THESIS

ASSESSING WILDLIFE HABITAT SUITABILITY FOR ECOLOGICAL SITES AND STATE AND TRANSITION MODELS

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ABSTRACT

EVALUATING WILDLIFE HABITAT SUITABILITY FOR ECOLOGICAL SITES AND STATE AND TRANSITION MODELS

Wildlife habitat is an important component of rangeland management plans. Unfortunately, there are few practical tools to assist managers in understanding how management and environmental variation affects habitat suitability. Ecological site descriptions (ESDs) have the potential to fill this role because they contain information on the biophysical features of the land and contain state-and-transition models (STMs) which describe ecological sites in terms of their potential vegetation dynamics. These characteristics can be the primary indicators of suitable wildlife habitat. Researchers and managers using ESDs and STMs have suggested that information on other aspects of ecosystem functions should be included so that they can be evaluated along with soils and vegetation. I developed greater sage grouse (*Centrocercus urophasianus*) and mule deer (*Odocoileus hemionus*) habitat models using published literature and a fuzzy logic knowledge representation and evaluation system. The resulting outputs were 0-1 scaled indices representing the relative suitability of habitat based on measured habitat attributes in different states of two ecological sites common in NW Colorado, claypan

and mountain loam. In Chapter 1, I tested hypotheses related to the habitat suitability of differing states in these two structurally divergent ecological sites Results support the hypotheses that states with degraded attributes or that were associated with aerial herbicide spraying are generally lower in habitat suitability, and that states with similar components as the reference state do not have significantly different habitat suitability than the reference states. In Chapter 2, I developed sage grouse habitat maps and compared the results with current habitat mapping procedures. The ecological site/ STM framework allowed for an understanding of the distribution, abundance, and value of habitat to be linked to management and environmental variation. This work is an important contribution towards incorporating wildlife habitat information into ESDs and understanding trade-offs in wildlife habitat suitability associated with different vegetation states.

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PREFACE

Ecological site descriptions (ESDs) and state-and-transition models (STMs) are being developed by the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS) as a framework for land management decision-making. Ecological sites are "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation" (USDA NRCS 2011). Ecological site descriptions provide information on biophysical properties, soils, vegetation dynamics, and other interpretations of ecological sites. State-and transition models are graphical representations of vegetation dynamics and soils characteristics on ecological sites (Bestlemeyer et al. 2003).

The research for this thesis was part of a collaborative effort to develop STMs, evaluate ecosystem services for different states, and create a linked ecological-economic model that will be used as an adaptive management learning tool. This research was focused on adding value to ESDs by developing a relative measure of wildlife habitat for vegetation states in the STMs. Information on wildlife habitat was incorporated by developing 0-1 scaled indices representing the suitability of wildlife habitat. These indices were used in the ecological-economic model to allow users of the learning tool to assess the impacts of management decisions and environmental variation on wildlife habitat.

Chapter one focuses on the habitat model development and comparison of wildlife habitat for different vegetation states. The following hypotheses were tested at the α = 0.1 level where H_o indicates the null hypothesis and H_a indicates the research hypothesis: 1) H_o: The overall (integration of forage and cover values) and forage values of reference states are equal to or less than the values of degraded states, within their respective ecological sites; H_a: Reference states have higher forage and overall habitat suitability values than degraded states, within their respective ecological sites, 2) H_o: There is no difference in overall habitat values between reference states and the western wheatgrass states, within their respective ecological sites; H_a: There is no difference in overall habitat values between reference states and the western wheatgrass states, within their respective ecological sites, and 3) H_o: The overall habitat values of the claypan reference state are equal to or less than the values of the claypan native grassland state; H_a: The reference state has higher overall habitat values than the grassland state on the claypan ecological site.

Chapter two assesses the applicability of the ESD and STM framework towards spatial wildlife habitat assessments. Habitat suitability maps were created for sage grouse breeding and wintering habitat and compared to existing sage grouse habitat maps. Comparisons are descriptive as opposed to statistical.

CHAPTER 1: INCORPORATING WILDLIFE HABITAT INFORMATION INTO ECOLOGICAL SITE DESCRIPTIONS AND ASSESSING HABITAT SUITABILITY OF STATES

Ecological site descriptions (ESDs) with state-and-transition models (STMs) are used as adaptive decision-making tools on rangelands. Wildlife habitat is an important component of land management and information on habitat should be included in ESDs. Models for two structurally divergent ecological sites, claypan and mountain loam, were used to incorporate wildlife habitat and assess differences in suitability of habitat within different states. States for both ecological sites included reference, degraded, and western wheatgrass. A native grassland state, associated with herbicide spraying, was also evaluated on the claypan ecological site. Forage, cover, and overall habitat models for sage grouse breeding and mule deer fawning were developed using literature information and the Netweaver^{TM} modeling framework, which utilizes a fuzzy logic knowledge representation and evaluation system. The resulting outputs were 0-1 scaled indices representing the relative suitability of habitat which were used to test three hypotheses: 1) reference states have higher forage and overall habitat suitability than degraded states, 2) there is no difference in overall habitat suitability between reference and the western wheatgrass states, and 3) the claypan reference state has higher overall values than the native grassland state. The results supported all three hypotheses, with one exception. On the mountain loam ecological site, the degraded or dense shrub state provides higher ($P<0.01$) cover values, but the reference state provides higher ($P=0.06$) forage values, resulting in no difference ($P=0.5$) between the state's overall values for mule deer. Managing for small, interspersed patches of the dense state in areas that are not adjacent to adequate cover may increase overall habitat suitability for mule deer. The results of this approach indicate that managing a majority of the land on the evaluated sites for reference or similar states increases habitat suitability for important production life stages of mule deer and sage grouse.

INTRODUCTION

Wildlife habitat is an important component of rangeland management plans (Holechek 1982). Unfortunately, there are few practical tools to assist managers in understanding how management and environmental variation affects habitat suitability (Kremen 2005, Robertson and Swinton 2005). State and transition models (STMs) have the potential to fill this role because they describe ecological sites in terms of their potential vegetation dynamics, which can be one of the primary indicators of suitable wildlife habitat (Stringham et al. 2003, Morrison et al. 2006).

Ecological site descriptions (ESDs) are reports that describe ecological sites in terms of their biophysical properties and ecological potential. Ecological sites are "a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation" (USDA NRCS 2011). STMs are graphical representations of vegetation dynamics on ecological sites that include information on states and transitions. States represent plant community assemblages with similar characteristics such as functional groups and processes, as well as management responses. Plant communities are assemblages of dominant plant species that are associated with certain climates and soil characteristics. Plant species composition and soils properties are often indicative of processes such as encroachment of shrubs or loss of organic matter. A transition occurs when a state shifts to a different state due to constraint alterations, such as precipitation patterns or disturbance, and a positive feedback system causes distinguishable changes in soils and vegetation. State transitions may be reversed unless a threshold is crossed resulting in a persistent state that often requires accelerating practices or inputs to change (Bestlemeyer et al. 2003, Stringham et al. 2003).

Ecological site descriptions and STMs are being developed by the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS) as a framework for land management decision-making, and are an improvement over past models of rangeland vegetation change due to their basis in alternate state theory (Westoby et al.1989). Bestlemeyer et al. (2003) suggested that information on other components of rangelands that are valued by land owners and society should be linked to STMs so that their responses can be interpreted alongside those of plants and soils. Ecological site descriptions and STMs could be a useful tool for incorporating wildlife habitat information in a framework that could allow managers to understand the impacts of environmental variation and management on habitat suitability.

The objectives of this study were 1) to develop relative values of wildlife habitat suitability for production life stages of the greater sage grouse (*Centrocercus urophasianus*) and mule deer (*Odocoileus hemionus*) for key states on claypan and mountain loam ecological sites in the Elkhead watershed of Northwest Colorado 2) assess differences in habitat suitability between states.

Forage and cover are the habitat variables that can be assessed in the context of STMs. Other variables, such as water availability and slope, are spatial features and STMs are not spatially explicit. In addition to providing relative and synthesized information on the provisioning of forage and cover for states, an understanding of the tradeoffs in terms of forage and cover associated with different states would assist managers in making more informed decisions. For example, conversion from a native shrubland to a native grassland could be assisted by aerial herbicide spraying. It is intuitive that the suitability of this site for sage grouse nesting habitat may decrease because this species relies heavily on sagebrush cover during this time. However, the management objective for the land may be to increase suitability of forage resources as opposed to cover resources and perhaps such a conversion increases the forage resources for a specific species. It is useful to know the degree to which attempting to transition states will meet the management objective as well as the degree to which it will impact the suitability of other habitat attributes. Thus, providing information on such trade-offs could be important for managers to assess the impact of different land management strategies on wildlife habitat suitability.

Sagebrush can become dense with lack of disturbance resulting in loss of understory herbaceous cover and diversity (West 1983). The degraded states in the STMs used for this study are characterized by high shrub densities and low herbaceous cover. Dahlgren et al. (2006) found that sage grouse use was higher in areas of sagebrush control. While these states may provide high cover values due to dense shrubs, it is assumed that a loss of forage resources, other than sagebrush, occurs. Evaluating this assumption in the context of STMs can contribute to our understanding of the effects of using accelerating practices, such as shrub treatments, to enhance wildlife habitat.

The reference community was identified as the community with more intact ecological processes, complex structure, and greater diversity. The most abundant state in the study area on the assessed ecological sites was the western wheatgrass state. This state has similar habitat components as the reference state but it has a high abundance of western wheatgrass (*Pascropyrum smithii*). Due to the spatial dominance of this state, and the fact that accelerating practices would be costly to implement to transition this state to the reference state, it would be useful to know whether this state has significantly different habitat suitability than the reference state.

The habitat suitability values were analyzed to test 3 hypotheses of interest: 1) reference states, have higher forage and overall (integration of forage and cover) suitability than degraded states, 2) western wheatgrass states in both ecological sites do not have significantly different overall habitat suitability values than the reference states within their respective ecological sites, and 3) the alkali sagebrush-claypan reference state has higher overall habitat values than the native grassland state, which is associated with aerial herbicide spraying.

Paper Organization

This study deviates from many traditional research studies by using several forms of models (STMs and habitat models), literature information to build the habitat models, and sampled habitat attributes. The introduction summarizes important literature regarding habitat and the habitat features that can be assessed in the context of STMs and outlines an overview of the habitat model knowledge representation and evaluation approach used. In addition to a description of the study area, data collection and analysis methods, the methods section contains the results of a detailed literature review used to develop the fuzzy logic habitat models for both species.

Habitat

Habitat can be defined as “the resources and conditions in an area that produce occupancy” (Hall et al. 1997). This relationship is organism-specific where occupancy is related to physical and biological characteristics of the area. Habitat preference is a function of selection processes governed by innate and learned behaviors of animals’ choice of resources at different scales (Hall et al. 1997). Selectivity of habitats and key elements occurs at multiple spatial scales: geographic species range, individual home range, use of general habitat features, and specific element selection (Johnson 1980, Hutto 1985). While geographic range is a function of genetics (Hutto 1985), finer-scaled selection may be a function of animal needs and resource availability across time and space (Manly et al. 2002). Wildlife habitat provisioning is inherently related to spatial processes and patterns, which presents a challenge for quantifying wildlife habitat in the context of STMs. The contribution of a vegetative state to providing wildlife habitat is a function of that state's spatial extent within the mobility patch of the animal and the degree to which the surrounding landscape meets annual animal needs. Because most STMs are not spatially explicit, the modeling efforts were focused on attributes of habitat, such as percent shrub cover, associated with each state, relative to those attributes in other states. Thus, the habitat suitability values provide information on the relative suitability of habitat attributes within a state.

The availability of habitat elements across time also plays an important role in the distribution of wildlife populations (Morrison et al. 2006). Wildlife habitats are modified by annual and seasonal variation (Morris 1990). Many wildlife species choose resources to accommodate temporal changes. The temporal needs of animals were considered by modeling species' needs according to physiological stage. These needs should be considered separately for habitat management because animals choose habitats that best meet their requirements and physiological stages capture relative requirement needs. A literature review was conducted in order to define important physiological stages by species and the relationships to habitat attributes within these stages.

Ecological research has produced an ample supply of information on habitat requirements and preferences and this information is commonly used to build habitat suitability models (Store and Jokimaki 2003). An examination of existing literature for sage grouse and mule deer resulted in well-defined and supported variables for establishing the relationships between habitat suitability and habitat attributes. Despite the credibility of the published sources of information, models based on existing research must also deal with the inherent imprecision and uncertainty of these relationships and in the quantitative data. Fuzzy logic is a quantitative tool that incorporates such attributes.

Using Fuzzy Logic to Build and Evaluate Habitat Models

It is difficult to quantify wildlife habitat for ranch planning models due to the inherent difficulties of representing the link between wildlife preferences and management decisions (Bernardo et al. 1994). In situations such as this, fuzzy logic can be used to build models for complex systems where parameters within the system are defined by expert knowledge (Salski and Speralbaum 1991) and the system can be developed to represent relative relationships. Fuzzy logic systems are formal, logical representations used to assess states and processes with the option of incorporating imprecise, linguistic expert knowledge with quantitative data (Zadeh 1965, 1968, 1975a, 1975b, 1976; Reynolds 2001). O'Keefe (1985) predicted that such systems will play an important role in decision-support systems.

Fuzzy logic was derived from fuzzy set theory as a formal, but generalized method to define a fuzzy set as a value scaling from 0 to 1, which indicates the degree of membership. A fuzzy set is a collection of elements or objects which may belong to the set as described by the degree of membership. For example, if X is defined as a vegetation state comprised of a collection of habitat elements defined as x, then the habitat suitability is a fuzzy set defined as A. The degree of membership is expressed as $\mu_A(x)$ which describes the degree to which x in A defines X to the fuzzy space between 0 and 1 (Palaniappan 2005). Mathematically this is expressed by equation 1.2

$$A = \{\left(x, \mu_A(x)\right) x \epsilon X. \qquad \text{Equation 1.2}$$

Thus, if one is interested in describing the fuzzy set "suitability of a vegetation state for sage grouse nesting in terms of sagebrush canopy cover," then one could define x as percent sagebrush cover. For each applicable continuous value of x, a degree of membership can be assigned to the value of x that describes the degree to which it belongs to the set. In terms of sagebrush cover, one could use a graphical relationship (Fig. 1.1) to define the degrees membership based on empirical knowledge that ideal sage grouse nesting cover should be between 15-25%, and that 70% is too dense.

Fuzzy logic was used to model habitat for this study due to its ability to incorporate empirical knowledge with quantitative data to produce a relative measure of the provisioning of wildlife habitat in the context of STMs. The Netweaver™ modeling interface and engine developed by Saunders and Miller (1999) was used for constructing and evaluating the models.

METHODS

Study Area

The Elkhead watershed is 60,704 hectares of sagebrush grassland and forested mountains. The region is considered semi-arid with most precipitation occurring as snow during the winter. Mean annual precipitation is 43cm in Hayden (the community just south of the watershed between Steamboat Springs and Craig). Average temperatures range from a high of 14.5 C to a low of -2.83 C (High Plains Regional Climate Center 2010). The area is dominated by claypan, brushy loam, deep loam, stony loam, mountain loam, and aspen woodland ecological sites (Soil Conservation Service, currently NRCS 1975; Soil Survey Staff, NRCS, USDA 2010). Claypan and mountain loam ecological sites were targeted for this study because they represent a majority of the rangeland in the watershed and various management techniques. The mountain loam ecological sites consists of variable vegetation and soils but is dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.)) stands, perennial grasses and forbs. Typically soils are moderately deep with good water holding capacity, and are moderately fine to moderately coarse-textured (Soil Conservation Service, currently NRCS) 1975). Claypan ecological sites in the watershed are characterized by alkali sage (*Artemisia arbuscula* Nutt. ssp. *longiloba* (Osterh.) L.M. Shultz), and other short-statured vegetation. Soils on the claypan ecological site are characterized by a thin clay loam or clay A horizon and a fine-textured subsoil that restricts water movement and availability (Soil Conservation Service, currently NRCS 1975).

States and Plots

The state and transition models (Figs. 1.2 & 1.3) used for this study were developed from integrating community knowledge-based models and data-driven models (Knapp and Fernandez-Gimenez. 2009, Knapp et al. 2011). Ecological field plots sampled to create the data-driven STM were also sampled for habitat attributes. These plots were randomly located within their respective ecological sites, stratified by management history (Knapp et al. 2009), and placed 200m apart. The focal states used for this study were chosen because there was a high amount of agreement among stakeholders and they were the most commonly represented in the data. States included in the claypan ecological site model were alkali sagebrush/ bluegrass shrubland (claypan reference, n = 6; the alkali sagebrush with diverse understory and alkali sagebrush with bluegrass states were combined because they are in a reference communities in the same state), alkali sagebrush/wheatgrass shrubland (claypan western wheatgrass, n = 9), native grassland (claypan grassland, n = 9), alkali sagebrush eroding (claypan degrading, n = 6). States included in the mountain loam ecological site model were mountain big sagebrush shrubland with diverse understory (mountain loam reference, n = 7), mountain big sagebrush/western wheatgrass shrubland (mountain loam western wheatgrass, n = 12), and dense mountain big sagebrush shrubland (mountain loam degraded, n = 5).

Vegetation Data Collection

Vegetation data used in the habitat models included percent composition by weight for each species, visual obscurity, percent shrub and herbaceous cover by species, and shrub height by species (Tables 1.1 &1.2).

Five, 50 m transects were established at equal intervals within each 20 x 50 m plot. Dry weight rank was collected by species within 15 systematically placed 40 x 40 cm quadrats (3 plots per transect) within each plot according to the procedure outlined in BLM (1996). Herbaceous cover was estimated using the line point intercept method along each of 5 transects at 1 m intervals for a total of 250 points per plot (Bonham 1989). Additionally, five systematically placed points along the two outside 50 m transects were established. Robel pole (Robel et al. 1970) readings were taken in four cardinal directions at a distance of four meters (string length). Visual obscurity (cm) was estimated by observing (from an eye level of 1 m high and 4 m away) 1.5-m-tall Robel poles and recording the point below which the vegetation completely obscures the pole (procedure as modified by Sveum et al. 1998). At each point, a 10.115 m^2 half-circle plot was established. In cases of extremely high shrub densities, plots were sub-sampled. Two dimensional measurements (long and short axis), height, species, and age class were obtained. The long axis was defined as the longest distance between two points over the canopy and the short axis was measured perpendicular to the long axis. Canopy area was assumed to be an elliptical projection and estimates were adjusted accordingly. Percent canopy cover was estimated by dividing the canopy area by sampled area. Height was measured to the tallest, non-flowering part of the plant (Connelly et al. 2003). Data was averaged by plot for variables of interest. Shrub summaries excluded non-mature shrubs (shrubs without woody main stems and/or flowering parts).

Habitat Models

Assumptions and Limitations. Site-specific animal preferences were not measured in this study. We used existing published literature on the preferences of our target species, sage grouse and mule deer, and assumed that the relationship of each species by applicable life stages is similar on this study area. The most applicable studies and most agreed upon variables were used to define these relationships. Given the non-spatially explicit nature of STMs all models were developed under the assumption that habitat suitability of a given state is correlated with the ability of the state to provide forage and cover needs of the animal for the specified life stage. While animals may use different habitat types for different needs, such as forage and cover, it was assumed that habitats that provide both needs are more valuable than sites that only provide one need.

Terminology and Functions. Elements in Netweaver™ consist of well-defined terminology. For simplicity, the terminology used here is defined as follows. A network represents the habitat suitability model for a specified species and life stage. A network is a collection of objects that represent habitat elements. The habitat elements were structured in terms of forage and cover. Forage and cover were further defined by sub-networks. For example, a network may be sage grouse breeding habitat consisting of the two sub-networks of forage and cover. Within each sub-network, a collection of objects such as sagebrush cover, shrub height, etc. were linked by one or more operators to define the logic with which to evaluate the network. Each of these objects represents real-world data, thus they are referred to as data links. Operators are used to express the relationships between two or more objects or data links. Degree of membership specifications (Fig. 1.1), within each data link defined the habitat suitability for each value of the data link.

Fuzzy logic degrees of membership may be interpreted in a way that is meaningful to the modeling problem (Reynolds 2001). The degrees of membership were purposefully scaled from 0-1, with 0 representing low suitability and 1 representing high suitability. The 0-1 scaled results of the model will hereafter be referred to as the suitability values. The models were developed using the best available knowledge (described in the following sections). In cases where only a minimum value of a variable is applicable, the graphs representing the degrees of membership for a data link are linear from 0-1 and then truncate at 1 on the y-axis at the level of the independent variable that is associated with the minimum requirement. For example, visual obscurity for mule deer fawning habitat is defined as a visual obscurity reading of 0.5 meters. At 0 on the x-axis, this corresponding y value is 0, at 0.5 on the x axis; the corresponding y value is 1. For higher values of visual obscurity, the corresponding y value is still 1. For the following discussion, such a data link is described as having data points of ((0,0), (0.5,1)). The calculation of habitat suitability values for linear data links as just described, is represented by equation 1.2 where μ(x) is the habitat suitability value, x is the value of the data link, a is the lower bound value of the data link, and b is the upper bound value of the data link. Following the mule deer visual obscurity data link example with data points of ((0,0), (0.5,1)), a=0, b=0.5, and x equals the visual obscurity estimate for a given plot. The sagebrush canopy cover data link (Fig 1.1.) would be described as having data points of ((0,0), (15,1), (25,1), (70,0)). This is a truncated habitat suitability function where it is assumed that there are lower and upper bounds on the value. The calculation of habitat suitability values for truncated curves is represented by equation 1.3. Following the sagebrush canopy cover example, a=0, b=15, c=25, d=70, and x equals the percent sagebrush canopy cover for a given plot.

$$\mu(x) = \begin{cases} 0, & x \leq a \\ 1 - \frac{b-x}{b-a}, & a < x < b \\ 1, & x \geq b \end{cases} \qquad \text{Equation 1.2}$$

$$\mu(x) = \begin{cases} 0, & x < a, x > d \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b < x < c \\ \frac{d-x}{d-c}, & c \leq x \leq d \end{cases} \qquad \text{Equation 1.3}$$

The operators used in the models were all AND operators. This is a limiting-factor weighted average operator used to express the dependence of the sub-network on the provisioning of each data link and the dependence of the overall habitat suitability on the provisioning of forage and cover. This operator is used to express the assumption that habitat elements are not compensatory. In other words, a high value of one habitat element cannot substitute for a low value of another habitat element, as would be the case with a simple average. Equation 1.4 expresses the operator in fuzzy terms and equation 1.5 expresses the operator in arithmetic terms. For equation 1.3, AND(t) represents the value of habitat suitability for the sub-network or network, min(t) represents the minimum habitat suitability value of the data links or cover or forage sub-networks, and average(t) represents the simple average of the habitat suitability values of the data links within a sub-network or the simple average of the cover and forage sub-networks.

$$\mu A \cap B(x) = \min\{\mu A(x), \mu B(x)\}, I \epsilon X \qquad \text{Equation 1.4}$$

$$\text{AND(t)} = \text{min(t)} + [\text{average(t)} - \text{min(t)}]*[\text{min(t)}+1]/2 \qquad \text{Equation 1.5}$$

Mule Deer Fawning. Mule deer fawning/summer habitat was modeled with a forage and cover component (Fig. 1.4). Pierce et al. (2004) found that wintering mule deer in Round Valley of California minimized predation by choosing habitat that was both safe from predation and consisted of quality forage. While all habitats do not provide both cover and forage in adequate compositions to meet needs, this work justifies the assumption that habitat that provides both forage and cover is more valuable to mule deer.

The cover sub-network considers thermal cover (Leckenby et al. 1982, Parker and Gillingham 1990) and hiding cover (Leckenby et al. 1982). Hiding cover for mule deer involves the structure of understory vegetation (Taber 1961). Gerlach and

Vaughan (1991) found that fawns bedded in sites with higher concealment cover than random sites and that fawns chose sites with approximately 80% coverage at 0-.5 meters of visual obscurity. Additionally, mule deer are approximately 1 meter tall (Anderson et al. 1974), where hind leg length is roughly half of this height (Fitzgerald et al. 1994). Thus, a bedded adult mule would be roughly 0.5 m in height. Hiding cover for fawning mule deer was modeled as a visual obscurity requirement of 0.5 meters with data points of ((0,0), (0.5,1)).

