159.4	0.6	135.3	2.8
		Year + Location + (Year*Location) + Shrub Cover	179.8	2.4	159.4	0.6	137.0	4.5
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	178.5	1.1	162.6	3.8	137.9	5.4
		Year + Location + (Year*Location)	178.6	1.2	**158.8**	**0.0**	133.1	0.6
		Null	198.7	21.3	177.8	19.0	162.3	29.8
Brown's Bench and Sheep Creek	Squirreltail	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	61.9	4.1	61.5	13.3	64.1	15.2
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	64.0	6.2	59.7	11.5	62.9	14.0
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	60.1	2.3	58.7	10.5	62.0	13.1
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	60.8	3.0	57.9	9.7	59.4	10.5
		Year + Location + (Year*Location) + Day + Precip	59.5	1.7	54.5	6.3	55.7	6.8
		Year + Location + (Year*Location) + Precip	59.8	2.0	52.8	4.6	54.2	5.3
		Year + Location + (Year*Location) + Day	**57.8**	**0.0**	51.9	3.7	53.3	4.4
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	66.5	8.7	53.2	5.0	56.4	7.5
		Year + Location + (Year*Location) + Grass Cover	64.2	6.4	49.2	1.0	52.4	3.5
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	65.0	7.2	48.6	0.4	55.3	6.4
		Year + Location + (Year*Location) + Forb Cover	65.6	7.8	49.9	1.7	51.9	3.0
		Year + Location + (Year*Location) + Shrub Cover	64.3	6.5	50.9	2.7	53.0	4.1
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	67.1	9.3	53.2	5.0	59.2	10.3
		Year + Location + (Year*Location)	61.8	4.0	**48.2**	**0.0**	**48.9**	**0.0**

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Null	79.8	22.0	52.5	4.3	65.2	16.3
	Sandberg Bluegrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	61.9	4.1	53.6	12.9	48.7	15.6
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	61.7	3.9	54.4	13.7	45.6	12.5
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	62.0	4.2	54.6	13.9	46.2	13.1
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	64.9	7.1	48.4	7.7	41.3	8.2
		Year + Location + (Year*Location) + Day + Precip	62.0	4.2	42.6	1.9	37.6	4.5
		Year + Location + (Year*Location) + Precip	62.8	5.0	**40.7**	**0.0**	33.3	0.2
		Year + Location + (Year*Location) + Day	61.9	4.1	41.5	0.8	33.2	0.1
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	61.2	3.4	51.2	10.5	43.0	9.9
		Year + Location + (Year*Location) + Grass Cover	58.8	1.0	47.3	6.6	39.2	6.1
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	59.3	1.5	45.5	4.8	38.4	5.3
		Year + Location + (Year*Location) + Forb Cover	59.1	1.3	41.4	0.7	34.1	1.0
		Year + Location + (Year*Location) + Shrub Cover	61.0	3.2	46.5	5.8	36.8	3.7
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	61.3	3.5	50.2	9.5	41.8	8.7
		Year + Location + (Year*Location)	**57.8**	**0.0**	42.5	1.8	33.6	0.5
		Null	79.2	21.4	53.8	13.1	**33.1**	**0.0**
	Bluebunch Wheatgrass	Year + Location + (Year*Location) + Day + Precip + Shrub Cover + Grass Cover + Forb Cover	65.6	5.2	60.3	0.0	60.7	7.9
		Year + Location + (Year*Location) + Precip + Shrub Cover + Grass Cover + Forb Cover	65.8	5.4	65.3	5.0	59.7	6.9
		Year + Location + (Year*Location) + Day + Shrub Cover + Grass Cover + Forb Cover	65.3	4.9	65.0	4.7	59.3	6.5
		Year + Location + (Year*Location) + Day + Precip + Shrub Cover	63.4	3.0	63.4	3.1	61.3	8.5

Location	Species	Model	Maximum Droop Height		Maximum Leaf Height		Effective Height	
			AIC	△AIC	AIC	△AIC	AIC	△AIC
		Year + Location + (Year*Location) + Day + Precip	60.7	0.3	60.6	0.3	57.9	5.1
		Year + Location + (Year*Location) + Precip	**60.4**	**0.0**	63.5	3.2	57.5	4.7
		Year + Location + (Year*Location) + Day	60.6	0.2	63.0	2.7	56.8	4.0
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover	76.3	15.9	60.9	0.6	54.3	1.5
		Year + Location + (Year*Location) + Grass Cover	76.3	15.9	60.9	0.6	**52.8**	**0.0**
		Year + Location + (Year*Location) + Grass Cover + Forb Cover	73.6	13.2	62.0	1.7	55.3	2.5
		Year + Location + (Year*Location) + Forb Cover	72.9	12.5	61.1	0.8	55.1	2.3
		Year + Location + (Year*Location) + Shrub Cover	76.1	15.7	62.5	2.2	56.7	3.9
		Year + Location + (Year*Location) + Shrub Cover + Grass Cover + Forb Cover	73.9	13.5	62.4	2.1	57.0	4.2
		Year + Location + (Year*Location)	75.8	15.4	**60.3**	**0.0**	53.3	0.5
		Null	91.1	30.7	67.5	7.2	69.3	16.5

Table A.3. Ecological sites found on the four study locations in southern Idaho.

Ecological Site ID	Ecological Site Description	Big Butte	Brown's Bench	Jim Sage	Sheep Creek
R011BY001ID	Loamy 8-12", Wyoming big sagebrush/ bluebunch wheatgrass	X		X	
R011BY010ID	Loamy 12-16", Wyoming big sagebrush/ bluebunch wheatgrass	X			
R011BY013ID	Shallow loamy 8-12", little sagebrush/ bluebunch wheatgrass			X	
R013XY014ID	Shallow stony 12-20", little sagebrush/ bluebunch wheatgrass			X	
R025XY003ID	Loamy 12-16", Wyoming big sagebrush/ bluebunch wheatgrass		X		
R025XY010ID	Claypan 12-16", little sagebrush/Idaho fescue		X		X
R025XY011ID	Loamy 13-16", mountain big sagebrush/ bluebunch wheatgrass-Idaho fescue		X		
R025XY016ID	Shallow calcareous loam 10-16", black sagebrush/bluebunch wheatgrass		X	X	
R025XY019ID	Loamy 10-13", Wyoming big sagebrush/ bluebunch wheatgrass				X
R025XY038ID	Ashy south slope 10-16", Wyoming big sagebrush/Indian ricegrass			X	
R025XY040ID	Very shallow stony 8-12", black sagebrush/Thurber's needlegrass		X		
R028AY013ID	Shallow loamy 8-12", black sagebrush/ bluebunch wheatgrass			X	
R024XY030NV	Shallow calcareous loam 8-10", black sagebrush/Thurber's needlegrass-Indian ricegrass		X		