Thermal cover involves overhead structure because animals are seeking shade or shelter from radiation, precipitation or wind (Robinson 1960, Leckenby 1977, Peek et al. 1982, Sargeant et al 1994). This shelter can consist of over-story canopy (Peek et al. 1982) or other elements that function as a block to environmental extremes (Sargeant 1994). Leckenby et al. (1982) discuss the important contribution of shrubs with heights greater than 70cm for thermal cover during fawning. Therefore, the model thermal cover requirements consisted of a shrub height data link with data points of ((0,0), (70,1)).

Leckenby et al. (1982) recommended that shrub communities for hiding and thermal cover needs for fawns should consist of at least 23% shrub cover. They also reported that canopy cover above 75% is equally preferred. An upper threshold for shrub cover was not discovered in literature review. It was therefore assumed that an upper shrub cover threshold would exist primarily to maintain sufficient understory growth. Such considerations were accounted for in the forage model, where offsets in palatable forage due to dense shrub canopies would result in lower values for forage. Because a limiting-factor operator is used to integrate the cover and forage model, the overall values should resemble the relative value of the site to mule deer. Thus, the shrub cover data link was modeled with data points of ((0,0), (23,1)). The visual obscurity, shrub height, and shrub cover data links were linked by an AND operator.

Mule deer diets are highly variable and this variation is often due to use-availability relationships which are spatial and social in context (Mysterud and Ims 1998). Mule deer are classified as concentrate selectors and they choose the highest available quality for consumption (Hoffman 1989). Given the large overlap in functional group consumption by mule deer reported in the literature, it was assumed that palatability by season is a more likely predictor of forage suitability than functional group composition. Additionally, STMs are not spatially explicit and this study was not focused on modeling habitat suitability for an absolute number of animals. Thus, it was not possible to determine the amount of production in terms of grams $\cdot$ meter $^{-2}$ that would correspond to different levels of habitat suitability. Mule deer forage suitability was driven by a palatability component. Percent palatability was calculated by categorizing each species from the dry weight rank data as palatable or unpalatable and calculating the percent composition by dry weight of all vegetation palatable to the species for a given species. Palatability data for mule deer were obtained from Kufeld (1973), which is a synthesis of mule deer diets where species are rated by season. The summer season data were used and species with values greater than 1.5 were categorized as palatable and species with values 1.5 or less were assigned as unpalatable. If the specific species information was unavailable, genus ratings were used. These ratings were cross-referenced with the PLANTS Database (USDA, NRCS). The data were aggregated by palatability and the resulting value reflects the relative percent availability of palatable forage.

The forage component of the model consisted of percent palatable forage and percent palatable sagebrush data links. Both data links consisted of species that were classified as palatable by season. It was assumed that high suitability (suitability value of 1) occurred at 70% composition or greater of palatable forage species other than sagebrush. The palatable forage data link had data points of ((0,0), (70,1)). Some species of sagebrush are palatable to mule deer during the assessed life stage (Kufeld et al. 1973). However, ingestion of sagebrush in quantities of greater than 30% in the diet is detrimental to mule deer (Nagy et al. 1967, Carpenter et al. 1979). In certain states, sagebrush makes up a majority of the plant composition which would have driven the forage value of the states higher than expected given the lower expected use to availability ratio in these states if sagebrush was included in the overall palatability calculation. To incorporate sagebrush, the forage model was developed such that 30% or less of the diet could be substituted for sagebrush. Another palatable forage data link with data points of ((0,0), (49,1)) was connected by an AND operator to a palatable sagebrush data link with data points of ((0,0), (21,1)). The highest suitability value was chosen between the single palatable forage data link and the connected palatable forage and palatable sagebrush links.

Sage Grouse Breeding Habitat. Sage grouse habitat models were developed for breeding habitat (Fig. 1.5). Breeding habitat is defined by Connelly et al. (2000) as areas of potential lek attendance, pre-laying hen, nesting, and early brood-rearing habitat. Hens often use resources near potential nesting sites for pre-incubating nutrition and thus it is an important consideration for breeding habitat management. Nesting habitat is an important consideration in breeding habitat management due to the risk of nest depredation and early chick-rearing habitat is considered within the breeding habit requirements because chicks are limited in mobility to the resources within the immediate vicinity of the nesting habitat.

Recommended cover for nesting sage grouse is sagebrush cover at 15-25% (Connelly et al. 2000). A meta-analysis by Hagen et al. (2007) reports a range of shrub coverage used during this time period. The highest is 59% (Sveum et al. 1998). This value was estimated in small areas (1-m^2) around a nest. When shrub coverage was measured in larger areas in the nesting habitat, which would be more comparable to the methods of shrub estimates used for this study, the shrub estimates generally fell within the range suggested by the sage grouse guidelines. This study also reported that successful nest sites (1-m^2) in the big sagebrush community had lower shrub cover (51%) than depredated nests (70%). It is therefore assumed that sagebrush canopy cover around

70% is too dense. A sagebrush canopy cover data link was included in the model with the following points ((0, 0), (15, 1), (25, 1), (70, 0)). Shrub height in successful nesting habitat is 40-80cm (Connelly et al. 2000). The average sagebrush heights by state were examined for potential issues with maximum values. The greatest value for height fell below the recommended 80cm, therefore a maximum value was not accounted for in the model. A sagebrush height data link was included in the model with the following points: ((0, 0), (40, 1)). The sage grouse guidelines suggest maintaining grass height at > 18cm. A preliminary assessment of grass height at plots showed that height was consistently greater than 18 cm. Therefore, instead of grass height, visual obscurity was measured as an indicator of screening cover. While many authors report visual obscurity results at successful nest sites, the exact procedure for measurement varied. Sveum et al. (1998) report results from a sage grouse nest study where visual obscurity was measured using the same procedure and is significantly different between nest and random sites for two years. The results from 1996 (VO= 32cm) were used for this model because the sample size was higher than the previous year results. The visual obscurity data link was created with the following data points: ((0, 0), (32, 1)). The sage grouse guidelines recommend grass cover of >15%. The importance of grass for cover is well-established. The perennial grass cover data link was created with the following data points ((0, 0), (15, 1)).

Sage grouse diets during pre-incubation consist primarily of sagebrush and forbs. Gregg, Barnett, and Crawford (2008) found that forbs comprised 30.1% and sagebrush comprised 65.7% of hen diets during pre-incubation. Connelly et al. (2000) recommend at least 10% forb cover and 15% sagebrush cover for this time period. Forbs are also an important component of the chick's diet during early brood rearing (Drut, Pyle, and Crawford 1994). Huwer et al. suggested that forb cover of ≥20% may lead to increased survival and productivity. The 20% guideline is also supported by Schroeder (1995) and Sveum et al. (1995, 1998). Due to this evidence, and the fact that the sage grouse guidelines recommend that forb coverage should exceed 10%, the 20% optimum value for forb cover was used. It was assumed that a site that meets the recommended forb cover amount where the forb species are palatable to sage grouse, is more valuable than a site that meets the recommended forb cover amount where the species are unpalatable. Each forb species in the cover data was categorized as palatable or unpalatable using information from Huwer (2004) and Bird and Schenk (2005). The percent of palatable forbs was calculated by dividing the percent cover of palatable forbs by the total cover of forbs. Thus, the forage sub-network consisted of a sagebrush canopy cover data link ((0, 0), (15, 1)), a perennial forb cover data link ((0, 0) (20, 1)), and percent palatable forbs data link ((0, 0), (100, 1)).

Statistical Analysis

Data were analyzed with SAS (9.2) using an analysis of variance with ecological site and state nested within ecological site effects. The model assumptions were met. Pairwise comparisons of means between states were used to test hypotheses with Tukey adjusted p-values (PROC GLM; SAS Institute 2008). Data were independently analyzed by animal species. Within a species, the forage values, cover values and overall habitat values were compared according to the following hypotheses which were tested at the α=0.1 level where H_o indicates the null hypothesis and H_a indicates the research hypothesis: 1) H_o: The overall (integration of forage and cover values) and forage values of reference states are equal to or less than the values of degraded states, within their respective ecological sites; H_a: Reference states have higher forage and overall habitat suitability values than degraded states, within their respective ecological sites, 2) H_o: There is no difference in overall habitat values between reference states and the western wheatgrass states, within their respective ecological sites; H_a: There is no difference in overall habitat values between reference states and the western wheatgrass states, within their respective ecological sites, and 3) H_o: The overall habitat values of the claypan reference state are equal to or less than the values of the claypan native grassland state; H_a: The reference state has higher overall habitat values than the grassland state on the claypan ecological site. Directional hypotheses were assessed using one-way tests; non-directional hypotheses were assessed using two-way tests.

RESULTS

Mule Deer Fawning

The claypan reference state has significantly higher forage ($\dot{x}$ = 0.36) and overall ($\dot{x}$ = 0.32) suitability than the claypan degraded state (forage $\dot{x}$ = 0.05, P = 0.03; overall $\dot{x}$ = 0.13, P = 0.08; Tables 1.3 & 1.4). The mountain loam reference state has higher forage suitability ($\dot{x}$ = 0.78) than the degraded state ($\dot{x}$ = 0.54, P = 0.06; Tables 1.3 & 1.4). The mountain loam reference does not have significantly higher overall suitability ($\dot{x}$ = 0.66) than the degraded state ($\dot{x}$ = 0.67, P = 0.5; Tables 1.3 & 1.4). There was no difference in overall suitability between reference states (CP $\dot{x}$ = 0.32; ML $\dot{x}$ = 0.66) and the western wheatgrass states (claypan $\dot{x}$ = 0.26, P = 0.88; mountain loam $\dot{x}$ = 0.67, P = 1.0; Tables 1.3 & 1.4), within their respective ecological sites. The claypan reference state has higher overall suitability ($\dot{x}$ = 0.32) than the native grassland state ($\dot{x}$ = 0.12, P = 0.03; Tables 1.3 & 1.4).

Sage Grouse Breeding

The claypan reference state has significantly higher forage ($\dot{x}$ = 0.55) and overall suitability ($\dot{x}$ = 0.57) than the claypan degraded state (forage $\dot{x}$ = 0.34, P = 0.06; overall $\dot{x}$ = 0.36, P = 0.04; Tables 1.5 & 1.6). The mountain loam reference state has significantly higher forage ($\dot{x}$ = 0.64) and overall ($\dot{x}$ = 0.67) suitability than the mountain loam degraded state (forage $\dot{x}$ = 0.34, P = <0.01; overall $\dot{x}$ = 0.45, P = 0.02; Tables 1.5 & 1.6). There is no significant difference in overall suitability between claypan and mountain loam reference and western wheatgrass states (claypan western wheatgrass $\dot{x}$ = 0.48, P = 0.66; mountain loam western wheatgrass $\dot{x}$ = 0.74, P = 0.64; Tables 1.5 & 1.6), within their respective ecological sites. The claypan reference state has significantly higher overall suitability ($\dot{x}$ = 0.57) than the native grassland state ($\dot{x}$ = 0.31, P = <0.01; Tables 1.5 & 1.6).

DISCUSSION

Habitat indices for sage grouse nesting and mule deer fawning/ fawn rearing were developed using published literature on the respective species' habitat requirements and fuzzy logic knowledge representation and evaluation. The model results were 0-1 scaled indices of habitat suitability in terms of forage, cover, and overall or integrated forage and cover suitability. These values were tested to assess differences in habitat suitability between states.

Sage grouse forage and overall breeding habitat values were higher for reference states than degraded states for both ecological sites. Mule deer forage and overall breeding habitat values were higher on reference states than degraded states for the claypan ecological site. On the mountain loam ecological site, the mule deer fawning forage values are higher for the reference state, but the cover values are higher for the dense state. Thus, there is a tradeoff in forage and cover values between the reference and dense states which results in no significant difference in the overall values between these states. Transition from the reference to the dense state is associated with lack of shrub disturbance and reduction in understory herbaceous production due to drought or heavy overgrazing. Because the dense state provides less forage value than the reference state, it would not be advantageous to allow large expanses of the dense state to occur. However, Leckenby et al. (1982) suggested the mule deer do not fully utilize forage areas that are greater than 125 meters from adequate cover. Managing for the dense state in small patches where distance to adequate cover is greater than 125 meters may be an important management practice to increase habitat value to mule deer.

There were no differences in overall habitat suitability between reference and western wheatgrass states on their respective ecological sites for both species' models. In the STMs evaluated in this study, the reference communities and the western wheatgrass communities have similar components and field conditions showed that they were highly interspersed. From a management perspective, this state would be difficult to delineate separately from the reference states across the landscape, and therefore difficult to manage independently of the reference state if one is interested in using the STM framework to convert this state to a different state. Thus, understanding whether such states are significantly different from one another in terms of habitat suitability could assist in developing management strategies. Cagney et al. (2010) discuss habitat values for a sagebrush rhizomatous grass state versus a sagebrush bunchgrass state in Wyoming. The sagebrush bunchgrass state was identified as preferred sage grouse habitat whereas the sagebrush rhizomatous grass state has variable values depending on condition, but in high vigor stands, this state can provide good quality habitat. In Wyoming, the sagebrush rhizomatous grass state was identified as highly resilient with large spatial extent, and therefore, important to maintain in healthy condition. In the Elkhead watershed, it is likely that this conclusion can also be applied to the sagebrush western wheatgrass states.

The claypan reference state has higher overall habitat values than the claypan native grassland state. The research hypothesis that the reference state has higher values than the native grassland state was formed because it was assumed that there would be a reduction in the abundance of sagebrush and forbs due to the association of aerial herbicide spraying with the claypan grassland state. However, there is similar coverage of forbs between the reference (average 19.73 %) and grassland (average 16.61%) states (Table 1). The low habitat values in the claypan grassland state are a result of low sagebrush cover, which was a contributing factor in the forage and cover sub-networks.

The results of this approach indicate that managing a majority of the land for reference or similar states, such as the wheatgrass states, on mountain loam and claypan sites increases habitat suitability for important production life stages of mule deer and sage grouse. This work shows how a synthesis of existing literature on the habitat requirements of fawning mule deer and breeding sage grouse can be used to evaluate the relative habitat suitability of two structurally different ecological sites and the potential vegetation states within each site by applying a fuzzy logic modeling approach. The disadvantages of this approach are that it inherits the uncertainty and biases of any study used to build the habitat models and the limitations of STMs, such as lack of spatially explicit information. Additionally, there is some level of subjectivity involved in building the models. The advantages of this approach are that wildlife habitat information from multiple sources and habitat guidelines are used to define important habitat attributes, that a large amount of data are synthesized into relative values, and that it incorporates habitat information into ESDs and STMs in a format that can be adapted to different land management units.

One of the advantages of the STM framework is that the non-spatially explicit nature of the model allows it to be applied to different land management units as opposed to a singular place at one point in time. Thus, this model can be adapted to land management units of varying size, purpose, and location. However, in order to validate habitat suitability for STMs, it would be necessary to map the spatial extent of each state within a study area, determine the preferred animal locations within that area, and then isolate the impacts of factors including distance to water and disturbances such as roads. Additionally, as Aldridge and Boyce (2007) point out, there is discrepancy between habitats that are chosen based on animal preferences and habitats where fitness is maximized. Such discrepancies could also make differentiating the suitability of a state for wildlife habitat difficult. However, such work should be conducted in order to validate that wildlife habitat quality can be linked to the ESD and STM frameworks. This work provides a stepping stone for such studies by demonstrating this link in a non-spatial manner.

Habitat suitability indices have been used extensively for management decision making. However, little work with these models has been published in peer-reviewed literature. The lack of validation, or testing with independent data, is a widespread criticism of such models. Brooks (1997) addressed the importance of these models for management, the lack of time and funding to conduct a full range of testing and validation, and that a forum for progress with these models would be useful. Brooks (1997) discussed three main steps in habitat suitability model development. These steps include development, calibration, verification, and validation. The models used here were developed using peer-reviewed literature. An indication of properly calibrated models is that the full range of suitability is represented by sites. In the case of these models, the full range of values is from 0-1. Habitat suitability values for the plots represented this full range however, once these values were averaged by state, the range of values was reduced. This is due to site characteristic variance within a states rather than the lack of the models to capture the full range of suitability values. Another step that can be used to calibrate models is sensitivity analyses which were not quantitatively conducted for this work. Verification involves selecting of a set of independent sites and ranking the habitat suitability of those sites by methods such as comparison to occurrence or abundance data (also validation), or by expert opinion of new observers. These measures of suitability are then statistically tested for correlation with the model output. Validation involves assessment of the model performance when compared to population data. Steps to achieve this are outlined above where the spatial extent of a state would need to be determined and factors that may influence abundance that are not related to the states would need to be accounted for. As Brooks (1997) pointed out, these habitat suitability models are a practical and useful tool for management. Further, a dialogue of these models should be available in the literature and the stage of completion of the model should be acknowledged and open to incremental improvements that should also be documented. This work represents an initial development and calibration of habitat suitability models that can be further scrutinized, assessed, and validated.

IMPLICATIONS

Additional information that is important to land managers and society should be included into ESDs so that responses of use values and ecological attributes beyond plants and soils can be evaluated (Bestlemeyer et al. 2003). The incorporation of wildlife habitat information into ESDs in the context of STMs is an important step towards accomplishing this. This work could be used for applications such as the Sage Grouse Initiative (SGI) (NRCS SGI 2011) which offers financial and technical assistance to land owners seeking to improve habitat quality. Managers could use the STM framework with associated habitat information to determine the actions necessary to transition to a state that meets the objectives and assess the potential costs of these actions. This work adds value to ecological site descriptions by including wildlife habitat information and increases the applicability of STMs for decision-making on rangelands.

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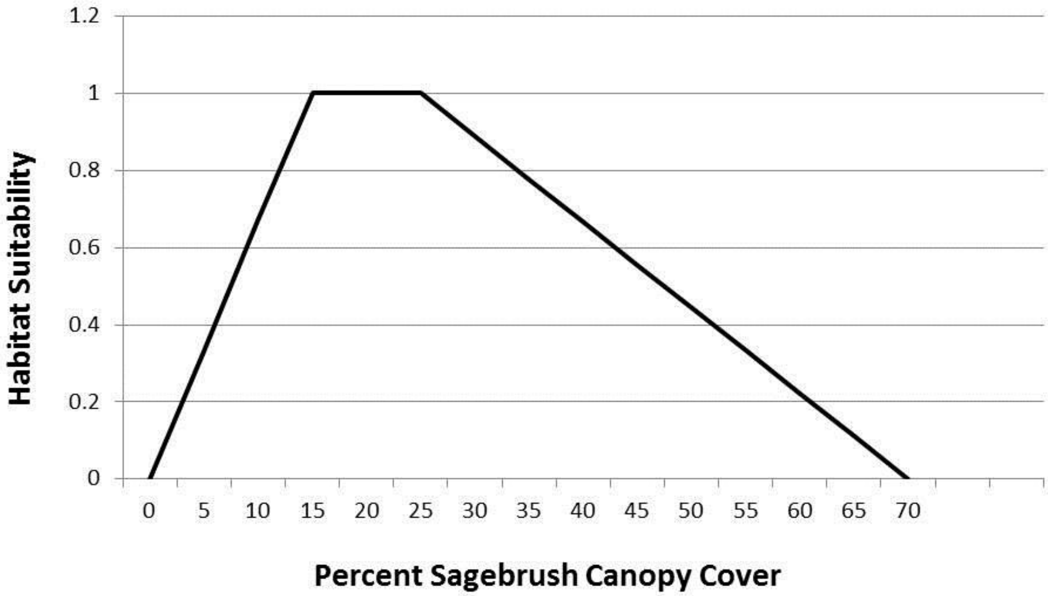
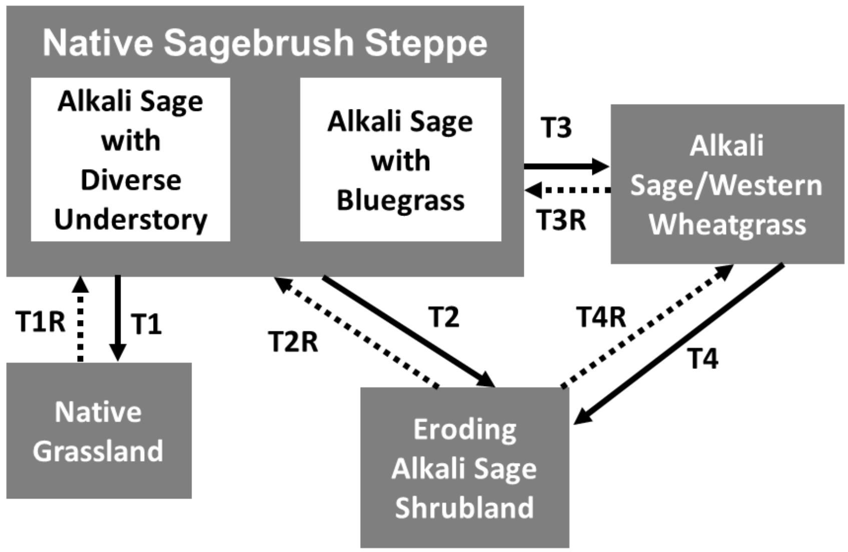


Figure 1.1. Fuzzy graph depicting habitat suitability (degree of membership) function for percent sagebrush canopy cover o*f br*eeding sage grouse.

Claypan STM

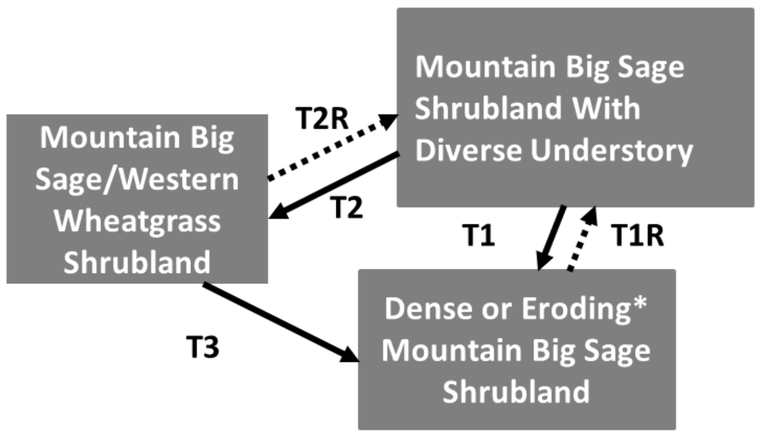


Transitions

T1: Fire and/or spraying reduces shrub cover, which causes the transition to native grassland
T1R: Shrubs re-colonize over time (but this takes a long time, especially for alkali sagebrush)
T2: A combination of high grazing pressure, drought, and/or fire reduce herbaceous plant cover, which triggers erosion on the site
T2R: A combination of lower grazing pressure, favorable precipitation, and/or lack of fire increase herbaceous plant cover, reducing erosion on the site
T3: Moderate (NRCS recommended) grazing in wetter years allows western wheatgrass to become dominant
T3R: Low grazing pressure combined with drought decrease wheatgrass cover; also occurs under heavy (above NRCS-recommended) grazing pressure
T4: A combination of high grazing pressure, drought, and/or fire reduce wheatgrass cover, which triggers erosion
T4R: A combination of lower grazing pressure, average precipitation, and/or lack of fire increase wheatgrass cover, reducing erosion

Figure 1.2. Claypan state and transition model used for habitat analysis.

Mountain Loam STM



*Whether it becomes Dense or Eroding depends on slope

Transitions

T1: Reduction of the herbaceous understory , caused by heavy (above NRCS-recommended) grazing and/or drought, combined with lack of disturbance that reduces shrub cover (fire, herbicide)
T1R: Disturbance that reduces shrub cover (fire, herbicide) combined with recovery of the herbaceous understory under lower grazing pressure and/or more precipitation
T2: Moderate (NRCS recommended) grazing in wetter years allows western wheatgrass to become dominant
T2R: Low grazing pressure combined with drought decrease wheatgrass cover; also occurs under heavy (above NRCS-recommended) grazing pressure
T3: Heavy grazing (above NRCS recommended rates) causes continued reduction in wheatgrass cover and an increase in shrub cover

Figure 1.3. Mountain loam state and transition model used for habitat analysis.