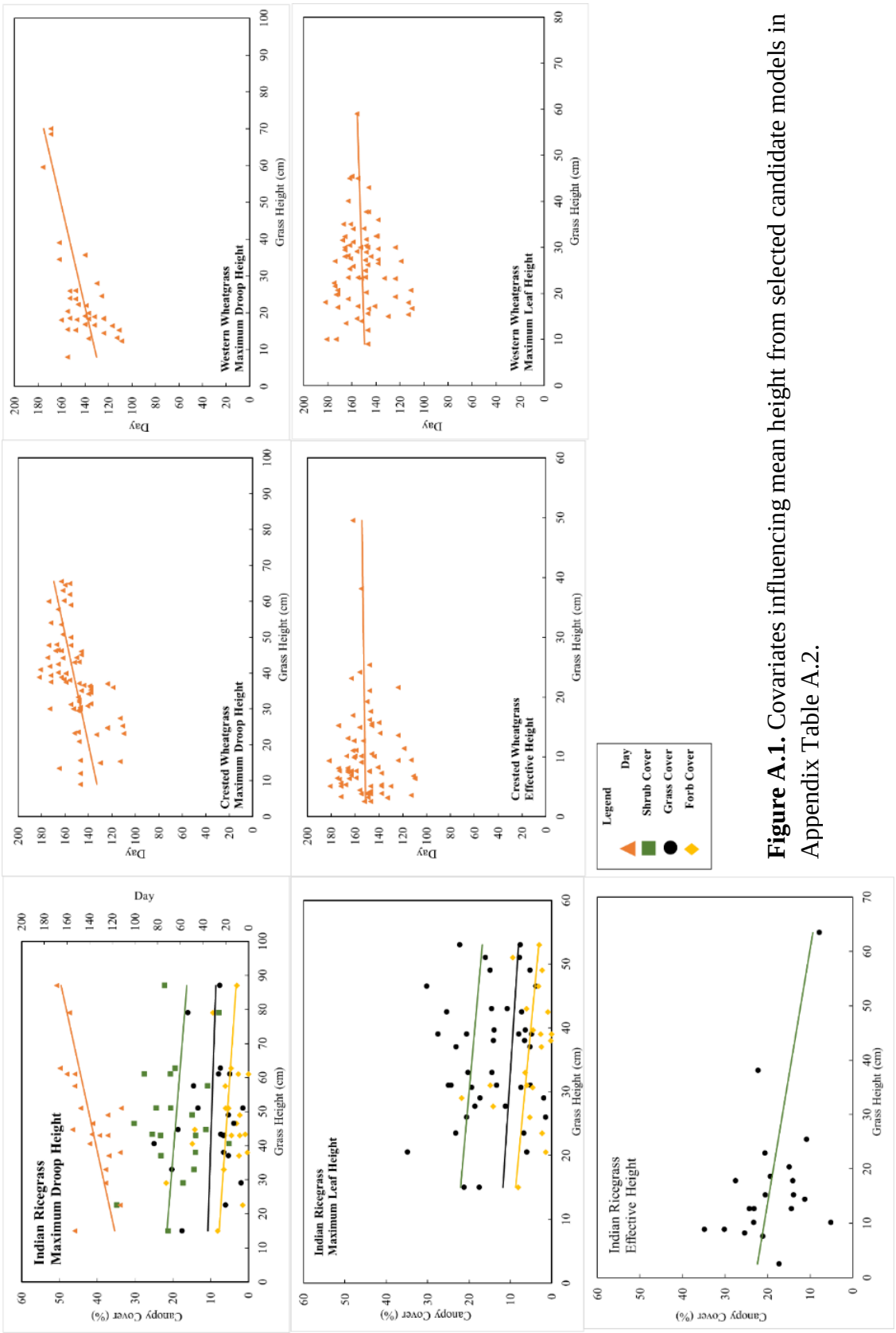

Figure A.1. Covariates influencing mean height from selected candidate models in Appendix Table A.2.

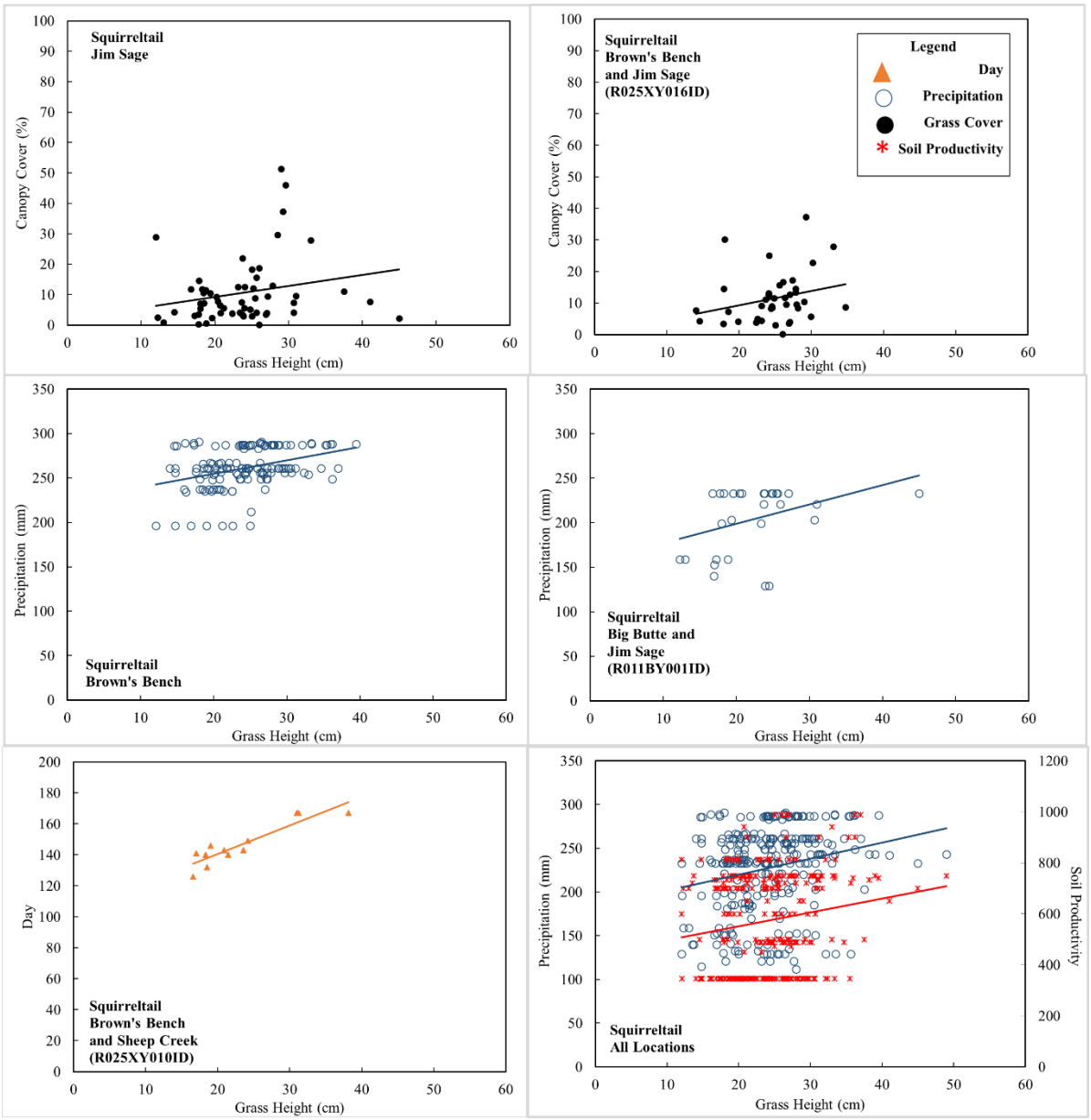

Figure A.2. Covariates influencing mean maximum droop height *including* inflorescence from selected candidate models in Appendix Table A.2.