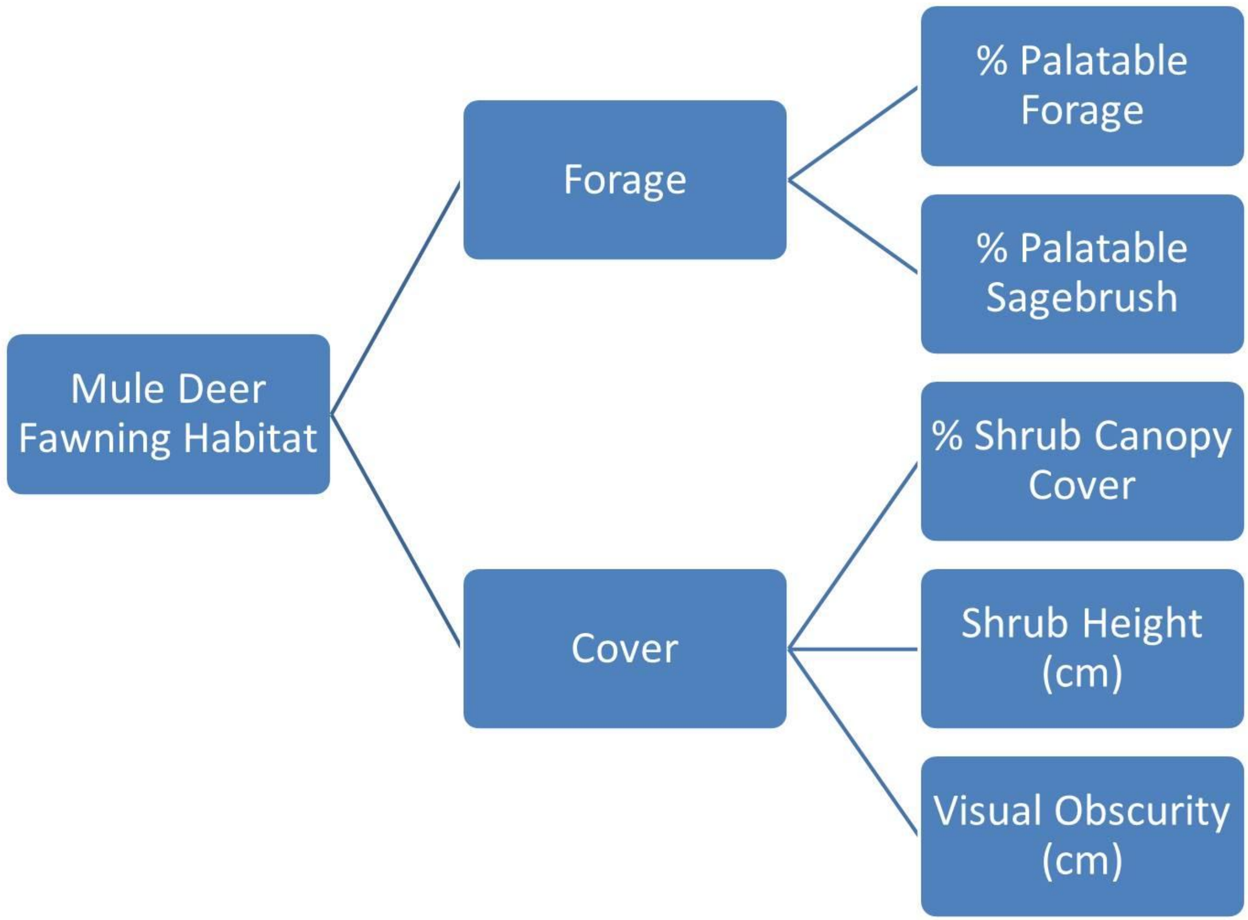


Figure 1.4. Mule deer breeding habitat model structure.

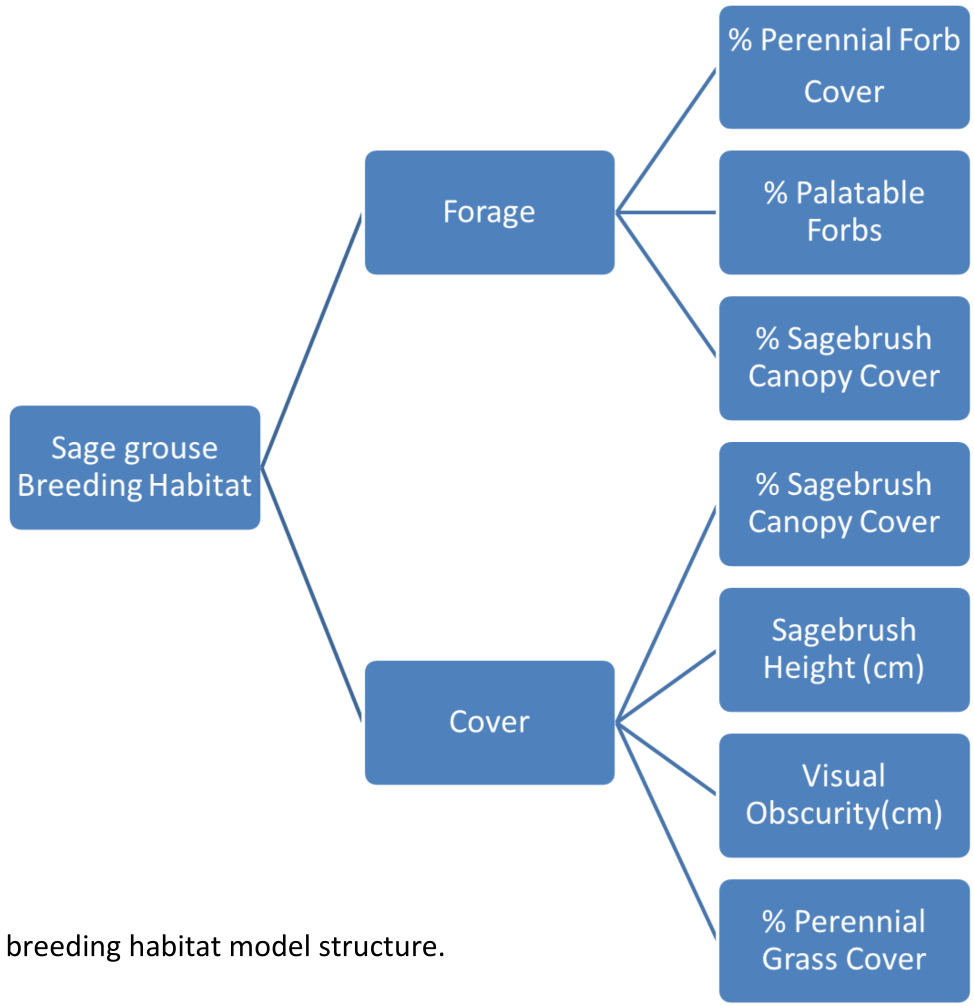


Figure 1.5. Sage grouse breeding habitat model structure.

Table 1.1. Mean and standard error (SE) of habitat variables for states[1] in the claypan ecological site that were assessed for habitat suitability.

Model Variables	Reference		Western wheatgrass		Native Grassland		Eroding	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
% Sagebrush Cover	21.84	6.79	7.11	2.06	5.76	4.26	39.12	6.04
% Shrub Cover	22.19	6.73	7.6	1.74	5.76	4.26	39.12	6.04
Sagebrush Height (cm)	26.06	1.58	23.38	5.77	11.21	3.85	19.11	2.58
Shrub Height (cm)	26.13	1.62	23.06	2.46	11.21	3.85	19.11	2.58
Visual Obscurity (cm)	0.14	0.01	0.09	0.02	0.06	0.02	0.1	0.02
Sage Grouse % Palatable Forbs	71.09	10.19	80.17	7.86	96.1	1.13	35.56	9.92
% Perennial Grass Cover	18.91	2.03	27.64	6.93	41.03	2.64	9.75	2.12
% Perennial Forb Cover	19.73	7.0	23.38	4.4	16.11	1.9	6.62	1.61
Mule Deer % Palatable Forage	21.92	8.96	24.66	3.63	13.45	1.94	2.6	0.73
% Palatable Sagebrush	3.96	3.96	2.82	1.82	1.4	0.99	0.78	0.78

[1]Data were averaged across plots associated with each assessed state.

Table 1.2. Mean and standard error (SE) of habitat variables for states[1] in the mountain loam ecological site that were assessed for habitat suitability.

Model Variables	Reference		Western wheatgrass		Dense	
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**
% Sagebrush Cover	13.29	4.04	15.42	2.22	52.48	4.93
% Shrub Cover	25.75	4.01	23.25	4.21	52.72	4.78
Sagebrush Height (cm)	50.98	6.6	56.16	2.95	66.89	6.5
Shrub Height (cm)	52.76	5.07	58.43	2.38	66.85	6.48
Visual Obscurity (cm)	0.21	0.03	0.28	0.04	0.48	0.06
Sage grouse % Palatable Forbs	68.65	6.17	53.34	6.31	36.12	8.63
% Perennial Grass Cover	22.74	4.94	22.31	3.67	19.12	2.54
% Perennial Forb Cover	23.03	3.16	31.71	3.32	12.24	3.76
Mule Deer % Palatable Forage	48.88	7.15	41.26	3.63	16.41	5.72
% Palatable Sagebrush	10.66	2.8	12.96	2.27	44.16	7.96

[1]Data were averaged across plots associated with each assessed state.

Table 1.3. Mean and standard error (SE) for cover, forage, and overall habitat values for mule deer fawning habitat.

			Mule Deer Fawning Habitat Values					
			Cover		Forage		Overall	
Ecological Sites	**State**	**n**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Claypan	Reference	6	0.38	0.06	0.36	0.08	0.32	0.06
Claypan	Western wheatgrass	9	0.22	0.05	0.38	0.06	0.26	0.05
Claypan	Native Grassland	9	0.11	0.05	0.21	0.07	0.12	0.05
Claypan	Eroding	6	0.36	0.06	0.05	0.08	0.13	0.06
Mountain Loam	Reference	7	0.58	0.06	0.78	0.08	0.66	0.06
Mountain Loam	Western wheatgrass	12	0.66	0.04	0.7	0.06	0.67	0.05
Mountain Loam	Dense	5	0.91	0.07	0.54	0.09	0.67	0.07

[1]Data were averaged across plots associated with each assessed state; df = 50 for SE calculation.

Table 1.4. Pairwise statistical comparisons of cover, forage, and overall mule deer fawning habitat values between states associated with hypotheses of interest.

			Mule deer					
			Cover		Forage		Overall	
Ecological Site	**State Comparison**		**Diff[1]**	**p-value**	**Diff[1]**	**p-value**	**Diff[1]**	**p-value**
Claypan	Reference	Eroding	0.02	0.5	0.32	0.03*	0.19	0.08*
Mountain Loam	Reference	Dense	-0.33	>0.99	0.24	0.06*	<-0.01	0.5
Claypan	Reference	Western wheatgrass	0.16	0.16	-0.02	1.0	0.06	0.88
Mountain Loam	Reference	Western wheatgrass	-0.07	0.54	0.09	0.65	<-0.01	1.0
Claypan	Reference	Native Grassland	0.27	<0.01*	0.16	0.23	0.2	0.03*

[1]Difference between the habitat value of the state in left-most column and the habitat values of the state in the following column.

[*] Significant difference between states at the α=0.1 level; df = 50 for each comparison; comparisons between reference and western wheatgrass states in both ecological sites are two-tailed tests, all other comparisons are one-tailed under the hypothesis that reference states have higher values.

Table 1.5. Mean and standard error for cover, forage, and overall habitat values for sage grouse breeding habitat.

Ecological Sites	State	n	Sage Grouse Breeding Habitat Values[1]					
			Cover		Forage		Overall	
			Mean	SE	Mean	SE	Mean	SE
Claypan	Reference	6	0.62	0.06	0.55	0.06	0.57	0.06
Claypan	Western wheatgrass	11	0.44	0.05	0.57	0.05	0.48	0.04
Claypan	Native Grassland	10	0.27	0.05	0.41	0.05	0.31	0.05
Claypan	Eroding	6	0.41	0.06	0.34	0.06	0.36	0.06
Mountain Loam	Reference	7	0.72	0.06	0.64	0.06	0.67	0.05
Mountain Loam	Western wheatgrass	12	0.86	0.05	0.66	0.04	0.74	0.04
Mountain Loam	Dense	5	0.68	0.07	0.34	0.07	0.45	0.06

[1]Data were averaged across plots associated with each assessed state; df = 50 for SE calculation.

Table 1.6. Pairwise statistical comparisons of cover, forage, and overall sage grouse breeding habitat values between states associated with hypotheses of interest.

			Sage Grouse					
			Cover		Forage		Overall	
Ecological Site	**State Comparison**		**Diff[1]**	**p-value**	**Diff[1]**	**p-value**	**Diff[1]**	**p-value**
Claypan	Reference	Eroding	0.21	0.06*	0.21	0.06*	0.21	0.04*
Mountain Loam	Reference	Dense	0.04	0.45	0.3	<0.01*	0.22	0.02*
Claypan	Reference	Western wheatgrass	0.18	0.16	-0.02	0.99	0.09	0.66
Mountain Loam	Reference	Western wheatgrass	-0.14	0.18	-0.02	0.98	-0.06	0.64
Claypan	Reference	Native Grassland	0.35	<0.01*	0.14	0.18	0.26	<0.01*

[1]Difference between the habitat value of the state in left-most column and the habitat values of the state in the following column.

* Significant difference between states at the α=0.1 level; df =50 for each comparison; comparisons between reference and western wheatgrass states in both ecological sites are two-tailed tests, all other comparisons are one-tailed under the hypothesis that reference states have higher values.

CHAPTER 2: **VISUALIZING THE EFFECTS OF MANAGEMENT AND ENVIRONMENT ON SAGE GROUSE HABITAT**

Land classifications are important tools for natural resource management. Several classification methodologies exist. This study focused on ecological sites because they have the potential to include state-and-transition models (STMs) which describe ecological sites in terms of potential vegetation communities as well as environment and management drivers that are associated with the presence of a state. In addition to land classifications, habitat classifications are an important management tool for understanding the distribution and abundance of habitats. Ecological site descriptions (ESDs) and STMs also have the potential to include information on habitat distribution and abundance as well as changes in habitat suitability due to environmental variation and management. Fuzzy logic representation and evaluation habitat models were used because they can incorporate expert knowledge with quantitative data. The objective of this work was to use relative sage grouse habitat models based on published literature to compare wildlife habitat mapping in the context of ESDs and STMs to a current habitat mapping procedure and to assess the tradeoffs in habitat suitability when ecological sites are managed for reference versus degraded states. More detailed information on habitat was included by using the ESD and STM framework. Additionally, when ecological sites of interest were mapped as degraded states there were visible reductions in relative habitat suitability when compared to the reference states. In cases where the habitat attributes of wildlife species, such as sage grouse, are well established, this approach can improve ability to use visualization tools to understand distribution, abundance, and suitability of wildlife habitats.

INTRODUCTION

Landscape management is in increasing demand over management which is isolated within ownership boundaries and political administrative units. This change in emphasis is also associated with a change in the guiding principles of management such as orderly succession and spatial homogeneity. Our conceptual models for how management operates now include considerations such as thresholds and spatial and temporal variability (Weins et al. 2002). In order to incorporate this variability in large, landscape-scale assessments, it is essential to use a land classification methodology in order to reduce this variation into discrete units that can be mapped and managed for purposes such as wildlife habitat.

The greater sage grouse (*Centrocercus urophasianus*) is a wildlife species that should be managed in a landscape context. Breeding populations of the species have declined by 17-47% in the past century (Connelly and Braun 1997, Connelly et al. 2000). Sage grouse use sagebrush habitats for a majority of their needs but these habitats are declining in quality and quantity (Connelly et al. (2000). Population home ranges can exceed 2,700km^2 which makes the connectivity of theses habitats a vital component of population success (Leonard et al. 2000).

In order to understand the abundance, distribution, and connectivity of sage grouse habitat, it is important to apply spatial mapping tools such as Geographic Information Systems (GIS). Land generalization methodologies are used to map vegetation across landscapes with GIS.

The USDA Natural Resource Conservation Service (NRCS), US Forest Service (FS), and Bureau of Land Management (BLM) use ecological sites for land classification. Ecological sites are “a distinctive kind of land with specific characteristics that differs from other kinds of land in its ability to produce a distinctive kind and amount of vegetation” (USDA NRCS 2011). Ecological site descriptions (ESDs) and state-and-transition models (STMs) are being developed by the USDA NRCS as a framework for land management decision-making. Ecological sites descriptions provide information on biophysical properties, soils, vegetation dynamics, and other interpretations of ecological sites. State-and transition models are graphical representations of vegetation dynamics and soils characteristics on ecological sites (Bestlemeyer et al. 2003). These models describe potential vegetation states along with associated environmental conditions, disturbances, and management actions. States represent plant communities with similar characteristics such as functional groups and processes, as well as management requirements. Plant communities are assemblages of dominant plant species and are associated with certain climates and soil characteristics. Plant species composition and soil properties are often indicative of processes such as encroachment of shrubs or loss of organic matter. A transition occurs when a state shifts to a different state due to constraint alterations, such as weather patterns or disturbance, and a positive feedback system causes distinguishable changes in soils and vegetation. State transitions may be reversed unless a threshold is crossed resulting in a persistent state that often requires accelerating practices or inputs to change (Bestlemeyer et al. 2003, Stringham et al. 2003).

State-and-transition models and ESDs encapsulate our understanding of rangeland ecology and can be useful for wildlife habitat management. State-and-transition models describe ecological sites in terms of their vegetation dynamics, which can be one of the primary indicators of suitable wildlife habitat (Stringham et al. 2003, Morrison et al. 2006). State-and-transition models are not spatially explicit. However, the potential exists to make them spatially explicit. Ecological sites are currently mapped throughout the U.S. and are the extent to which STMs can be mapped (Bestlemeyer et al. 2003). Mapping wildlife habitat is important for the conservation of species and habitats and for resource use purposes. Ecological sites and STMs have the potential to be used as a framework for mapping wildlife habitat and could incorporate information on drivers of ecological change such as management and environmental regime.

Other methods for mapping wildlife habitats are currently in place. For example, the Southwest Regional Gap Analysis (SWReGAP) mapped vegetation types such as sagebrush and prairie lands as sage grouse habitat (Lowry et al. 2005, Boykin et al. 2007). The Colorado Division of Wildlife (CDOW, 2010) created wildlife maps using species activity mapping. This method uses prominent animal location to map wildlife habitat. For example, the sage grouse production map is defined as an area that would encompass the majority of sage grouse nesting habitat. It is mapped as a 2 mile buffer around active sage grouse lek locations. The winter habitat map was created as a map of observed winter ranges. These methods provide important information for certain aspects of habitat and land management and have different strengths, weaknesses, and purposes. Ecological sites and STMs may address some of the weaknesses of these methods, and provide an alternative wildlife habitat mapping basis that incorporates more detailed information on vegetation dynamics. This study seeks to address the strengths and weaknesses of these approaches.

The objective of this work was to 1) use relative sage grouse breeding and winter habitat models based on published literature to compare wildlife habitat mapping in the context of ESDs and STMs to current habitat mapping procedures, and 2) assess whether the methodology allows for visual differences in maps based on a hypothetical situation of managing ecological sites for reference versus degraded states. These objectives will help assess this ability of these tools and frameworks to contribute to 1) visualizing the distribution, abundance, and suitability of habitat and, 2) the sensitivity of the tools to depict changes in habitat suitability based on changes in state.

METHODS

Study Area

A 20,000 hectare portion of the Northern Routt county was chosen for this study. The region is considered semi-arid with most precipitation occurring as snow during the winter. Mean annual precipitation is 43cm in Hayden (the community just south of the watershed between Steamboat Springs and Craig). Average temperatures range from a high of 14.5 C to a low of -2.83 C (High Plains Regional Climate Center 2010). The area is dominated by claypan, brushy loam, deep loam, stony loam, mountain loam, and aspen woodland ecological sites (Soil Conservation Service (currently NRCS) 1975; Soil Survey Staff, NRCS, USDA 2010). The area also has two creeks running through it. Further context on the location of this area and identification of creeks is not provided in order to protect the identities of private individuals whose land was sampled.

Ecological Sites, States and Plots

The state and transition models (Figs. 2.1 & 2.2) used for this study were developed from integrating community knowledge-based models and data-driven models (Knapp and Fernandez-Gimenez. 2009, Knapp et al. 2011). Plots that were associated with the reference (claypan n=15; mountain loam n=19) and degraded (claypan n=6, mountain loam n=5) states from the data-driven model were re-sampled for habitat attributes. The reference states/communities were characterized by plots from the reference states combined with plots from a state with similar habitat components to the reference states (CH 1). These plots were randomly located within their respective ecological sites, stratified by management history (Knapp et al. 2009), and placed 200m apart. The focal states used for this study were chosen because there was a high amount of agreement among stakeholders and they were the most commonly represented in the data. Plots in deep loam (n=1) and planted grassland (n=3) (an agricultural state that can occur on claypan and mountain loam ecological sites) were also sampled for habitat attributes. Data from range site descriptions (descriptions of ecological sites that are being updated to ESDs) were used to characterize the stony loam ecological site (Soil Conservation Service 1975 (currently NRCS)).

The mountain loam ecological site consists of variable vegetation and soils but is dominated by mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.)) stands, perennial grasses and forbs. Typically soils are moderately deep with good water holding capacity, and are moderately fine to moderately coarse-textured. Claypan ecological sites in the watershed are characterized by alkali sage (*Artemisia arbuscula* Nutt. ssp. *longiloba* (Osterh.) L.M. Shultz), and other short-statured vegetation. Soils on the claypan ecological site are characterized by a thin clay loam or clay A horizon and a fine-textured subsoil that restricts water movement and availability. Soils on the stony loam site are moderately deep to deep stone-filled sandy loams to clay loams with moderate permeability and reduced water holding capacity. Soils on the deep loam site are deep with good water holding capacity, and are moderate in texture. Riparian area soils are moderately deep to deep, with high amounts of organic matter, poorly drained and range from sandy loam to clay in texture (Soil Conservation Service 1975 (currently NRCS)).

Vegetation Sampling

Vegetation data used in the habitat models included percent sagebrush cover and sagebrush height, visual obscurity, percent perennial forb and grass cover, percent of forb cover palatable to sage grouse, and percent herbaceous cover (Table 2.1).

Sagebrush plots. Forb and grass cover was estimated using the line point intercept method along each of 5 transects at 1 m intervals for a total of 250 points per plot (Bonham 1989). Visual obscurity was measured at five systematically placed points along the two outside 50 m transects. Robel pole (Robel et al. 1970) readings were taken in four cardinal directions at a distance of four meters (string length). Visual obscurity (cm) was estimated by observing (from an eye level of 1 m high and 4 m away) 1.5-m-tall Robel poles and recording the point below which the vegetation completely obscures the pole (procedure as modified by Sveum et al. 1998). At each point, a 10.115 m^2 half-circle plot was established. In cases of extremely high shrub densities, plots were sub-sampled. Two dimensional measurements (long and short axis), height, species, and age class were obtained. The long axis was defined as the longest distance between two points over the canopy and the short axis was measured perpendicular to the long axis. Canopy area was assumed to be an elliptical projection and estimates were adjusted accordingly. Canopy cover was estimated as the percent of sampled area taken up by shrub canopy area. Height was measured to the tallest, non-flowering part of the plant (Connelly et al. 2003). Data was averaged by plot for variables of interest. Shrub summaries excluded non-mature shrubs (shrubs without woody main stems and/or flowering parts).

The range site descriptions were used to characterize habitat for stony loam. In these descriptions, vegetation composition is reported in terms of dry weight (Soil Conservation Service 1975 (currently NRCS)). To derive cover estimates, which were used in the sage grouse habitat models, regression models by species were developed between cover data and percent composition by weight from sampled sagebrush sites (See dry weight rank data collection CH1; Table 2.2). Estimates of visual obscurity and sagebrush height were derived from photographs taken of the stony loam ecological site (Roath, personal communication, February 2011).

Riparian plots. Ten randomly selected plots were established along the streams in the study area. Two stratification levels for plot selection were applied, open tree canopy and closed tree canopy, but these strata were applied for a different project and were not considered for this evaluation. Three transects were ran perpendicular to stream reach and spaced 15m apart. Length varied based on floodplain width. Visual obscurity was estimated along the outer two transects in the floodplain area at 15m from the greenline for a total of four points per plot. Estimates were obtained at an eye level of 1m at 4m towards the stream, downstream, away from the stream, and upstream. Shrub measurements (long axis, short axis, height) and shrub species composition were gathered at the two ends of the center transect. Points usually began at 15 meters from the greenline and ended at 10 meters from the greenline. Five sample points of 1.4 square meters each were recorded on each end of the transect for a total of ten points with a total area of 14 square meters. Canopy cover was estimated as the percent of sampled area taken up by shrub canopy area. Shrub summaries excluded non-mature shrubs (shrubs without woody main stems and/or flowering parts). Plant cover by species was measured using the line point intercept method along each perpendicular transect. The flood plain area was sampled at 1m intervals. Data for the riparian areas consisted of the flood plain measurements averaged across all plots.