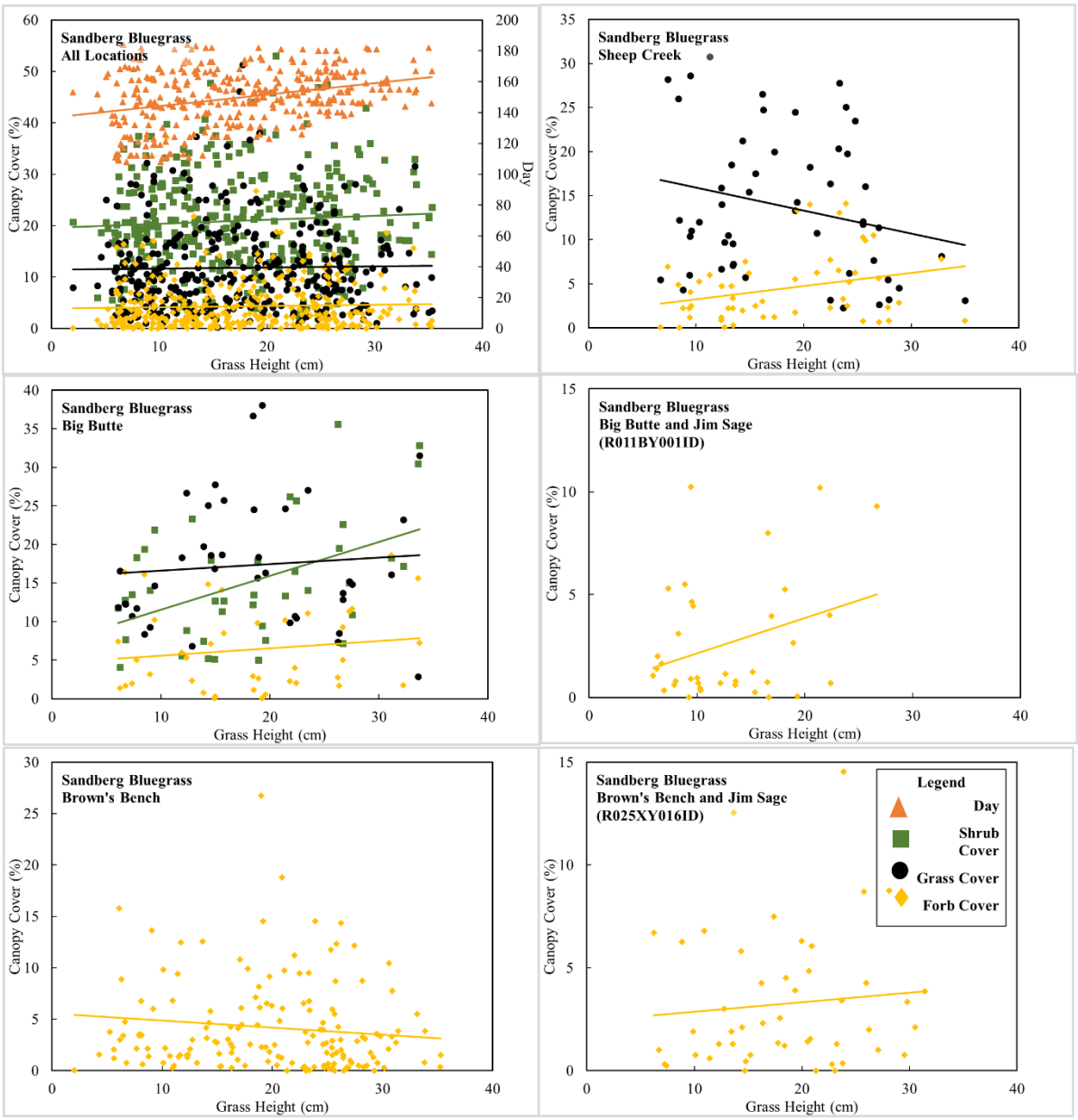

Figure A.3. Covariates influencing mean maximum droop height *including* inflorescence from selected candidate models in Appendix Table A.2.