Models

Fuzzy logic was used for knowledge representation in this study due to its ability to incorporate empirical knowledge to produce a relative measure of the provisioning of wildlife habitat in the context of STMs. The Netweaver™ modeling interface and engine developed by Saunders and Miller (1999) was used for constructing and evaluating the knowledge-based systems.

Elements in Netweaver™ consist of well-defined terminology. For simplicity, the terminology used here is defined as follows. A network represents the habitat suitability model for a specified species and life stage. A network is a collection of objects that represent habitat elements. The habitat elements were structured in terms of forage and cover. Forage and cover were further defined by sub-networks. For example, a network may be sage grouse breeding habitat consisting of the two sub-networks of forage and cover. Within each sub-network, a collection of objects such as sagebrush cover, shrub height, etc. were linked by one or more operators to define the logic with which to evaluate the network. Each of these objects represents real-world data, thus they are referred to as data links. Operators are used to express the relationships between two or more objects or data links. Degree of membership specifications (Fig. 1.1), within each data link defined the habitat suitability for each value of the data link.

Fuzzy logic degrees of membership may be interpreted in a way that is meaningful to the modeling problem (Reynolds 2001). The degrees of membership were purposefully scaled from 0-1, with 0 representing low suitability and 1 representing high suitability. The 0-1 scaled results of the model will hereafter be referred to as the suitability values. The models were developed using the best available knowledge (described in the following sections). In cases where only a minimum value of a variable is applicable, the graphs representing the degrees of membership for a data link are linear from 0-1 and then truncate at 1 on the y-axis at the level of the independent variable that is associated with the minimum requirement. For example, visual obscurity for sage grouse habitat is defined as a visual obscurity reading of 32 cm. At 0 on the x-axis, this corresponding y value is 0, at 32 on the x axis; the corresponding y value is 1. For higher values of visual obscurity, the corresponding y value is still 1. For the following discussion, such a data link is described as having data points of ((0,0), (32,1)). The calculation of habitat suitability values for linear data links as just described, is represented by equation 2.1 where $\mu(x)$ is the habitat suitability value, x is the value of the data link, a is the lower bound value of the data link, and b is the upper bound value of the data link. Following the mule deer visual obscurity data link example with data points of ((0,0), (032,1)), a=0, b=32, and x equals the visual obscurity estimate for a given plot. The sagebrush canopy cover data link (Fig 2.3.) would be described as having data points of ((0,0), (15,1), (25,1), (70,0)). This is a truncated habitat suitability function where it is assumed that there are lower and upper bounds on the value. The calculation of habitat suitability values for truncated curves is represented by equation 1.3. Following the sagebrush canopy cover example, a=0, b=15, c=25, d=70, and x equals the percent sagebrush canopy cover for a given plot.

$$\mu(x) = \begin{cases} 0, & x \leq a \\ 1 - \frac{b-x}{b-a}, & a < x < b \\ 1, & x \geq b \end{cases} \qquad \text{Equation 2.1}$$

$$\mu(x) = \begin{cases} 0, & x < a, x > d \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b < x < c \\ \frac{d-x}{d-c}, & c \leq x \leq d \end{cases} \qquad \text{Equation 2.2}$$

The operators used in the models were all AND operators. This is a limiting-factor weighted average operator used to express the dependence of the sub-network on the provisioning of each data link and the dependence of the overall habitat suitability on the provisioning of forage and cover. This operator is used to express the assumption that habitat elements are not compensatory. In other words, a high value of one habitat element cannot substitute for a low value of another habitat element, as would be the case with a simple average. Equation 2.3 expresses the operator in fuzzy terms and equation 2.4 expresses the operator in arithmetic terms. For equation 1.3, AND(t) represents the value of habitat suitability for the sub-network or network, min(t) represents the minimum habitat suitability value of the data links or cover or forage sub-networks, and average(t) represents the simple average of the habitat suitability values of the data links within a sub-network or the simple average of the cover and forage sub-networks.

$$\mu A \cap B(x) = \min\{\mu A(x), \mu B(x)\}, I \epsilon X \qquad \text{Equation 2.3}$$

AND(t) = min(t) + [average(t) - min(t)]*[min(t)+1]/2 Equation 2.4

Sage Grouse Breeding Habitat. Breeding habitat is defined by Connelly et al. (2000) as areas of potential lek attendance, pre-laying hen, nesting, and early brood-rearing habitat. Hens often use resources near potential nesting sites for pre-incubating nutrition and thus it is an important consideration for breeding habitat management. Nesting habitat is an important an consideration in breeding habitat management due to the risk of nest depredation and early chick-rearing habitat is considered within the breeding habit requirements because chicks are limited in mobility to the resources within the immediate vicinity of the nesting habitat.

Recommended cover for nesting sage grouse is sagebrush cover at 15-25% (Connelly et al. 2000). A meta-analysis by Hagen et al. (2007) reports a range of shrub coverage used during this time period. The highest is 59% (Sveum et al. 1998). This value was estimated in small areas (1-m^2) around a nest. When shrub coverage was measured in larger areas in the nesting habitat, which would be more comparable to the methods of shrub estimates used for this study, the shrub estimates generally fell within the range suggested by the sage grouse guidelines. This study also reported that successful nest sites (1-m^2) in the big sagebrush community had lower shrub cover (51%) than depredated nests (70%). It is therefore assumed that sagebrush canopy cover around 70% in nesting areas has little value to sage grouse. A sagebrush canopy cover data link was included in the model with the following points((0, 0), (15, 1), (25, 1), (70, 0)). Shrub height in successful nesting habitat is 40-80cm (Connelly et al. 2000). The average sagebrush heights by state were examined for potential issues with maximum values. The greatest value for height fell below the recommended 80cm, therefore a maximum value was not accounted for in the model. A sagebrush height data link was included in the model with the following points: ((0, 0), (40, 1)). The sage grouse guidelines suggest maintaining grass height at > 18cm. A preliminary assessment of grass height at plots showed that height was consistently greater than 18 cm. Therefore, instead of grass height, visual obscurity was measured as an indicator of screening cover. While many authors report visual obscurity results at successful nest sites, the exact procedure for measurement varied. Sveum et al. (1998) report results from a sage grouse nest study where visual obscurity was measured using the same procedure and is significantly different between nest and random sites for two years. The results from 1996 (VO= 32cm) were used for this model because the sample size was higher than the previous year results. The visual obscurity data link was created with the following data points: ((0, 0), (32, 1)). The sage grouse guidelines recommend grass cover of >15%. The importance of grass for cover is well-established. The perennial grass cover data link was created with the following data points ((0, 0), (15, 1)).

Sage grouse diets during pre-incubation consist primarily of sagebrush and forbs. Gregg, Barnett, and Crawford (2008) found that forbs comprised 30.1% and sagebrush comprised 65.7% of hen diets during pre-incubation. Connelly et al. (2000) recommend at least 10% forb cover and 15% sagebrush cover for this time period. Forbs are also an important component of the chick's diet during early brood rearing (Drut, Pyle, and Crawford 1994). Huwer et al. suggested that forb cover of ≥20% may lead to increased survival and productivity. The 20% guideline is also supported by Schroeder (1995) and Sveum et al. (1995, 1998). Due to this evidence, and the fact that the sage grouse guidelines recommend that forb coverage should exceed 10%, the 20% optimum value for forb cover was used. It was assumed that a site that meets the recommended forb cover where the forb species are palatable to sage grouse, is more valuable than a site that meets the recommended forb cover where the species are unpalatable. Each forb species in the cover data was categorized as palatable or unpalatable using information from Huwer (2004) and Bird and Schenk (2005). The percent of palatable forbs was calculated by dividing the percent cover of palatable forbs by the total cover of forbs. Thus, the forage sub-network consisted of a sagebrush canopy cover data link ((0, 0), (15, 1)), a perennial forb cover data link ((0, 0) (20, 1)), and percent palatable forbs data link ((0, 0), (100, 1)).

Sage grouse habitat during the modeled time periods, generally occurs on slopes < 15% (Rothenmaier 1979, Hausleitner 2003). Schroeder (1997) found that sage grouse eggs rolled out of the nest at a slope of 35 degrees; this value was used as the upper threshold for slope. The slope data link consisted of data points ((0,1), (15,1), (35,0)).

Sage Grouse Winter Habitat. Connelly et al. (2000) recommended sagebrush canopy cover of 10-30% with heights 25-35 cm exposed above snow during the winter which provides forage and cover (Patterson 1952, Wallenstad and Eng 1975, Remington and Braun 1985). The sagebrush canopy cover data link had data points of ((0,0), (10,1), (30,1), (80,0)). Because these habitat characteristics provide both forage and cover, the habitat model was developed using one network which was not further defined by sub-networks. The 100 year average snow depth across December through February, at the Hayden, CO climate station, is approximately 30.5cm. Snow depths in the area can exceed 100 cm, thus an upper limit on sagebrush height was not included. A shrub height data link was created with data points of ((30.5, 0), (55.5, 1)).

Hupp and Braun (1989) found that sage grouse used either drainages or slopes with south and west aspects for winter habitat. Schoenberg (1982), and Remington and Braun (1985) also found that sage grouse used drainages and draws during winter. Beck (1977) found that sage grouse used flat areas during winter. Most likely, these discrepancies are due to snow depth and sagebrush taxa differences (Hupp and Braun 1989). In years of high snow depth, drainages and wind-swept ridges may be the only source of exposed sagebrush. The southwest exposures receive higher solar radiation which exposes sagebrush and assists in sage grouse temperature regulation. During periods of low snow depth, sage grouse are less likely to be driven to steep slopes and drainages to find food sources. These considerations were included in the model where the highest value was selected from the following choices: Southwest aspects ((0,0), (1,180), (1,270), (0,360)) with slopes greater than 5%, drainages (derived from hillshade where value >200), or slopes of less than 5%.

Spatial Data and Map Production

The SSURGO database for Routt county was obtained from the USDA NRCS Soils Data Mart (Soil Survey Staff, NRCS, USDA 2010). A SQL query was run in Microsoft Access to create a table of ecological site classifications and associated identifying spatial unit. This table was joined in ArcGIS to the soils spatial data to produce an ecological site layer. The 20,000 ha area of interest was clipped from the county database. Ecological site classifications of interest were assessed for correctness by validation with assumed type through aerial photography. Agricultural fields were most poorly represented and were digitized based on aerial photography. A few extremely small areas of land were classified as ecological sites such as salt flats, where inadequate information was available to assess them. These areas were re-classified to the largest surrounding ecological site classification.

Digital elevation models were obtained from the USDA, NRCS Geospatial Data Gateway (Soil Survey Staff, NRCS, USDA 2010). Slope, hillshade, and aspect were derived from the elevation data using spatial analyst (ArcGis 9.3.2). Data were converted to integer rasters with a cell size of 30 meters and were displayed in the NAD 1983 coordinate system Zone 13N. Data were then converted to feature format and a spatial join was used to create one layer of data with information on ecological site, slope, hillshade, and aspect. A table join was used to assign each cell, by ecological site, the value of each variable in the habitat models for the associated states or ecological sites of interest. The agricultural fields were assigned values from the planted grassland state. The riparian data were used to classify the streams by vegetation characteristics. Stony loam sites were assigned the derived range site description variables. Two sets of data for the mountain loam and claypan sites. One of the data sets contained the values of the reference state variables and the other data set contained values from the degraded state variables. The habitat models were run on each of the spatially joined feature dbf files. These data were re-imported into ArcGIS and linked to the original file so that the habitat suitability could be displayed. Raster datasets of the habitat suitability values were output at the 30 m cell size in order to reduce pixilation (Fig. 2.4). The SWReGAP (USGS National Gap Analysis Program 2004, Boykin et al. 2007) and CDOW (2010) vegetation and habitat maps were created by clipping the spatial vegetation classification and habitat distribution data to the study area of interest.

RESULTS and DISCUSSION

The SWReGAP vegetation map (Fig. 2.5) was the basis for the sage grouse habitat map (Fig. 2.6) because the habitat was mapped by wildlife habitat associations. The CDOW land classification map (Fig. 2.7) did not contribute to the sage grouse production (Fig. 2.8) or sage grouse winter range (Fig. 2.9) maps because these were based on sage grouse lek, and winter range locations, respectively. The ecological site map (Fig. 2.10) contributed to the sage grouse breeding and winter habitat suitability maps for reference (Figs. 2.11 & 2.12, respectively) and degraded states (Figs. 2.13 & 2.14, respectively) of claypan and mountain loam ecological sites.

Land classification is important for land management and scientific inquires because they assist in creating a representative sample design and extrapolating the results of the study to make conclusions about how a specific unit of land operates. These classifications can also assist in identifying the distribution and abundance of wildlife habitat. Several methodologies are currently in place for land classification and 2 prominent classifications were assessed for this study.

The SWReGAp method mapped wildlife habitat by wildlife habitat associations. The assumptions of this model are that 1) Species are assumed to occur within a polygon representing potential habitat but are not predicted to occur at any particular point within that polygon. 2) Species are assumed to be present within a polygon, but no assumptions are made about the abundance of the species in the polygon. 3) Species are assumed to be present in a polygon at least once in the last 10 years but need not be present every year in the last decade. 4) Species are assumed to be present during some portion of their life history, not necessarily during the entire year (Boykin et al. 2007). This method produces a map representing the potential abundance and distribution of habitat but does not incorporate, or provide an opportunity to incorporate, an output of the differences in habitat suitability based on changes in variables such as precipitation and grazing. Such variables can result in large-scale changes in the suitability of wildlife habitat for a given species.

The CDOW method used animal locations to map wildlife habitat. The sage grouse production habitat map was produced by mapping a 2 mile radius around known lek locations. The production habitat area is defined as an area that would include a majority of important nesting habitat. However, nest site selection is independent of lek location (Connelly et al. 2000, Wakkinen et al. 1992). Further, the identified habitat of importance is mapped over habitats not used by sage grouse such as brushy loam ecological sites. Additionally, animal locations, such as sage grouse lek locations, may be related to factors that are not associated with high quality habitats that contribute to successful populations. For example, Crawford et al. (2004) summarized literature on sage grouse habitats. Lekking habitat is described as sparsely vegetated areas with low or absent vegetation canopy. There is no evidence that lekking habitat is limiting. In contrast, habitats used during the pre-laying, nesting, and early brood rearing seasons consist of key forbs, and relatively high grass and sagebrush cover. It has been proposed that such habitats are a limiting factor for sage grouse production (Heath et al. 1996). Therefore, habitat attributes such as forb, grass, and sagebrush cover should be considered when mapping habitat for production life stages of sage grouse.

This study used ecological site classifications which also incorporate STMs to further describe changes in communities based on variables such as environment and management. A robust habitat model based on peer-reviewed literature was applied to hypothetical state occurrences on two ecological sites. The results of this work show that ecological sites, by incorporating a more detailed framework of vegetation change, can provide more information about the suitability of wildlife habitat. Further, this methodology can produce maps which depict temporal differences in sage grouse habitat. Additionally, when ecological sites of interest were mapped as degraded states there were visible reductions in relative habitat suitability when compared to the reference states. It should be noted that for winter habitat, the reductions for the degraded states were less obvious because sage grouse rely on sagebrush for forage and cover during winter. The degraded states used here have high densities of sagebrush. The more obvious reductions for the degraded states in the breeding habitat model are due to the reductions in understory herbaceous components which are vital for sage grouse forage and cover during that time period.

The ecological site layers are formed by linking soil types of similar ecological potential. These soil types were mapped by the National Soil Survey which predicts soil occurrences by a using a methodology that considers soil-landscape relationships, stratigraphy, parent materials, and site history. Field locations are typically used to characterize ecological potential of sites (Soils Survey Staff, NRCS 2011). The SWReGAP method used Landsat imagery, ancillary data, and field locations to develop their land cover map (Lowry et al. 2007). The CDOW method used Landsat imagery to create land polygons, and literature, existing maps, and field locations to develop their land cover map (Schrupp et al. 2000). Because ecological sites are combinations of soils types, the ecological site maps are more general. The Landsat imagery classification use for the SWReGAP and CDOW methods resulted in smaller polygons of vegetation types. These smaller polygons may represent the heterogeneous nature of landscapes better. However, these methods do not link ecological theory with drivers of change such as management. A disadvantage to applying the ESD and STM frameworks to wildlife habitat mapping is that states are not spatially represented by available data. Remote sensing methods or resource inventories would need to be used in order to determine the spatial extent of states within ecological sites. However, the benefit of the ecological site approach is that it links land classification to ecological theory to provide a tool for adaptive management.

CONCLUSION

Ecological sites are a valid and useful land classification methodology. By incorporating STMs, the ecological site framework allows for investigations of wildlife habitat to include information on vegetation dynamics and the drivers of ecological change. This methodology is sensitive enough to display reductions in habitat suitability when ecological sites are in degraded state.

The data used to classify the ecological sites in terms of habitat variables was not consistent across ecological sites. However, the purpose of this work was to demonstrate the applicability of the tools towards assessing landscape-scale habitat. Additional work should be conducted to integrate animal use locations with habitat suitability in the ecological site and STM framework in order to validate these findings. To accomplish this, states should be interpolated within ecological sites and re-assessed on a time period corresponding with management decisions or state transitions. A habitat assessment approach similar to Aldridge and Boyce (2007) should be used in order to assess the conditions within a state that are related to habitat preferences and quality as well as habitats where fitness is maximized. While this study did not incorporate these procedures, it provides evidence that the integration of the ecological site and STM frameworks can contribute to visualizing the distribution, abundance, and suitability of habitat.

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Table 2.1. Data used to characterize ecological sites for sage grouse breeding and wintering habitat maps[1].

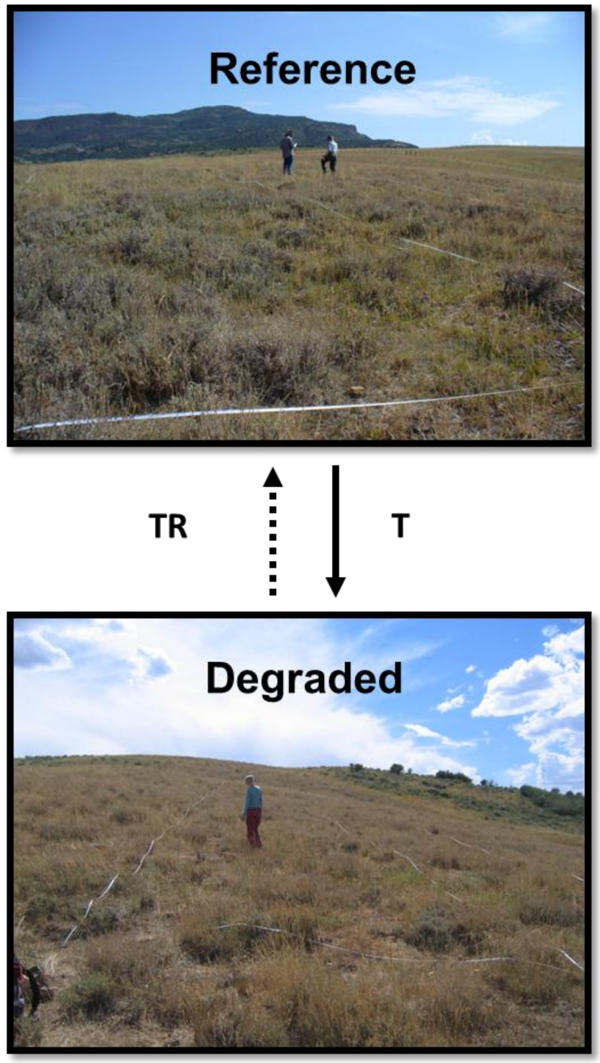
Ecological Site/ State	Perennial Grass Cover	Perennial Forb Cover	% Palatability Forbs	% Sagebrush Cover	% Sagebrush Height	Visual Obscurity
Reference Claypan	26.21	20.09	75.35	13.08	24.23	0.1
Degraded Claypan	9.75	6.62	35.56	39.12	19.11	0.1
Reference Mountain Loam	22.47	28.51	58.98	14.63	54.25	0.25
Degraded Mountain Loam	19.12	12.24	36.12	52.48	66.89	0.48
Deep Loam	25.5	11.94	56.65	14.37	51.55	0.19
Hayfield	30.67	15.73	73.52	2.2	10.54	0.25
Riparian	31.77	16.39	54.7	2.75	57.6	0.39
Stony Loam	34.42	16.57	80.2	3.02	30	0.25

[1]Two sets of maps were produced where one set was characterized by claypan and mountain loam reference state data, and the other with claypan and mountain loam degraded state data. All other ecological sites used the same data for both maps. Claypan, mountain loam, deep loam, riparian, and hayfield data were characterized using collected field data. The stony loam ecological site was characterized by data derived from the stony loam range site description and photos of the ecological site.

Table 2.2. Regression equations used to derive cover values for habitat assessment from the range site description for stony loam.

Species	% Composition[1]	% Composition[2]	Intercept	Slope	R2	% Cover[3]
Bluebunch wheatgrass	20	15.04	0.16	0.27	0.85	4.21
Serviceberry	15	11.28	0.18	0.33	0.57	3.87
Needlegrass	15	11.28	0.19	0.67	0.89	7.73
Indian ricegrass	15	11.28	no data, used ACLE equation			7.73
Muttongrass	10	7.52	1.64	0.45	0.71	4.99
Idaho/Arizona fescue	10	7.52	low r2 (0.02), used POFE equation			4.99
Western wheatgrass	10	7.52	1.3	0.46	0.88	4.79
Bitterbrush	5	3.76	no data, used ARTR equation			3.02
Big sagebrush	5	3.76	0.29	0.73	0.92	3.02
Snowberry	5	3.76	0.45	0.47	0.88	2.21
Balsamroot	5	3.76	0.05	0.82	0.94	3.15
Paintbrush	5	3.76	no data, used LUAR equation			3.28
Lupine	5	3.76	0.61	0.71	0.84	3.28
Eriogonum	5	3.76	0.1	1.14	0.88	4.37
Phlox	3	2.26	1.04	0.64	0.21	2.49

[1]Percent composition from range site description. Value exceeds 100 because composition may total as much as value listed in column.
[2]Percent composition if total is 100%.
[3]Derived percent cover of species.

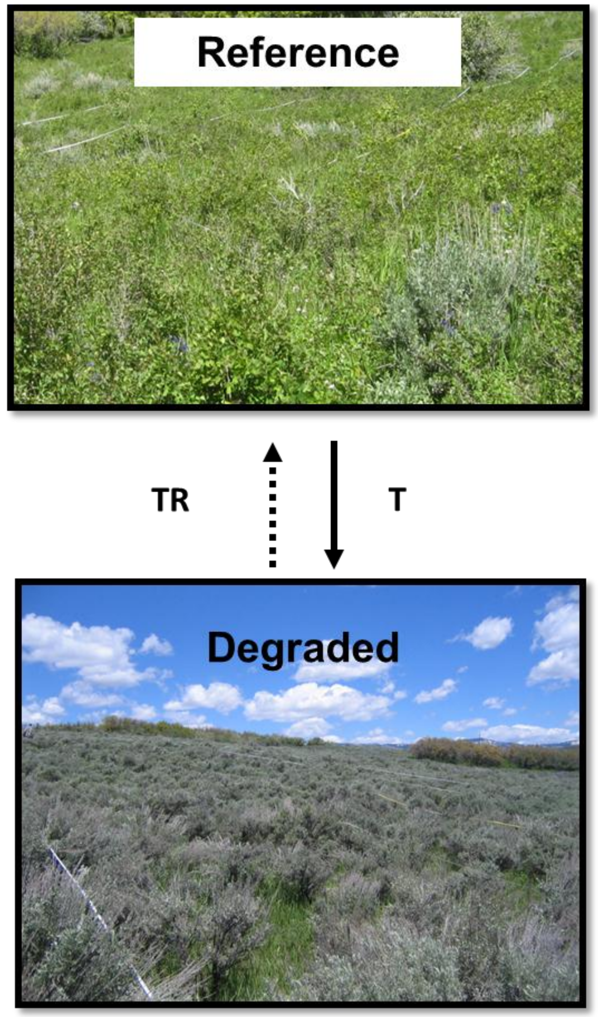


Transitions

T: A combination of high grazing pressure, drought, and/or fire reduce herbaceous plant cover, which triggers erosion on the site

TR: A combination of lower grazing pressure, favorable precipitation, and/or lack of fire increase herbaceous plant cover, reducing erosion on the site

Figure 2.1. Claypan state and transition model for the reference and degraded states only.