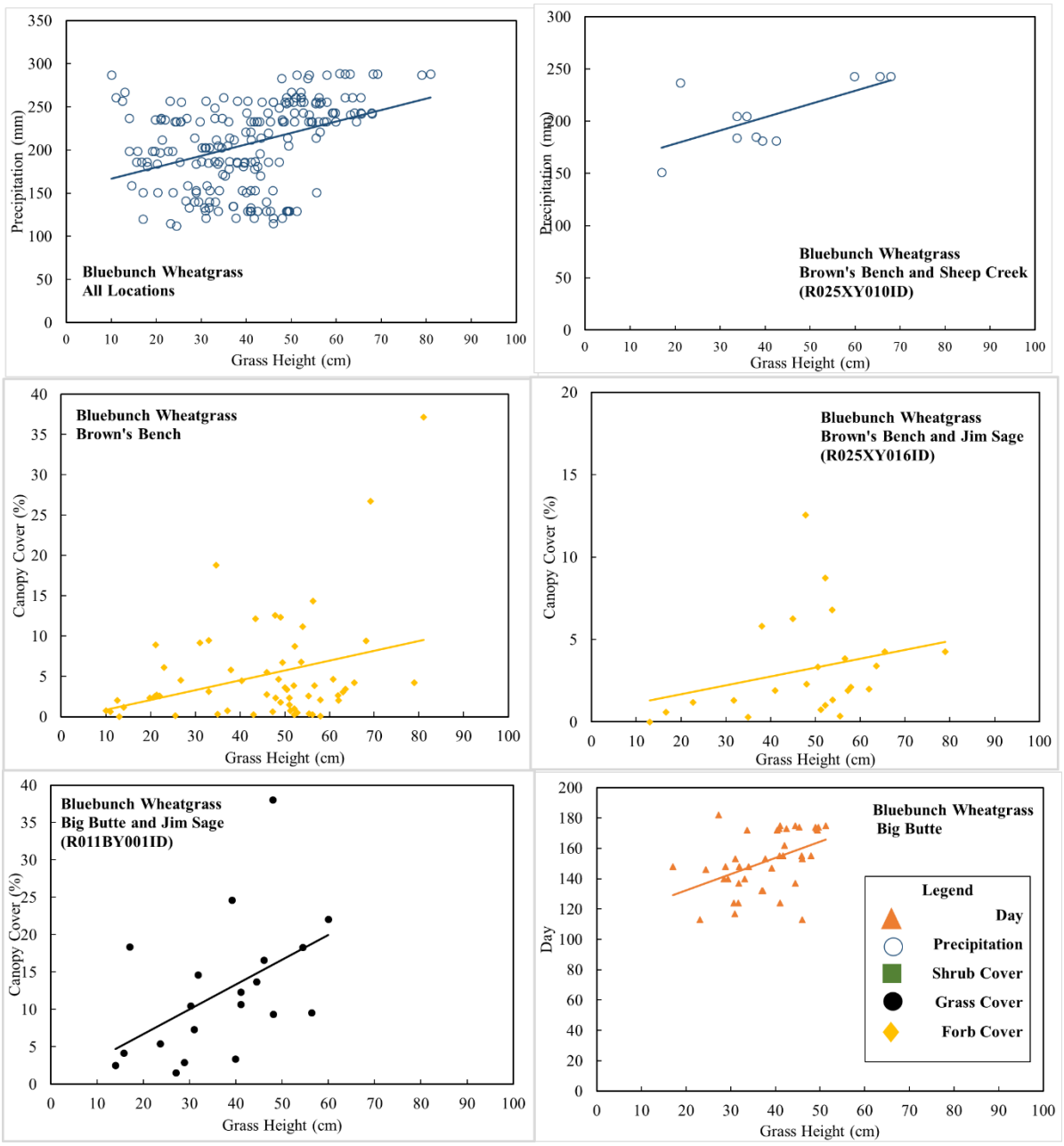

Figure A.4. Covariates influencing mean maximum droop height *including* inflorescence from selected candidate models in Appendix Table A.2.