Transitions

T: Reduction of the herbaceous understory , caused by heavy (above NRCS-recommended) grazing and/or drought,
combined with lack of disturbance that reduces shrub cover (fire, herbicide)

TR: Disturbance that reduces shrub cover (fire, herbicide) combined with recovery of the herbaceous understory under lower grazing pressure and/or more precipitation

Figure 2.2. Mountain loam state and transition model for the reference and degraded states only.

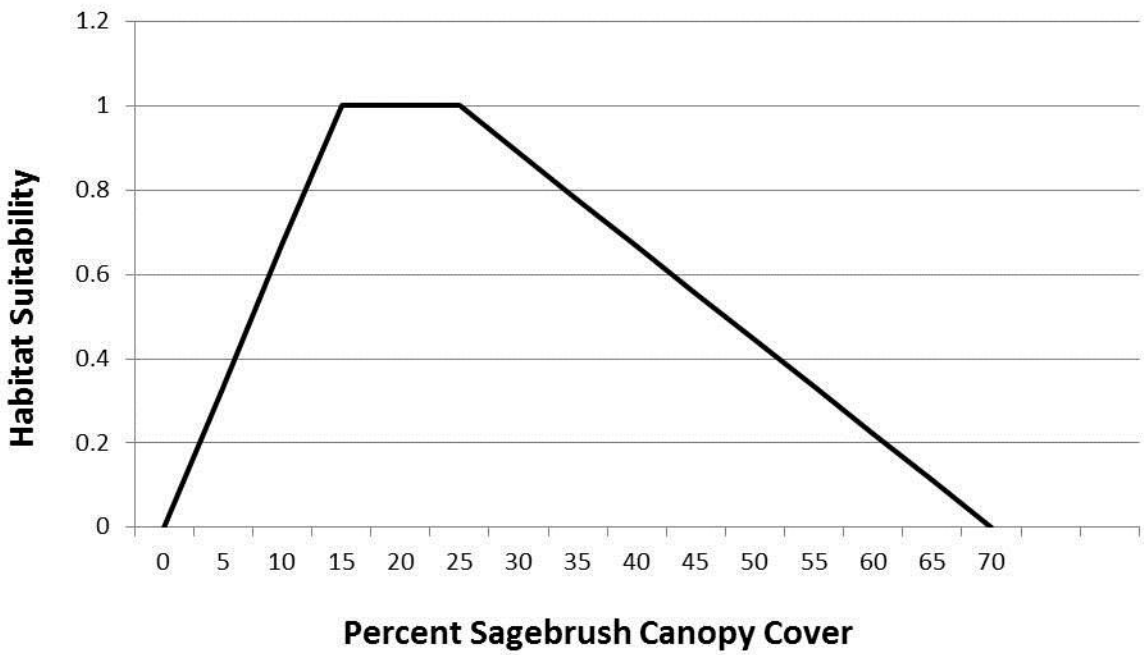


Figure 2.3. Fuzzy graph depicting habitat suitability (degree of membership) function for percent sagebrush canopy cover o*f br*eeding sage grouse.

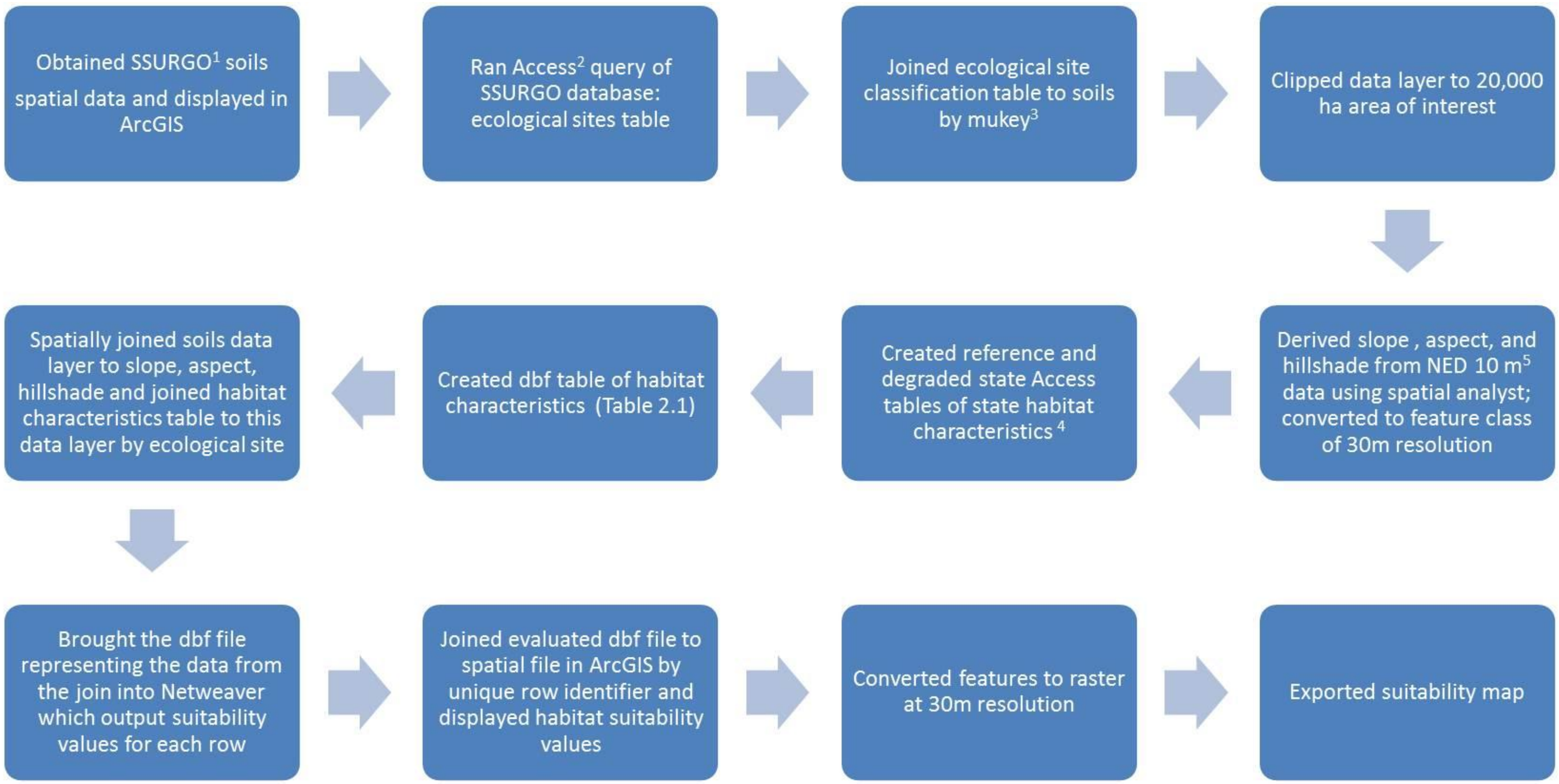


Figure 2.4. Flowchart of steps to create habitat suitability maps.

[1] Soil Survey Geographic Database for Routt County, CO NRCS, USDA

[2] Microsoft Access SQL Server Query

[3] Unique identifier of records in database

[4] Characteristics from vegetation measurements for represented state/ ecological site. One value for each habitat characteristic was assigned to each ecological site, values only differed for mountain loam and claypan where one table contained value for reference state characteristics and the other contained values for degraded state characteristics.

[5] National Elevation Dataset; data from NRCS, USDA Geospatial Gateway

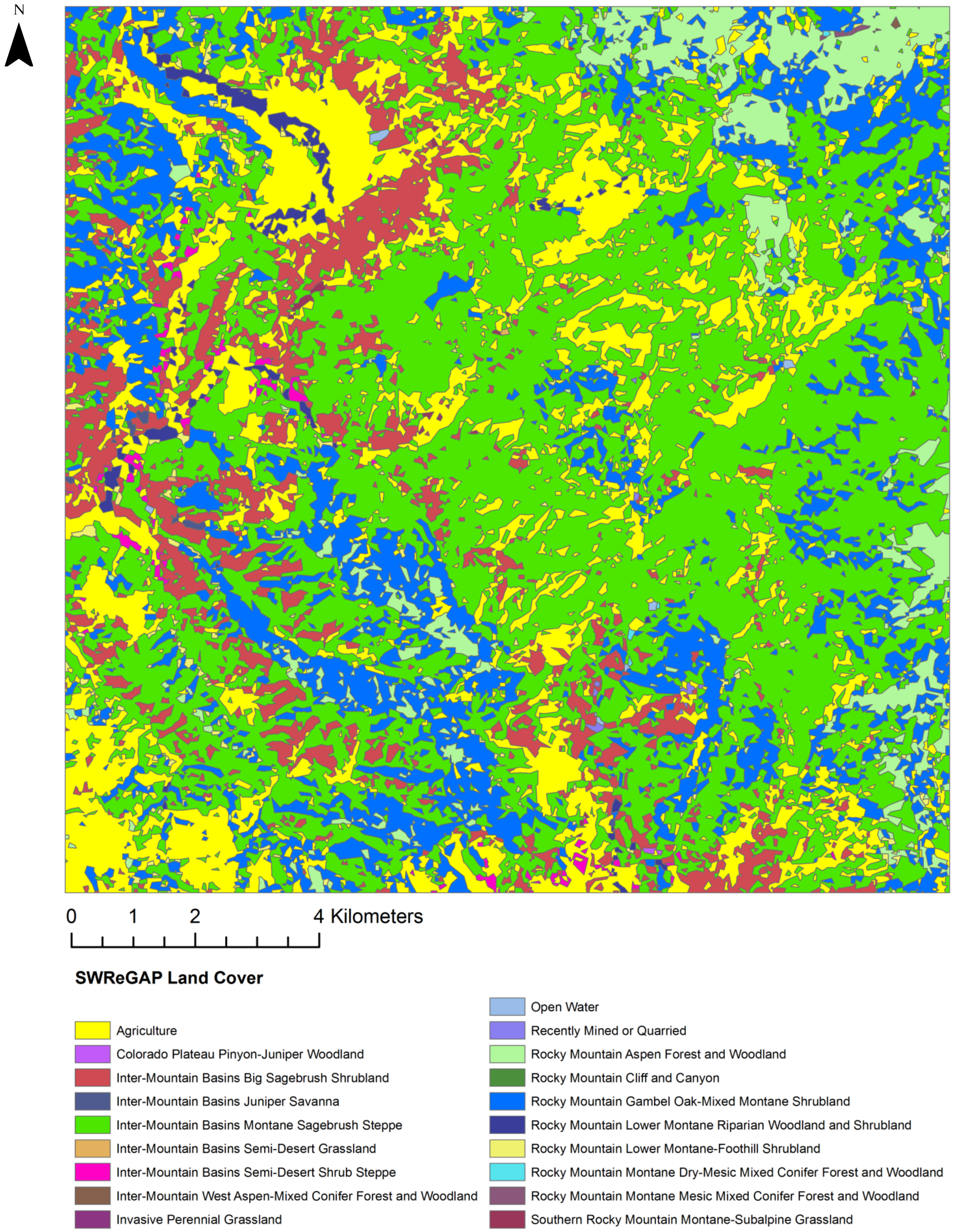


Figure 2.5. Southwest Regional GAP land cover classification for a 20,000 hectare portion of Northwest Routt county, CO.

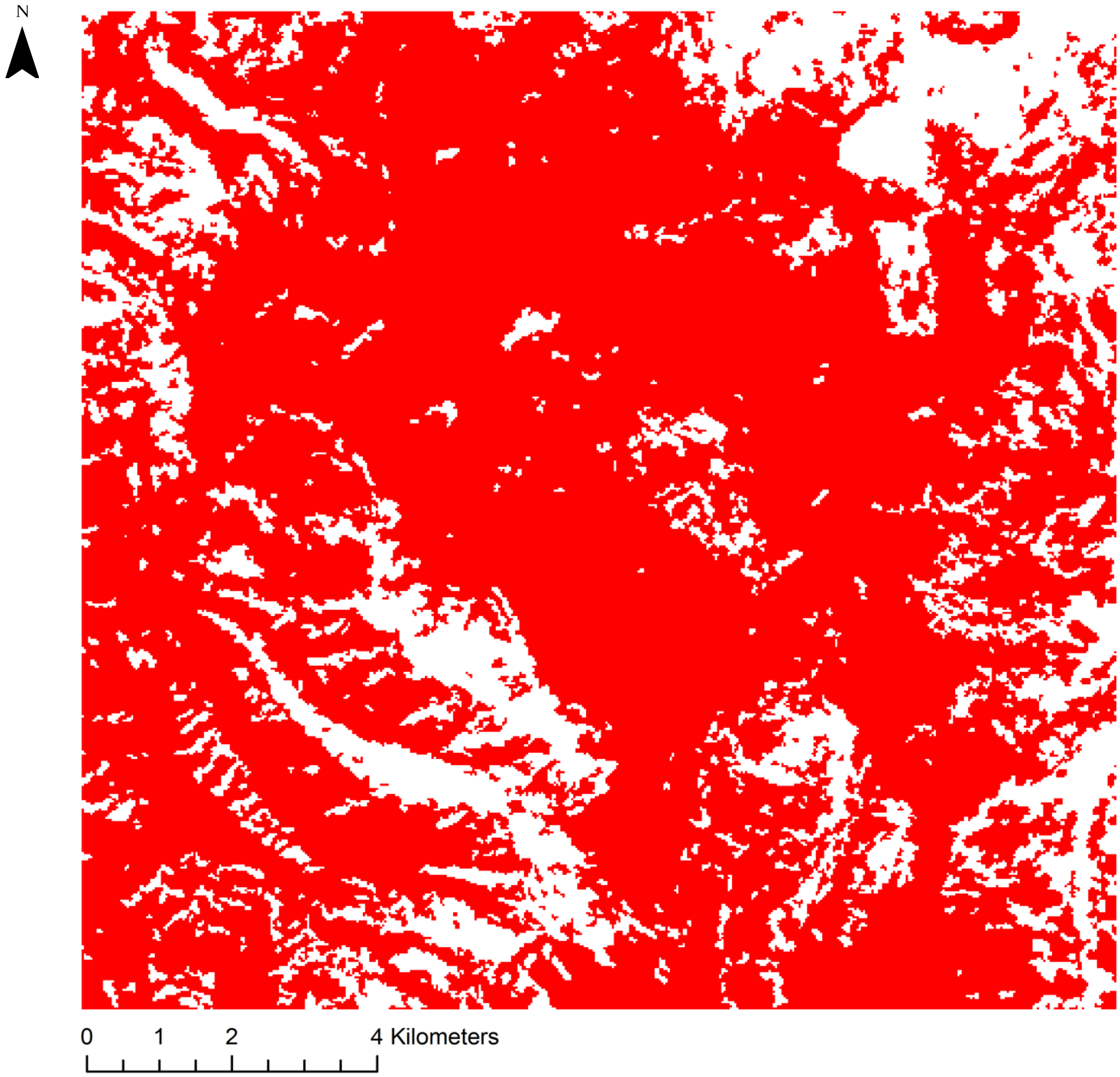


Figure 2.6. Southwest Regional GAP mapped sage grouse habitat.

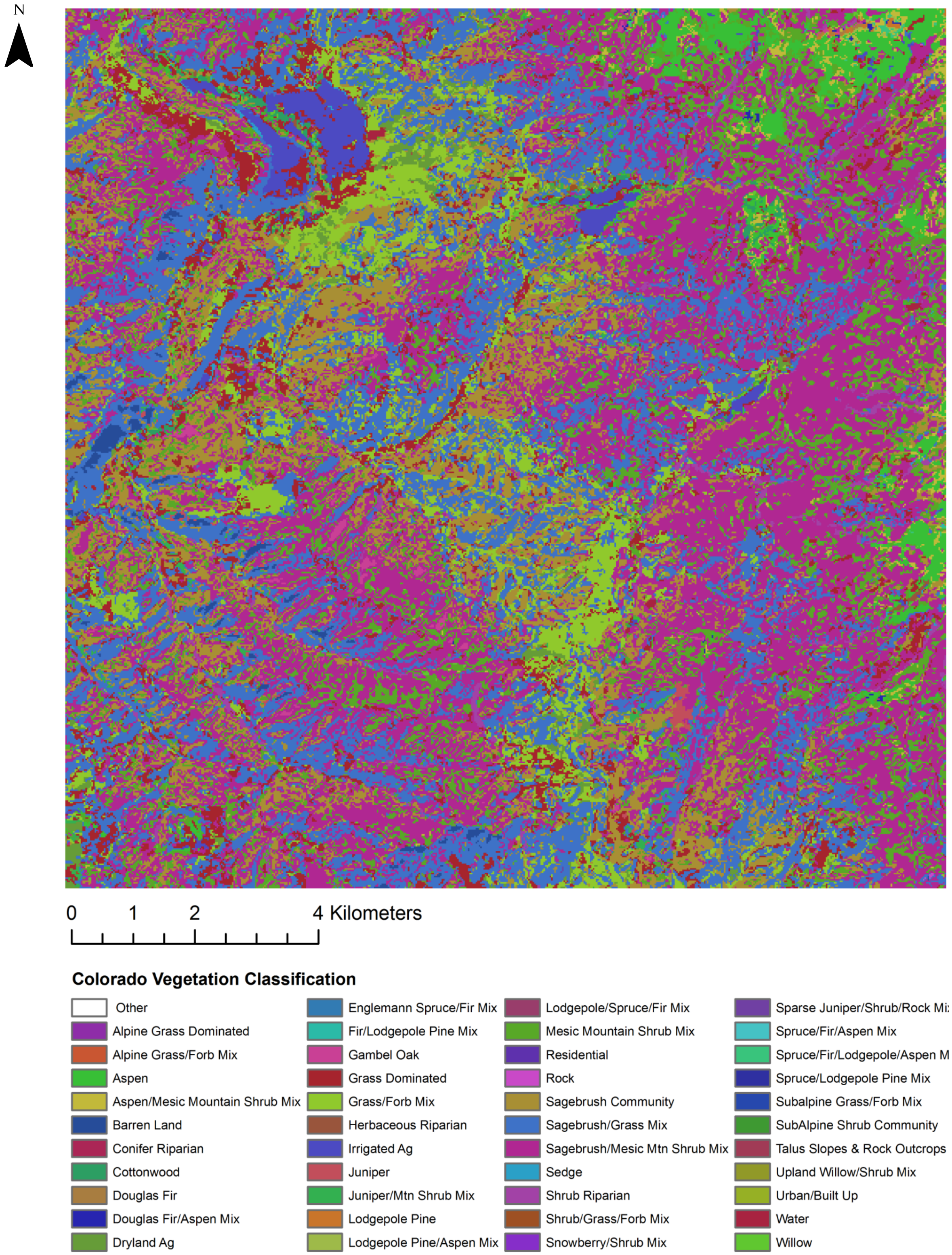


Figure 2.7. NDIS, CDOW Colorado Vegetation Classification for a 20,000 hectare portion of Northwest Routt county, CO.

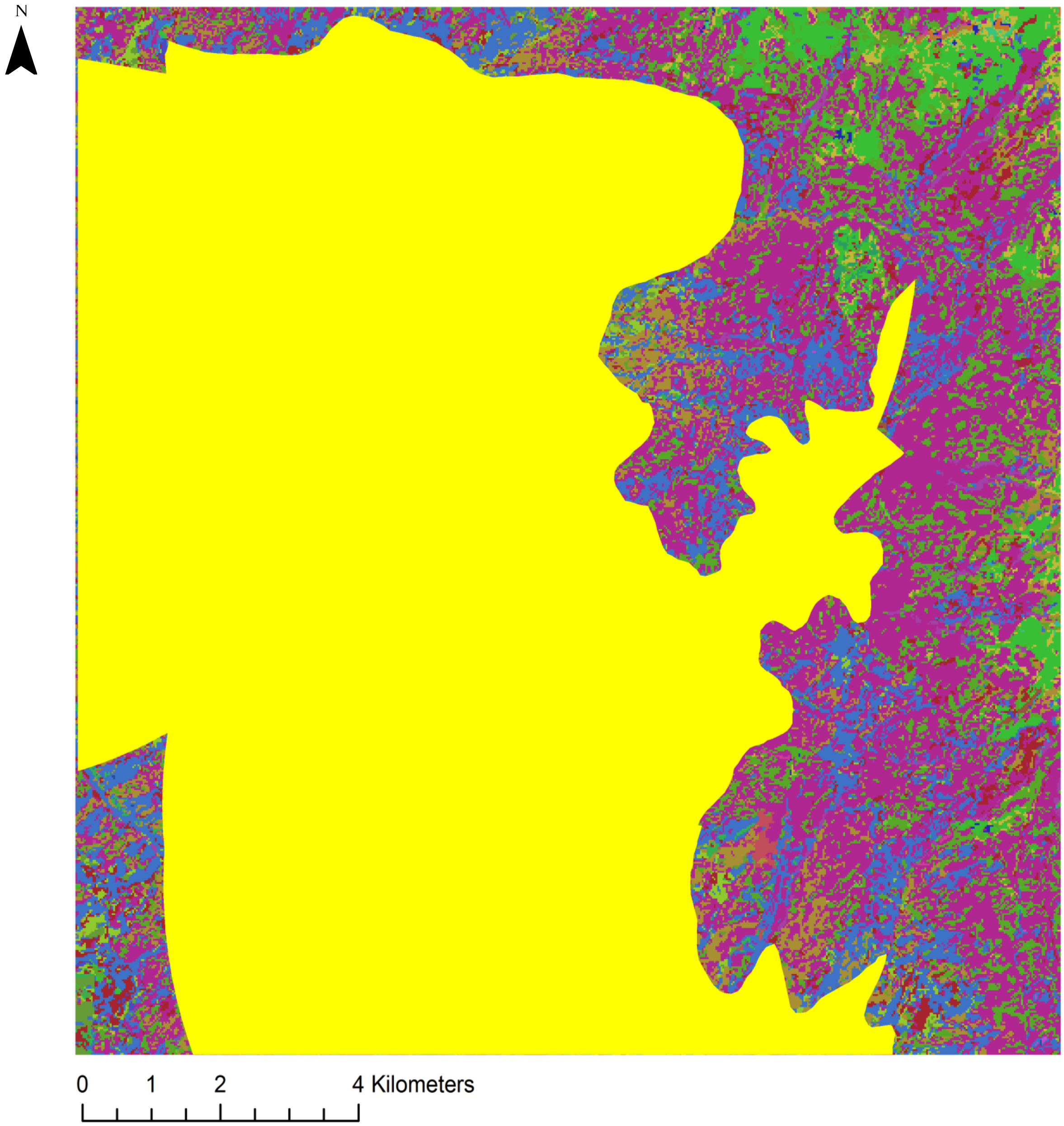


Figure 2.8. NDIS, CDOW sage grouse production area (yellow) displayed over Colorado Vegetation Classification land cover types 20,000 hectare portion of Northwest Routt county, CO.

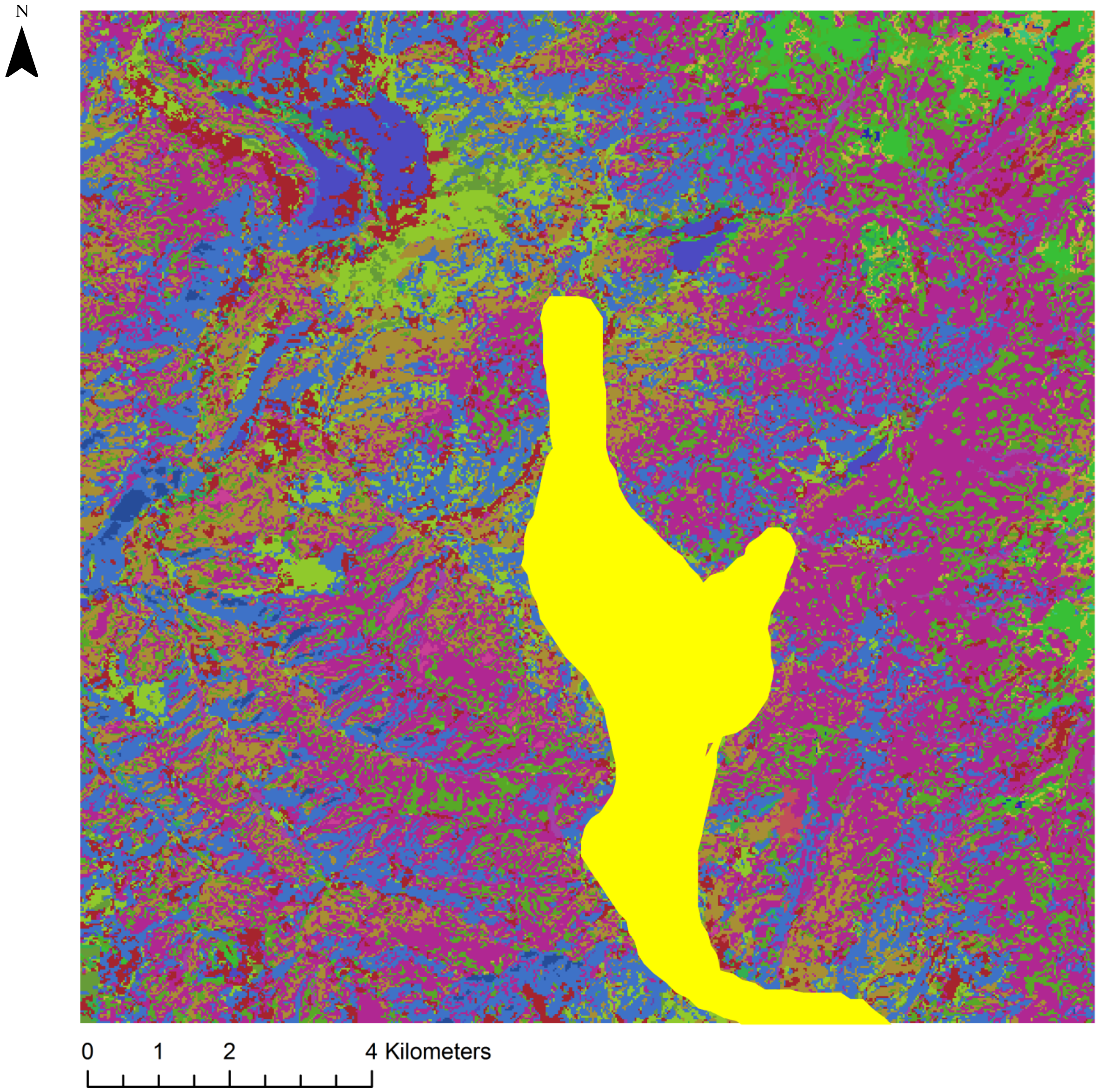


Figure 2.9. NDIS, CDOW sage grouse winter range (yellow) displayed over Colorado Vegetation Classification land cover types for a 20,000 hectare portion of Northwest Routt county, CO.

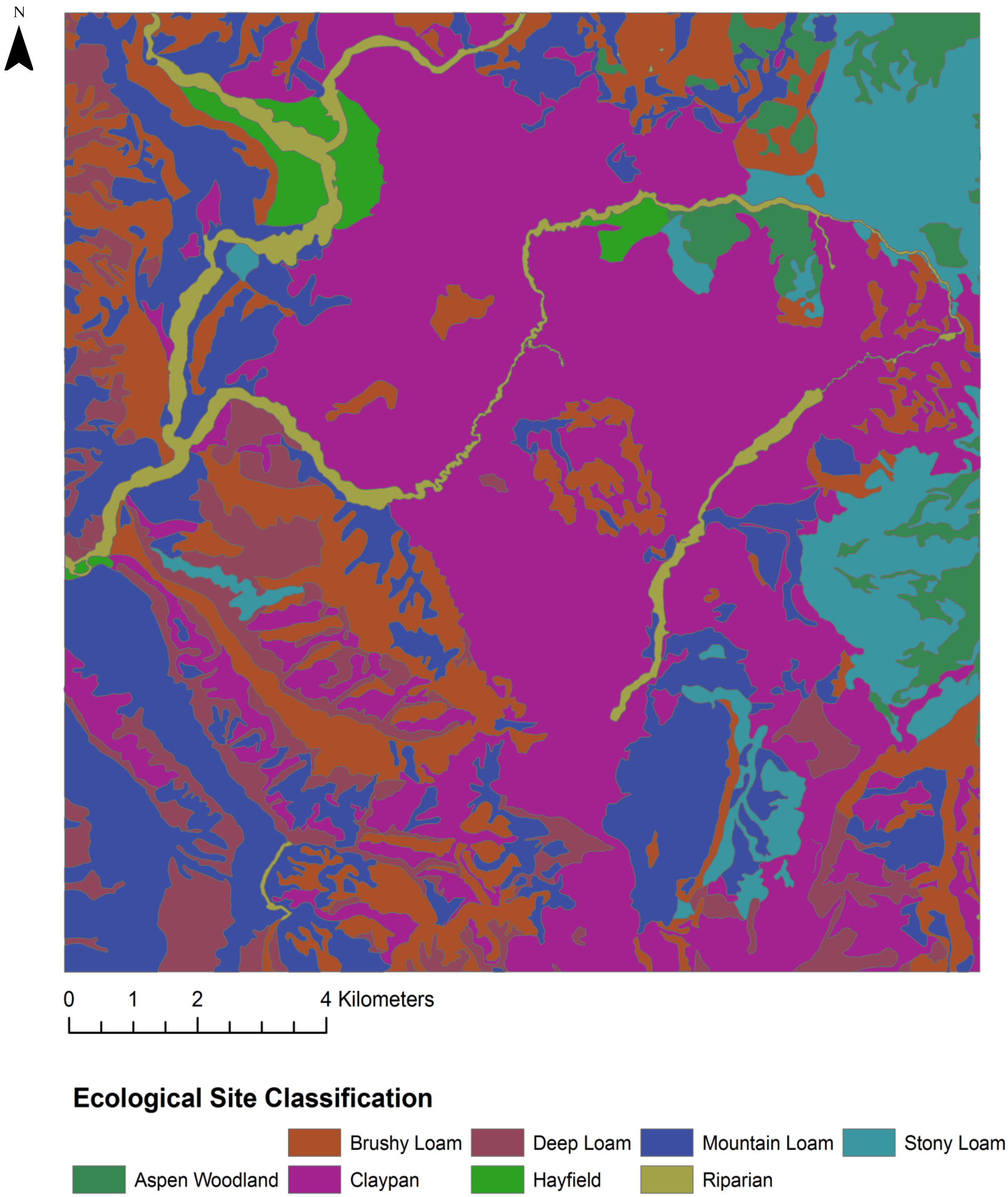


Figure 2.10. Ecological site classification for a 20,000 hectare portion of Northwest Routt county, CO.

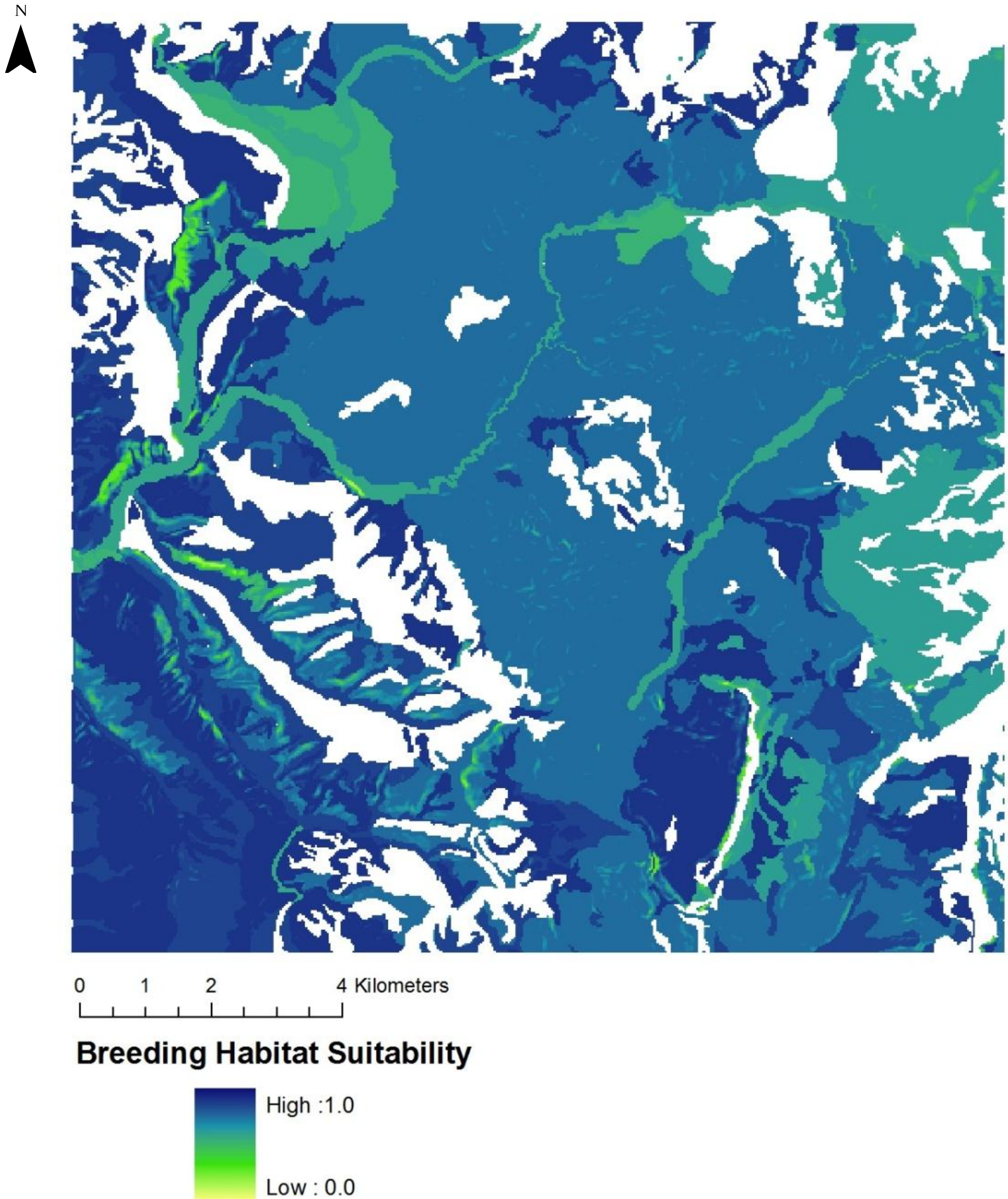


Figure 2.11. Fuzzy logic model output of sage-grouse breeding habitat for claypan and mountain loam references states on a 20,000 hectare portion of Northwest Routt county, CO.

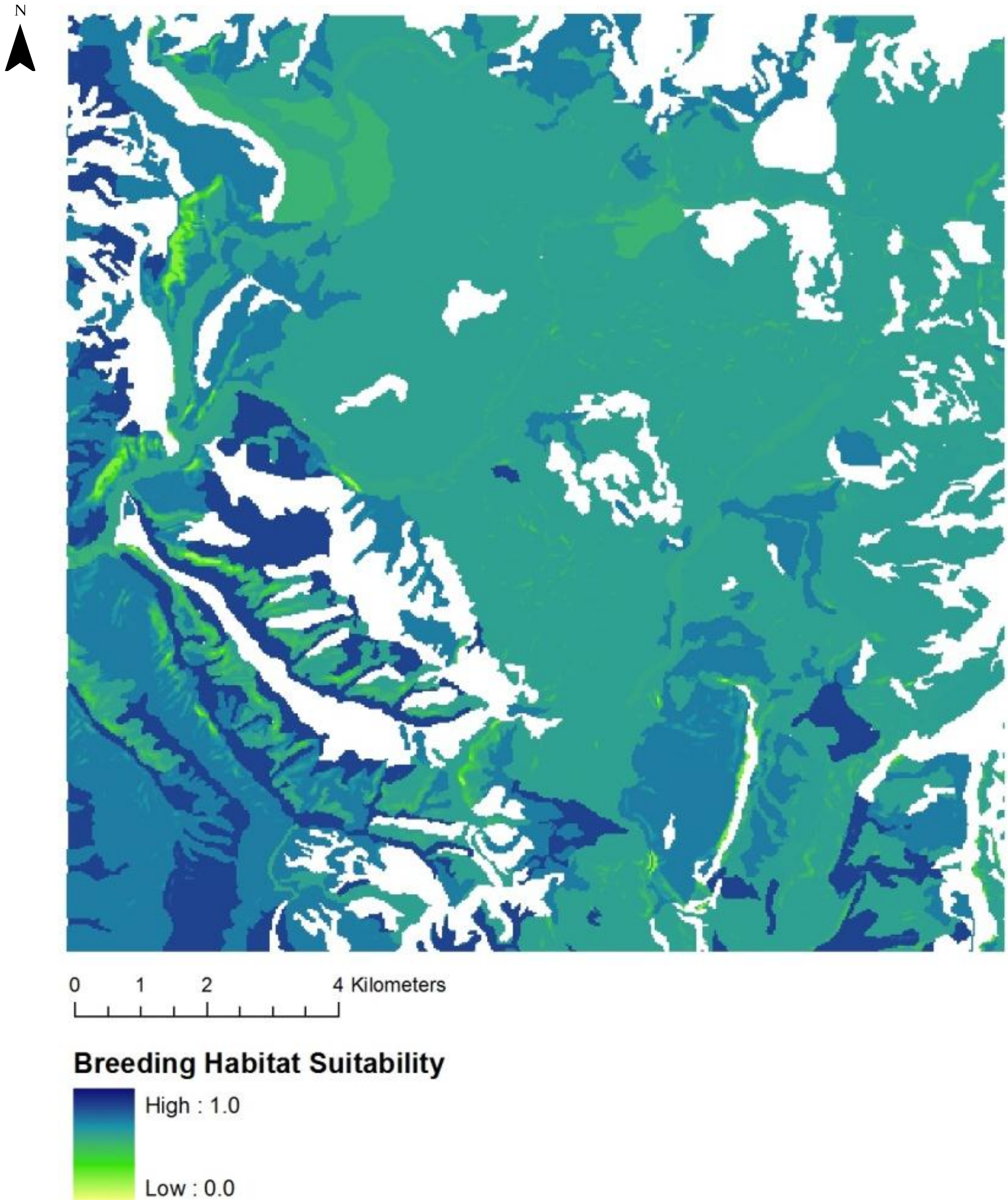


Figure 2.12. Fuzzy logic model output of sage-grouse breeding habitat for claypan and mountain loam degraded states on a 20,000 hectare portion of Northwest Routt county, CO.

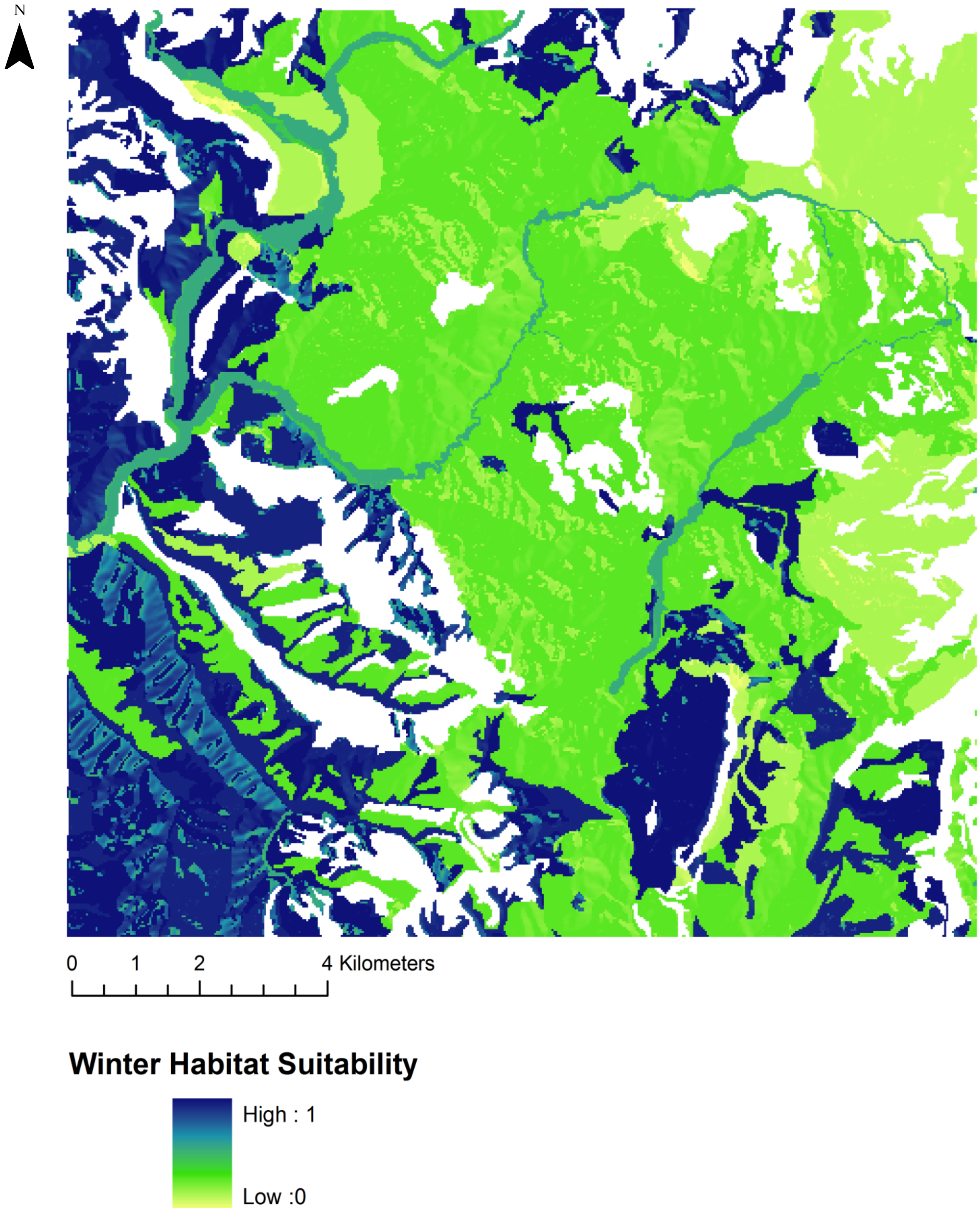


Figure 2.13. Fuzzy logic model output of sage-grouse winter habitat for claypan and mountain loam reference states on a 20,000 hectare portion of Northwest Routt county, CO.

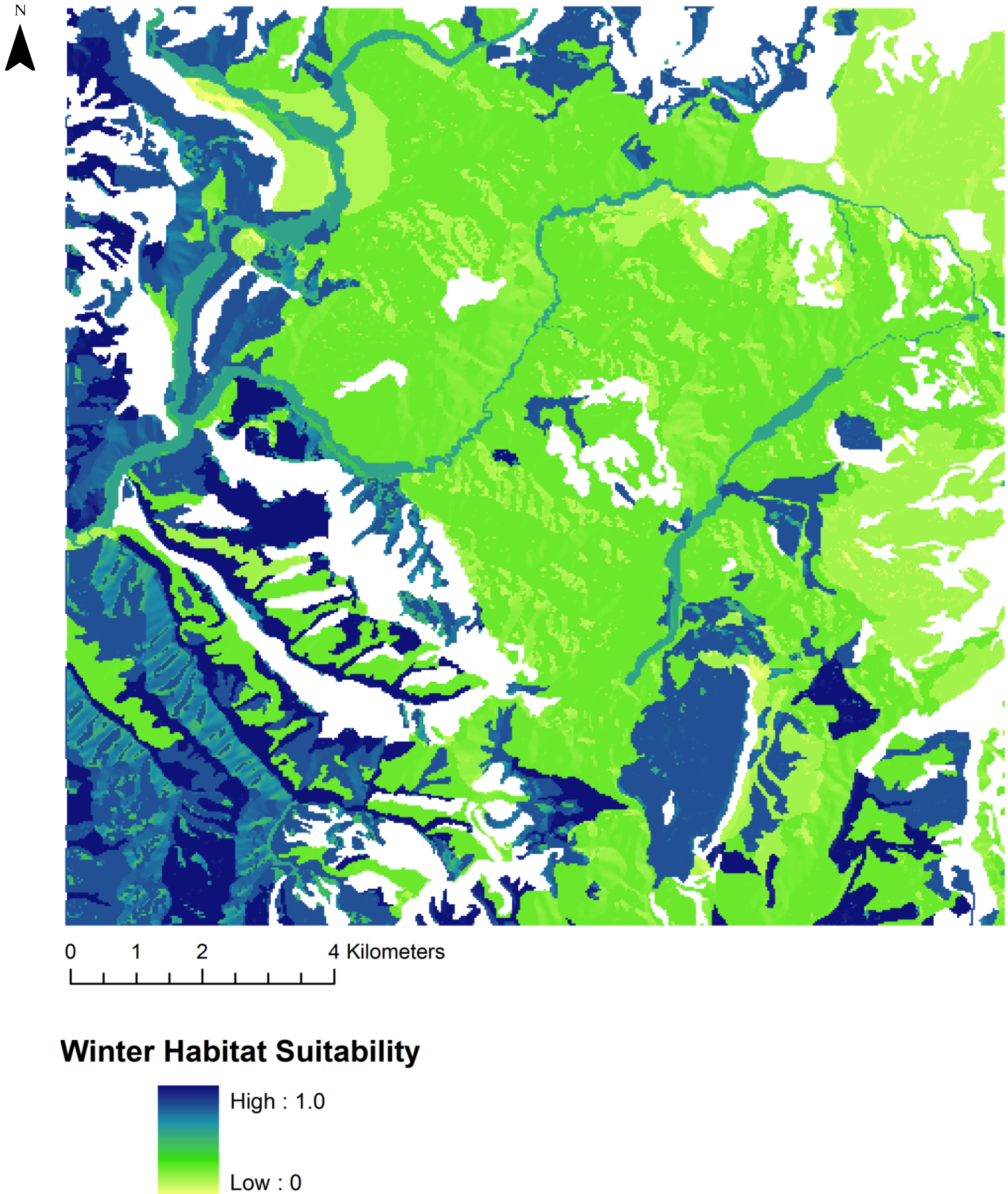


Figure 2.14. Fuzzy logic model output of sage-grouse winter habitat for claypan and mountain loam degraded states on a 20,000 hectare portion of Northwest Routt county, CO.

OVERALL CONCLUSIONS

Ecological site descriptions (ESDs) containing State-and-transition models (STMs) can organize complex information regarding multiple processes, ecosystem change, and the roles of management in directing the processes and change. Thus far, these frameworks have primarily contained information on plant and soils resources. Because management and environmental impacts on processes and change can also be linked to other ecosystem functions and resources, the ESD and STM frameworks can also be used for other assessments, such as wildlife habitat (Bestlemeyer et al. 2003). A fuzzy logic approach was used to build and evaluate wildlife habitat models for ESDs with STMs. This was an appropriate tool to assess wildlife habitat resources in this context because it allowed for a relative assessment in a non-spatial setting.

One of the criticisms of STMs is the lack of spatially explicit information. However, STMs are imbedded into ecological sites, which are the extent to which a STM can be mapped. Therefore, this approach incorporates the opportunity for spatial assessments. The fuzzy habitat models, ESDs, and STMs were applied to a hypothetical situation of managing a few ecological sites for reference versus degraded states. This approach allowed for an incorporation of factors such as environmental variation and management techniques into wildlife habitat maps. Other wildlife habitat mapping procedures, such as the Southwest Regional GAP analysis and the Colorado Division of Wildlife, map wildlife habitat in a manner that might display the potential distribution, abundance, and prominent animal use locations across the landscape. However, these approaches do not make the link between ecological theory and land management. Ecological sites and STMs could be important tools for landscape-scale assessments of wildlife habitat.

State-and-transition models have the potential to be used for spatial assessments. However, an advantage of STMs is that the non-spatially explicit nature of the model allows it to be applied to different land management units as opposed to a singular place at one point in time. Thus, this model can be adapted to land management units of varying size, purpose, and location. The ability to adapt this framework to both spatial and non-spatial assessments makes it a unique and powerful tool for land management and planning. This work is a valuable stepping stone for adding value to ESDs and STMs by incorporating wildlife habitat information and demonstrating the applicability of these frameworks to spatial and non-spatial assessments.