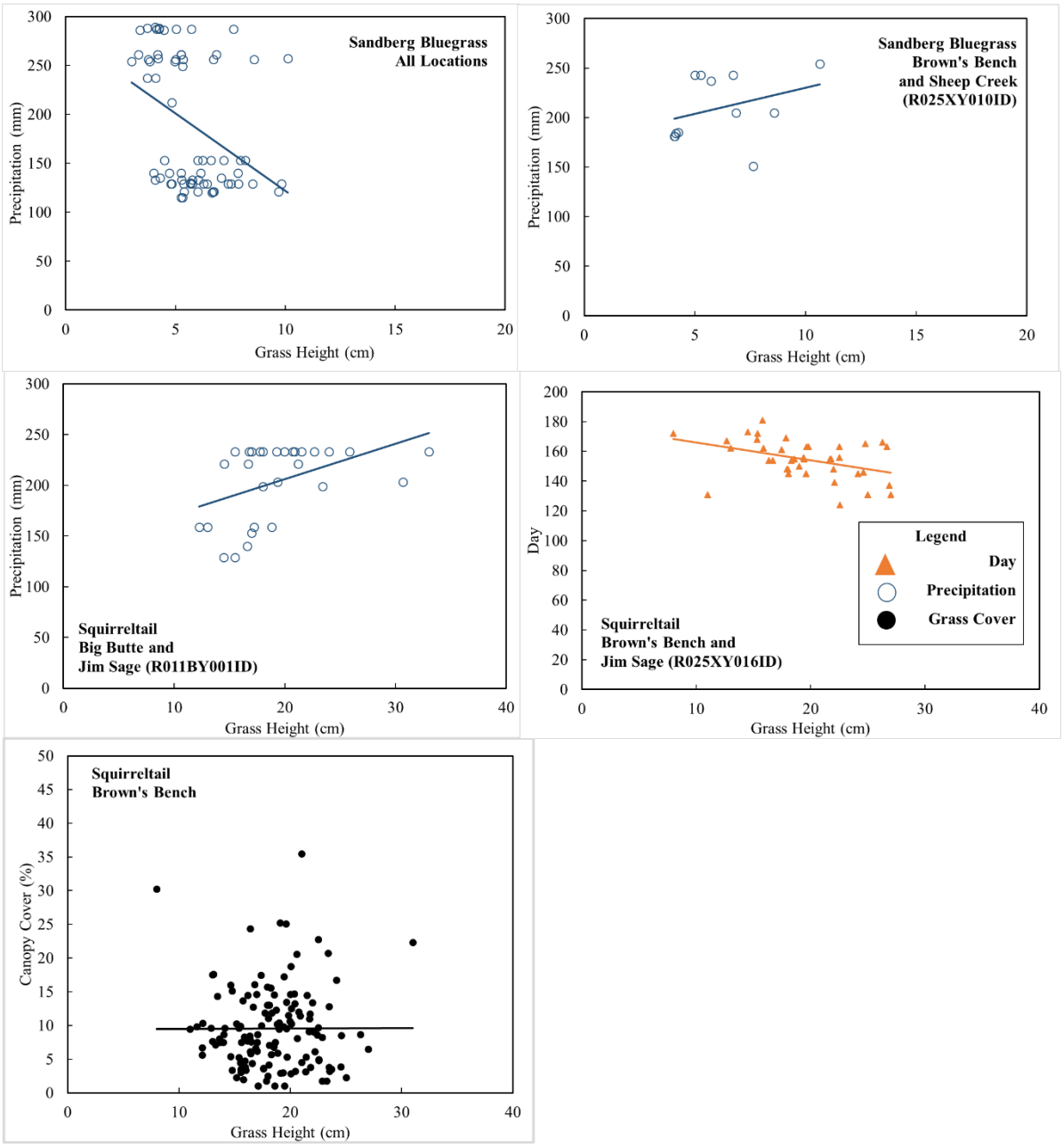

Figure A.5. Covariates influencing mean maximum droop height *excluding* inflorescence from selected candidate models in Appendix Table A.2.

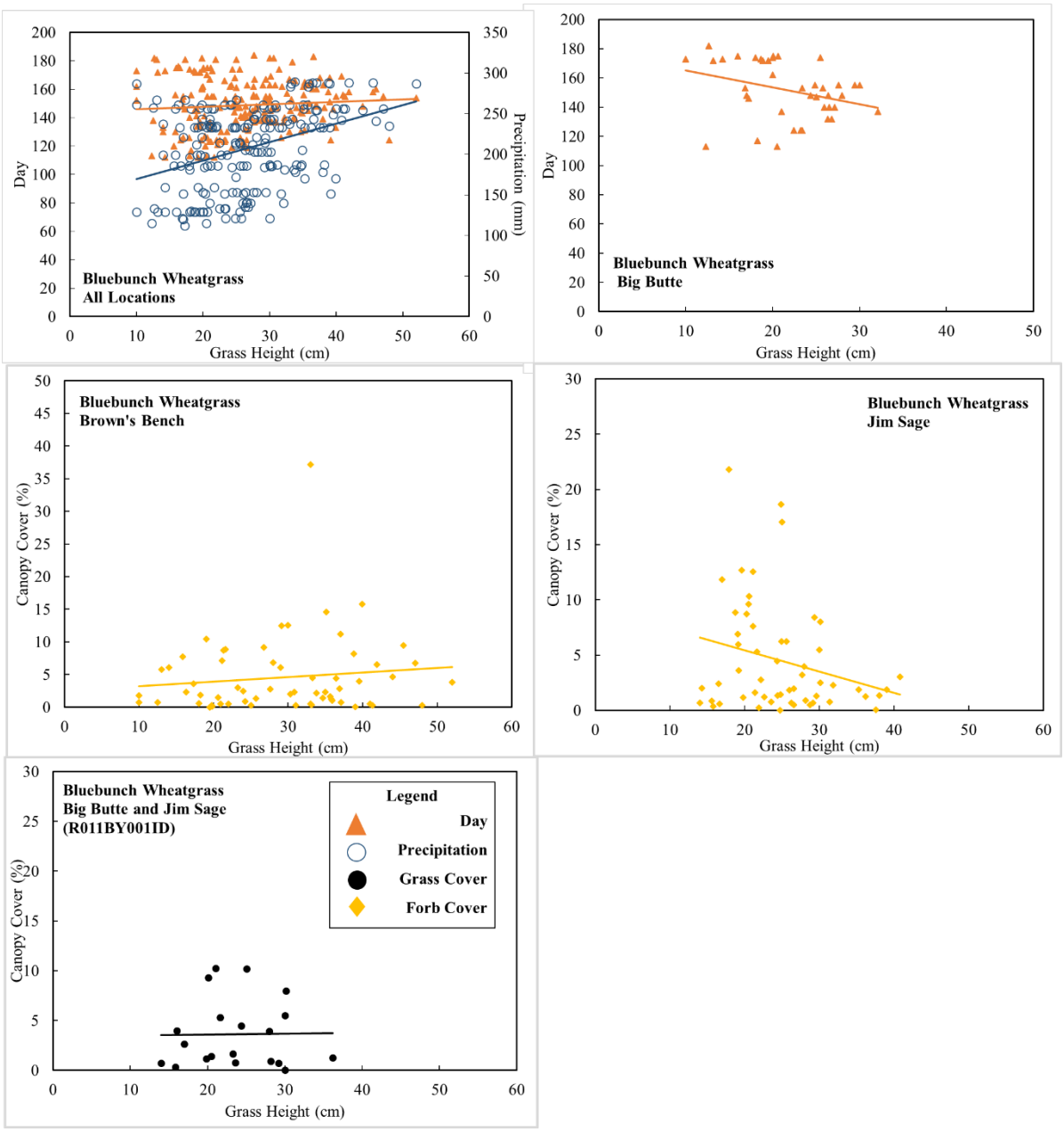

Figure A.6. Covariates influencing mean maximum droop height *excluding* inflorescence from selected candidate models in Appendix Table A.2.