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APPENDIX A: ADDITIONAL HABITAT MODELS

Several additional models were built using Netweaver^{TM} as described in chapter 1 for the linked ecological-economic model of the overall project. This is a complete explanation of the structure, data used for the models, and habitat values for each model used in the linked ecological-economic models. Information on vegetation data collection methods is included in chapter 1. Model output was assessed to ensure calibration (Brooks 1997; refer to chapter 1 for discussion). The full range of output (0-1) was represented at the plot level. The range was reduced when values were averaged across states which represents the variability of habitat characteristics within states as opposed to a lack of calibration in the models. Values may be different c=than those in chapter 1 because of slightly different model structure.

Elk Model

Winter. A model was created for elk wintering habitat for the claypan and mountain loam ecological sites. Winter is the most common time for elk to use the study area since they often migrate to lower elevations to sagebrush-grasslands during winter to avoid deep snows that impede movement or forage access (Leege and Hickey 1977, Sweeney and Sweeney 1984). Additionally, winter is the most likely time for forage to affect populations given the reduction in winter nutrition and resulting weight loss (Christianson and Creel 2007). The model consists of only a forage component since the benefits of thermal cover during winter are debatable given the positive inlux of solar properties on areas of low cover (Cook et al. 1998).

Literature review of elk diets shows moderate variability in estimates of the contribution of browse versus graminoids in the diet. Hobbs et al. (1981) reported that the trade-off in composition is based on the relative need of protein provided by browse, and readily digestible energy provided by graminoids. The trade-off relationship between energy and protein is well established (Hoffman 1989, Christianson and Creel 2007). Hobbs et al. (1981) found that elk diet composition was relatively stable between habitat types in comparison to availability of forage components in different habitat types. In the two years of their study Hobbs et al. (1981) also report that elk consumed 69% and 61% graminoids and 20% and 29% browse in sagebrush habitat types in Colorado. Christianson and Creel (2007) collected data on elk diets from 72 studies in western North America. They concluded that elk selected for graminoids at higher proportions than what the habitat provided, that forbs were not selected for, and that the proportion of browse was positively related to availability in habitat. They also report that when habitats provided about 80% availability of graminoids they consisted of >90% of the diet but when a 3-fold decrease in availability of graminoids occurred, only a 10% reduction in intake resulted. Their synthesis of elk diets resulted in the following averages and associated 95% confidence intervals: 65.8% (63.91, 67.69) graminoids, 29.1% (27.24, 30.96) browse, and 5.6% (4.95, 6.25) forbs. Hansen and Clark (1977) report that elk in Moffat County averaged approximately 57% graminoids and 27% browse. Torstenson et al. (2006) report 66%

(SE=12.8) graminoids and 12% (SE=9.4) browse consumption by elk in winter in Park County Wyoming. All other applicable diet studies found were included in the Christianson and Creel (2007) publication. In contrast to the findings of Christianson and Creel (2007), Kufeld (1973) found many species of forbs to be selected for in higher proportions than availability resulting in the classification of several forbs in the study area as palatable. Given that some measure of forb consumption during winter has been reported, this variable was allowed to contribute minutely to the habitat suitability evaluation.

The forage component for elk wintering habitat consisted of four data links which included %P/A of forage, % P/A graminoids, % P/A browse, and % P/A forbs. Given the large sample size of the Christianson and Creel (2007) synthesis and the proximity of the estimates to the Hobbs et al. (1981) and Hansen and Clark (1977) studies, the approximate estimates of the ideal composition of each group were taken from the synthesis study. A data link for the overall %P/A of forage had data points of ((0,0), (1,100)), where was assumed that site with the highest composition of palatable forage are valuable to elk for winter habitat. The graminoid %P/A with data points of ((0,0) (1,66)) was created due to the assumption sites with high graminoid composition are more valuable to elk for winter habitat. The browse data link had data points of ((0,0) (1,29)) and the forb data link had data points of ((0,0) (1,6)). These data links were connected by an AND operator.

Calving. Calving habitat was evaluated for the aspen ecological site states. The availability of succulent and nutritious vegetation during this time period (mid-May through Mid-June) is a driver of calving habitat quality (Skovlin et al. 1982). There is a large variation in the functional group composition of elk diets during this time period (Kufeld 1973). The percent composition of palatable forage for elk calving was calculating by categorizing each species from field data as palatable or not following ratings by Kufeld (1973), Cook (1982), and Mueggler (1985). The forage sub-network consisted of only a %P/A forage data link with data points of ((0,0),(1,100)). Hiding cover is also important for adult elk and calves (Skovlin et al. 1982). The shoulder height of an elk calf is approximately 74 cm (Schwartz and Mitchell 1945). Thus, it is assumed that visual obscurity of 74 cm is sufficient hiding cover for elk calving habitat. The forage and cover sub-networks were linked by an AND operator.

Mule Deer Models

Models were developed for year-round mule deer habitat which includes four major life stages: early gestation (approximately December- February), mid to late gestation (March-May) fawn-rearing (May-July), and late lactation/ fawn weaning (August-November). Each life stage consisted of forage and cover sub-networks linked by AND operators. Data links within each sub-network were also linked by AND operators. The cover component considers thermal cover (Parker and Gillingham 1990) during early gestation (winter) and fawn-rearing (early summer), and hiding cover (Leckenby et al. 1982) during all stages. The sagebrush states were evaluated for each life stage and the aspen states were evaluated for the fawning life stage. Each life stage was also linked together by an AND operator to produce an overall habitat value for mule deer on the sagebrush sites.

Pierce et al. (2004) found that wintering mule deer in Round Valley of California minimized predation by choosing habitat that was both safe from predation and consisted of quality forage. While all habitats do not provide both cover and forage in adequate compositions to meet needs, this work justifies the assumption that habitat that provides both forage and cover is more valuable to mule deer.

Hiding cover for mule deer involves the structure of understory vegetation (Taber 1961). Gerlach and Vaughan (1991) found that fawns bedded in sites with higher concealment cover than random sites and that fawns chose sites with approximately 80% coverage at 0-.5 meters of visual obscurity. Additionally, mule deer are approximately 1 meter tall (Anderson et al. 1974), where hind leg length is roughly half of this height (Fitzgerald et al. 1994). Thus, a bedded adult mule would be roughly 0.5 m in height. Hiding cover for fawning mule deer was modeled as a visual obscurity requirement of 0.5 meters with data points of ((0,0), (0.5,1)).

Thermal cover involves overhead structure because animals are seeking shade or shelter from radiation, precipitation or wind (Robinson 1960, Leckenby 1977, Peek et al. 1982, Sargeant et al 1994). This shelter can consist of over-story canopy (Peek et al. 1982) or other elements that function as a block to environmental extremes (Sargeant 1994). Leckenby et al. (1982) discuss the important contribution of shrubs with heights greater than 70cm for thermal cover during fawning. Therefore, the model thermal cover requirements consisted of a shrub height data link with data points of ((0,0), (70,1)).

Leckenby et al. (1982) recommended that shrub communities for hiding and thermal cover needs for fawns should consist of at least 23% shrub cover. They also reported that canopy cover above 75% is equally preferred. An upper threshold for shrub cover was not discovered in literature review. It was therefore assumed that an upper shrub cover threshold would exist primarily to maintain sufficient understory growth. Such considerations were accounted for in the forage model, where offsets in palatable forage due to dense shrub canopies would result in lower values for forage. Because a limiting-factor operator is used to integrate the cover and forage model, the overall values should resemble the relative value of the site to mule deer. Thus, the shrub cover data link was modeled with data points of ((0,0), (23,1)). The visual obscurity, shrub height, and shrub cover data links were linked by an AND operator. On aspen sites, tree canopy cover of 50% could substitute for the shrub cover (Leckenby et al. 1982). An OR operator was used to choose the highest value between the shrub canopy cover or tree canopy cover data link: ((0,0), (50,1)).

Mule deer diets are highly variable and this variation is often due to use-availability relationships which are spatial and social in context (Mysterud and Ims 1998). Mule deer are classified as concentrate selectors and they choose the highest available quality for consumption (Hoffman 1989). Given the large overlap in functional group consumption by mule deer reported in the literature, it was assumed that palatability by season is a more likely predictor of forage suitability than functional group composition. Additionally, STMs are not spatially explicit and this study was not focused on modeling habitat suitability for an absolute number of animals. Thus, it was not possible to determine the amount of production in terms of grams $\cdot$ meter $^{-2}$ that would correspond to different levels of habitat suitability. Mule deer forage suitability was driven by a palatability component. Percent palatability was calculated by categorizing each species from the dry weight rank data as palatable or unpalatable and calculating the percent composition by dry weight of all vegetation palatable to the species for a given species. Palatability data for mule deer were obtained from Kufeld (1973), which is a synthesis of mule deer diets where species are rated by season. The mule deer forage sub-networks for each life stage were identical with the exception that each life stage was associated with a different set of palatable species. Each life stage was matched the closest overlap of seasonal data. For each season, species with values greater than 1.5 were categorized as palatable and species with values 1.5 or less were assigned as unpalatable. If the specific species information was unavailable, genus ratings were used. These ratings were cross-referenced with the PLANTS Database (USDA, NRCS). The data were aggregated by palatability and the resulting value reflects the relative percent availability of palatable forage.

The forage component of the model consisted of percent palatable forage and percent palatable sagebrush data links. Both data links consisted of species that were classified as palatable by season. It was assumed that high suitability (suitability value of 1) occurred at 70% composition or greater of palatable forage species other than sagebrush. The palatable forage data link had data points of ((0,0), (70,1)). Some species of sagebrush are palatable to mule deer during the assessed life stages (Kufeld et al. 1973). However, ingestion of sagebrush in quantities of greater than 30% in the diet is detrimental to mule deer (Nagy et al. 1967, Carpenter et al. 1979). In certain states, sagebrush makes up a majority of the plant composition which would have driven the forage value of the states higher than expected given the lower expected use to availability ratio in these states if sagebrush was included in the overall palatability calculation. To incorporate sagebrush, the forage model was developed such that 30% or less of the diet could be substituted for sagebrush. Another palatable forage data link with data points of ((0,0), (49,1)) was connected by an AND operator to a palatable sagebrush data link with data points of ((0,0), (21,1)). The highest suitability value was chosen between the single palatable forage data link and the connected palatable forage and palatable sagebrush links.

Sage Grouse Model

Habitat models were built for prominent life stages of sage grouse including breeding, brood-rearing, and winter habitat life stages (Connelly et al. 2000). Forage and cover sub-networks and data links were linked by AND operators. Each life stage was also linked together by an AND operator to produce an overall habitat value for sage grouse.

Breeding Habitat. Breeding habitat is defined by Connelly et al. (2000) as areas of potential lek attendance, pre-laying hen, nesting, and early brood-rearing habitat. Hens often use resources near potential nesting sites for pre-incubating nutrition and thus it is an important consideration for breeding habitat management. Nesting habitat is an important an consideration in breeding habitat management due to the risk of nest depredation and early chick-rearing habitat is considered within the breeding habit requirements because chicks are limited in mobility to the resources within the immediate vicinity of the nesting habitat.

Recommended cover for nesting sage grouse is sagebrush cover at 15-25% (Connelly et al. 2000). A meta-analysis by Hagen et al. (2007) reports a range of shrub coverage used during this time period. The highest is 59% (Sveum et al. 1998). This value was estimated in small areas (1-m^2) around a nest. When shrub coverage was measured in larger areas in the nesting habitat, which would be more comparable to the methods of shrub estimates used for this study, the shrub estimates generally fell within the range suggested by the sage grouse guidelines. This study also reported that successful nest sites (1-m^2) in the big sagebrush community had lower shrub cover (51%) than depredated nests (70%). It is therefore assumed that sagebrush canopy cover around 70% in nesting areas has little value to sage grouse. Shrub height is also important for cover and for successful breeding habitat it should be 40-80cm (Connelly et al. 2000). The average sagebrush heights by state were examined for potential issues with maximum values. The greatest value for height fell below the recommended 80cm, therefore a maximum value was not accounted for in the model. The sage grouse guidelines also suggest maintaining grass height at > 18cm for breeding habitat cover. A preliminary assessment of grass height at plots showed that height was consistently greater than 18 cm. Therefore, instead of grass height, visual obscurity was measured as an indicator of screening cover. While many authors report visual obscurity results at successful nest sites, the exact procedure for measurement varied. Sveum et al. (1998) report results from a sage grouse nest study where visual obscurity was measured using the same procedure and is significantly different between nest and random sites for two years. The results from 1996 (VO= 32cm) were used for this model because the sample size was higher than the previous year results. The sage grouse guidelines recommend grass cover of >15%. The importance of grass for cover is well-established (Connelly et al. 2000). The cover sub-network consisted of the sagebrush canopy cover data link: ((0, 0), (15,1), (25,1), (70,0)), the sagebrush height data link: ((0,0), (40,1)), the visual obscurity data link: ((0,0), (32,1)) and the perennial grass cover data link was created with the following data points: ((0, 0), (15, 1)).

Sage grouse diets during pre-incubation consist primarily of sagebrush and forbs. Gregg, Barnett, and Crawford (2008) found that forbs comprised 30.1% and sagebrush comprised 65.7% of hen diets during pre-incubation. Connelly et al. (2000) recommend at least 10% forb cover and 15% sagebrush cover for this time period. Forbs are also an important component of the chick’s diet during early brood rearing (Drut, Pyle, and Crawford 1994). Huwer et al. suggested that forb cover of ≥20% may lead to increased survival and productivity. The 20% guideline is also supported by Schroeder (1995) and Sveum et al. (1995, 1998). Due to this evidence, and the fact that the sage grouse guidelines recommend that forb coverage should exceed 10%, the 20% optimum value for forb cover was used. It was assumed that a site that meets the recommended forb cover where the forb species are palatable to sage grouse, is more valuable than a site that meets the recommended forb cover where the species are unpalatable. Each forb species in the cover data was categorized as palatable or unpalatable using information from Huwer (2004) and Bird and Schenk (2005). The percent of palatable forbs was calculated by dividing the percent cover of palatable forbs by the total cover of forbs. Thus, the forage sub-network consisted of a sagebrush canopy cover data link ((0, 0), (15,1), (25,1), (70,0)), a perennial forb cover data link ((0, 0) (20, 1)), and percent palatable forbs data link ((0, 0), (100, 1)).

Late Brood Rearing. Recommended cover for brood rearing sage grouse is sagebrush cover at 10-25%, and recommended sagebrush height is 40-80cm (Connelly et al. 2000). Sveum et al. (1998) reported significant selection for VO of 17cm in big sagebrush habitat during this time period. The sage grouse guidelines recommend grass cover of >15%. The importance of grass for cover is well-established (Connelly et al. 2000). The late brood-rearing cover sub-network consists of the sagebrush canopy cover data link ((0,0), (10,1), (25,1), (70,0)), the sagebrush height data link ((0,0), (40,1)), the visual obscurity data link ((0,0), (17,1)), and the perennial grass cover data link ((0, 0), (15, 1)).

Late brood-rearing habitat selection is driven by a movement to more mesic sites as desiccation of forage due to increased temperature and decreased precipitation occurs (Drut et al. 1994, Wallestad 1971). Mesic sites are indicated by high herbaceous cover relative to shrub cover. Sveum et al. (1998) reported 61% herbaceous cover in brood habitats. Forb cover is important during late brood rearing as well and the 20% forb cover recommendation from the above model was used (Sveum et al. 1998, Huwer et al. 2008). Sage grouse also use sagebrush for forage during this time period. Connelly et al. (2000) recommended 10-25% sagebrush cover during brood-rearing. The late brood-rearing forage sub-network consisted of the herbaceous cover data link with data points of ((0,0), (61,1)), the forb cover data link with data points of ((0,0), (20,1)), the percent palatable forbs data link (following assumptions made above) ((0,0), (100,1)), and the sagebrush canopy cover data link with data points of ((0,0), (10,1), (25,1), (70,0)).

Winter Habitat. Connelly et al. (2000) recommended sagebrush canopy cover of 10-30% with heights 25-35 cm exposed above snow during the winter which provides forage and cover (Patterson 1952, Wallenstad and Eng 1975, Remington and Braun 1985). The sagebrush canopy cover data link had data points of ((0,0), (10,1), (30,1), (80,0)). Because these habitat characteristics provide both forage and cover, the habitat model was developed using one network which was not further defined by sub-networks. The 100 year average snow depth across December through February, at the Hayden, CO climate station, is approximately 30.5cm. Snow depths in the area can exceed 100 cm, thus an upper limit on sagebrush height was not included. A shrub height data link was created with data points of ((30.5, 0), (55.5, 1)).

RESULTS

Table A.1. Key to state acronyms for Appendix A.

Ecological Site	Acronym	State
Claypan	ASB	Alkali Sage/Bluegrass Shrubland
Claypan	ASW	Alkali Sage/Western Wheatgrass Shrubland
Claypan	BTS	Three-tip Sagebrush Shrubland
Claypan	ASE	Alkali Sage Shrubland/Sparse Understory
Claypan	NG	Native Grassland
Claypan	CPG	Claypan Planted Grassland
Mountain Loam	MBE	Mountain Big Sage Shrubland/Sparse Understory
Mountain Loam	MBU	Mountain Big Sage Shrubland with Diverse Understory
Mountain Loam	MBW	Mountain Big Sage/Western Wheatgrass Shrubland
Mountain Loam	MBT	Mtn Big/Three-tip Sagebrush Shrubland
Mountain Loam	MBD	Dense Mountain Big Sage Shrubland
Mountain Loam	MPG	Mountain Loam Planted
Aspen	AGS	Grass/shrub
Aspen	ATF	Tall Forb

Table A.2. Mean (ẋ) and standard deviation (SD) of variables used in mule deer forage models.

State	n	%P/A[1] Fall		%P/A Spring		%P/A Summer		%P/A Winter	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	24.8	16.0	33.0	14.8	21.9	22	27.4	17.5
ASW	11	3.0	4.3	23.1	19.3	24.7	12	5.2	5.5
BTS	4	20.2	20.0	32.8	20.6	18.2	11	21.5	22.0
ASE	6	5.1	4.8	8.9	8.7	2.6	1.8	16.1	13.3
NG	10	10.9	7.0	26.5	6.8	13.5	6.1	11.8	7.6
CPG	2	18.8	32.3	23.3	31.6	23.8	30.9	22.8	26.6
MBE	3	31.5	20.3	39.4	19.7	22.0	7.0	29.8	18.7
MBU	7	38.4	12.7	53.4	11.3	48.9	18.9	41.2	9.7
MBW	12	22.3	13.7	38.4	11.8	41.3	19.8	26.2	13.6
MBT	4	18.4	13.1	30.8	14.4	14.7	7.9	24.9	9.6
MBD	5	17.7	16.4	15.2	5.1	16.4	12.8	13.9	11.8
MPG	1	0.0	0.0	0.0	0.0	0.0	0.0	3.7	0.0
AGS	9	9.5	6.6	31.0	11.4	50.7	15.9	8.0	6.3
ATF	7	18.0	12.9	43.3	13.8	54.8	12.1	6.7	9.0

[1] Indicates percent composition of palatable vegetation species.

Table A.3. Mean (ẋ) and standard deviation (SD) of variables used in mule deer forage models.

State	n	%P/A[1] Sagebrush Winter & Spring		%P/A Sagebrush Summer		%P/A Sagebrush Fall	
		ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	30.9	21.3	34.0	9.7	30.9	21.3
ASW	11	15.0	10.4	2.8	6.0	15.0	10.4
BTS	4	31.5	14.9	15.3	16.5	19.1	16.9
ASE	6	63.8	18.7	0.8	1.9	63.8	18.7
NG	10	9.2	16.7	1.4	3.1	9.2	16.7
CPG	2	0.5	0.7	0.5	0.7	0.5	0.7
MBE	3	15.7	17.3	15.7	17.3	15.7	17.3
MBU	7	15.8	14.4	10.7	7.4	14.8	13.9
MBW	12	13.9	7.1	13.0	7.9	13.5	7.2
MBT	4	43.3	4.4	22.9	11.4	24.2	8.9
MBD	5	44.4	17.6	44.2	17.8	44.2	17.8
MPG	1	5.6	0.0	5.6	0.0	5.6	0.0

[1] Indicates percent composition of palatable sagebrush species.

Table A.4. Mean (ẋ) and standard deviation (SD) of variables used in cover models.

State	n	Visual Obscurity[1]		%Shrub Canopy Cover[2]		Shrub Height(cm)[2]		%Tree Canopy Cover[2]	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	0.1	0.0	22.2	16.2	26.1	3.9	0.0	0.0
ASW	11	0.1	0.0	7.6	5.8	23.1	8.2	0.0	0.0
BTS	4	0.1	0.0	11.7	6.1	32.8	6.5	0.0	0.0
ASE	6	0.1	0.0	39.1	14.8	19.1	6.3	0.0	0.0
NG	10	0.1	0.0	5.8	13.5	11.2	12.2	0.0	0.0
CPG	2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
MBE	3	0.2	0.2	18.6	15.4	34.0	29.4	0.0	0.0
MBU	7	0.2	0.1	25.8	10.6	51.0	17.5	0.0	0.0
MBW	12	0.3	0.1	23.5	14.6	54.9	9.5	0.0	0.0
MBT	4	0.2	0.1	40.4	4.3	47.8	13.5	0.0	0.0
MBD	5	0.5	0.1	53.3	10.2	63.7	12.0	0.0	0.0
MPG	1	0.2	0.0	5.3	0.0	45.3	0.0	0.0	0.0
AGS	9	0.3	0.1	3.9	6.3	36.0	29.1	83.4	15.7
ATF	7	0.4	0.2	0.6	1.2	32.1	41.4	76.4	11.8

[1]Used in elk, mule deer, and sage grouse cover models.
[2]Used in mule deer cover models.

Table A.5. Mean (ẋ) and standard deviation (SD) of variables used in the sage grouse model.

State	n	% Forb Cover		% Palatable Forbs		%Perennial Grass Cover		% Sagebrush canopy cover		Sagebrush Height(cm)	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	19.7	17.2	71.1	25.0	18.9	5.0	21.8	16.3	26.3	3.9
ASW	11	23.4	14.6	80.2	18.9	27.6	14.5	7.1	5.4	23.4	8.3
BTS	4	16.2	4.8	68.4	27.2	31.2	13.4	11.3	5.8	33.0	6.6
ASE	6	6.6	3.9	35.6	24.3	9.8	5.2	39.1	14.8	19.1	6.3
NG	10	16.1	6.0	96.1	3.6	41.0	8.4	5.8	13.5	11.2	12.2
CPG	2	23.2	31.7	99.6	0.6	30.8	17.5	0.0	0.0	0.0	0.0
MBE	3	12.7	1.0	63.6	3.5	11.7	3.2	14.6	12.8	37.8	15.9
MBU	7	23.0	8.4	68.6	16.3	22.7	13.1	13.3	10.7	52.8	13.4
MBW	12	31.7	11.5	53.3	21.9	22.3	12.7	15.6	7.8	57.2	8.1
MBT	4	9.0	5.4	61.5	37.0	31.0	5.6	38.9	4.7	48.3	13.9
MBD	5	12.2	8.4	36.1	19.3	19.1	5.7	53.1	10.5	63.7	12.0
MPG	1	0.8	0.0	21.4	0.0	30.4	0.0	5.3	0.0	45.3	0.0

Table A.6. Mean (ẋ) and standard deviation (SD) of variables used in the elk winter model.

State	n	% P/A Winter		% P/A Graminoids		% P/A Forbs		% P/A Browse	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	82.2	17	43.5	10.1	10.8	11.3	27.9	25.9
ASW	11	74.1	26.4	46.4	22.2	14.9	9.5	12.8	11.0
BTS	4	73.5	22.1	32.6	11.6	15.9	11.7	25.0	22.1
ASE	6	73.9	30.3	24.7	13.4	2.3	4.8	46.9	39.5
NG	10	85.8	8.8	72.6	19	4.1	3.2	9.2	16.7
CPG	2	48	0.7	43.6	2.7	3.9	2.7	0.5	0.7
MBE	3	68.9	10.1	30.4	15.1	12.4	9.2	26.1	11.0
MBU	7	79	6.3	26.7	14.6	11.4	9.8	40.9	12.3
MBW	12	57.4	14.6	35.1	16.2	8.5	6.9	13.8	11.6
MBT	4	81.1	15.4	32.3	12.7	3.3	4.3	45.5	5.3
MBD	5	60.5	35.1	13.1	7.8	12.7	14.4	34.6	26.1
MPG	1	88.9	0	83.3	0	0.0	0.0	5.6	0.0

Table A.7. Mean(ẋ) and standard deviation (SD) of variables used in the elk calving forage model.

State	n	% P/A Calving	
		ẋ	SD
AGS	9	90.4	8.1
ATF	7	87.3	9.1

Table A.8. Mean (ẋ) and standard deviation (SD) of elk habitat values for sagebrush states.

State	n	Winter	
		ẋ	SD
ASB	6	0.5	0.2
ASW	11	0.6	0.2
BTS	4	0.6	0.2
ASE	6	0.3	0.2
NG	10	0.4	0.2
CPG	2	0.2	0.1
MBE	3	0.6	0.1
MBU	7	0.6	0.2
MBW	12	0.5	0.1
MBT	4	0.5	0.3
MBD	5	0.4	0.2
MPG	1	0.3	0.0

Table A.9. Mean(ẋ) and standard deviation (SD) of habitat values for aspen states.

State	n	Elk Calving		Mule Deer Fawning	
		ẋ	SD	ẋ	SD
AGS	9	0.6	0.1	0.7	0.1
ATF	7	0.6	0.1	0.8	0.1

Table A.10. Mean (ẋ) and standard deviation (SD) of mule deer habitat values.

State	n	Late Gestation		Fawning		Late Lactation		Early Gestation		All[1]	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	0.4	0	0.3	0.2	0.4	0	0.5	0.1	0.3	0.1
ASW	11	0.3	0.1	0.3	0.1	0.2	0.1	0.2	0.1	0.2	0.1
BTS	4	0.3	0.1	0.3	0.1	0.2	0.1	0.4	0.2	0.2	0.1
ASE	6	0.3	0.1	0.1	0.1	0.2	0.1	0.4	0.1	0.2	0.1
NG	10	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CPG	2	0.4	0.4	0.2	0.2	0.4	0.4	0.1	0.1	0.2	0.1
MBE	3	0.5	0.3	0.4	0.3	0.5	0.2	0.5	0.3	0.5	0.3
MBU	7	0.6	0.1	0.7	0.2	0.5	0.1	0.6	0.1	0.6	0.1
MBW	12	0.6	0.2	0.7	0.2	0.5	0.2	0.6	0.2	0.6	0.2
MBT	4	0.5	0.2	0.5	0.2	0.4	0.2	0.6	0.1	0.5	0.2
MBD	5	0.7	0.1	0.7	0.1	0.7	0.1	0.6	0.1	0.6	0.1
MPG	1	0.1	0	0.1	0	0.1	0	0.2	0	0.2	0

[1]Limiting factor weighted average of late gestation, fawning, late lactation, and early gestation habitat values.

Table A.11. Mean (ẋ) and standard deviation (SD) of sage grouse habitat values.

State	n	Breeding		Late Brood-rearing		Winter		All[1]	
		ẋ	SD	ẋ	SD	ẋ	SD	ẋ	SD
ASB	6	0.6	0.1	0.6	0.1	0.2	0.1	0.4	0.1
ASW	11	0.5	0.2	0.5	0.2	0.1	0.1	0.3	0.1
BTS	4	0.5	0.1	0.6	0.2	0.4	0.2	0.5	0.2
ASE	6	0.4	0.1	0.4	0.1	0.2	0.1	0.3	0.1
NG	10	0.3	0.2	0.3	0.2	0.1	0.1	0.1	0.1
CPG	2	0.2	0.1	0.2	0	0	0	0.1	0
MBE	3	0.6	0.4	0.6	0.4	0.5	0.5	0.5	0.4
MBU	7	0.7	0.2	0.7	0.2	0.7	0.4	0.7	0.3
MBW	12	0.7	0.1	0.8	0.1	0.9	0.2	0.8	0.1
MBT	4	0.6	0.2	0.6	0.2	0.7	0.3	0.6	0.3
MBD	5	0.5	0.1	0.5	0.1	0.6	0.2	0.5	0.1
MPG	1	0.3	0	0.4	0	0.6	0	0.4	0.0

[1]Limiting factor weighted average of breeding, late brood-rearing, and winter habitat values.

APPENDIX B: DATA

Note: Data is averaged across plots by state. For data referred to in this thesis that is not included in this appendix, see Kachergis (2011) or Puntenney (In progress, Honors Thesis, Department Forest, Rangeland, and Watershed Stewardship, Colorado State University, Fort Collins, CO)

Seedling data is reported by density but measurements for canopy cover and height were not taken.

Table B.1. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Artemisia triparitata									
			Seedling		Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.02	0.02	0.09	0.13	0.08	0.06	0.00	0.00	0.19	0.15
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.37	0.32	0.60	0.43	0.30	0.18	0.00	0.01	0.94	0.60
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.2. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Amelanchier utahensis							
			Seedling		Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.01	0.01	0.03	0.05	0.01	0.01	0.04	0.07
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.01	0.01	0.02	0.01	0.04
Claypan	Native Grassland	10	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.01	0.05	0.06	0.04	0.10	0.10	0.12
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.03	0.04	0.05	0.05	0.00	0.00	0.08	0.09
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.01	0.01	0.03	0.06	0.02	0.04	0.06	0.09
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.02	0.03	0.00	0.00	0.02	0.03
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspen	Grass/shrub	9	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Aspen	Tall Forb	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.3. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Artemisia cana									
			Seedling		Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.18	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.47
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.17
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.03	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.03	0.06	0.01	0.02	0.00	0.00	0.00	0.01
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.01	0.01	0.03	0.03	0.09	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.4. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Artemisia longiloba									
			Seedling		Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.21	0.10	1.72	0.49	0.03	0.05	1.89	0.39
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.04	0.01	0.77	0.43	0.00	0.00	0.82	0.45
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.07	0.06	0.89	0.63	0.02	0.02	0.89	0.54
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.33	0.29	1.01	0.72	0.04	0.04	1.41	1.00
Claypan	Native Grassland	10	0.00	0.00	0.02	0.04	0.27	0.43	0.02	0.04	0.31	0.47
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.08	0.14	0.00	0.00	0.08	0.14
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.04	0.07	0.03	0.06	0.14	0.36	0.04	0.09	0.20	0.51
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.04	0.13	0.01	0.02	0.01	0.03	0.00	0.00	0.02	0.05
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.02	0.04	0.17	0.35	0.00	0.01	0.18	0.36
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.5. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	**State**	**n**	***Artemisia tridentata***									
			Seedling		**Juvenile**		**Mature**		**Decadent**		**Total**	
			ẋ	**SE**	**ẋ**	**SE**	**ẋ**	**SE**	**ẋ**	**SE**	**ẋ**	**SE**
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.09	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.06	0.08	0.19	0.19	0.66	0.62	0.08	0.14	0.99	1.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.02	0.04	0.03	0.06	0.07	0.21	0.00	0.00	0.11	0.28
Claypan	Native Grassland	10	0.14	0.27	0.04	0.07	0.08	0.16	0.01	0.03	0.13	0.24
Claypan	Claypan Planted Grassland	2	0.08	0.07	0.43	0.34	0.52	0.37	0.05	0.06	1.06	0.77
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.29	0.34	0.27	0.09	1.07	0.22	0.10	0.11	1.51	0.31
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.24	0.34	0.19	0.14	0.31	0.24	0.03	0.02	0.59	0.33
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.35	0.60	0.22	0.23	0.81	0.96	0.04	0.05	1.11	1.21
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.23	0.35	0.20	0.25	0.54	0.22	0.03	0.04	0.88	0.28
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.29	0.51	0.39	0.57	0.74	0.57	0.02	0.03	1.20	0.83
Mountain Loam	Mountain Loam Planted Grassland	1	0.43	0.00	0.43	0.00	0.20	0.00	0.00	0.00	0.71	0.00

Table B.6. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Chrysothamnus spp.									
			Seedling		Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.10	0.20	0.27	0.53	0.23	0.17	0.00	0.00	0.53	0.67
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.04	0.12	0.01	0.04	0.00	0.00	0.05	0.16
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.01	0.01	0.02	0.03	0.05	0.00	0.00	0.05	0.08
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.00

Table B.7. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	**State**	**n**	***Prunus virginiana***			
			Seedling		**Total**	
			ẋ	**SE**	**ẋ**	**SE**
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.04	0.08	0.04	0.08
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00

Table B.8. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Purshia tridentata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.06	0.12	0.07	0.13	0.02	0.03	0.14	0.29
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.9. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Quercus gambelii							
			Seedling		Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.06	0.21	0.01	0.01	0.00	0.01	0.02	0.07
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.10. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Symphoricarpus rotundifolius									
			Seedling		Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.02	0.02	0.01	0.01	0.00	0.00	0.03	0.02
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.01	0.02	0.00	0.01	0.00	0.00	0.02	0.03
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.01	0.02	0.03	0.04	0.05	0.11	0.00	0.00	0.08	0.15
Claypan	Native Grassland	10	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.02
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.02
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.01	0.19	0.17	0.33	0.39	0.00	0.01	0.52	0.51
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.16	0.29	0.38	0.47	0.36	0.21	0.00	0.00	0.83	0.59
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.01	0.02	0.12	0.13	0.12	0.13	0.00	0.00	0.25	0.22
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.11. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Symphoricarpus rotundifolius, cont'd					
			Juvenile		Mature		Total	
Aspen	Grass/Shrub	9	0.02	0.01	0.14	0.07	0.16	0.07
Aspen	Tall Forb	7	0	0	0.03	0.01	0.03	0.01

Table B.12. Mean (ẋ) and standard error (SE) of shrub density (#/m^2).

Ecological Site	State	n	Total Shrub Density ẋ	Total Shrub Density SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	1.90	0.40
Claypan	Alkali Sage with Diverse Understory	3	1.88	0.76
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.91	0.51
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	1.62	1.14
Claypan	Native Grassland	10	0.45	0.56
Claypan	Claypan Planted Grassland	2	1.34	0.70
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	1.53	0.30
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	1.45	0.37
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	2.76	1.60
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	1.32	0.49
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	2.39	0.61
Mountain Loam	Mountain Loam Planted Grassland	1	0.72	0.00
Aspen	Grass/Shrub	9	0.17	0.07
Aspen	Tall Forb	7	0.03	0.01

Table B.13. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Artemisia triparitata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.15	0.08	1.28	0.74	0.00	0.00	1.44	0.74
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.97	0.34	4.66	2.05	0.15	0.15	5.79	2.40
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.14. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Amelanchier utahensis					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.14	0.14	0.08	0.08	0.23	0.23
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.02	0.02	0.22	0.22	0.24	0.24
Claypan	Native Grassland	10	0.02	0.02	0.00	0.00	0.02	0.02
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.87	0.45	2.21	1.79	3.08	1.93
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.22	0.12	0.00	0.00	0.23	0.13
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.20	0.10	1.09	0.71	1.29	0.76
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.17	0.12	0.00	0.00	0.17	0.12
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00
Aspen	Grass/shrub	9	0.04	0.04	0.00	0.00	0.04	0.04
Aspen	Tall Forb	7	0.00	0.00	0.00	0.00	0.00	0.00

Table B.15. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Artemisia cana							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.10	0.06	0.04	0.03	0.00	0.00	0.13	0.09
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	1.61	1.61	0.00	0.00	0.00	0.00	1.61	1.61
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.33	0.33	0.03	0.02	0.00	0.00	0.36	0.35
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.16. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Artemisia longiloba							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.28	0.08	14.78	2.26	0.15	0.09	15.21	2.36
Claypan	Alkali Sage with Diverse Understory	3	0.07	0.03	9.09	1.84	0.00	0.00	9.17	1.81
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.15	0.10	8.93	3.23	0.16	0.12	9.24	3.22
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.43	0.11	7.83	1.56	0.49	0.16	8.76	1.69
Claypan	Native Grassland	10	0.05	0.03	2.49	1.38	0.12	0.07	2.65	1.43
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.98	0.83	0.00	0.00	0.98	0.83
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.04	0.03	1.12	1.08	0.33	0.33	1.49	1.44
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.14	0.10	0.00	0.00	0.15	0.10
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.08	0.08	4.51	4.51	0.02	0.02	4.64	4.64
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.17. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Artemisia tridentata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.50	0.38	14.80	10.21	1.60	1.60	16.91	12.14
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.03	0.02	0.74	0.59	0.00	0.00	0.77	0.61
Claypan	Native Grassland	10	0.09	0.05	0.86	0.52	0.04	0.04	0.99	0.59
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.57	0.22	7.57	3.00	0.14	0.10	8.28	3.16
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.48	0.08	45.37	8.11	3.47	2.20	49.33	9.50
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.27	0.06	8.87	2.48	0.40	0.21	9.56	2.49
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.50	0.24	17.69	10.32	0.57	0.33	18.77	10.88
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.99	0.47	15.14	2.33	0.50	0.17	16.65	2.38
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.93	0.56	17.88	6.79	0.69	0.48	19.50	7.33
Mountain Loam	Mountain Loam Planted Grassland	1	1.94	0.00	7.97	0.00	0.00	0.00	9.94	0.00

Table B.18. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Chrysothamnus spp.							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.01
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.06	0.06	0.00	0.00	0.06	0.06
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.38	0.38	1.71	0.91	0.00	0.00	2.10	0.94
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.13	0.13	0.45	0.45	0.00	0.00	0.59	0.59
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.03	0.03	0.88	0.69	0.00	0.00	0.91	0.72
Mountain Loam	Mountain Loam Planted Grassland	1	0.14	0.00	0.00	0.00	0.00	0.00	0.14	0.00

Table B.19. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Prunus virginiana			
			Mature		Total	
			ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00
Aspen	Grass/Shrub	9	0.33	0.33	0.33	0.33
Aspen	Tall Forb	7	0.00	0.00	0.00	0.00

Table B.20. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Purshia tridentata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.03	0.03	0.00	0.00	0.03	0.03
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.18	0.18	0.34	0.34	0.10	0.10	0.61	0.61
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.04	0.04	0.08	0.06	0.00	0.00	0.12	0.10
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.21. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Quercus gambelii					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.04	0.03	0.30	0.30	0.35	0.33
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00

Table B.22. Mean ($\dot{x}$) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Symphoricarpus rotundifolius							
			Juvenile		Mature		Decadent		Total	
			$\dot{x}$	SE	$\dot{x}$	SE	$\dot{x}$	SE	$\dot{x}$	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.06	0.04	0.47	0.41	0.00	0.00	0.53	0.38
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.05	0.05	0.03	0.03	0.00	0.00	0.07	0.07
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.14	0.06	0.49	0.38	0.00	0.00	0.63	0.41
Claypan	Native Grassland	10	0.04	0.03	0.00	0.00	0.00	0.00	0.04	0.03
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.31	0.18	0.00	0.00	0.31	0.18
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.40	0.40	0.00	0.00	0.40	0.40
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	1.11	0.50	12.24	3.10	0.03	0.03	13.38	3.22
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	1.43	0.99	22.04	16.98	0.00	0.00	23.60	16.39
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.63	0.19	7.15	4.19	0.00	0.00	7.79	4.13
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aspen	Grass/Shrub	9	0.06	0.02	3.21	2.09	0.00	0.00	3.26	2.09
Aspen	Tall Forb	5	0.00	0.00	0.61	0.44	0.00	0.00	0.61	0.44

Table B.23. Mean (ẋ) and standard error (SE) of shrub canopy cover (%).

Ecological Site	State	n	Total Shrub Canopy Cover ẋ	Total Shrub Canopy Cover SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	15.22	2.36
Claypan	Alkali Sage with Diverse Understory	3	26.84	10.08
Claypan	Alkali Sage/Bluegrass Shrubland	4	9.31	3.17
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	10.41	2.10
Claypan	Native Grassland	10	3.70	1.59
Claypan	Claypan Planted Grassland	2	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	11.07	3.87
Mountain Loam	Dense Mountain Big Sage Shrubland	5	49.73	9.71
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	27.67	4.04
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	46.94	15.75
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	27.29	5.85
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	31.02	3.97
Mountain Loam	Mountain Loam Planted Grassland	1	10.08	0.00
Aspen	Grass/Shrub	9	3.63	2.08
Aspen	Tall Forb	5	0.61	0.44

Table B.24. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Artemisia triparitata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	16.64	12.81	23.96	17.34	0.00	0.00	20.60	15.71
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	22.17	4.16	35.52	3.61	11.00	22.00	27.33	4.14
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.25. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Amelanchier utahensis					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	10.47	18.13	18.67	32.33	11.83	20.50
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	1.60	5.06	6.48	20.49	4.65	14.70
Claypan	Native Grassland	10	7.00	15.65	0.00	0.00	7.00	15.65
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	26.44	22.37	37.32	47.73	35.19	34.43
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	44.98	56.14	0.00	0.00	44.98	56.14
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	20.64	25.23	42.90	56.13	39.26	39.41
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	21.69	25.13	0.00	0.00	21.69	25.13
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00
Aspen	Grass/Shrub	9	18.96	6.32	0.00	0.00	18.96	6.32
Aspen	Tall Forb	7	0.00	0.00	0.00	0.00	0.00	0.00

Table B.26. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Artemisia cana					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	6.82	12.05	10.05	17.21	8.14	14.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	18.29	36.58	18.29	36.58
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	5.51	14.36	3.05	10.56	6.63	15.88
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00

Table B.27. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Artemisia longiloba							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	12.89	4.14	19.21	6.47	9.09	10.93	18.36	5.95
Claypan	Alkali Sage with Diverse Understory	3	17.33	3.71	29.97	3.31	0.00	0.00	28.96	2.44
Claypan	Alkali Sage/Bluegrass Shrubland	4	16.08	2.70	24.23	1.61	15.29	10.23	23.46	1.48
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	16.04	2.54	24.75	3.08	21.08	7.76	22.72	2.94
Claypan	Native Grassland	10	8.98	8.50	19.94	3.08	16.48	9.73	19.59	2.95
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	13.18	15.37	0.00	0.00	13.18	15.37
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	5.76	9.85	7.02	12.28	3.93	10.41	6.77	11.82
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	1.04	3.61	4.39	10.46	0.00	0.00	4.06	9.92
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	4.10	8.20	6.33	12.66	6.00	12.00	6.06	12.13
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.28. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Artemisia tridentata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	18.23	16.92	32.83	30.07	17.42	30.18	29.52	26.97
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	4.09	8.73	12.71	20.84	0.00	0.00	10.69	18.83
Claypan	Native Grassland	10	12.50	11.49	19.10	17.59	2.52	5.63	15.82	14.55
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	18.88	3.11	35.83	9.19	17.38	12.67	27.95	8.40
Mountain Loam	Dense Mountain Big Sage Shrubland	5	28.28	2.43	63.84	12.02	53.06	32.63	57.20	11.04
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	23.68	11.86	53.98	15.47	31.02	25.03	43.22	10.99
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	14.73	10.23	25.66	29.64	22.45	26.92	27.16	22.50
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	25.33	10.83	55.69	8.56	32.65	29.67	49.00	9.42
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	18.67	14.65	44.84	30.04	27.88	32.73	35.88	25.54
Mountain Loam	Mountain Loam Planted Grassland	1	25.27	0.00	45.33	0.00	0.00	0.00	31.61	0.00

Table B.29. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Chrysothamnus spp.					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	2.67	6.53	0.00	0.00	2.67	6.53
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	1.55	4.90	1.55	4.90
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	11.00	22.00	11.00	22.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	4.60	10.29	0.00	0.00	4.60	10.29
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	14.70	20.28	28.02	20.47	25.40	20.82
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	2.37	8.19	4.22	14.61	2.80	9.70
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	10.50	21.00	36.50	43.67	32.75	38.19
Mountain Loam	Mountain Loam Planted Grassland	1	31.00	0.00	0.00	0.00	31.00	0.00

Table B.30. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Prunus virginiana			
			Mature		Total	
			ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.00	0.00	0.00	0.00
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00
Aspen	Grass/Shrub	9	87.23	29.08	87.23	29.08
Aspen	Tall Forb	7	0.00	0.00	0.00	0.00

Table B.31. Mean (ẋ) and standard error (SE) of shrub height(cm)

Ecological Site	State	n	Purshia tridentata							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	7.14	18.90	0.00	0.00	7.14	18.90
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	4.13	8.27	7.11	14.22	5.25	10.50	5.62	11.24
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	2.75	9.53	6.08	14.77	0.00	0.00	5.54	13.21
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.32. Mean (ẋ) and standard error (SE) of shrub height(cm).

Ecological Site	State	n	Quercus gambelii					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Native Grassland	10	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	6.17	15.43	14.17	49.07	12.25	30.31
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00

Table B.33. Mean (ẋ) and standard error (SE) for shrub height.

Ecological Site	State	n	Symphoricarpus rotundifolius							
			Juvenile		Mature		Decadent		Total	
			ẋ	SE	ẋ	SE	ẋ	SE	ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Alkali Sage with Diverse Understory	3	23.67	26.31	25.67	22.28	0.00	0.00	38.33	13.05
Claypan	Alkali Sage/Bluegrass Shrubland	4	5.33	10.67	10.75	21.50	0.00	0.00	6.69	13.38
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	17.75	12.88	10.78	17.87	0.00	0.00	18.99	14.11
Claypan	Native Grassland	10	9.93	13.75	0.00	0.00	0.00	0.00	9.93	13.75
Claypan	Claypan Planted Grassland	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	0.00	0.00	22.50	26.79	0.00	0.00	22.50	26.79
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.00	0.00	12.30	27.50	0.00	0.00	12.30	27.50
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	30.82	6.06	53.23	10.61	4.71	12.47	44.65	10.63
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	15.12	10.77	52.39	29.01	0.00	0.00	44.57	31.23
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	25.63	13.99	47.60	27.34	0.00	0.00	40.58	20.58
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mountain Loam	Mountain Loam Planted Grassland	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B.34. Mean (ẋ) and standard error (SE) for shrub height.

Ecological Site	State	n	Symphoricarpus rotundifolius, cont'd					
			Juvenile		Mature		Total	
			ẋ	SE	ẋ	SE	ẋ	SE
Aspen	Grass/Shrub	9	9.22	3.07	16.89	5.63	18.1	6.03
Aspen	Tall Forb	7	0.00	0.00	27.82	10.52	27.82	10.52

Table B.35. Mean (ẋ) and standard error (SE) for shrub height (cm) averaged for all shrubs.

Ecological Site	State	n	Average Overall Height ẋ	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	19.11	2.58
Claypan	Alkali Sage with Diverse Understory	3	38.45	8.14
Claypan	Alkali Sage/Bluegrass Shrubland	4	24.25	0.82
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	25.72	0.91
Claypan	Native Grassland	10	23.57	1.32
Claypan	Claypan Planted Grassland	2	0.00	0.00
Claypan	Three-tip Sagebrush Shrubland	4	32.97	3.32
Mountain Loam	Dense Mountain Big Sage Shrubland	5	63.66	5.37
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	52.76	5.07
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	46.43	10.79
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	57.17	2.35
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	48.35	6.98
Mountain Loam	Mountain Loam Planted Grassland	1	45.33	0
Aspen	Grass/Shrub	9	24.04	8.01
Aspen	Tall Forb	7	27.82	10.52

Table B.36. Mean ($\dot{x}$) and standard error (SE) of visual obscurity(cm) summarized by state.

Ecological Site	State	n	Visual Obscurity	
			$\dot{x}$	SE
Claypan	Alkali Sage Shrubland/Sparse Understory	6	0.10	0.02
Claypan	Alkali Sage with Diverse Understory	3	0.21	0.04
Claypan	Alkali Sage/Bluegrass Shrubland	4	0.15	0.02
Claypan	Alkali Sage/Western Wheatgrass Shrubland	11	0.09	0.01
Claypan	Native Grassland	10	0.06	0.01
Claypan	Claypan Planted Grassland	2	0.28	0.08
Claypan	Three-tip Sagebrush Shrubland	4	0.06	0.01
Mountain Loam	Dense Mountain Big Sage Shrubland	5	0.47	0.06
Mountain Loam	Mountain Big Sage Shrubland with Diverse Understory	7	0.20	0.03
Mountain Loam	Mountain Big Sage Shrubland/Sparse Understory	4	0.31	0.11
Mountain Loam	Mountain Big Sage/Western Wheatgrass Shrubland	12	0.28	0.04
Mountain Loam	Mtn Big/Three-tip Sagebrush Shrubland	4	0.25	0.02
Mountain Loam	Mountain Loam Planted Grassland	1	0.19	0.00
Aspen	Grass/Shrub	9	0.32	0.02
Aspen	Tall Forb	7	0.39	0.06