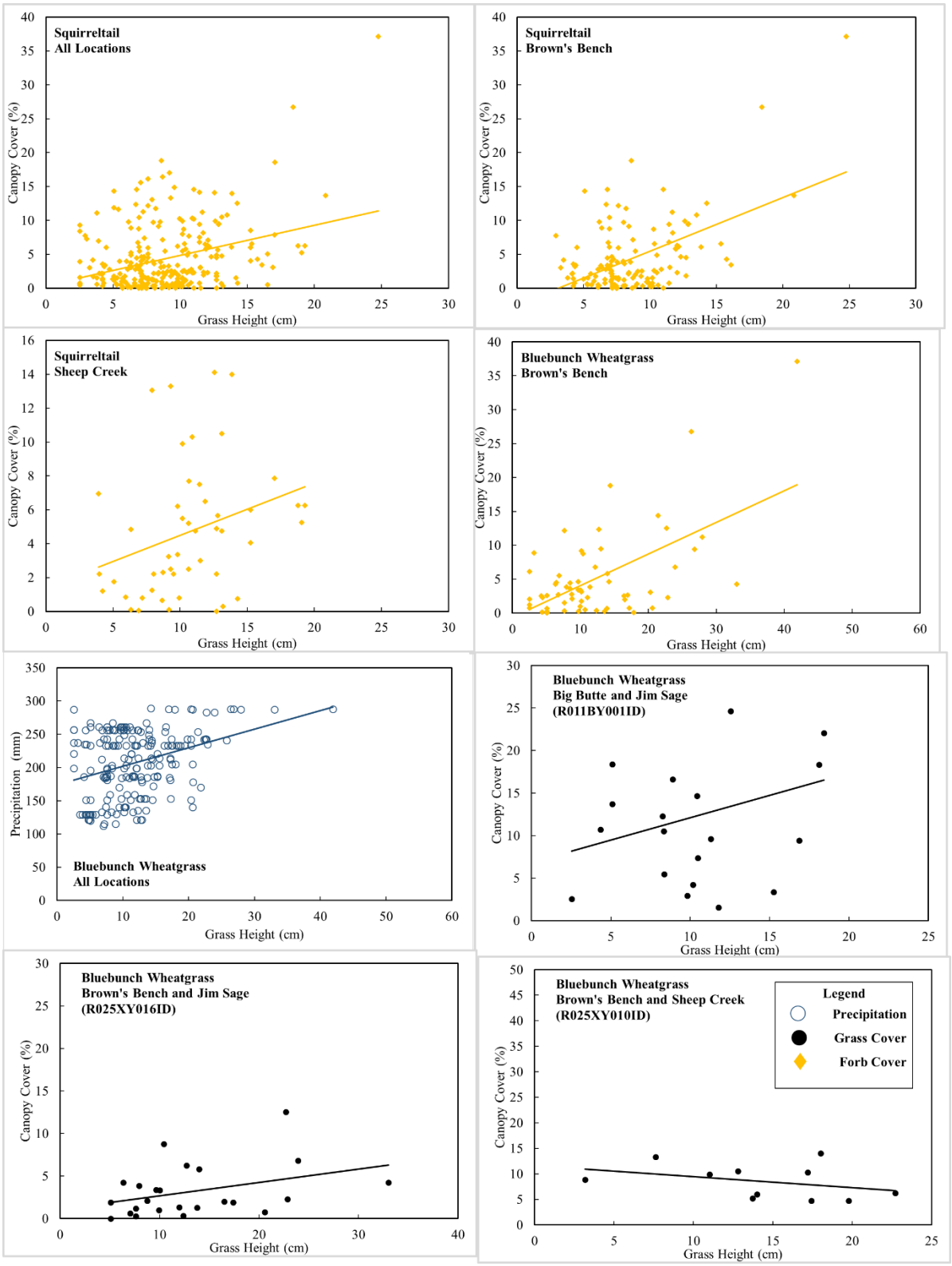

Figure A.7. Covariates influencing mean effective height from selected candidate models in Appendix Table A.2.